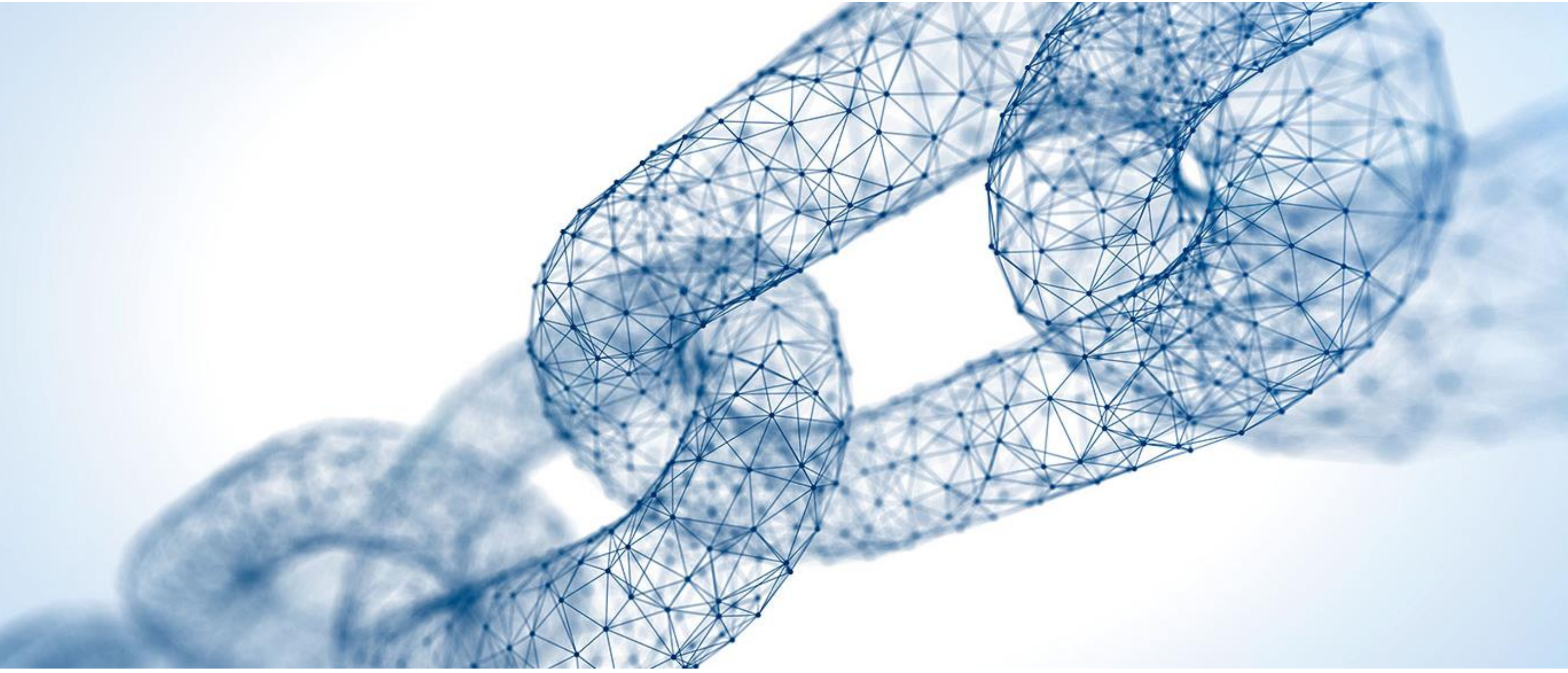

Blockchain Adoption for Circular Business Development

- A German Technology-Organization-Environment Framework on Influencing Factors

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Master Thesis

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ABSTRACT

Blockchain Technology (BCT) is being discussed as one of the enablers for the transformation of businesses towards a Circular Economy (CE). It promises to store and share data across a business' supply chain transparently and immutably, time efficient and without a third party involved. Recent studies have shown that Blockchain can be an enabler in the development of a shared information structure. However, the few actual applications in practice do not get beyond the pilot phase and there is no widespread implementation. The factors that may play a role in this have so far been discussed more comprehensively in theory than derived from empirical evidence and assessments from practice.

The goal of this study is to empirically investigate the adoption of innovative technologies, focusing on the promising technology Blockchain, in the context of companies that are embarking on the journey of driving Circular Economy. To get an estimation of the influencing factors from companies, possible barriers and facilitators of a Blockchain adoption are to be identified. In order to take into account versatile perspectives, the three contexts of Technology, Organization and Environment according to the TOE framework by Tornatzky and Fleischer (1990) will be addressed.

To methodologically address this goal, building on an extensive literature review on potential barriers and facilitators, a qualitative empirical study was conducted in which eight cases from different sectors were analyzed and assessed based on semi-structured interviews. Through a within-case and cross-case analysis, followed by a cross-case discussion differences with the existing literature were identified, most frequently mentioned factors from the cases were filtered out and differences between the cases were elaborated.

The cases showed that in the technological context, the focus is on the question of how to get information into the Blockchain system in the first place und how to integrate Blockchain with existing systems. In the organizational context, the focus is on the fact that businesses are still at the beginning of developing circular strategies, that's why a relative advantage of Blockchain applications is not directly apparent. In the environmental context, the focus is on the problem of how to get all players on board, using the same system, in the same way, with high data quality along and beyond the value chains. In almost all cases, the consensus mechanisms of Blockchain technology were seen as facilitators. Additionally, although the complexity of the technology is perceived as relatively high, it is perceived as an enabler to decrease complexity on the long run.

The recommendations for action derived subsequently relate primarily to overcoming the barriers mentioned. The sequence of necessary steps, the respective context (TOE) and the players which are the companies, the government and IT service providers, are addressed.

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1 Introduction

The hype around Blockchain

The hype around Blockchain Technology was first triggered in financial applications (Akram et al., 2020). Adoption of the technology with its unique capabilities is now rising in other domains as well (Tapscott and Tapscott, 2016). Anti-counterfeiting, the decentralized structure, track and trace applications, and tamper-proof traceability of data (Zheng et al., 2018) are also expected to revolutionize the Circular Economy (Stephan, 2020). Companies currently face major challenges in implementing circular strategies as one of the key challenges is to track and trace materials and products sufficiently (Böckel et al., 2021). The use of a new technology that can solve existing challenges should be tempting. But Germany is still a laggard in the use of Blockchain (Noyan, 2021) and the hype of the technology is put into perspective by the real challenges of adoption in the context of the Circular Economy.

The goal of this study is to empirically investigate the adoption of innovative technologies, focusing on the technology Blockchain, in the context of companies that are embarking on the journey of driving Circular Economy.

1.1 Motivation and Relevance

Business environments are constantly changing and to stay competitive on the market, businesses have to constantly adapt (Goulding, 1983). Today's economic system is based on a linear "take-make-dispose" principle, where resources are being extracted, processed, used and then disposed (Ellen MacArthur Foundation, 2013). However, companies are exposed to intensifying resource scarcity. Business as usual on the long run is no longer a competitive strategy (PWC, 2018a). A push for more resource-efficient approaches from customers and business partners and a pull from politics through increasing product responsibility are forcing companies to adopt new business strategies (Van Ewijk, 2018). Strategies that attempt to close linear business structures, thus returning resources and materials back into the businesses in a circular fashion (Ellen MacArthur Foundation, 2013). However, developing circular businesses is confronted with major challenges. Such is the flow of information about the manufacture, composition and treatment of materials and products throughout and beyond the value chain (Wilts, 2017). Transparent information about materials along the entire value chain is the basis for transforming material flows within a Circular Economy (Wilts, 2017). While the challenges of implementing circular business strategies are new and extraordinary, they peak at a time when technologies from the 4th industrial revolution are pouring into markets, driving technical change (PwC, 2018a). Blockchain is being discussed as one of the technical enablers for the transformation towards a Circular Economy (Alcayaga et al., 2019; Banerjee, 2019; Kouhizadeh, 2018, 2020). It promises to store and share data across a business' supply chain transparently and immutably, time efficient and without a third party involved (Xu et al. 2019; Zheng et al. 2018). The enabling role of Blockchain is the subject of a number of recent studies in research (Böckel et al., 2021). In particular, the studies of Kouhizadeh et al. (2018, 2020, 2021) have shown that Blockchain can enable the development of a shared information infrastructure that facilitates circular business development. In practice, the implementation itself is still in its infancy. This is also a conclusion that Kouhizadeh, Zhu and Sarkis (2020) had to draw, that the few actual applications do not get beyond the pilot phase. Barriers exist that need to be considered and that may still be hidden with respect to the presumed businesses. Especially sustainability information is typically sensitive, and the acceptance and management of coopetition tensions are still challenging areas according to research (Narayan and Tidström, 2020). Over the past four years, most of the existing literature has focused on the link between the two trends of the Circular Economy and Blockchain, covering application scenarios and implementation processes primarily in theory (Böckel et al., 2021). Until now, however, there has been little focus on the actual adoption in circular business development from practice.

1.2 Research Focus

The focus of this work greatly builds on the findings of a state-of-the-art literature review on the research-practice gap in the subject of Blockchain for the Circular Economy (Böckel et al., 2021). In this review, the findings of Kouhizadeh's studies are also included.

In the literature review, it was found that most research as well as practice questions relate to reuse and recycling strategies for achieving a Circular Economy (Böckel et al., 2021, p. 533). In both research and practice, the most frequently cited context for a Blockchain application was supply chain management, particularly in relation to tracking materials (Böckel et al. 2021, p. 532) and the most relevant use case is the possibility of tracking product-related information over the entire life cycle (Böckel et al., 2021, p. 533). Research has significantly addressed the challenges associated with the use of Blockchain, whereas these have hardly been discussed in practice. In theory, the main problem is thought to be that users and companies lack the understanding of Blockchain to allow its capabilities to unfold in practice (Böckel et al., 2021, p. 533).

Building on these current findings it is seen as critical to gather further insights of perception and experiences from practice. Especially in exchanges with company representatives who have considered the application of Blockchain in regard to their respective business. Further, the focus in this work is set on companies operating in industries where recycling and the return of materials and products are the readiest strategies towards a Circular Economy, as these have a particularly high relevance in theory and practice. Such relevant industries are manufacturing, building materials, plastics and electronics (McKinsey, 2016). Furthermore, the cooperation with partners over the entire supply chain and value chain will be particularly addressed, as this is the key point to obtain information and implement circular strategies.

1.3 Problem Statement

Companies are under pressure to implement circular strategies, but the development towards this is stalling. Studies have shown that Blockchain can be an enabler in the development of a shared information structure. Despite the said capabilities and opportunities that come with the technology, the adoption rate in German companies is rather low. The factors that may play a role in this have so far been discussed more comprehensively in theory than derived from empirical evidence and assessments from practice.

1.4 Research Goal

In order to put the hype of Blockchain into perspective, assessments and experiences from practice are to be collected, analyzed and compared with the current literature. In order to get an estimation of the influencing factors from the companies, which deal in particular with the implementation of recycling and reuse, possible barriers and facilitators of a Blockchain adoption are to be identified. Since the subject area is complex and concerns not only the technology itself, but also the corporate structure and culture, as well as the environment of a company, the possible factors are to be assigned to the areas of Technology, Organization and Environment according to the TOE framework by Tornatzky and Fleischer (1990).

The aim of this work is to answer the main research question that states:

What are the influencing factors of Blockchain adoption for the development of circular businesses?

Further the aim is to clarify the following sub-research questions:

a) What are the perceived barriers that need to be addressed in the future?

b) What are the perceived facilitators to be expanded in the future?

c) In what context do these factors occur (technological, organizational or environmental)

d) What are recommendations of action?

1.5 Structure

This work is divided into seven sections. First, the theoretical foundations are outlined. These are derived from the issues of the research question and thus include an overview of adoption theories of innovations, the basics of Blockchain Technology, an overview of strategies behind the concept of Circular Economy and finally the overlap of the two topics, how Blockchain can be an enabler for Circular Economy. This is followed by a presentation of the methodology used and the decision-making process for deciding on the method.

This is followed by the structure and outcome of the literature review, which forms the basis for the interviews, case studies and discussion. In the main part, the analysis, the cases are analyzed individually in a within-case study and the influencing factors are extracted. In the following discussion, the cases are compared with each other and with the literature. The most frequently mentioned factors are discussed and similarities as well as discrepancies with the underlying literature review are worked out. Based on this, recommendations for action are formulated for various players at different levels. Finally, the limitations of this work are discussed, an outlook for future research is given and the work is concluded with a comprehensive summary and conclusion.

1.6 Delimitation

It must be noted that this work does not do justice to being all-encompassing. Accordingly, three main delimitations are defined:

This work is written from a business perspective and not from a technical perspective. Accordingly, the focus of this work is on practical experiences and use cases rather than the detailed functionality of the technology of interest. Alternative technical solutions besides Blockchain, such as cloud solutions, are considered but not compared and discussed in detail.

Furthermore, it is the aim of this work to collect assessments from practice and to extract and discuss possible influencing factors for the adoption of Blockchain. The chosen method and the state of the art of the companies does not allow to develop a grounded theory and does not aim to prove an absolute truth. Lastly, the basic concept of Circular Economy is not fundamentally questioned in the context of this work. This is justified by the fact that the focus is on Blockchain adoption. The concept and the strategies behind it are merely introduced and not discussed. Nevertheless, possible trade-offs and limitations are considered.

2 Theoretical Foundation

2.1 Innovation Adoption Models

The issue of Blockchain adoption can be analyzed from different perspectives, based on different approaches of technology adoption models. In this chapter, different models from theory will be introduced and discussed. The TOE Framework is the model that will be applied in this study. However, to get an overview of further approaches, in the following models which generally refer to the adoption of innovations will be presented.

The stages of the adoption process

The adoption of an innovation in the marketplace does not usually occur simultaneously, but rather represents a process that unfolds in stages (Fichman, 1992). In this process, individuals may exhibit different behaviors, or companies may pursue different strategies. The stages represent the timing and the quantity of adopters (see Fig. 1).

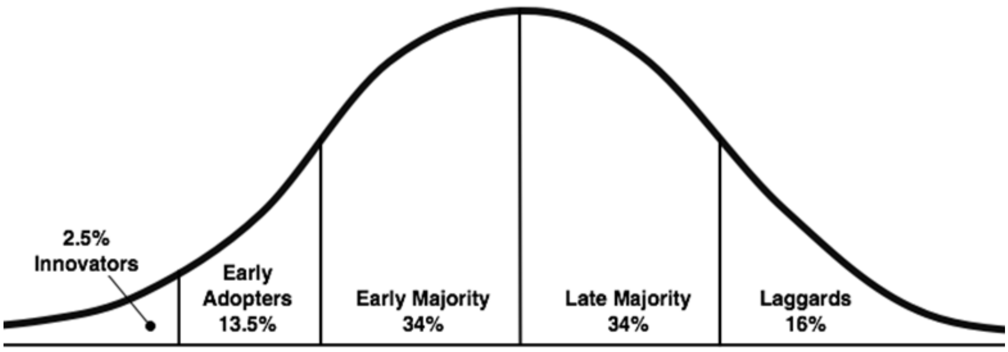


Figure 1: Diffusion of Innovation Theory by E.M. Rogers (Rogers, 2003)

The **Early Adopters,** or **First Movers** are the individuals or companies who are opinion leaders and are the first to adopt an innovation. The **Early Majority,** or **Fast/First followers** represents the group that adopts new ideas earlier than the average but must have already observed a certain degree of success with the innovation. The **Late Majority** represents the group who is skeptical of the innovation and adopts only after the innovation has been tested by the majority. **Laggards** are all those who are very conservative in nature and skeptical of change. Often, they can only be convinced of the innovation by pressure or success statistics.

The transition from Early Adopters to the Early Majority is crucial for the further diffusion of an innovation. Once the Early-Adopters have entered the market, it takes what is called **Critical Mass** to reach the next diffusion stage. Critical mass describes the process that when enough members of a society or industry have adopted an innovation that further adoption becomes self-sustaining (Gruenbaum, 2015).

Adoption decision factors

To better understand the factors that influence the decision to adopt, numerous models have been developed for analysis. While the first models focused primarily on adoption innovations by individuals (Davis, 1986; Fichman, 1992), current theories of innovation have been extended to adoption processes in organizations (Tornatzky & Fleischer, 1990). In the following, three of the most prominent models are presented: Rogers' (1983) Diffusion of Innovations (DOI), Davis'

(1986) Technology Acceptance Model (TAM), and Tornatzky and Fleischer's (1990) Technology-Organization-Environment (TOE) framework.

Diffusion of Innovations (DOI)

The model was developed by Rogers in 1962 and proposes five attributes of an innovation that influence adoption (Rogers, 1983). According to Roger, the perception of these attributes by a person or a company, is crucial. The 5 attributes are: **Relative Advantage, Complexity, Compatibility, Trialability, and Observability**. In relation to technological ideas, the aforementioned attributes for innovation are assumed to be direct antecedents of innovation adoption decisions (Rogers, 1983; Puklavec et al., 2014).

The Technology Acceptance Model (TAM).

Davis' (1989) model aims to explain the acceptance and use of IT by filtering out the determinants for adoption behavior. The TAM model is widely used in describing individual acceptance of an innovation and is considered one of the most influential theories in this regard (Lee et al., 2003). The main criteria in the study of user behavior by the TAM model is the user's **perception of the usefulness and the ease of use of a technology**. Usefulness describes the degree of perceived improvement in performance and ease of use describes the degree of perceived effort that should be minimized (Davis, 1989). TAM assumes that the intention to use directly affects the actual use. Since this theory is mainly applied to the adoption behavior of individuals and their perceptions towards an innovation, this theory will not be discussed further in depth. However, individual attributes such as relative advantage, complexity and compatibility are also included within the framework applied.

The Technology Organization-Environment (TOE) Framework

Tornatzky and Fleischer's (1990) TOE framework aims to address the elements of the organizational context in order to filter out multifaceted factors that influence the adoption decision. Accordingly, the TOE framework is not only applicable to individuals, but is particularly suitable for analyzing the perspectives of an adoption decision from a company's point of view. According to this framework, technological, organizational, and environmental factors can be both facilitators and barriers to technology adoption. The **Technological Context** includes the factors of the technology to be adopted such as complexity, compatibility, and advantages and disadvantages. The **Organizational context** includes the organizational culture, leadership structure, and resource capabilities. The **Environmental context** includes industry structure, competitive pressures, and the regulatory environment (Baker, 2011).

TOE from a Circular Economy perspective

Applying the TOE framework opens new perspectives when looking at a company's organization, how it perceives the technology itself, and what factors influence the attitude towards a new technology. The framework offers a way to explore the different perspectives of a company that come into play in the process of developing circular business strategies and approaches, and to get an overview of the different influencing factors in the decision to adopt enabling technologies such as Blockchain. Applying the TOE framework for Blockchain adoption in the context of the Circular Economy opens up further perspectives that encompass all three areas of the framework and can lead to new insights in the adoption literature.

Technology origin: In the technological context, the factor of technology origin comes into play. The technology has emerged from the context of the financial sector, namely cryptocurrencies (Akram et al., 2020). Its application in new areas, and especially in a context that contrasts somewhat with the economic principles of cryptocurrencies, is not yet widespread.

Double burden: In the context of the organization itself, the factor of double burden comes into play. Companies are faced with the challenges of moving towards a circular business, while at the same time having to think about the application of new technologies. Those new technologies promise to reduce complexity on the one side but may represent a further burden on the other side (Wong et al., 2020; Yadav et al., 2020). Investing in both processes at the same time could be challenging.

Coopetition: In the context of the environment, the coopetition factor comes into play. To implement circular approaches and business models, complex and interconnected problems need to be solved that can only be addressed through cooperation (Narayan and Tidström, 2020). For the development of circular businesses, both competition and cooperation between actors are important. In this context, trying to find the balance between necessary cooperation and simultaneous expansion of competitiveness can have a further impact on the adoption of new technologies such as Blockchain (Narayan and Tidström, 2020).

2.2 Blockchain Technology

Relevance

The availability and ability to share data is becoming more important and therefore also one of the drivers for innovation (Richter and Slowinski, 2019). According to a study by PwC (2018b), however, data protection is one of the biggest concerns in digitization. Cloud solutions or other data sharing platforms are also susceptible to being associated with insufficient transparency or unauthorized use of data by third parties (Richter and Slowinski, 2019). As one of the current highly discussed innovations in the field of databases is Blockchain Technology, which is associated with characteristics such as "decentralization, persistency, anonymity and auditability" (Zheng et al., 2018, p. 354). In 2019, the German government adopted a national Blockchain strategy. This includes a roadmap to unleash the opportunities of Blockchain Technology and drive digital transformation in the country (BMWI, 2019).

Definition

One of the definitions is provided by Casino et al. (2019) and states that Blockchain is “a distributed database that is organized as a list of ordered blocks, where the committed blocks are immutable” (Casino et al.,2019, p. 55). Accordingly, a “block” is created whenever a new transaction was executed. “Chain” refers to the chain that continues to grow in length with each subsequent transaction, thus storing and making visible the history of transactions by connecting the blocks (Dinh et al., 2018).

Blockchain Technology is based on a distributed ledger network, which enables some of the core functions. Distributed ledger differs from the other two network types Centralized network and Decentralized network (see Fig. 2).

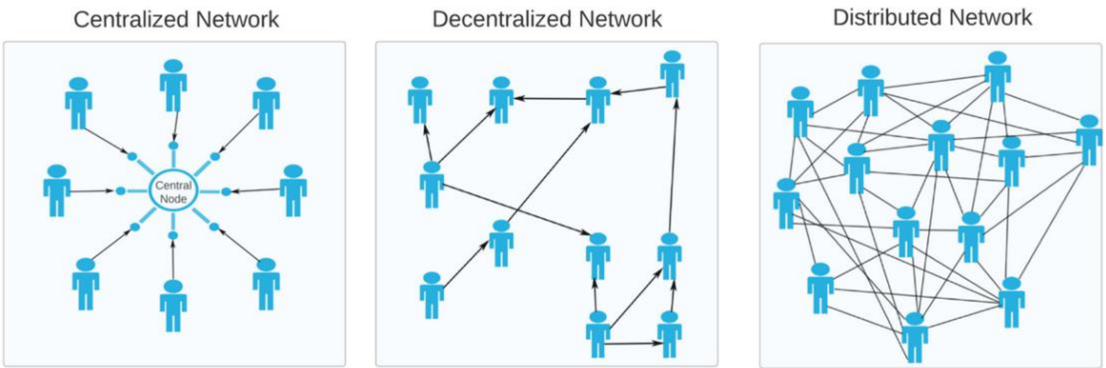


Figure 2: The three different types of network structures (from Khoshavi et al., 2021)

The centralized network, on which for example cloud solutions are based, has a central node that connects the nodes of an entire network. In decentralized networks, there are multiple connections between multiple nodes, without a central node. Some nodes may still lose connection to the network. Distributed networks are characterized by multiple communication paths between nodes, ensuring that nodes are always connected without relying on a central account (Khoshavi et al., 2021).

Functionality

The functionality of BCT is in most cases presented in a highly abstract way. In the following, the basic structure and the mode of operation will be outlined. In doing so, this section is based on the presentation and explanation by Casino et al. (2018).

As outlined above, Blockchain can be viewed as a distributed data structure. It is intended to provide a distributed peer-to-peer network in which members can interact with each other without relying on trust, while at the same time not relying on a third party mediator (Christidis and Devetsikiotis, 2016). In the following, the interconnected mechanisms that enable this type of network will be presented (see Figure 3).

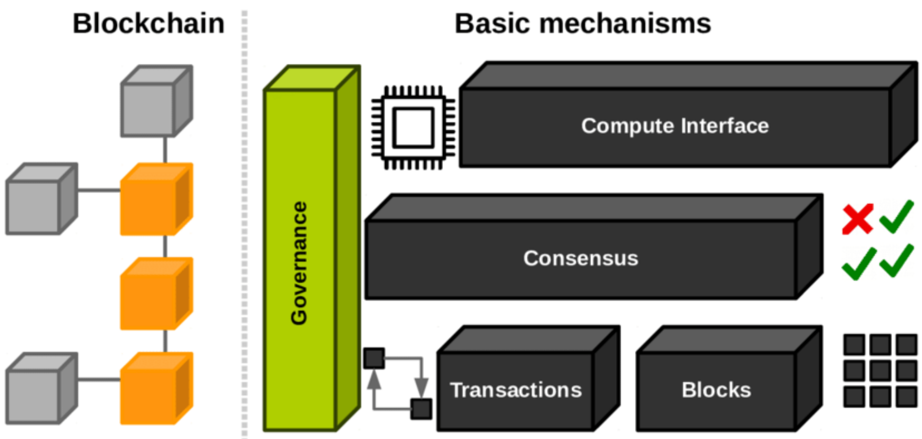


Figure 3: An overview of Blockchain architecture (from Casino et al., 2018. p.57)

1. Transactions and Blocks: At the lowest level are the transactions between peers, which may involve various agreements. Once this transaction is signed by at least one person, it is passed on to the respective neighbor. Entities that verify the rules of a Blockchain are called nodes.

Full nodes have the function of checking all the rules and are the ones that have to group the transactions into blocks and determine if a transaction is valid.

2. Consensus: Whether there is a discrepancy in the transactions that may indicate an attempt to deceive is performed by the nodes using consensus mechanisms. Depending on the Blockchain type, there are different consensus mechanisms. The most commonly used is Proof-of-Work, or PoW, which is based on an elaborate computational process. However, this method is very time-consuming, costly, and a method that consumes a lot of energy. Another method that is gaining more focus is the approach of Proof-of-Stake, or PoS protocols that divide stake blocks proportionally to the miners' current wealth (Pilkington, 2016; Casino et al., 2018). This method is simpler and less costly (Schiller, 2019). The computational effort involved in distributing information across the network depends on the application. For example, in practice, the account balance of each user can be calculated if the information about the transactions made by each user is stored. For complex applications, such as supply chain management, a much higher computational effort must be accomplished, using distributed computing to dynamically update information (Casino et al., 2018).

3. Governance: At the top level is the governance layer, which connects the Blockchain's digital network to the physical world. This layer serves the goal of producing and maintaining inputs by actors so that, for example, Blockchain protocols can be improved (Casino et al., 2018).

Functions of Blockchain Technology

The structure and functioning of the Blockchain as described above unleashes capabilities that are unique to a database. These include security, decentralization, transparency and immutability, as well as the use of smart contracts.

Security: A secure network for sharing and storing and data can be ensured by encrypting information across ledgers in the Blockchain system, using cryptography and the consensus mechanism PoW and PoS (Kouhizadeh et al., 2020).

Decentralization: Blockchain technology does not require a third party mediator, thus enabling direct transactions. Information can be processed and updated in real time (Wang et al., 2019; Böckel et al., 2021)

Transparency - Traceability: In the Blockchain, all records and transactions are stored in so-called digital ledgers, which can then be viewed by all authorized participants in the network. This significantly increases transparency and traceability (Francisco and Swanson 2018; Kouhizadeh et al., 2020). These ledgers are then constantly updated with the latest transactions, activities, and events (Kouhizadeh et al., 2020). Tracking information can then be enabled, for example, by additions of IoT or GPS (Kouhizadeh et al., 2020).

Immutability: Data stored and connected as blocks in the Blockchain is immutable. The immutability of data is one of the key features of the technology (Viriyasitavat and Hoonsopon, 2019). The fact that the data cannot be changed, but can only be augmented with more information, means that once it is in the system, it is also tamper-proof (Kouhizadeh and Sarkis, 2018).

Smart contracts: Smart contracts are more of an application that arises from the capabilities of the Blockchain, rather than a capability itself. They are rules or contract terms that are stored in the Blockchain and define the interaction of actors in the network (Saberi et al., 2019, 2021). During the duration of the contract, certain actions, such as payouts, linked via the Blockchain can be executed automatically if a corresponding trigger is present. This trigger can be, for example, the fulfillment of contract conditions (Mitschele, n.y.).

Blockchain and Supply Chain Management

With the above listed capabilities, Blockchain is not only an attractive database for cryptocurrencies, but is also increasingly discussed in the context of supply chain management (Bauman et al., 2016). Currently, supply chains are based on centralized information management systems, such as ERP systems (enterprise resource planning systems). When using these systems, a high level of trust is required in the single provider of this system (Abeyratne and Monfared, 2016) and the risk is relatively high that the whole system is hampered if the main node fails (Dong et al., 2017). With the application of Blockchain in supply chain management, it is hoped that complete transparency and verifiability through the ledgers, will increase the security and retrievability of information (Saberi et al., 2019; Kouhizadeh et al. 2021). Another factor is that supply chain data can be shared and accessed in real time (Brody, 2017).

Types of Blockchains

BCT can also be categorized by four basic types that differ in their respective read, write, and transfer permissions (Hileman and Rauchs, 2017). These four types are public permission less, public permissioned (or hybrid or semi-public), consortium, and private permissioned (Böckel et al., 2021) (see Fig 4).

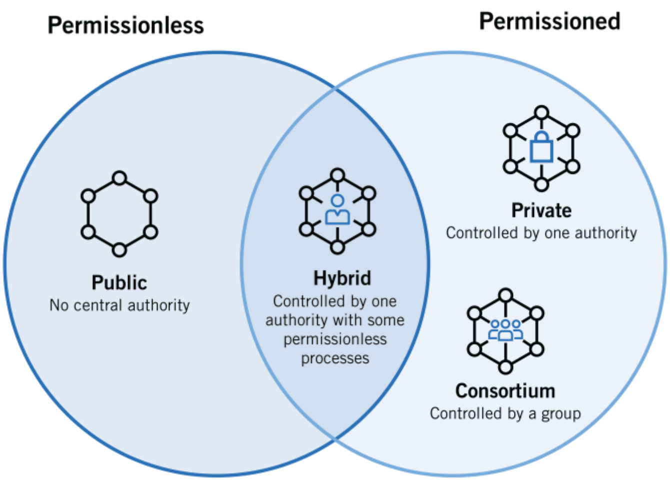


Figure 4: Types of Blockchain (from Wegrzyn and Wang, 2021)

Public Blockchains are permission less, allowing anyone to join, and they are fully decentralized. Private Blockchains are permissioned Blockchains controlled by a single organization. Consortium Blockchains are permissioned Blockchains that are managed by a group of organizations available only to the organization that is part of that consortium (Akram et al., 2020). Hybrid Blockchains have a private part that can only be used for transactions between certain partners and a public part that is accessible to any other participants (Schiller, 2018).

The choice of type has a direct impact on the application areas and the scope of the unique capabilities described earlier. For example, the private Blockchain has the advantage of being very efficient, transmitting transactions in real time, and having a minor PoW. However, the sticking point is that this type of Blockchain is based on a centralized network (Casino et al., 2019). Therefore, there are also discussions about whether a private Blockchain truly lives up to the name Blockchain (Jeffries, 2018; Kouhizadeh, 2020). However, it is used in the context of internal corporate purposes. A so-called whitelist defines the approved users with certain properties and authorizations for network operation (Casino et al., 2019).

Excursus: Blockchain and Circular Economy

Hardly any of the research dealing with the application of Blockchain for the Circular Economy distinguishes between the four types (Böckel et al., 2021). Especially with regard to the complexity and size of global supply chains, a public solution seems to be necessary. For example, the implementation of a startup (Circularise) to track plastic is based on a public Blockchain. Since companies are currently also considering different approaches and see both an in-house private Blockchain and a public one via a provider as possible or are somewhat unable to distinguish between the different types, this study will refer to Blockchain in general terms and keep the option open to address a specific type.

Limitations

Hughes et al. (2019) summarized the following limitations as part of a literature review:
One limitation is lack of privacy. Having a full history of transactions associated with each node in the network has its advantages in terms of security but can be critical when privacy needs to be protected. Certain transaction patterns can make an actor's identity visible in certain cases. In addition, there are high costs. Continuously storing transaction histories and copying them for each node is computationally highly intensive. This can slow down transaction time in large networks and lead to high energy costs. In addition, there is limited flexibility. The information in the Blockchain is immutable. If there is a need to change a transaction, any error or misinformation will still be retained in the system. (Hughes et al., 2019)
Additionally, there are still some legal and logistical issues to be resolved. At the moment, there are no regulations on the implementation and applications of such technological structures especially in the companies outside the financial world. The decisions on design and type, as well as the aforementioned limitations, mean that few companies are moving beyond prototype testing towards implementation (Hughes et al., 2019).

2.3 Circular Economy

Relevance

The current economic system is based on the principle of extracting, processing, using and discarding resources. However, this economic system is facing an intensifying scarcity of resources. In 2020 alone, resources were overused by a factor of 1,75 based on the earth’s capacity and footprint per capita (Global Footprint Network, 2020; Böckel et al., 2021).
This linear economic model is not only shaking because of the degradation of the environment, but also because of the production of large amounts of waste. Current recycling methods can hardly counteract this because of lacking material infrastructure and recovery mechanisms that are able to recover materials from today’s compact products (Tansel, 2017).
This negative trend causes a shift of mindset leading to the development of concepts for new economic systems. Such is the Circular Economy which is based on the fundamental principle of moving away from degrading and wasting resources and, instead closing and expanding resource loops by returning resources back into a cycle (European Commission 2015; Blomsma and Brennan, 2017; Böckel, 2021).

Political Agenda

The transformation of global economic patterns towards a Circular Economy is therefore high on the political agenda. The goal of sustainable production and consumption is also anchored in goal #12 as one of the United Nations SDGs and states: "Substantially reduce waste generation through prevention, reduction, recycling and reuse" (United Nations, 2020).
Additionally, the European Commission has presented an action plan for the Circular Economy, which includes legislative proposals for the waste management sector addressing the reduction of landfilling, increased preparation for reuse and recycling of key waste streams such as municipal waste and packaging waste, as well as improvement of extended producer responsibility schemes (European Commission 2015; Tansel 2017). In the action plan, the European Commission seeks to strengthen the European Economic Area by shifting the linear economic system to a circular economic system. If the action plan were to be implemented, the Commission expects 580,000 new jobs, a reduction in greenhouse gases of 450 million tons by 2030, and cost savings of 600 billion euros for European companies (European Commission, 2015)

Definition and Concept

Several approaches exist to define Circular Economy. One of the most prominent definitions comes from the Ellen MacArthur Foundation (2013) and states: "A Circular Economy is restorative by design, and aims to keep products, components, and materials at their highest utility and value at all times." Ultimately, as the concept behind it evolves, the definitions diverge further and further rather than agreeing on a single understanding (Bocken et al., 2016; Homrich et al., 2018). The basic principle captures the goal of closing and extending resource loops. Taking on further, this general principle is based on an integrated approach that refers to several phases: It considers the recyclability of products in the design phase, attempts to extend the use phase, and lastly aims to return products to the cycle for further use after the use phase (Ellen MacArthur Foundation, 2013).

Differentiation from the concept of sustainable development

Geissdoerfer et al. (2017) emphasizes that the concept of sustainability is much broader than Circular Economy, which primarily refers to the handling of resources. Companies often understand Circular Economy as a way to become a more sustainable company. Geissdoerfer was able to illustrate that, in addition to the beneficial relationship between CE and sustainability, a compromise solution may also emerge (Geissdoerfer et al., 2017).

Strategies

While the overall goal of a Circular Economy and the principles behind it are apparent, the practical implementation is rather unspecific. In order to make the implementation towards a Circular Economy tangible, various strategies have been developed that are to be applied. The most prominent are the R-strategies and the ReSOLVE model.

Reduction as one of the three basis R strategies refers to resource efficiency to minimize material and energy consumption. Reuse refers to the multiple use of a used product for the same purpose. Recycling aims to return waste and material flows. In this context, the recycled products can serve both the original and another purpose in the reuse (Ghisellini et al., 2016).

With the need for circular modes of production in mind, the Ellen MacArthur Foundation in cooperation with the McKinsey Center for Business and Environment (2015) developed the

ReSOLVE model. It proposes six action areas for implementing the CE transition, namely: Regenerate, Share, Optimize, Loop, Virtualize and Exchange.

Regenerate aims at the transition to renewable energies and materials, as well as the recovery and storage of energies and materials. Fossil fuels are to be avoided in this way and the biological resources recovered as a result are to be returned to the biosphere.
Share aims at increasing the total value of goods by sharing them. The waste and duplication of effort caused by individual use should be minimized in this way. The repair and reprocessing of products and materials plays a key role in this.
Optimize aims to optimize manufacturing, operational and consumption processes to maximize resource efficiency while improving product performance. At the same time, non-value-adding activities are to be reduced. Under this strategy, Big Data analysis is also included.
Loop aims to recover and reprocess materials and goods to return resources to the economic cycle. Doing so is intended to counteract the linear approach of make-use-dispose.
Virtualization aims at the virtual provision of materials and services in order to dematerialize processes that do not necessarily have to be carried out physically.
Exchange aims to replace old materials and ways of working with environmentally friendly materials and new ways of working with technology support.

Limitations

However, consideration should also be given to any project or approach in applying the strategies to determine whether the approach is actually making a positive contribution. Which also refers to the possible compromise outcome of a Circular Economy and sustainability relation. Korhonen et al. postulate that: “A cyclic flow does not secure a sustainable outcome” (Korhonen et al., 2018, p. 42).

The transformation to a Circular Economy from a business perspective should not be traded as a cure-all. This approach is also limited by the natural boundaries, and there are negative effects and risks that need to be taken into account. In their paper "Circular Economy: The Concept and its Limitations," Korhonen, Honkasalo, and Seppälä (2018) compiled the limitations and potential risks of the Circular Economy:

Spatial problem shifting and problem displacement: Circular Economy is not implemented as a one-company closed-loop system. Organizational and also geographical boundaries are crossed by material flows. This automatically creates the risk of shifting the reduction of an environmental impact on one part of the system to another part of the system. Through global supply chains and value chains, regional efficiency gains can lead to problems in other locations (Korhonen, 2004).

Temporal problem shifting and problem shifting: Measures that have a positive effect on material flows today may have a negative effect in the long term. Circular Economy strategies are still in the early stages of implementation, and long-term effects of specific measures are not yet measurable (Robèrt et al., 2013).

Rebound and boomerang effects: The efficiency gains that can be achieved through CE strategies also reduce production and material costs, as well as potential regulatory penalties. This, in turn, can boost consumption if product prices become more affordable. As a result, the gained eco-efficiency would decrease again (Berkhout et al., 2000; Huppes and Ishikawa, 2009).

The role of businesses

The concept of Circular Economy is a holistic concept that calls for change on different levels (Yuan et al., 2006). Along with nations standing at the macro level and industry networks at the meso level, businesses and consumers play a leading role at the macro level (Ghisellini et al., 2016). Implementation lies with economic actors and thus, to a large extent, with businesses directly. The challenges for the transition are high, as the current way of producing, providing and using materials needs to be rethought (Narayan and Tidström, 2020).

On the one hand, companies are under pressure to adapt their way of doing business due to increasing resource scarcity; on the other hand, they are attracted by new business options. Massive cost savings could be achieved due to current regulations, emissions and landfill prices. In addition, expensive resources can be saved as they are recycled back into the system. Finally, increasing customer demand for more sustainable products is a factor that can positively impact a company moving to a circular model (Korhonen, 2004; Korhonen, 2018).

Companies are following multifaceted approaches to see Circular Economy as a new source of value creation by realigning areas such as product design, operations management, distribution, but also new materials and new technologies. Business relationships can also change, with suppliers becoming partners who are transparent about the production and composition of their products, rather than producing "black box" materials with no knowledge of their composition (Hofstetter et al., 2021).

Circular business development with global supply chains and value chains

Especially in the recycling and optimization strategies mentioned above, the inclusion of the supply chain and value chain plays a key role. A recent study by Ernst & Young (2021) assessed the role of the supply and value chain for the Circular Economy and captures the objective as: "Value chain members take ownership of their products and services throughout their supply chains, designing strategies to bring resources full circle for reuse without quality degradation - and with an aim of zero waste" (Steingberg et al., 2021)

In order to implement a Circular Economy within a company and beyond its borders, the following goals must be pursued: First, closing material loops at all stages of the supply chain, and second, aiming for zero waste along the entire value chain (see Fig. 5).

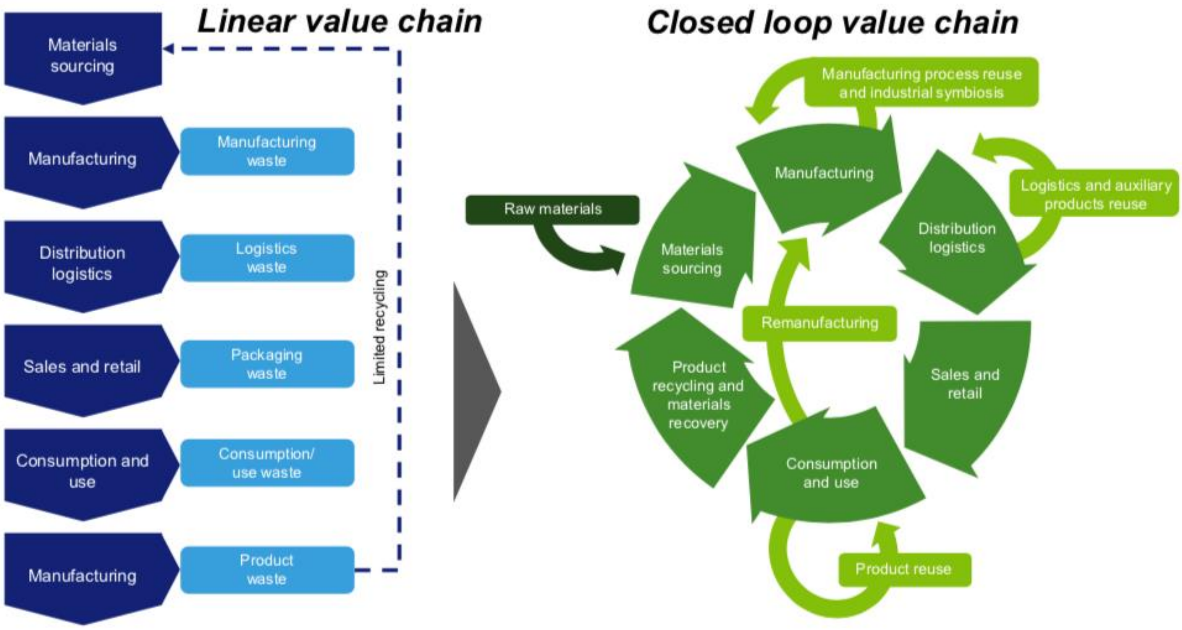


Figure 5: From a linear value chain to a closed loop value chain (Deloitte, n.y.)

However, a major challenge arises from the dependency on diverse partners in the supply chains and value chains. One of the biggest obstacles is bringing together all the participants in a value chain. On top of that, there is the added complexity of the supply chain. A circular supply chain tends to be larger and significantly more complicated than a traditional linear model (Steingberg et al., 2021). This challenge becomes even more pressing by the fact that production is increasingly taking place in company networks that span international borders. These networks, called Global Value Chains (GVC), are cross-industry and cross-national (De Marchi, 2020; Hofstetter et al., 2021).

Transition is stalling

The reality shows that the Circular Economy has not yet been implemented on a large scale in companies (Circle Economy, 2020; Kristoffersen, 2020). One of the main reasons for this is the lack of information, which is also caused by the challenges just described in implementing loop and optimize strategies.

The lack of information sharing is consistently cited as a barrier to the success of circular initiatives (Winans et al., 2017). However, the information about material and material flows is a prerequisite for the transition to a Circular Economy. Information about quantities and qualities of products and raw materials must be carried along in the cycle so that products can be turned back into a usable resource at the end of their life cycle. A key challenge is to effectively generate, collect, process and provide the mass of information about the origin, composition and processing of each material and product (Wilts, 2017).

2.4 Blockchain as an Enabler for Circular Economy

Intersection of two trends

According to the German WBGU (2019) Circular Economy is closely related to digitization strategies. In particular, technological solutions stemming from the 4th Industrial Revolution are seen as promising to support the transformation towards a Circular Economy (EMF, 2015, 2016). Studies by Kouhizadeh (2019, 2020) see Blockchain as one of the key enablers to overcome existing challenges in implementing a Circular Economy.

CE implementation challenges

Especially for the strategies Loop and Optimize within the ReSOLVE framework, i.e. the flow and backflow of resources and materials is of fundamental importance. However, in order to mainstream these and other strategies, some challenges need to be overcome (EMF, 2013, 2015). Currently, there is no infrastructure for Circular Economy to provide and share information about products and materials transparently across the supply chain and value chains of industries (Derigent and Thomas, 2016; Böckel et al., 2021)

What is needed

It needs a flow of information about resources, materials, products and processing steps that is cross-sectoral (Richter and Slowinski, 2019). By intensifying business-to-business data sharing, large and high-quality data sets can be made possible (Richter and Slowinski, 2019), which then provide a basis for the realization of closed-loop strategies. A system is needed that reflects product biographies and highlights value creation opportunities (Narayan and Tidström, 2020).

The role of Blockchain

Blockchain is currently seen as an enabler for circular strategies. It is seen to facilitate and accelerate the application of each of the ReSOLVE strategies in different ways. With a particular focus on the Loop and Optimize strategies, special attention is paid to the technical capabilities of a Blockchain, especially the transparency-traceability and reliability-security capabilities enabled by the consensus mechanisms (Kouhizadeh et al., 2019). "By building up a shared information infrastructure on a Blockchain, the technology can enable circular sourcing of renewable inputs and support resource efficiency" (Böckel et al., 2021, p. 528). Kouhizadeh et al. (2020, p. 963) further add, "Collaboration, standardization and harmonization are expected outcomes of Blockchain consortia that can promote effective and successful implementation of CE initiatives." By replacing single databases for information sharing with a distributed ledger system, it is hoped that more access to more relevant data will result and a better information-sharing environment will develop in industries and across industries (Alexandris et al., 2018).

Main features of BCT

The main features of Blockchain Technology allow not only to store data on a platform, but also to share it securely, while eliminating the need for manual distribution of data to selected parties when a record is changed (Zheng et al., 2018). The main features of BCT are the consensus mechanisms that can ensure transparency-traceability and reliability-security.

Decentralization is an important feature of Blockchain Technology. The fact that there is no need for a third party to mediate data prevents the manipulation of information. In addition, security is increased at the same time. A centralized database is more vulnerable to hacker attacks or crashes (Tian, 2016; Saberi et al., 2019). According to this, a new information about the composition of a material that can be used in many ways is entered into the Blockchain and shared with the parties for whom this information is and who are authorized to receive this information as the system distributes these datasets to different nodes and builds consensus on the location of the data they contain (Sahu, 2020).

The business case: Win-Win-Situation and synergies

Considering the adoption of Blockchain in the context of Circular Economy only makes sense if an added value or win-win-situation can arise from it. Basically, the idea here is: Circular Economy increases resource efficiency, thus saving on input costs and output disposal. If Blockchain can increase this efficiency again, one can see an added value here.

Especially the optimization strategy according to the ReSOLVE framework relies heavily on efficiency, which can lead to eco-efficiency measures (Kouhizadeh et al., 2020). Closer cooperation between relevant value chain partners can also be intensified on the basis of a secure system and thus have a positive economic impact (Kouhizadeh et al., 2020).

As already emphasized, supply chain management plays a key role in Loop and Optimize strategies. Saberi et al. (2019) summarized the economic benefits of Blockchain Technology in the supply chain in their work.

1) Blockchains can lead to the elimination of a third party in the supply chain. With fewer stages, transaction costs and time are expected to be reduced (Ward, 2017; Saberi et al., 2019).

2) Any changes to data are shared instantly, allowing for potentially rapid adoption of products and processes, not only saving time but also minimizing human error.

3) Demand for transparency within the supply chain from customers and government is increasing. From providing such transparency, early adopters can develop a competitive advantage (Ward, 2017; Saberi et al., 2019).

An excursus on use cases and a provider from practice can be found in the appendix (appx. 1).

Limitations

However, this promised added value is only truly realizable if certain, usually optimal conditions are fulfilled. Since reality does not yet offer optimal conditions, there are also limitations in the promising application.

Still, the technology is strongly criticized especially in the context of Circular Economy due to the high energy consumption by the PoW mechanism (Zheng et al., 2018). Here, a trade-off between resource efficiency and the consumption of energy, which can potentially be sourced from renewable sources, needs to be found. Blockchain-CE linkage may also involve an imbalance between short-term costs and long-term gains, so that a win-win situation cannot always be guaranteed (Kouhizadeh, 2020). In addition, the capabilities of the technology must also be properly deployed. If it comes to a deployment where the technology is built in the context of a business model that is not circular, the benefits of Blockchain may still be unleashed, but from a motivation that does not align with the goals of a Circular Economy. Pure eco-efficiency may not be the optimal underlying motivation for a Blockchain application (Esmaeilian et al., 2020). Lastly, the German Wuppertal Institut (2017) emphasizes that cycles should only be closed where they also contribute to resource preservation. With products that are not CE-oriented in design, a return to the supply chain can be problematic, since these are not always suitable for recycling.

3 Methodology

The research goal is to determine factors that influence the adoption of Blockchain technology in circular business development. This chapter will describe how this goal is approached methodically. Building on an extensive literature review on potential barriers and facilitators, a qualitative empirical study was conducted based on semi-structured interviews to analyze and evaluate the cases of companies from different industries.

3.1 Research Design

Exploratory study

The design of this research is of an exploratory nature. Exploratory research is particularly suitable for developing an understanding of a problem. The goal is to lay a foundation for further research and develop a basic understanding of a phenomenon (Saunders, 2012), instead of arriving at a final and conclusive solution. This approach turns out to be particularly suitable as there is no comprehensive literature or theories on the adoption of Blockchain in the context of Circular Economy based on practical experiences.

Qualitative design

Aligned with the rationale for an exploratory study, a qualitative approach is appropriate in light of the novelty of the topic (Kwon et al., 2014). At the same time, due to the novelty of the issue, there is not yet a sufficiently large sample of companies so that a representative quantitative statement could be made about possible influencing factors. In addition, factors that can support or hinder Blockchain adoption are mentioned in the literature, but the aim of this work is also to investigate the situation of companies in practice, to understand their behavior and to capture and evaluate their experiences with both the development of circular strategies and the application of Blockchain. These aspects can be covered particularly well with a qualitative research design (Gibson et al., 2004).

TOE framework

As a theoretical foundation and guideline, the Technology-Organization-Environment (TOE) framework is applied in this study to cover and classify the factors of adoption from multiple perspectives within a company's point of view. Especially in the context of the Circular Economy, questions arise not only about the complexity of the technology, but also about the influence of environmental factors such as regulations and the willingness of market participants to cooperate. The framework is particularly suitable for studying technological adoption at the firm level, taking multiple perspectives into account (Schmitt et al., 2019). Accordingly, the framework serves both as a basis for the literature review, on which the questionnaire is then based, and further as a basis for the qualitative content analysis.

Literature review and inductive reasoning

As a basis for the empirical study, a comprehensive literature review is conducted. The purpose of this is to get an overview of the factors that have already been presented and discussed in the existing literature. That is to ensure that this work builds on existing knowledge and that complementary insights can be gained. The results of the literature research do not only serve as a basis for the questionnaire, but also allow the comparison to existing literature and the empirical results of the qualitative research obtained here. Accordingly, an inductive approach is applied in a further step, the aim of which is to gain new practical knowledge from the collected data and to connect it with the existing literature (Saunders, 2012). An inductive approach is also suitable for smaller samples, which can then be examined precisely within their context (Saunders et al., 2009).

3.2 Case Study Research

Case studies are particularly suitable when a phenomenon is to be investigated holistically and the context of the research object is to be included in the analysis. Thus, this approach is especially suitable for the investigation of businesses (Yin, 2009). A multiple case study is particularly suitable in this topic area, as two issues are brought together here that must be considered in the respective context of the company, i.e., the industry, the position in the value chain, the type of products, and the general experience with novel technologies. Accordingly, potentially valuable and new information would not be captured by a quantitative or a pure cross-case analysis.

Case selection

For the selection of the cases, two criteria were set for the companies: First, they must be part of the movement towards a Circular Economy in one form or another. That includes all companies that are at the beginning or in the process of applying circular strategies such as returning resources by recycling, refurbishing or passing on materials for reuse, as well as companies that use recycled materials in their products or production, are eligible. Each of the ultimately selected companies is involved in think tank projects that address and develop circular strategies for German companies. This is relevant as an adoption of Blockchain in the context of circular business development can only be considered if there are at least long-term goals to move a company towards a circular business.
The second criterion for selecting companies was that they have to be a German company. The reason for this is that subsidies and regulations for both circular business and digitalization strategies can differ from country to country. The goal is to set a level playing field here and to exclude another level that can influence the decisions of companies.
Limitation to one specific industry was rejected, as there is hardly any differentiation in the industries in terms of blockchain application rate. There is no industry where Blockchain is applied heavily and then one where there is none at all. However, attention was paid to the diversity of the cases, so that one industry is not overly represented. In addition, the companies as a whole represent different positions in the respective value chains of the industries. From extraction of raw materials, to chemicals, metal processing, automotive supplier, OEM and a trading company.

The sample includes both companies that are already participating in pilot projects where Blockchain is used to drive circularity, as well as companies that are not yet adapters but could potentially be suitable. A total of 8 companies (see Table 1) were included in this study. All companies are classified as large enterprises based on the number of employees and turnover (OECD, 2021).

Table 1: Overview of companies in the case study sample

Case	Industry	Specification	Turnover	Employees
A	Manufacturer of building materials	Aggregates, cement, ready-mix concrete	> 17 billion	> 50,000
B	Manufacturer of connection and automation technology	Industrial automation, interconnection, and interface solutions	> 2 billion	> 17,000
C	Automotive supplier	Wiring systems, electrical and electronic components, interiors and battery systems	> 4 billion	> 75,000
D	Trade and service group	Retail, financing and logistics, and mail order	> 15 billion	> 50,000
E	Specialty chemicals company	Development, production and distribution of chemical intermediates, additives, specialty chemicals and plastics	> 6 billion	> 14,000
F	Provider of steel coating	Galvanizing and coating of steel applications	257.33 million (2018)	> 1,700
G	Automotive manufacturer (OEM)	Sports car manufacturer	> 28 billion	> 36,000
H	Chemical company	Chemicals, Materials, Industrial Solutions, Surface Technologies, Nutrition & Care, Agricultural Solutions	> 59 billion	> 100,000

When selecting the interview partners, one criterion in particular had to be fulfilled: The person must be in a position that enables him or her to have a good overview of the Circular Economy strategies that are being strived for or implemented in the company. In the request for the interview, the topic and the research interest were already presented in such a way that only people reported back who had a good overview of the company's strategy focus and could at least assess the advantages and disadvantages of a Blockchain application.
However, since this was not a set prerequisite and knowledge of the technology nevertheless varies, the questionnaire was structured in such a way that it allowed for an assessment on different aspects. An overview of the interview partners can be found in the appendix (appx. 2)

3.3 Data Collection

Semi-structured, open-ended interviews

In order to explore the factors influencing the adoption of Blockchain in companies, semi-structured interviews were conducted with one employee from each company. An interview guide is provided that is intended to offer a certain degree of standardization, but which allows for heterogeneity in the answers due to the open response options (Froschauer and Lueger, 2003).

Interview guide

The interview guide (appx. 6 & 7) primarily served the purpose of covering a wide range of influencing factors from different aspects. The guide was based on the literature review, in which factors from the literature were collected and structured according to the TOE framework. This procedure resulted in a list of factor categories and sub-factors. For example, a category in the technological context is "Compatibility", under which other sub-factors fall; in the organizational context, "Organizational culture" is an example of a category; and in the environmental context, the category “Cooperation” is an example. Since the sample consists mostly of companies that do not yet have practical experience with Blockchain in the context of circular strategies, it had to be assumed that without an interview guide many points could have been assessed because they are relevant but would not have come up during the interview due to a lack of structured questioning. It also had to be assumed that knowledge of the capabilities and risks of Blockchain Technology would differ among the interview partners. Therefore, the interview was structured as follows: The current state of research on the TOE contexts was briefly summarized and possible factors and their discussion in the literature were presented, so that the interview partner could comment on them if they appear relevant and bring in further aspects and empirical experiences.

Interview setting and process

The interviews were conducted via the videoconferencing tools of Zoom or Microsoft Teams. At the beginning, permission was obtained from the interviewee to record the interview and assurances were given that both the company and the interviewee would be presented in anonymous form. All but one of the interviews were conducted in German, as this was the native language of both parties, allowing for a fluent conversation.

Transcribing and translation

Following the interviews, the audio files were transcribed using the transcription program Amberscript. The program provided a good basis for the presentation of the spoken text, but a detailed revision was necessary, especially with regard to industry-specific terms. Furthermore, the company names and products mentioned were anonymized by assigning the companies to a letter. As soon as the transcript was available in German, the text was translated into English in a further step. However, the actual analysis was conducted in German. This is due to the fact that during the translation it was noticed that connotations, accentuations and language usages can get lost. In a last step, the results of the analysis were finally translated into English, because here it is only about the factors themselves and no longer about the interpretation of coherent sentences.

3.4 Analysis

Within-case analysis

In order to take the context of the different companies into account, a within-case analysis was performed. The aspects mentioned in the interviews were to be extracted for each company independently and classified in the TOE-framework. The analysis of the transcripts was done with software support according to Franklin et al. (2010) to ensure the highest possible reliability. The software used is called Atlas.ti.

Coding and analysis

Coding serves the purpose of categorizing a large mass of data and extracting the key messages (Recker, 2013). Accordingly, coding statements turned out to be an appropriate analysis tool to extract the factors from the transcripts. This approach does not strictly refer to thematic analysis. Clarke and Braun (2013) emphasize in their approach to thematic analysis that one of the common pitfalls of coding is to focus too much on the interview questions. Here, the right balance had to be found. On the one hand, the questionnaire is structured according to factors that are to be considered and thus also the answers, but on the other hand, an openness to extract new insights from the companies should also be maintained. The method of coding nevertheless proved to be necessary, since individual factors had to be filtered out of page-long transcripts, long nested statements had to be interpreted and broken down, and answers to one question were given in the context of multiple questions. Environmental aspects, for example, were also discussed in the context of questions regarding the organization. The coding process is summarized in Fig. 6 below.

In order to initially ensure openness to the data, preliminary codes were created in a first round of coding using data-driven coding (Kuckartz, 2019). In the framework, all aspects that influence the adoption of Blockchain in any way were summarized as code (e.g. No political push-factor or Missing business case). The coding was based solely on the interview transcripts without taking into account the literature research. After this round, it was evaluated which codes could be assigned to a specific context of the TOE framework and sorted accordingly.

In a second round of coding, more preliminary codes were created using concept-driven coding (Callari et al., 2019). In this framework, the factors of the literature search were used (here the literature findings serve as a form of concept), and it was checked whether factors in the transcripts had been overlooked and needed to be added. These were also assigned to the categories of the TOE framework.

In a third round of coding, the final codes were formulated. In this framework, preliminary codes were combined if they had the same meaning. Both concept-driven and data-driven work was done here. Concept-driven in the sense, that code formulations based on factors derived from the transcripts were compared with those of the literature research and adjusted. This should allow for consistency and thus comparability between the literature and the interview analysis. Data-Driven in the sense that the codes reflecting factors that shed light on a new aspect that hasn't been mentioned in literature were placed as final codes. With the help of the Atlas.ti software, it is also possible to refer back to the original text from the code. The result of the coding is an overview of factors, sorted according to the TOE framework, for which the company-specific context summarizes the reasoning and interpretation of the factor.

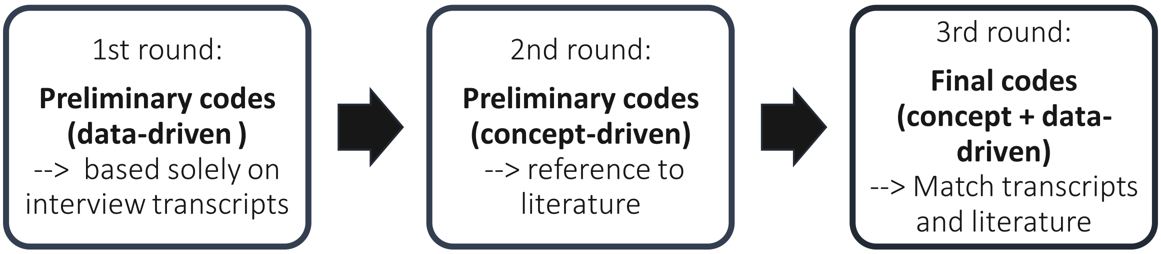


Figure 6: Overview of the coding process

Cross-Case analysis

When analyzing the individual cases, certain patterns emerge in view of all cases, which factors are mentioned more frequently, which observations are possibly shared and which aspects seem to be rather individual instances. In order to gain insights from the totality and diversity of the cases, a cross-case comparison was carried out. In this comparison, it was examined which factors were mentioned how often and in which cases, in order to be able to make a statement about a tendency of the importance of certain barriers and facilitators.

4 Literature Review

4.1 Search and Selection of Literature

In a next step, a comprehensive literature search is conducted. The purpose of this is to get an overview of the factors that have already been presented and discussed in the existing literature. That is to ensure that this work builds on existing knowledge and that complementary insights can be gained.

The aim of the literature review is to establish a sound basis for the questionnaire that serves for the qualitative interviews. The interview guidelines can be found in the appendix (appx. 6 & 7). Adopting BCT for pushing circular business strategies is a still a very new topic, that's why it is expected that the interview partners in the companies do not have a comprehensive view of all factors and respectively the knowledge about BCT varies. Therefore, the extracted factors from the literature search will serve to provide an overview of discussed barriers and facilitators and thus enable the interview partners to address the factors with regard to their company.

Keyword search

The primary keywords are derived directly from the research question. Accordingly, these are the terms "Blockchain", "Circular Economy" and "Adoption".
A total of 4 search streams (see appx. 3) with different keyword combinations were performed and evaluated collectively. This is mainly due to the fact that individual adoption factors are mentioned in the context of CE and BCT, but the papers do not directly use the term adoption in their title or abstract. Also, the term Circular Economy includes other subtopics that may be relevant. For example, some papers only deal with one strategy, such as recycling or waste streams in connection with some Blockchain application, but do not use the term Circular Economy. Therefore, synonyms and alternative terms were entered in a further search. The division into four streams is also useful for distinguishing which combination generates how many hits. Here, for example, it is apparent that the general term "Circular Economy" is discussed more in connection with Blockchain and less the individual strategies behind it, such as "Refurbish" or "Recycling". Only with regard to the keyword "supply chain" further relevant papers could be obtained. Also, the separate search for the combination of BC, CE and adoption shows how few research papers specifically refer to adoption.

Search platform

The digital database for scientific literature "Scopus" was used for the comprehensive search. As one of the world's largest databases, Scopus is suitable for literature searches of this kinds. One criterion was that journals covering topics related to Circular Economy are included in the database. Such as the Journal of Cleaner Production or the journal Resources, Conservation & Recycling. Use of the database search filters was made only with regard to language (English only).

Search results: Inclusion and exclusion

Including all four search streams, the search resulted in 478 records. In a next step, all titles and abstracts were scanned. All those were excluded that had no sustainability reference, had too strong a focus on another form of digitalization or another specific I4.0 technology, or focused too much on one function of the Blockchain (such as credit systems/ tokenising). A total of 428 papers were excluded by the exclusion criteria. Especially the search stream 2 produced too many papers that were not directly related to the topic.

Search stream 1 produced the most successful results with a total of 30 papers. In total 45 papers were downloaded and fully screened. In this step, 23 additional papers were excluded. On the one hand, this is due to the fact that the factors discussed are not sufficiently generalizable. This includes all those that are too specific with regard to a type of organization, a nationality or an industry. On the other hand, papers were also excluded that were too broad in terms of subject matter, i.e., that did not have a direct reference to businesses, but rather addressed transformation processes in general. Finally, duplications caused by the parallel search streams had to be removed. Using the snowballing principle and as a result of the references in individual papers, 5 additional records could be identified and added.

Finally, a total of 27 records were included in the synthesis (see appx. 4). All records meet the criteria of mentioning factors that can be interpreted as adoption barriers or facilitators in relation to use cases, pilots and literature reviews in the context of Ce or CE strategies or sustainable supply chains and Blockchain.

Background of literature sample

Out of these 27 records, 16 turned out to be particularly relevant, discussing a wide range of factors that simultaneously shed light on different aspects. Of these, 3 were published in 2019, 7 in 2020 and 6 in 2021. This again shows that the application and adoption of Blockchain in the context of Circular Economy is a new research field and can be explored in many ways. Alone 4 of the studies were recently published in the Journal of Cleaner Production and 3 more in 2019 and 2020 in the journal Resources, Conservation & Recycling.
The context of the studies differs little over the years. Most of the studies refer to the general concept of Blockchain as an enabler for Circular Economy, supply chain management, agriculture or manufacturing. However, in terms of methodology, a clear trend can be seen. The three relevant studies from 2019 follow a rather generic approach by implementing a framework, examine the research field critically or building grounded theory from case studies. 6 out of the 7 articles published in 2020 are based on a literature review. Accordingly, sufficient literature has already accumulated on Blockchain on the one hand and on Circular Economy on the other, so that both concepts and their linkage and application could be examined with the help of a literature review. The latest articles from 2021 supplement the literature review with expert interviews, examine use cases, or simulate Blockchain applications. Here, practical experience has been already evaluated and reference has been made to the first use cases. The possibility of programming Blockchains on a small scale and conducting a simulation also provides new insights into the application of Blockchain in practice.
However, only a handful of articles put their focus on the actual adoption in practice. The factors listed in this work were drawn from all 27 papers. None of the papers covered factor in all categories.

4.2 Extracting Adoption Factors

Having identified the relevant literature, the next step is to extract the relevant content. To do this, factors that are said to influence the adoption of Blockchain in the context of Circular Economy are to be filtered out and sorted.

The factor extraction process

First the full text of the papers had to be read and the factors that are being mentioned to be marked. The identified factors where then collected in an excel sheet and if available additional information on the barrier or facilitator was added. This procedure resulted in a list of 268 factors sorted by papers. Since the aim of the study is to highlight the three contexts according to the TOE framework the collected factors from literature are assigned to the areas of Technology, Organization or Environment. Tornatzky (1990) defines in his original framework further categories under the three contexts that supposed to influence the adoption of an innovation in a corporation. These categories were adapted, and the factors were assigned to the respective categories. Since the topics of Blockchain and Circular Economy are both nascent to the companies and the adoption question also generates novel aspects, additional categories had to be defined and formulated as appropriate. In total 92 factors in the Technology area, 86 factors in the Organization Area and 96 factors for the Environment area could be extracted from the literature. In a next step, the same factors or factors with the same meaning had to be merged. For these an overarching heading was formulated. This process resulted in a list of adoption barriers and facilitators each assigned to the areas of Technology, Organization or Environment (see appx. 5 for an overview of the process).

4.3 Extracted Barriers and Facilitators of Blockchain Adoption

In the following, the extracted barriers and facilitators of Blockchain adoption are presented sorted by the TOE framework. The abbreviation B stands for Barrier and F for Facilitator.

Technological Context

According to Rogers (1995) the technological context incorporates technical capability, complexity/ difficulty, and availability of the innovation that is considered for adoption. An additional factor category formulated in this specific context of the research field and based on the literature is compatibility.

Table 2: Factors in the technological context

Technological Context		
Factor-Category	B/F	Sub-Factors
Compatibility	B_T1	Integration challenges [1] [13]
	B_T2	High technology entry threshold [4]
	B_T3	Data transmission challenge [15]
	F_T1	Combination with other technologies [15]
Technical Capabilities	B_T4	Immaturity [3] [1] [56]
	B_T5	Security and privacy concerns [2] [14] [53]
	B_T6	Critical public image [44] [53]
	B_T7	No mechanisms against fraud [32] [3]
	B_T8	Undesirable features [44] [56]
	F_T2	Consensus mechanisms [32] [35] [3] [4] [9]
	F_T3	Data availability [35] [26] [32]
Complexity/ difficulty	B_T9	Lack of Interoperability of BC systems [11] [14]
	B_T10	High complexity of system design [14] [45]
	F_T4	Complexity reduction [6] [3] [12] [11]
Availability	B_T11	Accessibility and complexity [53]
	B_T12	Ownership and application [53]

Compatibility

Integration challenges (B_T1) i.e., the combination with other technologies that are already used in a company is seen as a possible barrier [13]. According to literature, Blockchain must be used in harmony with other existing systems and technologies as well as integrated with already existing traditional information management systems [1].
An additional factor is **High technology entry threshold (B_T2)**, since in addition to a functional IT, new software and hardware is also required [4], as this is not yet existing for such a new technology.
Data transmission challenge (B_T3) plays another role. Even if the hardware and software are available, the real world has to be connected with the digital world. Information about a product, material or substance must be digitally transmitted and fed into the Blockchain [4]. Data transmission therefore is a barrier when it comes to compatibility.
The factor **Combination with other technologies (F_T1)** serves as a facilitator, in which Blockchain Technology is seen as promising in combination with other technologies such as big data analytics or internet-of-things (IoT). If companies are already working or plan to work with other I4.0 technologies, the combination with Blockchain can contribute to seamless product traceability, authenticity and legitimacy [15].

Technical Capabilities

Even though the technological capabilities of Blockchain technology are exactly what make this technology so unique and relevant, individual capabilities pose a barrier to adoption.

One factor contributing to this is **Immaturity (B_T4)**. BCT is at an early stage of development and is considered as an immature technology (Yli-Huumo et al. 2016 [56]). This immaturity is particularly reflected in the system scalability and the capacity limits [1]. According to Shojaei et al. (2021), Blockchain Technology would have problems with processing a large number of transactions and storing increasingly large blocks. Thus, the problem of storage capacity is a challenge in the implementation of the technology for life cycle assessment, which deals with large amounts of data [1].

The fact that the technology is not yet fully mature can be seen as an obstacle in the adoption [1]. Another factor that makes technical capabilities a potential barrier, is **Security and privacy concerns (B_T5)**. The main concerns here are related to privacy and security of the decentralized digital system [14] [53]. Even though Blockchain Technology promises to secure the anonymity of users, the security of consensus algorithms is still a concern [2]. Privacy is particularly important in the entrepreneurial context, where many actors are competing with each other. Therefore, maintaining a certain level of privacy is an existing challenge [53].
This also directly relates to the next barrier, the **Critical public image (B_T6)**. Here, reputation [44] and trust in the technology [53] play the main role.
The public image and perception of Blockchain technology is not flawless. However, image plays a major role in the acceptance of a technology. Individuals may associate Blockchain technology with cryptocurrencies such as Bitcoin [44]. High volatility of the financial value of cryptocurrency reduce the general trust of the public in the technology behind it [53]. At the same time, this system has also already been hacked. Therefore, companies may be hesitating in adopting Blockchain technology in general [44].
Fraud (B_T7) addresses a problem that cannot be solved by the technical capabilities of the Blockchain. Also referred to as the “last mile problem”, is the fact that the output can only be as strong as the input. The authentication of data cannot take place via technology [3] and therefore presents a potential barrier. Verifying the accuracy of the data uploaded to the

platforms is a challenge as fraud cannot be fully avoided [3]. In terms of sustainability reports that are built on the data layer in a Blockchain, this can mean that if the tracking of sustainability information is not easy to verify that inaccurate sustainability data will result [32].

Additionally, there is the factors of **Undesirable features (B_T8)**. Even if the features are the strength of the technology, the feature "immutability" is also discussed critically [44] [56]. Immutability ensures that records cannot be removed from the ledgers once they are added. However, this also means that if a flawed record is entered into the Blockchain, that flawed record will always be present in the Blockchain [44].

On the other hand, as illustrated above, the technical capabilities of the technology are the strongest facilitator for adoption in companies when it is fully matured and optimally implemented. One factor that supports this is the **Consensus mechanisms (F_T2)** factor. Due to these consensus mechanisms capabilities of traceability and immutability [32], transparency and trust [35], availability [3], security [3] [4], tracking [9] and reducing fraud [9] are to be enabled.

Another factor that represents technical capabilities as a strength is **Data availability (F_T3)**. This facilitator is a result of improved data collection and management [35], increased information sharing, and increased data availability [26] [32]. Blockchain technology can facilitate a system for storing data on local and global product and material flows [35]. Through a Blockchain, quality, quantity, location, and ownership can be collected and retrieved at any point in time. This would ensure traceability and identification of the supply chain of products and materials [32].

Complexity

The factor **Lack of interoperability of BC systems (B_T9)** can pose a barrier. Having existing systems operate smoothly with each other is not necessarily guaranteed. However, according to Dutta et al. (2020), it is of great importance that different Blockchain based systems interoperate flawlessly and are standardized if used parallelly in different corporations or units. Otherwise, running the systems becomes increasingly complicated and hinders the simplification of processes [11].

This is compounded by the factor of the **High complexity of the system design (B_T10)** itself.

Not only is the convergence of different systems a challenge, but the technology and its design are inherently complex. Blockchain complexity can be expressed in terms of process efficiency, usage, and system functionality. If the perception of complexity is too high, it will lead to lower adoption. Swan (2015) confirms that the perception of Blockchain complexity is very high [45]. In addition, the system itself is also complex in terms of programming and requires a high level of skill [14].

On the other hand, the factor of **Complexity reduction (F_T4)** can pose as a facilitator in this category. Once established, BCT promises to reduce complexity. This is supported by the fact that there is no longer an intermediary [6], the system is a decentralized one [3] [12 [11], and there is increased flexibility [12].

Availability

To this category the factor **Accessibility and complexity (B_T11)** adds to possible barriers. Kamilaris et al. (2019) illustrate that Blockchain needs to become more accessible, but this is a major challenge. This is also related to the increasing complexity as more and more components are integrated into the underlying technology (IoT, RFID, robots, biometrics, Big Data, etc.) [53]. Even if the decision is made to apply the technology despite the high level of complexity, the **Ownership and application (B_T12)** factor represents a further barrier. For example, there is the question of who should own the Blockchain (Pearson et al., 2019), whether it should be permission-based or permission-free or closed. All these questions have an impact on who has access to a Blockchain and from whom the initiative to initiate a Blockchain systems comes from [53].

Organizational context

According to Tornatzky et al. (1990) the organizational context incorporates factors and issues related to internal focal firm concerns. Such are Top management support, Data driven organizational culture, Perceived cost and Industry type. Additional factor categories formulated in this specific context of the research field and based on the literature are Resources, Personnel, Ce design decisions and Application.

Table 3: Factors in the organizational context

Organizational Context		
Factor-Category	B/F	Sub-Factors
Perceived cost	B_O1	High costs [1] [8] [11] [44] [52] [2] [14] [6]
	B_O2	Unclear relative advantage [45] [52] [11]
	F_O1	Cost savings [2] [4] [8] [3] [26]
Data driven organizational culture	B_O3	Resistance to change [3] [11] [44] [6]
	B_O4	Adjustment effort [9] [12]
Personnel	B_O5	Lacking new Personnel [1] [11] [44] [14]
	B_O6	Unskilled existing Personnel [4] [8] [21] [44]
Resources	B_O7	Lack of resources [4] [44]
Top management support	B_O8	Lack of management commitment and support [44][21]
Industry type	B_O9	Property rights [21] [12]
	F_O2	Reputation [4]
	F_O3	Cross-company application [2]
Application	B_O10	Challenging BC design decisions [21] [53] [44]
CE design decisions	B_O11	Challenging business development [2] [11] [44]

Perceived cost

High costs (B_01) can pose a barrier, being composed of high development costs [1], high technical infrastructure setup costs [1] [8] [11] [44] [52], and data storage and processing costs [1], as well as high upfront investment [2] [14] [6]. The implementation process includes design, development, deployment, migration, maintenance, and upgrade. Development costs can be very high in this process [1]. Significant investments in software and hardware are also required at the beginning [1]. Expertise needs to be invested for setup and operation [2] [11]. Blockchain is thus costly for the company and system partners, not only for the technology, but also for the supporting staff and process infrastructure [44] [52].
In addition, another inhibiting factor is the **Unclear relative advantage (B_O2)** of such high investment costs. In the context of the Circular Economy, there is a question of relative benefit, between investment and profit. Not all companies are yet significantly affected by sustainability issues. As a result, the development of closed-loop supply chains is not a top priority across the board. Companies would not invest in networks that do not yield a profit [52]. In addition, the technology is not yet fully mature and there are also regulatory uncertainties, so that a company must weigh the economics of implementation in terms of costs and risks [11].

On the other hand, the cost factor can also be a motivator to adopt. Indeed, **Cost savings (F_O1)** promises the enormous savings potential offered by Blockchain Technology once the initial investment has been made. Here, the main aspects are efficiency improvement [2] [4] [8], time reduction [2], cost sharing [3] and eco-efficiency [26]. By linking the distributed ledgers, databases, and actors in the supply chain, efficiency can be increased, time can be saved, and thus costs can be reduced [2]. Lastly, however, the crux with regard to Circular Economy also lies in the economic-environmental win-win opportunities through which eco-efficiency can be increased [26].

Data driven organizational culture

Organizational culture is primarily a barrier to the adoption of Blockchain. One factor here is **Resistance to change (B_O3)**. In addition to general resistance [3] [11] [44] [6], these include lack of trust [3], lack of understanding [11], as well as uncertainty and conflicting interests [11]. The implementation of a decentralized digital system such as Blockchain would entail enormous changes in the existing company. Changing mindsets and working methods involves many stakeholders, among whom conflicting goals may arise as well as reluctance to adoption stemming from uncertainty and fear of job loss [11] [44].

An additional factor is the **Adjustment effort (B_O4)**. As soon as Blockchain is to be introduced and applied, the new data volumes and flows must be dealt with. Due to the masses of data, novel data-driven decision-making is required [9] [12]. In addition, not only is usable new data being built upon, but potentially a lot of useless, incorrect, and erroneous data is in circulation. Based on this, new software tools and data reasoning techniques are needed to analyze the data in an effective way to be able to interpret results and extract decisions in a short time [9].

Personnel

Lack of new personnel" factor (B_O5) as a barrier refers to the unmet need for technical expertise to implement and use Blockchain [1] [11] [44]. Companies lack skilled workforce [14], technical expertise, and also sufficient knowledge about sustainable supply chains [44].

The factor **Unskilled existing personnel (B_O6)** underlines the fact that not only new personnel must be brought into the company, but that existing personnel also lacks knowledge about the technology. This factor is related to lack of training to use BCT [4], increased need for skills [8], lack of knowledge [21], and also lack of understanding [44]. According to [44], there is a lack of comprehensive understanding of Blockchain in enterprises, which hampers its implementation. Especially in connection with the range of subjects around Circular Economy, there is a growing need for knowledge and experts. Inexperience with the technology, combined with a new organizational practice such as the Circular Economy, has a negative impact on perceived ease of use [44].

Regardless of the personnel, **Lack of resources (B_O7)** comes into play. According to this, there is a lack of standards and appropriate methods, tools, metrics and techniques for implementing Blockchain technology and measuring sustainability performance in organizations [44] [4].

Top management support

Top management support (B_08) is essential for the adoption of Blockchain technology. Accordingly, the lack of commitment from top management can lead to problems. Especially for risk-averse companies, this factor represents a major barrier. This is in partly due to the fact that some managers lack the long-term commitment to support sustainability practices and the adoption of disruptive technologies [44] [21].

Industry type

The Type of Industry can be a barrier with regard to the factor **Property Rights (B_O9)**. Transparency of information and sharing of protected information in Blockchain can lead to challenges for various existing privacy policies related to data use and sharing between partners [21] [12]. According to Leng et al. (2020) the lack of a mechanism for collaboration between partners with different operational goals can be a barrier to implementing and operating Blockchain to achieve closed-loop supply chains [12].

However, depending on the industry, factors such as **Reputation (F_O2)** and **Cross-company application (F_O3)** can play a supporting role. Thus, a circular approach enabled by Blockchain can increase a company's competitiveness by, for example, increasing resource efficiency, saving overall costs, and lastly, improving the company's reputation and minimizing its environmental impact [4]. The latter factor is aimed at cross-company application. In the automotive industry for example, Blockchain can be used not only to track and trace their products, but also to advance automated driving technology [2].

Application

The factors **Challenging BC design decisions (B_O10)** includes both the initial steps in the implementation and the design in the actual application. For example, agreeing on the platform type is a major problem [21]. Platforms for managing products and materials can be designed in different ways. For example, a key issue at the outset is whether all Blockchain participants need access to all supply chain information [44]. Design decisions must be made repeatedly at the beginning and during use, as there is no one perfect solution to buy. However, these decisions impact the operation of the Blockchain system, leading to some lack of flexibility [53].

Another challenge results from the design towards circularity, which is shown in the factor **Challenging business development (B_O11)**. This includes reconfiguration of the business model [2], a lack of digital infrastructure [11] and different standards [44]. In order to transform a business and with this the supply towards circularity not only the introduction of a new type of technology is required, but also business models need to be rethought and reconfigured [2]. However, a major challenge is also the lack of standardization. Closing the loop of a long supply chain requires information to be exchanged via a platform. Since each company has its own standards for both the use of technologies and security aspects, there may be difficulties in establishing connectivity and intersections between the companies [44].

Environmental context

According to Tornatzky et al. (1990) the environmental context includes factors related to the regulatory environment, industry characteristics, competitive pressure and the linkages among firms (referred to cooperation in this work). Additional factor categories formulated in this specific context of the research field and based on the literature are Customer pressure, Standards and Business relationships.

Table 4: Factors in the environmental context

Environmental Context		
Factor-Category	**B/F**	**Sub-Factors**
Competitive pressure	B_E1	Undesired Codependency [1] [2]
	B_E2	Not reaching a Critical Mass [3] [44]
	B_E3	Fierce competition [4] [27] [44]
	B_E4	Lack of CE-oriented products [27] [56]
	F_E1	Imitation effect [26] [45]
Cooperation	B_E5	Inhibition through Codependency [3]
	B_E6	Alignment challenges [4] [21][44] [52] [54]
	B_E7	Resistance [14] [6] [11]
	B_E8	Integrity concerns [11] [14] [32][15] [6]
	B_E9	Lack of collaboration [14] [26] [44] [56]
	F_E2	Cost sharing [3]
Government regulation	B_E10	Lack of regulations [11] [44] [14] [21] [6] [1]
	B_E11	Laws as roadblock [11] [21] [9]
	B_E12	Lack of incentives [44]
	F_E3	Compliance and audit [2] [8] [53][15]
Standards	B_E13	Lack of common standards [21] [26] [35] [44] [56]
Customer pressure	B_E14	Lack of demand and awareness [12] [56] [44]
	F_E4	Ensure product quality [2] [40]
Business relationships	F_E5	Improved business relationships [2] [6] [8] [12] [27]

Competitive pressure

Undesired Codependency (B_E1) relates to the principle of coopetition, i.e., simultaneous competition and cooperation within a Blockchain in the Circular Economy that can lead to undesired co-dependencies and thus conflicts and issues of trust [2]. According to Yildizbasi (2021) transparency and traceability via the database may be seen as a problem by some partners.

Another critical factor is **Not reaching Critical Mass (B_E2)**. With a certain mass that has had experience with an innovation, an initial learning curve can be formed [3]. However, according to Yildizbasi (2021), there is currently a lack of experience with implementing such large-scale applications. At the same time, Kouhizadeh and Saberi (2021) notes that there is a lack of industry commitment to safe practices in sustainability and Blockchain technology. Accordingly, a lack of sufficient experience in industries may be a barrier to adoption.

This phenomenon is closely related to the factor **Fierce Competition (B_E3)**. This includes conflict of interest [4] and lack of trust [4] [27] [44]. Organizations consider sharing their data critically as they view information as a competitive advantage (Wang et al., 2019b) [44]. The strong competitive mindset leads then to the emergence of conflicts of interest, making the required collaboration a major challenge [27].

Another factor revolves around the products that are on the market and with which a company is connected through the supply chain. The factor **Lack of CE oriented products (B_E4)** can be a barrier. The adoption of Blockchain is being considered with the belief that it can drive Circular Economy. However, not in every industry and sector do companies deal with circular products. Some products, for example, cannot be disassembled or recycled [27]. Not only is transforming the linear supply chain a challenge, but current technologies, designs, and materials must be improved according to Circular Economy criteria [56] to truly realize the potential of a Blockchain.

Finally, the factor **Competitive pressure (F_E1)** can also act as a facilitator. As soon as a certain number of players in the market or the direct competitor of a company has made positive experiences with Blockchain for circularity, these practices can also increase the pressure in a positive sense and lead to imitations and fast followers [26].

Cooperation

Inhibition through codependency (B_E5) can pose as another barrier. While cooperation is a prerequisite for a functioning Circular Economy and thus for the adoption of an enabling technology, it is also a condition that all players must use the system for it to fulfill its function [3]. However, this is a major challenge.

One of the biggest challenges and barriers is represented by the factor **Alignment Challenges (B_E6)**. These include aspects such as lack of alignment [4], lack of overall consensus [21], accessibility issues [44], geographic differences [44], managing different data [52], and heterogeneity [54]. A problem already mentioned, is the lack of coordination between systems of different organizations [4]. However, bringing together different stakeholders is also a challenge. Different stakeholders have their individual perspectives, with different definitions of Blockchain functions and elements as well. According to [21] the lack of a general consensus on Blockchain is a key barrier to its adoption [21]. However, there are also fundamental concerns about the accessibility of Blockchain. It is not clear whether the IT infrastructure will be accessible to all Blockchain stakeholders. The IT infrastructure may be inadequate in some supply chain organizations [44]. In addition, there are cultural and geographic differences among supply chain partners. These may also hinder the adoption of Blockchain technology [44].

Thematically, this is also related to the topic and thus to the factor **Resistance (B_E7)**. These include resistance to Blockchain culture [14] and reluctance of sharing information [6] [11].

Accordingly, convincing all stakeholders to share information is a challenge. Organizing such large amounts of data and using it efficiently is a problem [11].

In addition to resistance to innovative technologies, **Integrity concerns (B_E8)** also plays a role in collaboration. This includes fraud [14] [32], data manipulation challenges [15], and false initial information [6]. Once the digital network is established and all key players are integrated, information can be easily shared via the Blockchain, but the integrity of input data is not guaranteed [11]. Since the Blockchain-based system has no control over the data that is fed into system, it may lead to unreliability of data [14] [15] [32] and thus weakening the willingness to collaborate.

However, this willingness is absolutely necessary. Another barrier is therefore the factor **Lack of cooperation (B_E9).** A high level of collaboration in the supply chain is imperative to fully realize the benefits of Blockchain implementation [26][14]. However, collaboration can be hindered by a lack of cooperation and coordination among actors with different goals and incentives [44]. All of these factors lead to less cooperation, hindering the circularity of supply chains, and thus inhibiting the potential of Blockchain technology.

One factor on the other hand can be a supporting factor and that is **Cost sharing (F_E2)**. Cooperation has the potential to reduce the overall cost of initiating and maintaining the technology [3].

Government regulation

Lack of regulations (B_E10) includes the lack of clear laws and regulations [11] [44], the lack of regulatory concerns [14] [21] [6] [1] as well as regulatory uncertainty [14].

Since Blockchain technology is still very new and also still under development, there are no clear and defined regulations on the rules of implementation and application yet. In addition, the adoption of Blockchain technology certainly varies from one sector to another [1]. [14] even highlights that most countries are not yet ready for Blockchain adoption and therefore do not have regulations in place. This leads to uncertainty among stakeholders due to the lack of appropriate laws for adoption [11].

At the same time, regulations can also become a barrier, which is reflected in the factor **Laws as roadblocks (B_E11)**. Laws can often become a barrier to innovation and thus also with regard to Blockchain. As a result, the need to involve government agencies for compliance with rules and regulations in the development of new Blockchain-based solutions is steadily increasing [11]. Regulations are needed, but they must be based on practical experience and needs. If government regulations and policies are not carefully considered, it will increase barriers to adoption rather than limit the challenge [21].

The reluctance of governments to regulate can also be applied to the introduction of incentives. **Lack of incentives (B_E12)** is another barrier to Blockchain adoption. A problem with promoting sustainable practices and Blockchain technology is a lack of rewards and incentives. Reward systems have the potential to help ensure data integrity and increase the willingness to share data [44].

On the other hand, the factor **Compliance and Audit (F_E3)** is the facilitator in this category. This includes the support of climate neutrality [2], compliance with safety standards [8], mitigating fraud [53] and monitoring [15] [53]. For example, a distributed carbon ledger is proposed to link carbon asset management with carbon trading systems to control greenhouse gas emissions [2]. In addition, life cycle assessments based on data in a Blockchain can help a company to review and improve the monitoring and management of the sustainability performance of their supply chain activities. This can also minimize the risk of green washing [15].

Standards

Lack of common standards (B_E13) could be identified. This includes the lack of policies [44] as well as differing policies [56]. To avoid conflicts and ensure data quality, Blockchain application at the inter-firm level requires overarching defined standards and effective governance structures [26]. Currently, however, these standards are lacking, leading to regulatory concerns and making Blockchain technology seem like the "Wild West" of emerging technologies [21].

In waste management alone, for example, there are hundreds of waste types that are categorized differently by each state [35]. Lack of guidelines for information sharing raise questions about how much and what type of information should be shared [44]. In addition, not only the lack of guidelines, but also the existence of different guidelines regarding the use and release of information and data in supply chains if a hurdle [56].

Costumer pressure

The factor **Lack of demand and awareness (B_E14)** refers to consumer demands for sustainable and safe products [12]. Investing in an innovative technology to drive Circular Economy is only

profitable if there is a demand for circular products and their quality proof in the market. Accordingly, the uncertainty of demand for sustainable products can affect market competition (Kaur et al. 2018) and hinder the integration of sustainability and Blockchain technology [56]. Organizations need to ensure that their investment on green products, sustainable processes, and a new technology like Blockchain would be compensated by their customers" [56, p. 2126]. Potential uncertainty about demand for products created by a Blockchain-based Circular Economy can be a barrier to adoption [44].
Lastly, the factor **Ensure product quality (F_E4)** includes the proof of quality and the provision of information and thus acts as a facilitator. Accordingly, Blockchain enables to warrant product quality and clean production beyond local and global boundaries [2]. Especially in the B2B sector, Blockchain technology and its output can help provide customers with sufficient information about quality and quantity, and thus facilitate the marketing of circular products [40].

5 Case Study Analysis

In the following chapter, the interviews with the representatives of the companies are summarized and evaluated. First, the individual cases are presented by analyzing the most important factors and then (within-case analysis). In a further step, the most frequently mentioned factors of all eight cases are presented and discussed (cross-case analysis).

5.1. Within-Case Analysis

Preliminary the companies, their business case, their approach to Circular Economy and their view on Blockchain Technology and its potential are presented. In a further step, the factors that turned out to be most relevant for the case are presented. The total number of factors mentioned in each case, together with their description, can be found in the appendix.

5.1a CASE A

	Manufacturer of building materials
	Aggregates, cement, ready-mix concrete
Employees: > 50,000; Revenue: > 17 billion; Locations: > 50 countries	
BCT Application: ● Non-Adopter O Early-Adopter	

Background Information

The business of Case Company A

Case A is a manufacturer of building materials and specializes in the production of aggregates, cement and ready-mix concrete. As a cement supplier, the company is thus at the beginning of the value chain of the construction industry.

Circular Economy Motivation and Approach

The initial situation of the company represents a linear business model. The cement industry counts as a heavy industry, and the focus in terms of innovation and sustainability has long been on the process technology (the kiln line). One motivation to push the topic of Circular Economy in the company is to decrease emissions that are generated in cement production both during quarrying and through firing limestone and burning cement. Another motivation is the issue of resource efficiency. A reorientation is seen as indispensable, as the areas suitable for new mining sites are steadily decreasing: *"It is becoming more difficult to open up new sites also in ten years' time"*. According to the interviewee, the urgency for the company results from classic issue management, meaning scarcity of resources poses an increasing threat to the company. Additionally, acceptance in society towards raw material mining is decreasing. As a concrete measure, the company is planning to break down concrete demolition in a more efficient way by avoiding down-cycling processes, thus natural sand and gravel is saved.

The current role of Blockchain

Blockchain technology does not play a role in terms of a circular supply chain yet. However, the development and use of the technology is being watched intensively. The starting point for a potential use is data availability in terms of potential sources of raw materials as cities or built-up areas can be an alternative source of raw materials. For that, tracing back information such as composition and quality of concrete in old buildings is crucial.

Potential of Blockchain

The potential of BCT is seen primarily in the networking of various data points. The acceptance for raw material mining is going down and the shortage of raw materials is increasing. The company wants to approach this issue from the technology side. Statistical data on waste flow reports lack access. *"How do we secure raw materials and information about the raw materials that are out there in the world?"* That's where digitization could massively assist in solving these blind spots. From the interviewee's point of view, BCT is an enabler that leads to having better information and being able to work out better business models based on it. The technology is seen as a long-term opportunity rather than a short-term risk.

Perceived Barriers

In total 12 barriers (appx. 11) for the application and adoption of Blockchain could be found in the categories of Compatibility and Technical Capabilities, Perceived costs, Organizational culture, Application and CE design decisions and finally Government regulations, Standards and Customer pressure. Seven of the most prominent factors are presented in the following:

Technology	Organization	Environment
- Integration challenges - Data transmission challenges	- Unclear relative advantage - Challenging BC design decisions - Challenging business development	- Lack of regulations - Lack of demand and awareness

Integration challenges

The integration of Blockchain with existing programs is seen as a challenge. First, interface management poses a challenge as Blockchain must correspond well with software systems such as ERP systems. Second, the transfer of historical data poses a challenge. The process can be very time-consuming as diverse and sensitive data is involved. Integrating historical data is relevant for tracking the development of a plant's performance, i.e. in terms of CO_2 emissions or energy efficiency.

Data transmission challenges

To enable a flow of data in the Blockchain, real data must be converted into digital data. A challenge for the company is that there is no available data on the built-in environment, including what has been built and what the quality of the materials is, in order to decide how to reuse them. Since the company itself is not active in demolition or deconstruction of buildings, this presents a barrier: *"Actually, you have to send people out now to have them look at the built environment and collect data."*

Unclear relative advantage

Unclear relative advantage refers primarily to the fact that it is assessed as difficult to guarantee economic profitability. Company A acts as an economic enterprise for which, at the end of the day, there must be an added value from an investment. Generating profits is the key point where it all rises and falls. Even though Blockchain, according to the interviewee, improves the data situation in a world with incomplete information and one can actually only benefit from it, the financial advantage is not without doubt.

Challenging BC design decisions

When it comes to the factor of how a Blockchain application can be designed, the challenge of the first steps and the strategic relevance play a role for company A. According to the interviewee, it is not a question of whether to use Blockchain or not but rather to decide on the specific project to start with. Also, whether to make a hard cut and accept the loss of historical data or to run a parallel system. Another issue is the attribute of relevance, i.e. the decision whether the application should be based on a project or whether it should be developed into a strategic implementation.

Challenging business development

For the interviewee it is not so much the complexity of the technology that is seen as a challenge, but much more the complexity of the transformation to a Circular Economy. Even though technology is seen as an enabler in this case, it is still a challenge to move from a linear to a circular business model. As the conventional business model is still more favorable, the company faces conflicting goals. While the integration of Blockchain for Circular Economy is seen as an opportunity to open new business areas, the question remains where revenues are managed and then possibly shared in an integrated concept.

Lack of regulations

The interviewee refers to lacking requirements in the area of EU taxonomy and corporate reporting, but also to the contradiction that conventional dismantling processes in the cement industry are still more favorable than dedicating oneself to recyclates, partly due to the lack of regulations. The question of what information can be provided, in what form and how it can be shared is open as well. These are all questions that are considered to be insufficiently regulated.

Lack of demand and awareness

The lack of demand and awareness is seen as a barrier. Cement quarry is currently mainly used for down-cycling. This process is still the cheapest way and therefore predominant. Additionally, in the cement industry, standardized mass products are offered. Thus, the purchase decision is still predominantly price based. *"Whether they buy a product from my direct competitor doesn't matter to the customer, the stuff will work. Accordingly, price is actually the differentiating factor for the customer's buying decision."*

Perceived Facilitators

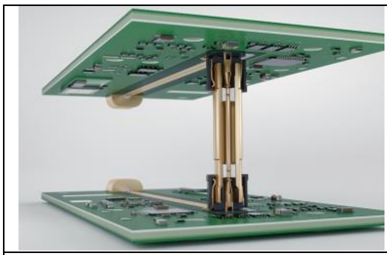
Complexity reduction

According to the interviewee, the complexity of technology is less of a challenge than the complexity of reality. The view is that digitization and Circular Economy go hand in hand. Though Circular Economy is seen as the more complex issue. *"I would say the complexity of the technology is now a barrier to approaching the topic from that point of view. I see it more as an opportunity to manage the complexity in the real world."* The complexity of Blockchain is acknowledged, and the fact that it will take experts to implement, but at the same time the technology is seen as a way to bring actors together in reality and track materials.

Compliance and audit

With the expectation that the European Commission will tighten the requirements for sustainability reporting and that data on issues such as circularity must be retrievable, BCT is attractive as a support for compliance and audit. At the same time, it is seen as a way to improve the auditing workflow: *"If I can just drag that, that's better than if I have to call five people and then somehow blend North American data with Asian data with European data and then somehow make a spreadsheet for myself via Excel."*

5.1b CASE B

	Manufacturer of connection and automation technology Industrial automation, interconnection, and interface solutions
Employees: > 17,000; Revenue: > 2 billion	
BCT Application: ● Non-Adopter ○ Early-Adopter	

Background Information

The business of Case Company B

Company B is a manufacturer of connection and automation technology and specializes in industrial automation, interconnection and interface solutions. As a supplier with a product portfolio of 60.000 connection and interface parts, the business is located in the center of several value chains, sourcing from raw material suppliers and supplying to markets in the automotive industry, renewable energies and infrastructure.

Circular Economy Motivation and Approach

The company's business model is currently based on a linear structure. Though, the management of recycling cycles is already high on the agenda using tools like Product Lifecycle Management systems (PLM). The importance of recycling materials is rated as relatively high by the interviewee, especially in the future. The challenge in closing material flows is primarily associated *with* lacking information about the complex composition of electronic products. Returning materials for recycling is also a major challenge due to the high dispersion of customers. The chain of traceability breaks as products are shipped to diverse customers worldwide. *"With the products that leave our company boundaries, that's when the chain of recyclable material ultimately breaks. We then no longer know what happens to our products, end of life."* Accordingly, the active control of traceability also involves a great deal of effort and a lot of manual intervention.

The current role of Blockchain

Company B is not applying any kind of BCT yet. However, according to the interviewee, a digital exchange already exists with the company's own suppliers and also with customers. Here, mainly classic platforms that are established on the market are used. The next step is currently to further expand, simplify and intensify the digital exchange via the digital identification plate.

Potential of Blockchain

The idea of expanding the Circular Economy with the help of the digital twin is assessed as a kind of precursor to the Blockchain. The digital twin in the supply chain has the importance of providing the information about further processing of all recyclable products and materials in the first place. From the interviewee's point of view, the topic of Circular Economy can only be mastered digitally in the future, as the complexity and also the effort in the daily business is far too great. especially as a manufacturer of hundreds of thousands of products, which are also configurable.

Perceived Barriers

In total 10 barriers (appx. 12) for the application and adoption of Blockchain could be found in the categories of Compatibility and Availability, Personnel and CE design decisions and finally Competitive pressure, Cooperation, Government regulation and Standards. Five of the most prominent factors are presented in the following:

Technology	Organization	Environment
- Application and ownership	- Lack of knowledge - Challenging business development	- Inhibition through codependency - Lack of common standards

Application and ownership

Initiating a Blockchain application is hardly seen as reasonable, since the development is triggered by the companies that are larger than Company B. *"There we are dependent on them having the same conviction, so to speak, and jumping on the same bandwagon."* Even if the integration of Blockchain is considered impossible at the moment, the interviewee shares the opinion that large companies can overcome the integration hurdle if they ambitiously design solutions. Adding to this, there's the global diverse customer base, which has different requirements for information. Company B would not consider itself able to meet the requirements simultaneously, or to build Blockchain networks for 20 different industries.

Lack of knowledge/ awareness

"The main problem for us in the company is lack of knowledge." This lack of knowledge relates to both the topic of the Circular Economy and the topic of Blockchain. Apart from the topics of sustainability and Circular Economy, other topics have been prioritized for a long time, so the company is still relatively at the beginning of the process. As part of the sustainability activities, the company is only in the process of establishing this in IT and also in the corresponding product development areas. *"With digitalization, people have thought about all kinds of things, but not about the exchange of material information."*

Challenging business development

The topic of the Circular Economy has to be brought into focus even more and more competencies have to be built up. It is seen as necessary to initially link IT with the topics relating to the Circular Economy. According to the interviewee, deficits exist when it comes to displaying material information in their IT systems. Both topics must first be linked across the company. An application and the examination of Blockchain is only feasible once more foundations have been laid with regard to sustainability.

Inhibition through Codependency

A certain dependence on the cooperation partners represents a barrier. Company B is therefore dependent on the larger companies using Blockchain applications. In addition, there is the great dependence on the customers. The few big players in the industry are seen as the drivers, on which then also the adoption in the own enterprise depends.

Lack of common standards

Common standards are seen as the basis for the exchange of material information and thus for circular business strategy. However, there is a lack of German or EU-wide standards for this. Even within individual industries there are no uniform standards. The prerequisite for Blockchain adoption, according to the interviewee, is to agree on an open-source code. *"Because if everyone does their own thing again, then unfortunately and I have to underline this unfortunately, it's doomed to fail from the start."*

Perceived Facilitators

Complexity reduction

Even though the complexity of the technology is relatively high the technology can be seen as offering help in reducing complexity. *"I believe that you can significantly reduce complexity with the digital twin and Blockchain."* Blockchain, however, is not seen as the solution, but as the implementation, while the digital twin is the prerequisite.

Ensure product quality

The possibility of proving the quality of products is also seen as a facilitator. On the one hand, to pass on the composition from the products to the customers, but also to remain credible in the public eye. A technology is seen as particularly suitable for providing proof that cannot be disputed.

5.1c CASE C

<table>
<tr><td rowspan="2"></td><td>Automotive supplier</td></tr>
<tr><td>Wiring systems, electrical and electronic components, interiors and battery systems</td></tr>
<tr><td colspan="2">Employees: > 75,000; Revenue: > 4 billion; Locations: 20 countries</td></tr>
<tr><td colspan="2">BCT Application: ● Non-Adopter ○ Early-Adopter</td></tr>
</table>

Background Information

The business of Case Company C

Company C is an automotive supplier and specializes in wiring systems, electrical and electronic components, interiors and battery systems. As an automotive supplier the business is located in the center of the value chain, sourcing from raw material as well as components suppliers and supplying to OEMs in the automotive industry.

Circular Economy Motivation and Approach

The company is currently based on a linear business model. The company aims to enforce Circular Economy approaches such as product disassembly and recyclability in all areas of the business. The main motivator behind the Circular Economy program, is to generate profits with sustainable products. **"***A sustainable product has many dimensions, and that's where Circular Economy principles are just the vehicle to get there."* The company's internal interest in the Circular Economy is primarily to increase efficiency. The challenge for Company C, however, also lies in the comprehensive availability of data. If the objective of **"***climate-neutral products made in Europe"* is to be achieved, it must first be proven that they are better than alternative cheaper products from abroad. This requires an extremely precise database covering the entire supply chain.

The current role of Blockchain

Blockchain technology has not yet been applied in the context of Circular Economy approaches. The company is working on the digital twin where many issues are digitally stored. Accordingly, comprehensive information from the upstream supply chain is already stored in digital form.

Potential of Blockchain

For now, Blockchain technology does not play a role in the company. According to the interviewee, the basis of the digital transformation lies in the speed and efficiency to which the entire industry is currently geared. The perspective of the sustainability department, the relevance of Blockchain technology is rated as low. **"***It really has to fit into our day-to-day economic business. I don't see the advantage of that yet, for what that would be needed."*

Perceived Barriers

In total 19 barriers (appx. 13) for the application and adoption of Blockchain could be found in the categories of Compatibility, Technical Capabilities, Complexity and Availability, as well as Perceived cost, Organizational culture, Personnel, Top management support and CE design decisions and finally Competitive pressure, Cooperation, Government regulation, Standards and Customer Pressure. Seven of the most prominent factors are presented in the following:

Technology	Organization	Environment
- Immaturity - High complexity of system design	- Unclear relative advantage - Resistance to change - Lack of management commitment and support	- Lack of CE-oriented products - Lack of demand and awareness

Immaturity

The fact that the technology is not yet fully developed presents another barrier for company C. According to the interviewee, it is not imaginable for the company to invest in a technology that is immature. The company is described as being rather reluctant to change, and the entire industry is also described as being less nimble and agile.

High complexity of system design

Another issue in the technological context is the general complexity of system design, which is a barrier. For the company, linking two transformation processes is too much at once. Since the benefits of technology adoption are considered low, a possible reduction in complexity through a Blockchain-enabled Circular Economy is also not visible.

Unclear relative advantage

The unclear relative advantage is a major barrier to Blockchain adoption. The basic requirement for company C to adopt a new system is a visible added value in the form of increased efficiency. In addition to the implementation or licensing costs, there are also new personnel costs, so the return on investment must be clearly positive. From a sustainability perspective, however, no relative advantage is currently seen, according to the interview partner: "*Purely from a sustainability perspective, there's nothing impactful that we currently have to do that would then justify us being able to look at quite a lot of supply chains quite quickly.*" Accordingly, from this perspective, even the data availability that Blockchain might open up is not a direct benefit.

Resistance to change

The underlying resistance to change is rated as a major hurdle. The company, including the automotive industry, is not considered to be willing to change and to move quickly in a new direction: "*The automotive industry is a huge tanker, it is not nimble and not agile, especially we as Company C are not nimble and agile. It takes far, far, far too long for us to initiate a transformation.*"

Lack of management commitment & support

The influence of top management is very high in this company, as it is owner-managed. According to the interviewee, the owner has understood that a digital transformation is necessary in order to be able to do business in the future. However, the positive impact of an Blockchain application for circular strategies on the rest of the company is too small yet. The interviewee, Head of Sustainability, says **"***I could use something like that [Blockchain capabilities] from the overall approach. But I'm in a side world there."*

Lack of CE-oriented products

The parts that company C supplies may well be produced in a recyclable manner, but then they do not correspond to the quality that is expected in the end product at the OEM. Thus, the dismantlability of a part is feasible, but undesirable if the parts rattle or become unappealing in the use phase of the car. Also, the reusability of recyclable car parts play only a minor role if the car is scrapped or dumped abroad.
In addition, there are design trade-offs for products. **"***What is more important now? Do I have to put a renewable raw material in it now? Or do I have to make it decomposable again with a 1-substance system? No one has been able to answer me which is better at this point."* A renewable raw material is more favorable in terms of emissions, but at the end of life can only be burned. The 1-substance system is recyclable, but not necessarily based on renewable raw materials.

Lack of demand and awareness

The lack of demand and awareness is a major barrier to providing recyclable products. According to the interviewee, the customer (OEM) doesn't care about the dismantlability and reusability of the car parts, as they currently take back less than 15% of the vehicles at all. As a supplier, company C is driven by the customer and will produce what is required. So, they can only move within certain limits. **"***The customer requirements are there and they're not going to change."*

Perceived Facilitators

Potential cost savings

If a Blockchain application makes it possible to increase the efficiency of processes, for example by creating interfaces and thus saving money, the aspect of cost saving through efficiency is a supporting factor.

Ensure product quality

The proof of a certain product quality is especially relevant in the context of competition. Being able to prove the quality compared to cheap conventionally produced products from abroad is therefore seen as a great advantage and thus would push the adoption of Blockchain.

5.1d CASE D

	**Trade and service group** Retail, financing and logistics, and mail order
Employees: > 50,000; Revenue: > 15 Billion; Locations: 30 countries	
BCT Application: ● Non-Adopter ○ Early-Adopter	

Background Information

The business of Case Company D

Company D is a trade and service group in the field of retail, financing and logistics as well as mail order. The business is located at the end of the value chain, positioned between the product producers and the end consumer. The Group also operates its own brands, which are produced in cooperation with selected suppliers. The majority of the business is based on the trade of external brands.

Circular Economy Motivation and Approach

The company is currently based on a linear business model. The company is just at the start of its development towards a circular business. The goal is to obtain comprehensive information about the structure and recyclability of its products and to demonstrate this transparently. It is essential for the company to ensure the quality of products and materials: Upstream, in cooperation with the suppliers, to work on the recyclability through design of the products and downstream to reliably provide information to recycling companies. In a best-case scenario, materials would also be returned to the company's supply chain through traceability.

The current role of Blockchain

BCT does not yet play a role in the company. At the moment, information coming from the suppliers is entered manually into a central database. The company's goal is to first create recyclable products and then to incorporate the topic of digitization. Based on this, the aim is to create a form of digitalized material platform in which the components (especially chemicals) of the materials and products can be retrieved across the entire supply chain with the greatest possible transparency. This can no longer be realized manually, as the processes would otherwise be far too comprehensive.

Potential of Blockchain

The potential of BCT is seen in the requirement that the data from the suppliers must not only be retrievable, but also secure, and that in the context of a global supply chain. In addition, there is not only the transparent verification of ingredients, but also the traceability of products as soon as they leave the company, as product responsibility is seen as increasingly important. BCT is clearly seen by the interviewee as a longer-term opportunity that outweighs the risks that come with a new technology.

Perceived Barriers

In total 15 barriers (appx. 14) for the application and adoption of Blockchain could be found in the categories of Compatibility, Technical Capabilities and Availability, as well as Data driven organizational culture, Personnel and CE design decisions and finally Competitive pressure, Cooperation, Government regulation, Standards and Customer pressure. Seven of the most prominent factors are presented in the following:

Technology	Organization	Environment
- Integration challenges - High technology threshold - Fraud	- Adjustment effort - Challenging business development	- Critical mass - Lack of regulations

Integration challenges

The integration challenges turn out to be particularly large for the company as a group of other subsidiaries, as these are already embedded in different IT systems. So, the Blockchain technology would have to be compatible with all the systems and be able to establish interfaces in order to be able retrieve the data that has been collected.

High technology threshold

The high technology threshold also poses a barrier. Although digitization is one of the key topics for Company D, it is still more of a future topic. Budget is given for the digitization of the company, but other topics are prioritized first. According to the interviewee, a good basic level of digitization must first be achieved so that the next steps, such as Blockchain, can be initiated.

Fraud

It is seen as a major challenge that the verification of the data is not guaranteed by the technology. *"That's for example where I don't know if Blockchain offers the all-encompassing solution now."* For Company D, it must be ensured that the data is entered correctly. Because of the importance of this issue, it is necessary to find solutions to this challenge regardless of Blockchain technologies.

Adjustment effort

Company D is a family business, with long-standing traditions that are often described as having grown historically. **"***Many processes have been in place for a very long time. And redefining them, breaking them down, rethinking them is also challenging in a large corporation."* The adjustment effort is greater because decision-making and process optimization tend to happen at a slower pace. Since sustainability and Circular Economy are also topics that are under development, employees find themselves overwhelmed when they have to consider other aspects such as material composition and familiarization with new systems in addition to their daily work. The basic knowledge is anchored in the company, but the implementation at all levels is still seen as very challenging.

Challenging business development

Since for company D the perception of urge is not yet great enough to implement a truly circular business, the topic is not prioritized. The interviewee speaks of a trade-off between what management wants to drive for its own sake and what is currently profitable for the company.

There is also the factor that within the company topics such as Circular Economy are not yet sufficiently linked to supply chain management and the topic of circular supply chains is not yet linked to IT. Therefore, the interviewee sees a high need for knowledge transfer.

Critical Mass

Critical mass is seen as relevant to convince top management and to build on positive experiences from relevant competitors. The interviewee sees Company D more as a follower in the adoption curve: *"With us, it is probably more the case that we often only act when we realize, okay, this is now also developing into a form of market standard".* The fact that no critical mass in the industry already exists is seen as a barrier.

Lack of regulations

Regulators are seen as potential push factors, and when they are absent, that can pose a barrier. Specifications on the proportion of recycled material in products, for example, or bans on chemicals are seen as beneficial. By introducing further regulations, the need for action could be increased and the Circular Economy would be given higher priority. **"***So, if there are requirements from the regulatory side, it is of course the case that we want and have to implement them. That's why this is an important point. If there is a level playing field specified there, that would be, yes, super helpful for us."* At the same time, the lack of uniform international regulations is a barrier. Especially in global supply chains, regulations and specifications are needed on how product data must be collected and how certain qualities are defined.

Perceived Facilitators

Complexity reduction

The interviewee points out that the interface between the Circular Economy and Blockchain should be understood as a holistic concept in which everything is interrelated. E.g., circular products are of no use if they are not recycled. The information must therefore be passed on to the respective partners. And this effort can only be carried out digitally. Although company D also faces certain challenges in tackling both processes at the same time, however, scalability is only seen as realistic with digital support.

Knowledge Transfer and Ensure product quality

For the company, it represents a great opportunity to prove the quality of certain products in a transparent and tamper-proof way. **"***There will be completely new synergies that cannot yet be estimated in this form, also with regard to communication with customers."* Proof also represents a prerequisite for a fair, transparent circular supply chain from the perspective of company D.

5.1e CASE E

<table>
<tr><td rowspan="2"></td><td>Specialty chemicals company</td></tr>
<tr><td>Development, production and distribution of chemical intermediates, additives, specialty chemicals and plastics</td></tr>
<tr><td colspan="2">Employees: > 14,000; Revenue: > 6 billion; Locations: 33 countries</td></tr>
<tr><td colspan="2">BCT Application: ● Non-Adopter O Early-Adopter</td></tr>
</table>

Background Information

The business of Case Company E

Company E is a company for specialty chemicals and specializes in the development, production and distribution of chemical intermediates, additives, specialty chemicals and plastics. Supplying various industries with its substances, materials and products, the company is located far at the beginning of the value chains of a wide variety of products in numerous sectors.

Circular Economy Motivation and Approach

Company E is currently pursuing a linear business model. The development towards a circular business is still at the beginning. For the company, Circular Economy plays a role in three areas. First, the raw materials used to power the facilities and the goal of switching to alternative energy, as well as using recyclates and bio-based raw materials in production. Second, waste management and the goal of going further into smaller side streams in order to increasingly go in circles. Lastly, products and the goal of acting as a solution provider. This refers to enabling mechanical recycling with the company's own enabler products and to enabling chemical recycling with technologies and processes developed in-house. The focus is thus primarily externally on the development of companies that are higher up in the production chain. For the company, the urge of implementing circular strategies is considered relatively high.

The company faces the challenge to be able to trace the material where it is used after it leaves its borders. Traceability and returning is even more difficult, especially at the molecular level. In this regard, the interviewee sees the company in the role of chemically disassembling products and materials in a recycling process or purchasing end products and reintroducing them into production. Tracking is also challenging because materials are further processed and sometimes even chemically altered in the course of the value chain.

The current role of Blockchain

Blockchain technology does not yet play a role in the ideas for development. However, the interviewee sees a great opportunity for the technology to support both downstream material tracking and thus create the basis for the return of materials. And to create an opportunity upstream to be able to prove the recyclability of the products.

Potential of and view on Blockchain

However, the technology is not seen as a panacea that solves all problems related to the transformation to a Circular Economy. According to the interviewee, complex organizational issues must first be addressed, and the goals set for a circular business.

Perceived Barriers

In total 7 barriers (appx. 15) for the application and adoption of Blockchain could be found in the categories of Compatibility, as well as Perceived cost, Application and CE design decisions and finally Competitive pressure and Cooperation. Six of the most prominent factors are presented in the following:

Technology	Organization	Environment
- Data transmission challenges	- Unclear relative advantage - Challenging BC design decisions - Challenging business development	- Fierce Competition - Inhibition through codependency

Data transmission challenge

The transmission of data represents a barrier. Although I4.0 technologies such as IoT are already being used in the company, this is only for process technology and not in the context of the Circular Economy, where materials could be tracked. Therefore, it is seen as a challenge to get all relevant data together. However, according to the interviewee, this is less a system issue and more an individual issue, which is also caused by the question of trust.

Unclear relative advantage

The unclear relative advantage is seen as a barrier, especially in relation to a business case that does not yet exist. The need for a Circular Economy is seen as very high, especially in the chemical industry, but the associated strategies are perceived as costly. Therefore, the interviewee emphasizes that the cost of investing in a technology must also be in proportion to the cost, especially in comparison to conventional raw materials purchase. For the company, a business case has not yet emerged from the Blockchain-enabled Circular Economy. And since the company is business case driven, that presents a major barrier to adoption. **"***The need for a Circular Economy is huge. The need for Blockchain technology in the Circular Economy is a nice to have. If you want me to overstate it now. Or: it is a possible technology to enable certain processes or to enable certain transparency. Is it the best now? I honestly can't judge that at all yet."*

Challenging BC design decisions

The advantage of traceability and secure data sharing, enabled by BCT is recognized. However, for a chemical company at the beginning of multiple value chains challenges arise. If one thinks in terms of industrial value chains, there are a wide variety of applications, from color pigments in artificial turf or printing cartridges, additives in car tires or drinking bottles. The Blockchain system, once set up, can potentially track anything. However, the challenge then is that the openness of this respective chain must be given in order to enable traceability of these products. However, this is made even more difficult when talking about the basic chemistry, which continues to react with the next customer and is given in some form by the customer after the next. Then according to the interviewee, it is no longer worth tracking because it no longer exists as it originally was. The interviewee also questions whether Blockchain can be the best solution. Especially in the chemical industry, case-specific solutions are needed at the moment.

Challenging business development

The company is at the beginning of the implementation of circular business strategies. However, this initial stage also shows that the company still has many development steps to take. According to the interviewee, the company still has many organizational questions to answer - how to organize the teams, what kind of metrics to use, how to deal with competitors and customers. For the interviewee, Blockchain adoption is a matter of time and sequence. *„How do you get such a big tanker like us [...] turned in a direction towards Circular Economy and also anchor it seriously. That's where I think technology can be this famous enabler. But not stand in front of the process."*

Fierce Competition

To truly exploit the capabilities of a Blockchain application, data must be fed into the system by all players. However, a barrier is seen here, as competition is still fierce, and it is questioned whether organizations have the right mindset and openness to share data with third parties.

Inhibition through Codependency

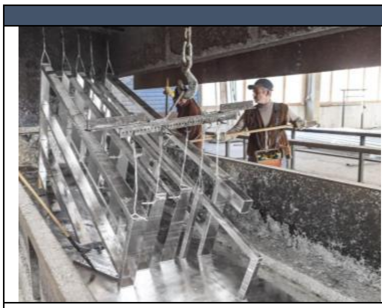
The interviewee is aware that the Blockchain can ensure a certain anonymity of the participants. Nonetheless, the trust issue is something the interviewee sees as a barrier. If there is no trust, then there will be no cooperation, which is urgently needed. Thereby the point "critical mass" is also determined. This refers directly to the participants in a potential Blockchain. The technology does not fulfill its purpose if there are not enough players in the system. **"***It just doesn't make sense, if you're somehow two in there, then you might as well send the data over. In my opinion, that's the linchpin. A system like this stands and falls with the breadth of the participants."* The interviewee reports on a pilot project with Blockchain from another professional context that failed not because of the technology, but because of the lack of participants.

Perceived Facilitators

Consensus mechanisms

The one factor that was explicitly mentioned as a facilitator is the capabilities of the technology itself. In this case, the focus is primarily on the ability to encrypt data within the Blockchain, or to feed in data points anonymously and then make them impossible to change or tamper with.

5.1f CASE F

	Provider of steel coating
	Galvanizing and coating of steel applications
Employees: > 1,700; Revenue: > 255 million (2018); Locations: 5 countries	
BCT Application: ● Non-Adopter ○ Early-Adopter	

Background Information

The business of Case Company F

The company operates in the metal processing industry and thus does not carry its own component. The product is the surface that is applied on steel components. The company's mission is to extend the life of the steel. With its coating of steel components, the company is relatively far down the value chain from automobile manufacturers or the construction industry.

Circular Economy Motivation and Approach

Company F is already pursuing strategies for a Circular Economy. In order to implement structured processes and goals, the company has formulated the rule *"for us there is no sustainability without innovation, and what is most important: no innovation that is not sustainable."* The goal is to switch completely to secondary zinc. For this, however, this resource must be returned to the company after use. Individual coatings are already Cradle to Cradle certified, which means that the company already collects a lot of data. In addition to the quality assurance of its own products, the return of resources is also a goal of the company. The challenge is to access the raw materials that have been put into the market and the usage in order to reapply them to new surfaces. The focus for the company is therefore on tracking the raw materials when they leave the company. This requires data exchange over the usage path, since the product with the coating is ultimately no longer owned by the company.

The current role of Blockchain

Blockchain does not yet play a role in current strategies and approaches. However, the interviewee expects the first initiatives to come soon. Particularly in view of the increasing shortage of raw materials, the need for action is seen as very high in the industry.

Potential of Blockchain

The interviewee sees potential for the company in the exchange of data and information in order to obtain raw materials and to return them to the coating processes. This includes information about the processing and usage of components as well as their ownership. This information needs to be stored securely and should not be publicly accessible. Blockchain technology is seen as a possible technology to meet these needs. However, it is not seen as a requirement here, but ultimately as an enabler: **"***The requirement to know my physical product with all the processes, with all the materials, all that and also to provide information about it, is rather increasing. And theoretically, of course, I can do all of this manually, but the fact* *remains that the entire IT machine is then really only an aid, an enabler, a facilitator, in order to be able to manage this complexity at all."*

Perceived Barriers

In total 12 barriers (appx. 16) for the application and adoption of Blockchain could be found in the categories of Compatibility, Technical Capabilities and Availability, as well as Personnel and CE design decisions and finally Competitive pressure, Cooperation, Government regulation, Standards and Customer pressure. Six of the most prominent factors are presented in the following:

Technology	Organization	Environment
- Data transmission challenges - Ownership and application	- Challenging business development	- Lack of CE-oriented products - Inhibition through codependency - Lack of common standards

Data transmission challenge

Information about products, where they go, and what parts they are created from overall is needed. For this, the interviewee sees great potential in the digital product passport or digital twin. The data must be stored securely and shared with the respective actors. However, the digital twin has not yet been implemented and is very complex. However, the approach of a digital product passport is the prerequisite to receive the data, which is then fed into a Blockchain, in the first place.

Ownership and application

The company does not see initiating Blockchain adoption on its own as an option. Due to the position in the value chain, there is a dependency on the customers and their motivation to initiate an application of Blockchain. "*It is not, that we would be in a project. Unfortunately, I have to say. Where a value chain related to our product or to the products of our customers opens up to use Blockchain technologies, which then actually make it possible to share this data somewhere safely among each other. But that that will come, that's as certain as the Amen in the church."* In the case of application, the uncertainty in long-term planning poses a barrier. If it comes to the point where the company provides data on the that can be used to negotiate what will happen to the zinc at the end of the use phase, long periods of time will have to be bridged as zinc-applied products exist over long cycles. It must therefore be guaranteed that the technology will last as long as the physical product does.

Challenging business development

The company also faces industry and product-specific challenges. In fact, zinc is a major issue in the recycling process at scrap yards. The zinc has to be removed in a complex process or else it would reduce the quality of the steel. The collection of data is a first step to be able to share important information between the companies. For company F therefore, the order and timing is currently still a barrier to Blockchain application. First, it needs a digital form of the products. Then, the accuracy of the captured data must be validated via certification processes. Only after that is the use of Blockchain reasonable.

Lack of CE-oriented products

This barrier primarily relates to the understanding of the circularity of the products. If the information about them is to be shared in a Blockchain, it must also be interpreted and evaluated correctly otherwise it can be a hurdle for companies to share information that might be misinterpreted. For Company F, the CO2 emission levels during the product life cycle are very high due to the high energy required. On the other hand, the longevity of the coated products is extended several times, which in turn can save on new production. The interviewee therefore calls for a life cycle assessment by which the CO2 burden is then divided by the number of years of use.

Inhibition through codependency

The dependency on customers leads to the situation that Blockchain does not yet serve as a platform for company F to feed in information. According to the interviewee, the company already has all the information about its products at its disposal but is not yet finding any recipients: *"Basically, I hear very little about these topics in the environment of our customers, so to speak. That is today also still, I would say not consistently, everything requested, so we document a lot and when I ultimately see how many customers actually use it, it is little and even more regrettable than where we actually want to go."* From the interviewee's perspective, much of the responsibility about the final products lies with the customer, who is far down the value chain. If the customer takes responsibility for the product, both downstream and upstream and recycling step, they will have to ask the parties involved in the final product to provide appropriate information.

Lack of common standards

Another barrier is the lack of standards. According to the interviewee, a Blockchain application can only make sense if it is standardized. An open-source variant would be conceivable, for example.

Perceived facilitators

Consensus mechanisms

For the interviewee, especially the possibility of smart contracts is a big advantage of BCT. The benefit is seen in Blockchain's ability to allow two parties to agree on something without a third party involved, and that agreement is then frozen. *"I can imagine that you talk to customers and you already make agreements about the zinc that' s on the steel components, that we get that back."* Another advantage is expected in terms of interfaces. For instance, that when a change is made by adding information, and this change is automatically adjusted wherever it makes sense to do so.

Cost sharing

The interviewee does not necessarily see cost sharing as an option when initiating Blockchain, as this would have to be initiated by the customer. However, a kind of selling system is conceivable in which the digital twin is sold together with the product. It is then ultimately up to the customer to decide what to do with the information and where the benefits lie.

5.1g CASE G

	**Automotive manufacturer (OEM)**
	Sports car manufacturer
Employees: > 36,000; Revenue: > 28 Billion	
BCT Application: ○ Non-Adopter ● Early-Adopter (Pilot)	

Background Information

The business of Case Company G

Company G is an automotive manufacturer (OEM) and specializes in the production of sports cars. As an OEM the company is positioned at the end of the automotive value chain.

Circular Economy Motivation and Approach

Company G currently follows a linear business model. The company is still in the early stages of developing strategies for a Circular Economy. The relevance of the topic though is seen as increasingly important for the company, especially due to the pull factor of Eu regulations. The board aims to steer the company towards considering the end of life of products. Taking back certain materials from cars, such as batteries, is becoming increasingly important. The main motivator for the company is compliance with evolving legislation.

The big challenge for the company in handling end-of-life products and materials and returning them to the cycle is the lack of information about the composition in the first place. Traceability therefore sets the prerequisite for the company as an OEM to enable a return of materials and to make a transparent sustainability claim verifiable. The challenge is intensified by the long complex supply chains from which the individual parts of the automotive as the final product are sourced. **"***It's a complex beast, basically, and it's really hard to get clarity on every part of the product, what actually went into it. And can we recycle it in the end? Can we put it back in the loop and how do we keep track of that? I think it's a big challenge."*

The current role of Blockchain

Company G has piloted a few Blockchain solutions already. A project shared with the public takes place with a start up that offers a Blockchain solution in the context of Circular Economy. The goal of this pilot is to find out if a Blockchain solution is the right way to collect all information about the different parts in the supply chain. As well as testing how high the barrier is for other parties to join. **"***We wanted to really understand the hurdles, how hard is it and also how easy is it for us to then tap into this solution and actually extract data from it. So that was, let's say, up first how it started."* As part of this pilot, a test run was conducted with a polymer supplier. The evaluation was initially positive, as the data could be used in practice. However, the interviewee sees the crux in the expansion to further industries, materials and actors. **"***It's nice and good if you use it for, you know, three companies or six companies or 10 companies, and maybe only for one type of material."*

Potential of Blockchain

The interviewee recognizes the urgency in finding ways to manage the supply chain in such a way that it provides the transparency that is needed from a legal perspective. However, the solution does not necessarily have to be Blockchain. Even if the pilot has been successful, the main problem is still to get a large number of players into one system and at the same time justify the relatively high effort that feeding in data currently requires.

Perceived Barriers

In total 13 barriers (appx. 17) for the application and adoption of Blockchain could be found in the categories of Compatibility, Technical Capabilities, Complexity and Availability, as well as Perceived costs, Data driven organizational culture, Industry type, Application and CE design decisions and finally Cooperation, Government regulation and Standards. Six of the most prominent factors are be presented in the following:

Technology	Organization	Environment
- Data transmission challenges - Lack of interoperability of BC systems	- Unclear relative advantage - Adjustment effort	- Inhibition through codependency - Laws as roadblocks

Data transmission challenge

The transfer from a physical product to a digital one is seen as one of the main problems. For a final product like a finished car, there is the possibility to apply and scan codes or use chemical tagging. However, the problem lies mainly with the numerous materials of various components in the car. In order to enter data into a Blockchain, these would first have to be collected and made digitally available.

Lack of interoperability of BC systems

The factor that different BC systems cannot operate with each other is seen as a major barrier. If each player builds up its own Blockchain system along the way, the risk is high that these different systems cannot work together. The fact that this means that companies cannot simply build their own system or that there is a high risk that other companies will not be able to cooperate with their own systems is a barrier.

Unclear relative advantage

The interviewee sees the potential in being able to track and deceptively detect substances. However, the profit in the automotive industry is currently still considered too low. "*You know, is it worth it to come up with a super complicated system and in the end know that this part of my mirror on the car has like twenty five percent recycled content.*" Here, the question is what the effort for the implementation is worth in the end, compared to the costs that have to be spent

Adjustment effort

The adjustment effort for a potential application is considered to be very high and thus represents a barrier. All suppliers involved at different levels would have to be introduced to the system of how information is entered. There are also questions as to whether costs should be covered by the suppliers. Within the company, the effort is also seen as very high in the area where personnel have been using established systems for many years, which are now to be replaced. *"Why would you then need some kind of complex thing that's keeping track of how many kilograms of material went where and you know, it basically adding a whole layer of complexity indeed on top of it?"* The high effort required to adapt the company's internal processes is seen as very high and demands a justification to overcome this challenge.

Inhibition through codependency

For one thing, Blockchain technology can only unleash the desired functionality if all the necessary players are on board. **"***Unless all the partners basically in the supply chain are joining, it's going to be useless because we need to have everyone involved from beginning to the end."* Without a critical mass, providing a sufficient mass of data that encompasses the entire supply chain, a system based on Blockchain can't work. The aspect of critical mass also turned out to be the main factor for failure in the pilot project.

Laws as roadblock

Uncertainty about changing or upcoming regulations adds a barrier to Blockchain adoption. Especially with regard to the first-mover strategy, the interviewee sees the risk that regulations change, and other technologies become obligatory or the competitive advantage is lost if competitors also use Blockchain technology, for example because it is promoted. **"***So it's quite often not the technology that's defining what's going to happen, it's more the politics or the internal market."*

Perceived Facilitators

Compliance and audit

The interviewee sees a necessity in being able to prove where a product comes from and how it is composed. To meet the increasing demands of sustainability reporting, it is seen beneficial to be able to extract more data about the supply chain via a Blockchain and use it for auditing.

5.1h CASE H

Chemical company

Chemicals, Materials, Industrial Solutions, Surface Technologies, Nutrition & Care, Agricultural Solutions

Employees: > 100.000; Revenue: > 59 billion; Locations: 80 countries

BCT Application: ○ Non-Adopter ● Early-Adopter (Pilot)

Background Information

The business of Case Company H

Company H is a global chemical company and operates a wide product portfolio of chemicals, materials, industrial solutions, surface technologies, nutrition & care as well as agricultural solutions. The company is located relatively far at the beginning in the value chains of versatile industries. With regard to Surface Technologies and Nutrition& Case, the company is further in the middle of the respective value chains of the underlying industries.

Circular Economy Motivation and Approach

Due to the versatile supply of a variety of industries, different teams are working on different problems with regard to circular strategies. Most projects are basically about keeping materials in the loop, getting them back from customers, which in turn is attractive to customers if they can offer a product that is completely recirculated. The projects relate to anything from mattresses to sneakers. The company sees itself as very progressive in terms of Circular Economy approaches. For the company, however, the challenge also lies in its comprehensive product range. It should be possible to trace where they come from, but it is a great challenge to prove to the customer what went into the products and where they are sent.

The current role of Blockchain

Company H is one of the two early adopters in this sample that has already gained experience through several pilot projects. The application of Blockchain for tracking and tracing materials represents a competitive strategy for the company. Above all, the question of a business model in the application of Blockchain is the main issue in the current applications. The interviewee explains that the biggest challenge is to develop a business model on how to generate money with the information collected through Blockchain. Blockchain is currently playing a role in that different providers are being tested and it is being examined in which direction the developments are going.

Potential of Blockchain

The potential of Blockchain is estimated by the interviewee as very high. The company has already established a department for Blockchain applications in the context of sustainability. For the Interviewee, as part of the team, there is no question whether Blockchain is a short-term risk or a long-term opportunity. It would be absolutely clear that Blockchain technology will be usable in the future for Circular Economy to track materials. But also, to make sustainability attributes tradable by tokenizing certain properties and making attributes of circular products trackable and tradable.

Perceived Barriers

In total 9 barriers (appx. 18) for the application and adoption of Blockchain could be found in the categories of Compatibility and Availability, as well as Personnel and Application and finally Cooperation, Government regulation and Standards. Six of the most prominent factors are presented in the following:

Technology	Organization	Environment
- Ownership and application	- Challenging business development	- Inhibition through codependency - Alignment challenges

Ownership and Application

For the interviewee, after the experience with some pilot projects, the question is still open how many solutions there will be in the end, what the boundary conditions will be and where the limits will be. It is not received as reasonable to develop a solution for the chemical industry alone. However, it is absolutely open where the initiation should take place so that companies agree on a single solution. *"Of course, quite a few suppliers dream of being the solution. Big and small alike offer their products and want to provide THE industry solution. The question is then, how do people react to that? Because nobody then wants to be fully dependent on one company."*

Challenging business development

Challenging design decision in relation to the Circular Economy as well as to the Blockchain application are directly related in this case, because from the point of view of the interviewee the Circular Economy can only be thought together with technologies which in this case is Blockchain. In this regard, there is the question about who verifies the entries in the Blockchain, who is paid for this and who is generally allowed to earn money with the system. In addition, with the information in the Blockchain, something must also be initiated. In some cases, companies have not yet reached the point where they can really use the flow of information strategically for themselves. The interviewee also emphasized that Blockchain is not a panacea cure-all and that it must be weighed up on a case-by-case basis to determine where its use can add value and appears to make sense.

Inhibition through Codependency

Without a critical mass in the Blockchain itself that reflects all the important players in an industrial value chain, the purpose of a Blockchain cannot be fulfilled. "*Because there's no point in saying, I'll make us a solution for the chemical industry. That's no use, because we sell our products to practically every other industry. And that will also be the exciting thing: Which group of industries, of companies, will be able to agree on which solution. So, as I said, at the moment there are many pilots, many ideas, but nothing that you can say, oh yes, that's so advanced, that's so great, that's it."*

Alignment challenges

Alignment challenges arise primarily in the respect that for many materials there is no specified way of calculating relevant values that allow a statement to be made about the environmental impact of a material. The more players in different industries and countries, the more the interpretations of sustainability criteria and circularity diverge. Since the quality of the data is a prerequisite for reasonable further use of the data, alignment challenges pose a barrier.

Perceived Facilitators

Complexity reduction

Blockchain is seen as a tool for the company to manage the complexity of the Circular Economy. *"If you go in the direction of Circular Economy, then our whole system becomes arbitrarily complex and you can really only manage that with digital solutions. And one of them is Blockchain."*

Compliance and audit

Another advantage of a Blockchain application is that materials can be managed, and the Blockchain offers the possibility to prove the origin of materials over the entire value chain. This also simplifies the auditing workflow, as all information could be pulled from one system.

Facilitators in the Environmental Context

The ability to ensure product quality is seen as a facilitator. According to the interviewee, customers are asking for information about the origin and composition of materials. With Blockchain, there is an opportunity to keep track of material flows, raw material usage and substitution of materials.

Summary and implications

The within-case analysis showed that each company faces an individual combination of industry- and company-related challenges. Some companies are not yet advanced enough in technology development, some do not have the circular economy high enough on their agenda, some see their position in the value chain as a challenge or do not see sufficient demand for circular products or are rather laggards than early adopters with regard to the adoption of innovations.

That being said, there are factors that play a role in all cases, which are collected and presented below and on which the next steps will focus.

However, not all factors can be discussed, even if they might be more important for an individual case. In this paper, the further analysis and recommendations for action focus on the factors that are relevant for all cases and are to some degree generalizable.

5.2 Cross-Case Analysis - Generalizing the findings

With the help of cross-case analysis, the results of the individual case studies are to be generalized so that certain trends in the relevance of factors can be derived.
For this purpose, all factors, barriers separately from facilitators, were compiled across all 8 cases. Next, it was assessed which factors were mentioned how often and in which cases. The factors were color-coded according to their frequencies. The result of this procedure can be found in the appendix (see Appendix 6).

Cross-Case analysis on the perceived barriers

A total of 3 barriers were mentioned in at least in 7 cases. A further 6 barriers were mentioned in at least 5 of the cases. Here it must be pointed out again that these factors were integrated in the questionnaire. This evaluation is therefore based on the factors that the interview partners addressed and which they also see as barriers in their own company setting.

The stated barriers are mainly intended to reflect factors that can be used to explain the low adoption rate of Blockchain. One way of representing the influencing factors of a phenom is the Ishikawa diagram or fishbone diagram. In this diagram the barriers, which were mentioned in at least 5 of 8 cases, were represented and marked according to the affiliation to the TOE-areas (see Fig 7). The whole graph represents possible reasons that lead to the low adoption rate of Blockchain in the context of circular business development. Each of the main vertical ribs represents a factor category and the horizontal fish bones represent the associated sub-factors.

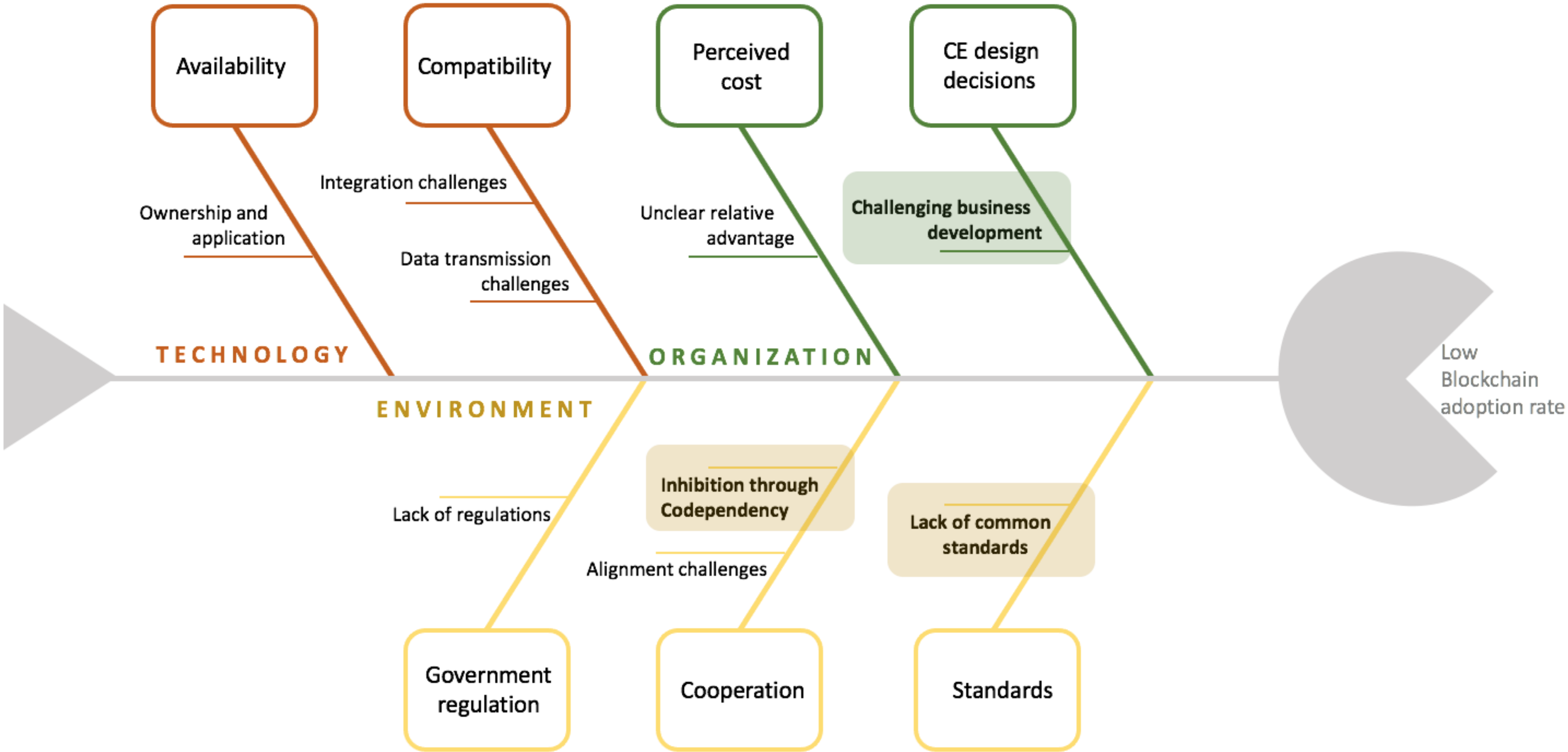


Figure 7: Cross-Case analysis - most frequently mentioned barriers (own presentation)

This generally reflects the consensus between the factors that, based on the literature research, were raised in the interview and taken up by the companies. Within this framework, further aspects could be extracted in the analysis of the interviews. In addition to the factors just mentioned, which were also discussed in the literature, further dimensions were added to the factors from the practical experiences of the company representatives.

In the appendix (appx. 9), the additional aspects from practical experience are illustrated and the barriers mentioned by the two company representatives who have already had experience with pilot projects as early-adopters are marked as black circles. They are to be considered in particular here, since their statements are based not only on considerations and assessments, but also on practical experience. Only the factors that were mentioned by both company representatives were marked.

Challenging business development

A major barrier is the fact that the companies in this case study are still at the beginning of the development towards a circular business and face challenges in transforming their businesses.

The complexity is seen less in the technology and more in the world itself, in the transformation to a Circular Economy. There are conflicting goals, as conventional business models are often still more favorable. In some cases, more competencies in the areas of Circular Economy and digitalization needs to be built up. At the same time, in some cases the intrinsic drive for circular business is missing. The pressure to act is not yet perceived as high enough for the topic of circular business to be sufficiently relevant in the company (Case A, B, C, D). As an early adopter, Case H does not yet see a business model behind the application of Blockchain for Circular Economy. As a result, companies need to learn what to do with the data entered and extracted from Blockchain and questions need to be answered about how to make profit with the Blockchain application and who earns from it.

→ Order and time, industry specific challenges and separated IT und Sustainability unit

To implement circular strategies order and time is a critical barrier and leads to the fact that Blockchain is not yet applied. An application of Blockchain is only feasible once more foundations have been laid with regard to sustainability and tangible goals. Blockchain adoption is a matter of time and sequence. "How do you get such a big tanker like us [...] turned in a direction towards Circular Economy and also anchor it seriously. That's where I think technology can be this famous enabler. But not stand in front of the process." (Case D). In addition, a way to digitalize product information is needed and the accuracy of the captured data must be validated via certification processes. Only after this condition is met the use of Blockchain becomes reasonable (Case B, C, F). Additionally, it can be seen as a barrier that the intersection of digitalization and sustainability does not yet exist in some companies. The sustainability department is separate from IT, so the need for knowledge transfer is rated as very high (Case B, C, D).

Unclear relative advantage

For the adoption of Blockchain it is an important factor that the investment is profitable and worthwhile. For some companies, the added value of the investment or the business case behind it is not yet obvious (case A, C and G, H). Since the companies are all rational players in the economic market, this is a barrier. "The need for a Circular Economy is huge. The need for Blockchain technology in the Circular Economy is a nice to have. If you want me to overstate it now. Or: it is a possible technology to enable certain processes or to enable certain transparency. Is it the best now? I honestly can't judge that at all yet." (Case E).

Lack of common standards

The lack of common standards poses a challenge to almost all organizations in that there is no consensus on what information would be shared, how, where and when (Case A). It is also seen as a hurdle if too much freedom is left, and it is not clear which companies share which information with what level of detail (Case G). There should be some kind of protocol to follow here. Case B and C are in favor of an open-source code. "Because if everyone does their own thing again, then unfortunately and I have to underline this unfortunately, it's doomed to fail from the start." (Case B).

→ Data quality

The lack of common standards poses a challenge due to the lack of standards for the definition of criteria that make a product circular ready, or for the process of collecting data on whether it can be disassembled, recycled, or its carbon footprint. There are no cross-industry or cross-country standards for this. Sharing information via a Blockchain is only useful if the quality of the information can be kept consistently high through standards (Case F, H).

Inhibition through codependency

A number of suppliers among the companies see themselves as dependent on the large companies that are the main buyers of their products. The decision of a Blockchain application is therefore also strongly dependent on the strategic decision of the companies on higher manufacturing levels in the supply chain (Case B, C, F).

→ Critical Mass

The deciding factor that is a major barrier for companies is the critical mass in a Blockchain itself (Case D, E, G and H). "Unless all the partners basically in the supply chain are joining, it's going to be useless because we need to have everyone involved from beginning to the end." (G). The risk is seen high when investing in a technology and the partners one depends on do not buy in (Case D). Without a critical mass, providing a sufficient mass of data that encompasses the entire supply chain, a system based on Blockchain can't work.

Lack of regulations

Global supply chains require regulations and specifications on how product data must be captured and how certain qualities are defined (Case D). Additionally, the contradiction that conventional processes are often cheaper than circular approaches is striking, partly due to the lack of regulations. Case H also raises questions about who is responsible for proofing data on the Blockchain and who is allowed to make money from it. Without a policy framework, these open questions present a barrier.

→ Missing Push-Factor

In some cases, government is being called upon to push companies to develop circular business strategies (Case A, D, F, and D). If this push does not come, company representatives also do not see the use of Blockchain as feasible. "So, if there are requirements from the regulatory side, it is of course the case that we want and need to implement them. That's why that's an important point. If there is a level playing field given, then that would be, yes, super helpful for us." (Case D)

CE-oriented products

Not all companies can match the standards required by customers for products that are recyclable or based on renewable raw materials (Case C). Another hurdle for companies can be if the information is not interpreted and evaluated correctly. If this is not done with a consideration of the entire lifecycle for example, it can be a barrier for companies to share information that might be harmful if wrongly interpreted (Case F).

→ Trade-Offs

In individual cases, trade-offs occur when deciding on a strategy (Case C, F). A material decision can have a positive effect in one aspect and a negative effect in another. If there is no clear optimization potential, this also has a negative effect on the application of technologies that could further exploit the potential.

Integration challenges

Most companies already work with classic programs from vendors such as SAP and with LPM systems and see the integration with another system as a great challenge up to currently impossible (A, C, F).

→ Interfaces problematic

According to the companies, the main reason for the integration challenge is the interfaces. Connecting various software applications to be workable is a big challenge, especially because interface management is one of the main cost items in digitization.

Data transmission challenges

To enable a flow of data in the Blockchain, real data must be converted into digital data. A challenge for the companies is that there is not always available data that can be just put into a system. To have something like a digital twin of a product or material is the prerequisite to receive the data, which is then fed into a Blockchain, in the first place. Though the digital twin has not yet been implemented and is very complex. Accordingly, having physical products in digital form is a barrier to using Blockchain in further steps (A, F G, H).

Ownership and application

Most companies don't see themselves initiating a Blockchain application on their own. On the other hand, there is the possibility to rely on software providers. But here some questions are still open: "Of course, many suppliers dream of being the ultimate solution. Both large and small offer their products and want to provide THE industry solution. The question is then, how do people respond to that? Because nobody wants to be completely dependent on one company that way." (Case H)

→ Trust and reliance on Supply Chain

The question of ownership is closely related to trust, which is not necessarily present. Especially when considering the option of a Blockchain provider. While the system is secure and data can no longer be modified, there is a responsible operator running the system (Case G, H).

Another factor is the reliance on supply chain partners that a typically positioned at higher production levels. Some companies don't see themselves in the position of owning such a technological system. They see the role of initiating by the big players. If they don't require detailed information, there is no use case for Blockchain adoption (Case B, C, F). *"It is not, that we would be in a project. Unfortunately, I have to say. Where a value chain related to our product or to the products of our customers opens up to use Blockchain technologies, which then actually make it possible to share this data somewhere safely among each other. But that that will come, that's as certain as the Amen in the church."*

Cross-Case analysis on the perceived facilitators

In this next step the focus is on the facilitators. They will gain in relevance especially when the implications for practice are discussed.

Consensus mechanisms

In almost all cases, the consensus mechanisms of Blockchain technology were seen as facilitators. The main focus is, first on the possibilities to encrypt data within the Blockchain or to feed data points anonymously and thus make them immutable or manipulable (Case A, E), the ability to store and share information with restricted and verified access (Case B, C, G) and lastly application possibilities of smart contracts (case F, H). Regarding the last point: "I can imagine that, for example, you talk to customers about the zinc that is on the steel parts, that you already make agreements there that we get that back. And that one also defines what is on there." (Case F)

Reducing complexity

More than five cases also frequently expressed the view that Blockchain technology can provide a way to reduce complexity. Although the complexity of the technology is relatively high, it is perceived as an enabler of complexity. "I believe that with the digital twin and Blockchain, you can reduce complexity significantly." (Case F). The manual exchange of information with individual customers is seen as very time-consuming and increasingly complex, so the majority of companies share the view that this effort can only be done digitally (Case D, B, A, F, H).

Compliance and auditing

Several companies note that sustainability reporting requirements are tightening and data on topics such as Circular Economy need to be retrievable. Therefore, Blockchain technology is seen as an attractive tool to support compliance and audit (A, C, G, F).

An additional factor mentioned only in the case studies and not in the literature is that Blockchain could improve the process of auditing (Case A, C, H). "If I can just pull that, that's better than if I have to call five people and then kind of mix North American data with Asian data with European data and then kind of make a spreadsheet for me through Excel." (Case A)

Ensuring product quality

In three cases, being able to credibly demonstrate that a product is of a certain quality is seen as a competitive advantage (Case A, B, C).

Summary and implications

In the technological context, the focus is on the compatibility of the technology, i.e., the problem of how information can be captured in the first place and then fed into a Blockchain system and how interfaces can then be established with the existing system in the companies. This represents a kind of precondition for overcoming other barriers.

In the organizational context, the focus is on CE design decisions and perceived costs. This relates to the two points that the evolution towards circular businesses needs a push, as well as the question of business cases behind data collection so that an investment also pays off. The clear advantage of data flow through cooperation needs to become apparent.

In the environmental context, the focus is on barriers in the area of cooperation and standards. More specifically, the problem of how to get all players on board, using the same system, in the same way, with high data quality along and beyond the value chains. This is one of the barriers that have to be tackled when other prerequisites have already been created. These types of barriers seem particularly large because they depend on a large number of diverse players.

6 Discussion

In the previous chapter, the individual case studies were comprehensively presented and analyzed within the framework of the "within-case analysis”. This allowed for taking individual characteristics of the respective cases into account and considering them in the respective context. Large amounts of data from the interviews were summarized and structured in order to provide a basis for the cross-case analysis. For this purpose, the results of the case studies are combined at a higher level of abstraction and summarized in a generalizing manner (Zwicker, 2009). Furthermore, in this chapter, the findings from “within case analysis” will be discussed by assessing a cross-case comparison with the results of the underlying literature review.

6.1 Cross-Case valuation - Comparison with the underlying literature review

The previous section summarized the factors that are in consensus with the underlying literature review. In addition, the factors from the literature could be supplemented with further aspects from practice. In the next step, the factors where there is a discrepancy with the underlying literature research and between different cases will be considered. Primarily, the barriers from both literature and practice will be considered here. With regard to the facilitators, hardly any inconsistencies could be found. The cross-case valuation was derived based on table (see appx. 10).

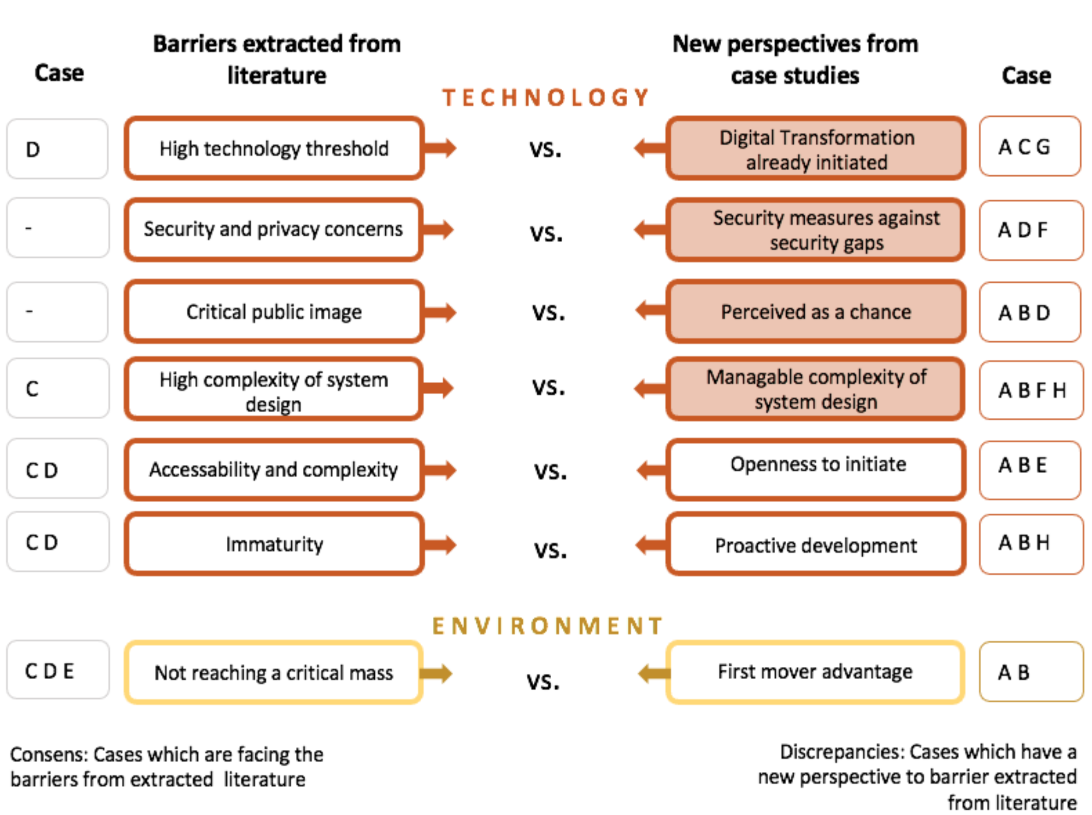


Figure 8: Cross-Case discussion - Differences to underlying literature (own presentation)

In this overview, the factors are highlighted in color where more cases are clearly in consensus or in contradiction with the literature (difference from at least 2).

High technology threshold

The company representative from Case D sees the high technology threshold as a barrier, just like in the literature. In Case A, C and G, the hurdle is not seen as being too great, as these companies are already in the digital transformation process and therefore consider themselves to be well equipped to establish further innovative technologies.

Critical public image

None of the companies actively raised the issue of the critical public reputation of the technology and classified it as a barrier. Company representatives from Companies A, B and D, on the other hand, stated that they see Blockchain technology as a long-term opportunity rather than a short-term risk for their respective companies.

High complexity of system design

While the high complexity of the system design is rated as a barrier for Case C, the complexity for the Cases A B F and H is rated as manageable. The main argument here is that the hurdle of complexity must be overcome at the first stage in order to then be able to benefit from the positive features.

Security and privacy concern

Also, the security risks referred to in the literature, which could also exist with Blockchain technology, are not actively addressed by any of the company representatives. For Cases A D F, these do play a major role, but they provide the following argumentation: the companies are dependent on digital solutions and develop security measures to check, test and ensure the security of systems. Another point is that no technology is truly secure. This cannot therefore be the decisive factor that causes the whole thing to fail.

With regard to the other factors, the assessments of the company representatives seem to diverge further.

Immaturity

With regard to the immaturity of the technology described in the literature, this is seen as a barrier for Case C and D, but is not a barrier for Case A, B and H. In contrast, the interviewees share the opinion that a promising technology can only be developed further if it is worked with. Quite the opposite of the perception of an overwhelming obstacle, the representatives of the three companies see the immaturity as an opportunity to be a part of the development, to actively shape it, and to use this as a competitive advantage.

Accessibility and complexity

The same is true for accessibility and complexity, which is seen as a barrier for Case C and D, and not for case A, B and E. Finding a way to test and apply the technology in a pilot, with partners or in-house is seen as feasible here, based on a certain openness to different approaches.

Not reaching critical mass

The only point that is not in the technical context, but in the environmental context, refers to competitive pressure. The barrier in the category of not having a critical mass of adopters in the market is a barrier for more companies than those for whom it is not a barrier. For Case C, D and E it is seen as a barrier that there are not yet examples of large players or even competitors demonstrating successful implementation. The representatives consider their respective companies to be first followers or early majority adopters. On the other hand, a different strategy is proposed for Case A and B. Seeing the low adoption rate as an opportunity to be one of the first on the market to benefit from the first mover advantage.

Summary and implications

This illustration showed that the perception of barriers can vary. Whether a factor is classified as a barrier also depends on the perspective of the company representative, the company's industry and the company's general willingness to take risks and pioneering spirit.

While some company representatives consider a wide range of aspects to be real barriers and tend to be conservative rather than agile and open to technology, other company representatives open up new perspectives for their companies that make it possible to overcome barriers and prevent potential barriers from appearing as such in the first place. Cases C and D, an automotive supplier and a trade and service group that grew out of a family business, see many factors as real barriers. Companies like Case A, B, and H, a global manufacturer of building materials, a manufacturer of connection and automation technology, and a global chemical company, on the other hand, characterized by agile management, openness to technology, and seeing themselves as forerunners in innovation open up a different perspective. The diagram also shows that barriers especially in the technological context in particular are not always considered as such. Environmental factors on the other hand discussed in the literature also represent barriers in reality almost without exception. They are less controllable and influenceable by the companies themselves.

6.2 Factor discussion

The factors that have an influence on the adoption of Blockchain in the context of the Circular Economy were considered mainly independently of each other in the previous sections. At first, the focus was on finding out which factors were mentioned, to what extent, and why. However, factors that have an influence on the adoption of innovative technologies are likely to be related to each other to a certain extent and can also potentially influence each other.

Conditional relation

Some of the factors discussed are interrelated in the sense that they are mutually conditional. It should be emphasized, however, that no statements are made here about correlations, but rather a discussion of where trends in connections can be identified.

For instance, an agile organizational culture is closer related to the strategy of a company that would adopt a new technology as a first mover, if the advantage were recognizable, than to a very conventional organizational culture. Another point is that the lack of top management support also affects the challenge there is in driving and prioritizing circular strategies in the company. The fact that the decision to prioritize Circular Economy in the company is not easy can again be related to the regulations and the lack of a push factor from the government. The positions in the industry-specific value chains may also be related to the dependency on larger companies at upper manufacturing levels and the resources available to initiate such a new technology. Last, the lack of critical mass of successful applications in the market is also due to the fact that there is no critical mass within Blockchain applications yet. If participation in Blockchain pilots is too low, the pilots may not be as successful as they need to be in order to derive more applications from them and develop critical mass in the market.

Temporal relation

Conditional relations have already shown that there is also a condition in the sequence. Thus, some barriers can be overcome in the short term, thereby paving the way for other barriers to be overcome. For example, the introduction of a complex technology can be carried out in the short term, and immaturity can also be worked on at a relatively earlier stage than the development and implementation of standards in the application. If, for example, security aspects can then be improved and there are more pilot projects, it will be possible to focus on the other barriers.

6.3 Recommendations for action

The analysis and valuation have shown which barriers have an impact on the adoption rate of Blockchain in the development of circular businesses. They have also shown which aspects are facilitators that make adoption attractive if certain barriers can be overcome. Addressing these barriers requires multifaceted actors, numerous steps, and time management, all at different levels.

In the following, conclusions will be drawn from the case study analyses and discussions and recommendations for action for relevant actors will be formulated.

As already mentioned, not only do the initial situations of the various companies determine the perception of barriers, but the factors are also interrelated. Barriers and facilitators have been considered in the context of the TOE-framework throughout this study. These three areas simultaneously reflect a level of action. In this context, the environmental context represents a macro-level, the organizational context represents a meso-level, and the technology represents a micro-level.

In discussing the factors that play a role at these levels, they can also be influenced and controlled by different players. Thus, in the technological context (micro level) it is primarily IT service providers, in the organizational context (meso level) it is the companies themselves, and in the environmental context (macro level) it is the politicians or government. The assignment to the three areas plays a key role in determining how the factors extracted from the case studies should be addressed.

In order to deal with the multifaceted barriers from different contexts, some orchestration is needed. An overview should first be created of which players are most likely to have and should have influence on which factors and at which points it is reasonable to start. As already touched upon, there are conditional and temporal relations that need to be considered.

The barriers, which have been elaborated in the cross-case analysis, are mapped under the mentioned aspects in the following illustration (see Fig. 9). Taking all of these aspects into account, recommendations for action are derived, which primarily relate to the sequence of phases.

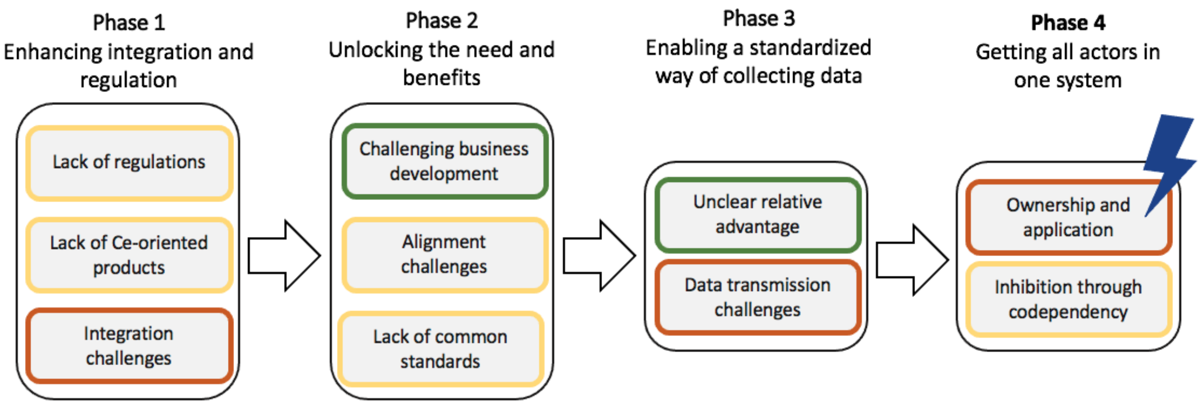


Figure 9: Overview of sequence and phases for actions to overcome barriers (own presentation)

The factors are again color-coded according to the TOE framework. The grouping of several factors stands for the fact that these factors can be tackled chronologically, as they are not dependent on each other. However, this also reflects only a rough classification and not a scaled classification. Barriers in phase 1 are rather short-term in the sense that they represent barriers for which there are hardly any preconditions, so that they can be implemented if the motivation is present. Barriers in phase 2, 3 and 4 are rather mid- and long-term in the sense that they only make sense to tackle when certain framework conditions are in place that are not in place at the moment.

Phase 1: Enhancing integration and regulation [Technology and Environment]

In phase 1, the first step is to create the right framework conditions. This concerns the adoption of Blockchain-specific regulations and promotion, as well as the holistic consideration of Ce-oriented products in the environmental context and interface management in the technological context. Accordingly, there is an urgent need for a level playing field defined by government policy. The government needs to provide guidance on how and what information can be shared by companies and how Blockchain systems can be implemented and applied. In addition, regulations can be a push factor for many companies. Both through stricter requirements in terms of product responsibility, increased recycling quotas, stricter reporting requirements and higher disposal costs. And on the other hand, by setting incentives, i.e. projects that are promoted and financial benefits of recyclable products and business models. With regard to the promotion of CE-oriented products, it is important for the government not only to no longer favor conventional products financially, but also to evaluate CE-oriented products holistically, e.g. through life-cycle assessment requirements. Finally, Blockchain providers need to focus in particular on interface management. It must be ensured that existing systems can work with Blockchain systems and solutions must be found for the transfer of historical data.

Phase 2: Unlocking the need and benefits [Organization and Environment)

Phase 1 could potentially set good conditions for phase 2. However, the barriers in this phase pose a greater challenge and affect not only the macro level but also the meso level, i.e. the companies themselves. This involves prioritizing circular businesses, managing heterogeneity and setting general standards. Accordingly, stronger prioritization in the companies of the development of circular strategies initiated by the managers is needed to overcome development challenges. An important basis for this must be created in phase 1, in which legislation is a push factor and sets incentives. This also enables the top managers in the companies to prioritize circular strategies. At the same time, it must be seen from a sense of self-responsibility that linear economic strategies can no longer be a long-term strategy for success. This is where the top managers of the companies are most in demand.

With regard to the alignment challenges, foundations must also be created in phase 1 with regard to a common playing field and the integration of Blockchain into existing systems. These must then be extended to further nations as otherwise there will hardly be any applications beyond the national supply chains. Here, not only the government is required to create a consensus, but also companies to take into account the heterogeneity of actors within the value chains and to set standards. This is closely related to the next aspect which is setting standards. This point is a prerequisite for overcoming further barriers, however, this is also one of the most challenging points. Here, accountability links the macro and meso levels. Politicians are generally not responsible for the formulation of standards in companies. However, there is a need for binding specifications in the calculation of data that reflect the circularity of products. The quality of the data must be given and the obligation to comply with standards can be a way to achieve this. However, these standards must also be internationally valid, for example when it comes to calculating emissions of different parts from different countries. At the same time, companies must set standards for their internal business environment. An employee should be able to know when which information should be entered, how often, and to what extent.

Phase 3: Enabling a standardized way of collecting data [Technology and Organization]

In the third phase, the steps of the previous phase build on each other in the organizational and technological context. In this phase, the aim is to gain a relative advantage from the adoption of Blockchain for closed-loop strategies and to manage the transmission of data. One of the prerequisites for gaining a relative advantage is overcoming business development challenges. If circular strategies are not embedded in day-to-day business, no profit can be gained by using a Blockchain technology. However, when it comes to the evaluation of investment and profit, a company must also fundamentally ask the question what changes and influences the introduction of Blockchain technology will have on the company instead of focusing on the hype of an innovative technology. Ernst & Young recommend that companies focus on what their business would look like in a Blockchain-enabled world, rather than how Blockchain fits into the current model (Canterbury and Morrell, 2017). If it is true that Blockchain could drive certain processes and enable important information flows, there is still the question of how to earn money with the information in the system. One suggestion comes from one of the Cases itself (Case F). This one relies on a selling system where the information about a material or product in the form of a digital twin comes along with the product. The information is, so to speak, an additional service.

The point of a digital twin is also closely related to the point of data transmission challenges. This point is an inevitable precondition for the further phase in overcoming adoption barriers. A Blockchain system is of no use if the information about a product is not captured in the first place. With a multitude of products that, depending on the industry, are molecular-based, configurable, or in most cases untraceable once they leave the company's boundaries, it is a major challenge to capture important information. This must be solved first and foremost technologically. The companies in this case study are not collectors or recyclers. It takes a service provider to capture data sets and make them available to industries. For company-specific tracking of materials and products, it needs linking with other I.40 technologies such as the Internet of Things and tracking tools that work with GPS, for instance, and are built into materials via codes or chemical trackers and captured via the IoT and then fed into a Blockchain.

Phase 4: Getting all actors into one system [Technology and Environment]

Finally, this is followed by the 4th phase, which is largely dependent on overcoming previous barriers. The barriers in this phase must be solved in the long term, but they are extremely difficult to overcome. Finding a way to overcome the barriers in the area of ownership and application, as well as inhibition through codependency, is not guaranteed. Accordingly, it needs a clear line which Blockchain type is used and by whom it is initiated. And it needs a common goal and genuine incentives to let companies collaborate in a system.

To connect all partners and avoid isolated solutions from individual companies, public Blockchains seem to be the only solution. In terms of application, companies need to get away from the idea of developing an in-house solution. There may be IT service providers that offer a solution where licenses are paid by companies. However, here again there is the risk of not reaching critical mass or being dependent on an operator. Another way is to develop a solution on Government or even EU level, where governments can simultaneously utilize Blockchain for auditing. Both approaches have the advantage for companies that they do not have to entirely reorganize themselves internally and do not have to make large initial investments. Closely related to this is the problem that a critical mass must be reached in each system in order to be able to develop the functions of a Blockchain. How this can be achieved is still a big question mark in companies and also in politics.

Basically, there needs to be a common goal among companies in an industry and clear incentives for cooperative, resources-conserving action in order to remain competitive in the long term in the face of increasing resource scarcity. There must be more political incentives to make circular strategies more favorable for companies compared to conventional approaches. The relative advantage must become clear at the earlier stage. Ultimately, there needs to be some sort of protocol by which a Blockchain application is deployed so that information can flow. By whom which system is established and how a critical mass can be achieved in this system, even beyond national borders, remains an open question.

Overall, it becomes apparent that the barriers that should be addressed in the short term are also the ones that tend to be easier to overcome. When these are overcome, the way is prepared for the next phases. However, overcoming the long-term barriers becomes increasingly difficult. In addition, the color highlighting shows that the barriers within each level or TOE area build on each other. Both the barriers in the three areas of technology, organization and environment influence each other, and the players in these three levels, the politicians, the IT service providers and the companies themselves, also influence each other and are dependent on each other.

6.4 Practical and theoretical Contribution

Practical Contribution

The practical contribution refers to the comparison of different companies, the classification in the three relevant TOE areas and the provision of recommendations for action. By presenting experiences and assessments from practice with regard to different industries and Circular Economy approaches, companies can learn from each other and take off the blinders of their own industry. The classification of the factors into the three TOE areas allows to distinguish between factors and to classify the importance of the different company perspectives.

Furthermore, the overview of barriers and facilitators, which can give the companies themselves, possible Blockchain providers, but also the government an overview of where to expand facilitators and where problems must be overcome or possibly cannot be overcome initially. Finally, the classification of the factors into the three TOE areas and the discussion of the factors, which are then used to formulate recommendations for action, can serve as an orientation for practice.

Theoretical Contribution

The theoretical contribution is primarily based on the complementary examination of the factors behind the low adoption rates of Blockchain. On the one hand, the discussion in theory can be complemented by further empirical data from practice. And secondly, the considered factors in theory can be questioned again by empirical research. Another contribution can be made through sampling. While the first studies on Blockchain for Circular Economy were published about four years ago, more knowledge about Blockchain applications and Circular Economy around business contexts has emerged. Previous studies mostly had to use the method of conducting surveys about Circular Economy in enterprises and then bringing an external Blockchain expert in. In this study, impressions and assessments could be made by the same person, which brings the context of the CE in the adoption of Blockchain more into focus. Additionally, for the applied TOE framework, new perspectives arise from the context of the Circular Economy. This aspect is taken up under the theoretical basis in the chapter on innovation adoption theories.

7 Conclusion

The aim of this work is to answer the main research question: What are the influencing factors of Blockchain adoption for the development of circular businesses?

This question also emerged as relevant among the representatives of the companies from the case studies. They recognize that a digital solution is needed to manage the mass of data and the complexity of circular business strategies. They perceive the need to find a path to circular business development in order to remain competitive while resources are becoming increasingly scarce and legislations might become stricter. However, companies currently still face major challenges in implementing circular strategies, which is also why adoption rates of Blockchain application are currently low. Additionally, collecting and sharing information comes at a high financial cost, which means that investing in technology that supports these activities must pay off. Although a technological solution seems to be needed in the future, Blockchain is not necessarily the key solution. Barriers in the organizational, technological and environmental context become so great that they are difficult to overcome.

Main Findings

The main findings refer to the sub-research questions:

a) What are the perceived barriers that need to be addressed in the future?
(5.2 Cross-Case analysis on the perceived barriers)

b) What are the perceived facilitators to be expanded in the future?
(5.2 Cross-Case analysis on the perceived facilitators)

c) In what context do these factors occur (technological, organizational, or environmental)
(5.2 Summary and implication)

d) What are recommendations of action?
(6.3 Recommendations for action)

Barriers

In the technological context, companies face the challenge of capturing and transmitting information in the first place to then feed those into a Blockchain system. As well as how interfaces can then be established with the existing system in the companies. In the organizational context, companies deal with the fact that the transformation towards circular businesses needs a push. As well as on the question of how to build business cases behind data collection so that an investment into a new technology also pays off. In the environmental context, companies focus on the challenge of how to get all players on board, using the same system, in the same way, with high data quality along and beyond the value chains. These types of barriers seem particularly large because they depend on a large number of diverse players.

Facilitators

In almost all cases, the consensus mechanisms of Blockchain Technology were seen as facilitators. The focus is, first on the possibilities to encrypt data within the Blockchain or to feed data points anonymously and thus make them immutable, and second the ability to store and share information with restricted and verified access and lastly application possibilities of smart contracts. Additionally, although the complexity of the technology is perceived as relatively high, it is perceived as an enabler to decrease complexity on the long run. Several companies note that sustainability reporting requirements are tightening and data on topics such as Circular Economy need to be retrievable. Therefore, Blockchain Technology is seen as an attractive tool to support compliance and audit.

Recommendations for action

A common goal is needed among companies and clear incentives for cooperative, resources-conserving action in order to remain competitive in the long term in the face of increasing resource scarcity. There must be more political incentives to make circular strategies more favorable for companies compared to conventional approaches. The relative advantage of sharing data must become clear at the earlier stage. Ultimately, there needs to be some sort of protocol by which a Blockchain application is deployed so that information can flow. By whom which system is established and how a critical mass can be achieved in this system, even beyond national borders, remains the most pressing but still open question.
Both the barriers in the three areas of technology, organization and environment influence each other, and the players in these three levels, the politicians, the IT service providers, and the companies themselves, also influence each other and are dependent on each other.

Research limitations

The choice of research design enabled the research questions to be answered, however, the chosen method cannot capture all factors, their interrelationships, and exclude all types of biases associated with qualitative research. In the following, the limitations of this work will be outlined.

Limitations of qualitative research

One of the main limitations of this work is the choice of a qualitative research design, which is based purely on empirical values and tendencies in a specific context. No quantitative statements can be made, thus no causal relationships between factor and initial situation of the company, as well as no correlations between individual factors can be drawn.

Limitations of case study analysis

Eisenhardt and Graebner (2007) see a risk in case study research that only derivations for very specific phenomena are developed. Regarding this work, however, it was accepted from the outset that no generally valid theories would be derived, but rather a comprehensive picture on possible influencing factors. However, whether these can be applied to a large number of other German companies and non-German companies cannot be guaranteed. In addition, all eight cases analyzed in this work come from different industries. Industry-specific challenges regarding technology openness and the preference for certain circular strategies will have an influence on the statements. Thus, the position of companies in industrial value chains will make a difference in whether they have more of an interest in tracing or tracking products. For certain industries, conventional production routes are still more favorable than circular strategies. Customer demand also varies greatly by industry and position in the supply chain.

Limitations of data collection through interviews

Conducting interviews also entails limitations and involves certain biases. It must be considered that the representatives of a company generally speak from the perspective of their own perception and that this is based on individual experience. There is also the possibility that an interviewee does not have all the information that would be relevant. For example, there is a possibility that a pilot project with Blockchains has already been carried out on a small scale or that decisions have been made on certain circular strategies, but the interviewee does not have all the comprehensive information on this.

Limitations from factor-analysis

When analyzing influencing factors, they cannot be evaluated in depth in a qualitative framework. For example, certain factors have a particular importance in the individual cases and would have to be weighted differently than less relevant factors. Also, a particular combination of barriers and facilitators cannot be discussed in the context of this work. Some barriers could be overcome or are not seen as such in the first place. Nevertheless, Blockchain is not yet used in these companies. Which composition of which factors would then lead to adoption cannot be answered within the scope of this work.

Outlook

This work would benefit from future research in both qualitative and quantitative domains addressing the application of different and developing Blockchain types as well as specific circular strategies in diverse industries.

Qualitative research

Qualitative research approaches are particularly useful for looking at more differentiated aspects of Blockchain adoption in the context of circular business development. On the one hand, this is applicable with regard to industry-specific studies. Different industries have different characteristics in terms of technological openness as well as the relevance of circular strategies and are at different development points. Setting a focus here could lead to detailed insights and more concrete recommendations for action for individual industries.

In addition, in a further research approach, a precise distinction should be made between the different Blockchain types, their respective advantages and disadvantages, and possible applications, such as smart contracts. In this context, research that focuses on specific use cases from practice can also open up new perspectives. What types of Blockchain are being used by providers in the market and what barriers are experienced by companies already participating in pilot projects.

Finally, a beneficial approach could be to define the needs of companies that are moving towards a Circular Economy and to compare different data platforms with their features and capabilities in terms of usefulness. Especially regarding the finding of this work - BCT application for information sharing might not be practical feasible due to critical mass, other applications using other functions or only serving certain industries or parts of the value chain should be considered and investigated for their feasibility. Such an approach could be tokenizing as an incentive tool. Relevant in this aspect is also to map the knowledge of the respective actors about BC types and applications. And which expectations are placed on digitalization and which expectations can BCT fulfil? The last point is that BCT is constantly evolving and developments in terms of proof mechanisms, reinforcing security aspects and improving user interfaces should be included in further studies.

Quantitative research

As more companies gain experience with pilot projects and as soon there is a larger available sample of companies at the intersection of Circular Economy and Blockchain applications, this work will benefit from quantitative research approaches in the future. This will allow investigation of correlations between individual factors, as well as linking the starting point of companies to adoption behavior. Also, exploring the weighting of certain factors quantitatively can add value to focus on certain factors in practice and theory rather than talking about a multitude of diverse factors that we do not yet know enough about how they are related.

Concluding words

Even if the application of Blockchain in the context of circular businesses still seems several steps in the future, discussing upcoming barriers appears to be reasonable now. Especially regarding the prospect that Blockchain turns out to be impractical. Also, for other technologies, barriers like the lack of regulations, lack of common standards, integration challenges, and challenging business development have to be addressed and solutions have to be found. However, once ways have been established to translate real products into digital ones and material tracking has been implemented in companies, solutions that enable the exchange of this collected, standardized data must already be considered today. This work could show that even after overcoming some barriers, the biggest most pressing barriers are still ahead in the long-term. Potentially, no solutions can be found to establish a Blockchain system where critical mass is achieved. Strengthening collaborations, developing a business case from providing and retrieving data about products and materials, and creating the political framework for a level playing field must be addressed today regardless of the technology ultimately used.

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Appendices

Appendix 1: Excursus on use cases and a provider from practice

In practice, applications of Blockchain technology in the context of Circular Economy and supply chain management are planned or implemented in pilot tests. In the following, a successful project and a startup as a provider for a Blockchain solution are briefly presented.

Food provenance tracking - Walmart

In 2016, Walmart (American multinational retail corporation) collaborated with IBM to pilot test Blockchain technology for food provenance tracking. The company hoped to find a solution characterized by immutability of data and high speed (Business Insider, 2017).
IBM's Blockchain is based on a Hyperledger Fabric that uses consensus mechanism and can enforce restrictions on memberships (Kamath, 2018). Records fed into the Blockchain system included audits, agricultural treatments, identification numbers, manufacturers, available devices, known security issues, permissions granted, and security logs, all logged in real time and stored permanently as e-certificates. McDermott, the VP of IBM Food Trust in 2017 summarizes the success of the Blockchain application as follows (Business Insider, 2017): "One of the key benefits to Blockchain in the enterprise is the trust it delivers, which enables more efficient and complete sharing of the critical data that drives enterprise transactions." The Blockchain solution for Walmart in the pilot was developed specifically for the products of mangoes and pork. With regard to the pork in China, by uploading certificates of authenticity to the Blockchain, issues with the credibility of the system could be resolved. The time required to determine the origin of mangoes in the U.S. was reduced from 7 days to 2.2 seconds through the application (Kamath, 2018).

Circularise

Circularise (2020) is a Dutch start up that sets the goal to “facilitate a shift to a Circular Economy by digitising and tracing materials across complex supply chains on a public Blockchain without risking confidentiality.” The start up has already carried out pilot projects mainly in the field of plastics. One of them is application in the field of plastics with Domo and Covestro. In this pilot project, the tracking of plastics via Blockchain is being tested. Participants are the Polyamide supplier Domo and polymer manufacturer Covestro (Clancy, 2020).
The aim of the project is to create an open standard for exchanging data on the origin of materials and, in this context, resins in particular. The ability to share information via the Blockchain is expected to help the plastics industry increase the use of recycled content and thus reduce the use of virgin plastic (Clancy, 2020).

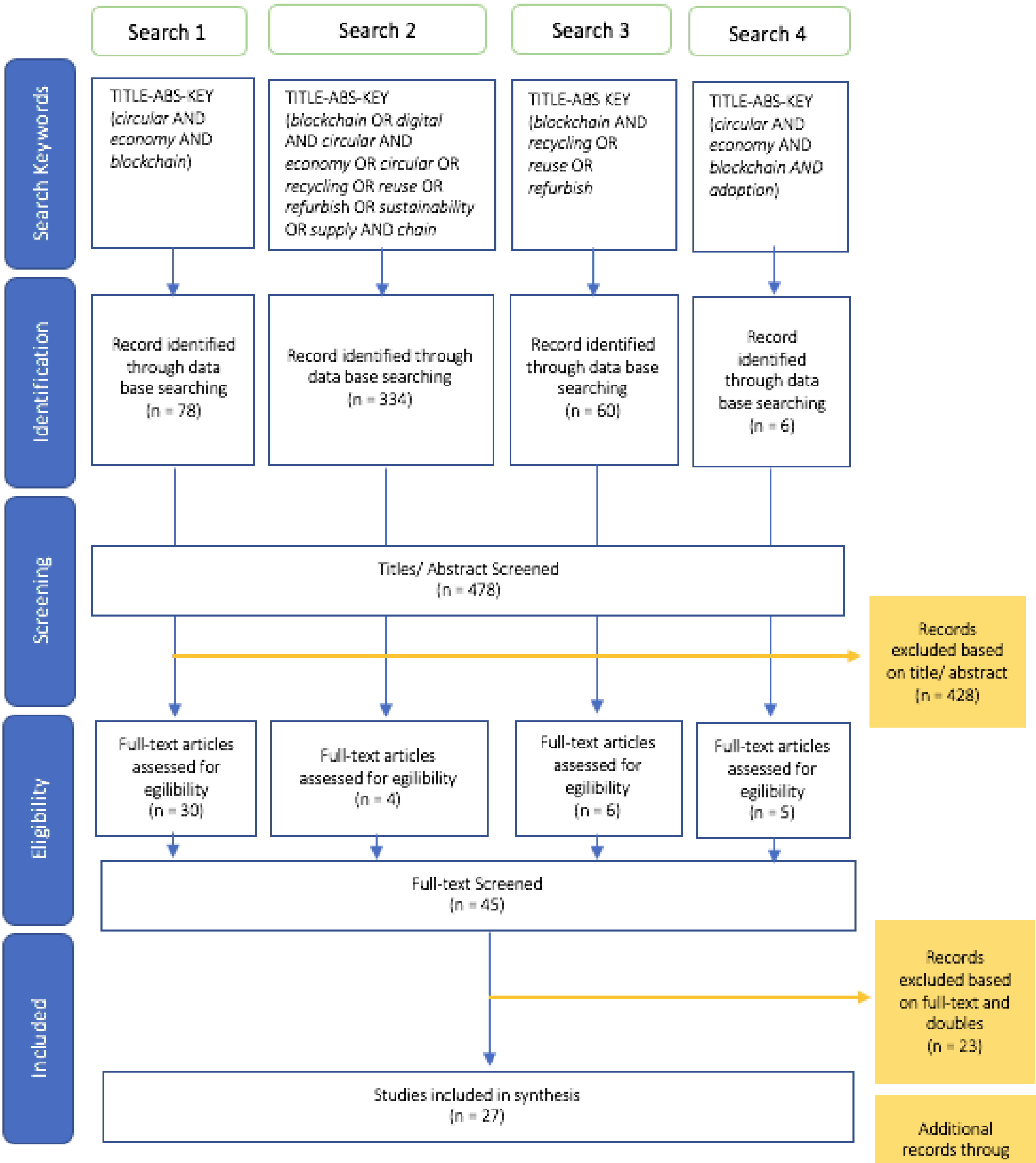
Regardless of this specific pilot, in general the USP of Circularise is to distinguishes between two use cases, where it wants to offer a solution in each case. The use cases include recycling on the one hand and auditing on the other (Circularise, 2020).
If a recycling company wants to recycle a product, it must know how the product is to be recycled. To do this, the company needs to know, for example, what materials it contains, whether they are toxic, for example. This can currently be done by manual inspection. However, this is very time-consuming because the manufacturer of the product itself sources from suppliers all over the world and does not have detailed knowledge of the composition of the individual parts. The goal of Circularise is to connect information users to information providers, and that involves: someone in need of information has to be connected to someone who has the information, and a channel has to be set up to allow information exchange. To do

this, they provide a public Blockchain system that allows companies to share information while maintaining control over sensitive information and not having to rely on a central organization. The second use case is auditing. When inquiring about product quality, people want to be sure that the information is accurate. Circularise builds on the comparison between the claims made about a product and the information shared in the system. For example, "if a recycler were to encounter suspicious materials that were stated otherwise in the manifest of the product, an immutable, digital trail is left for the auditor to find the source of mischief" (Circularise, 2020, p. 5).

Appendix 2: Overview of interview partners in the case study sample

Case	Interview partner	Interview date	Interview length
A	Head of Liaison Office Berlin	30.07.2021	01:06
B	Business Unit Manager Corporate Quality & Product Compliance	09.08.2021	00:48
C	Head of Corporate Sustainability	04.08.2021	00:43
D	CR Manager Materials & Circularity	17.08.2021	00:52
E	Programme Director E-Mobility & Circular Economy	07.09.2021	00:59
F	CEO	17.08.2021	01:12
G	Project Lead Innovation Research	25.08.2021	01:07
H	Senior Digital Innovation Developer	10.09.2021	00:53

Appendix 3: Overview Literature Review



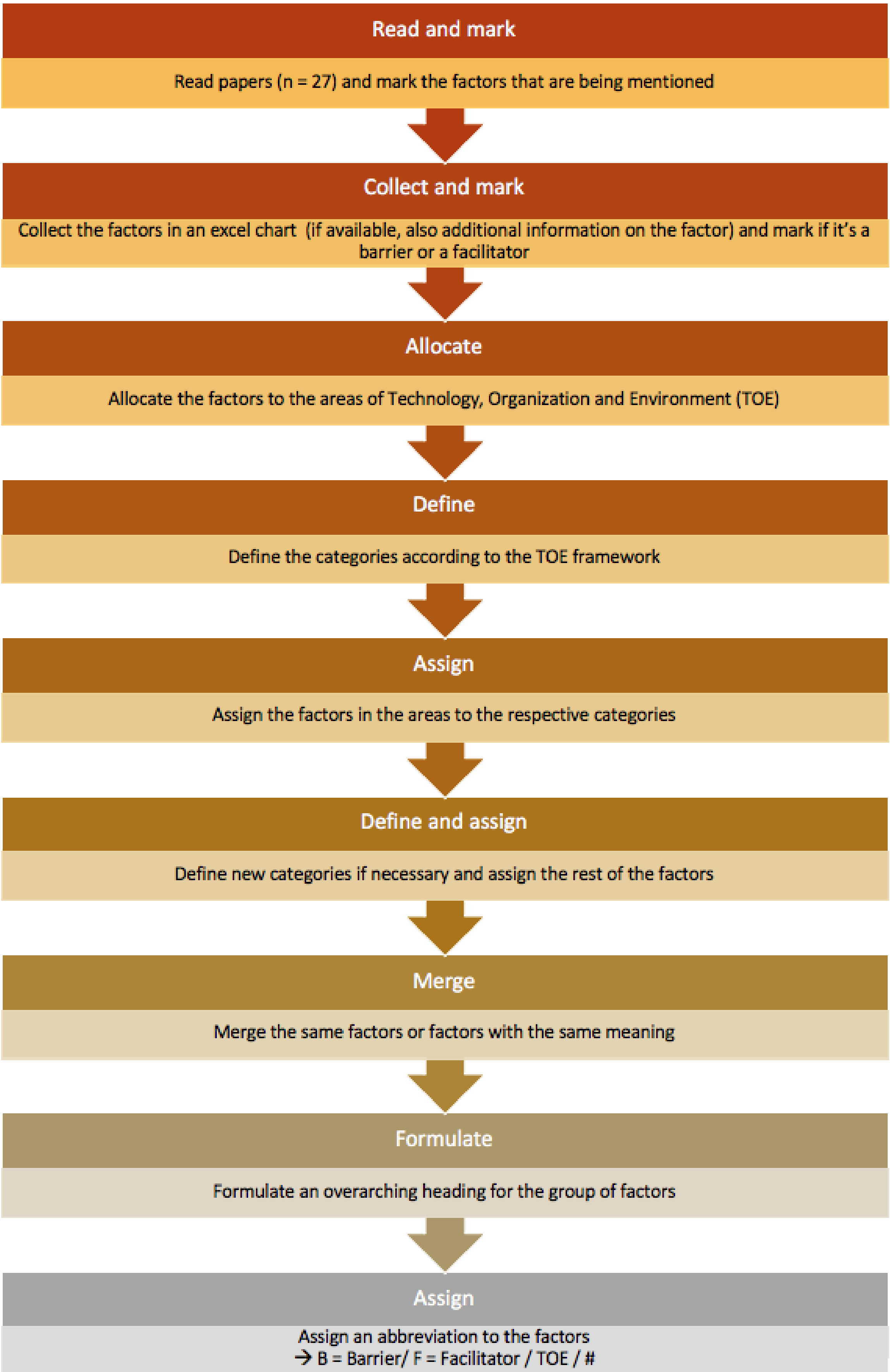
Reasons for exclusion: missing sustainability reference, focus too much on another specific I4.0 technology, focus too much on one function of the blockchain, discuss factors that are too specific with regard to type of organization, nationality or industry, that are too broad in terms of subject matter (addressed transformation processes in general)

Reasons for inclusion: mentioning of factors that can be interpreted as adoption barriers or facilitators in relation to use cases, pilots and literature reviews in the context of Ce or CE strategies or sustainable supply chains and blockchain.

Appendix 4: Overview of records that where included in the synthesis

#	Author	Year	Journal	Industry/ topic	Methodology
52	Borangiu et al.	2016	Studies in Computational Intelligence Springer Verlag	Manufacturing	
54	Kouhizadeh and Sarkis	2018	MDPI Sustainability	SCM	Literature review
15	Zhan et al.	2019	Resources, conservation & recycling	LCA	Literature review and implementation framework
56	Saberi et al.	2019	International Journal of Production Research	SCM	Critical examination
26	Kouhizadeh	2019	Production Planning & Control	General concepts	grounded theory building from multiple case studies
45	Wong et al.	2019	International Journal of Information Management	SCM	Literature review TOE
53	Kamilaris et al.	2019	Trends in Food Science & Technology	Agriculture SCM	Project investigation
35	Schmelz et al.	2019	2019 IEEE 35th International Conference on Data Engineering Workshops (ICDEW)	Waste flow	
40	Riesener et al.	2019	2019 IEEE International Symposium on Innovation and Entrepreneurship (TEMS-ISIE)	Manufacturing	
4	Wang et al.	2020	Computers in Industry	SCM	developing a system architecture of blockchain-enabled circular supply chain management
6	Böckel et al.	2020	Sustainable Production and Consumption	General concepts	Literature review
9	Esmaeilian et al.	2020	Resources, conservation & recycling	SCM	Literature review
11	Dutta et al.	2020	Transportation Research Part E	SCM	Literature review
12	Leng et al.	2020	Renewable and Sustainable Energy Reviews	Manufacturing and Product Lifecycle	Literature review
14	Yadav et al.	2020	Resources, conservation & recycling	Agriculture SCM	literature search and expert interviews
44	Kouhizadeh et al.	2020	International Journal of Production Economics	General concepts	Literature review TOE
13	Schinckus	2020	Energy Research & Social Science	General concepts	Literature review
27	Demestichas and Daskalakis	2020	MDPI Sustainability	General concepts	Literature review
32	Bakarich et al.	2020	Ad	Sustainability reporting	Literature review
1	Yildizbasi	2021	Renewable Energy	Energy sector	Expert opinion and literature contributions
2	Upadhyay et al.	2021	Journal of Cleaner Production	General concepts	narrative and integra- tive literature review approach
3	Shojaei et al.	2021	Journal of Cleaner Production	Built environment	synthetic case study (simulated scenario)
8	Dey and Shekhawat	2021	Journal of Cleaner Production	Agriculture	Data collection from use cases
57	Kumar	2021	Journal of Cleaner Production	Agriculture SCM	literature search and expert interviews
21	Bekrar	2021	MDPI Sustainability	SCM	Example use cases
17	Chen and Ogunseitan	2021	Frontiers of Environmental Science & Engineering	E-Waste	Example investigation
18	Magrini	2021	MDPI Sustainability	Electronic Equipement	Interviews

Appendix 5: Overview of factor extraction process



Appendix 6: Interview Guide (Non-adopter)

Interview Guide - Non-Adopter

Interview partner:
Company:

Thank you for your time!

<u>Relevance and aim</u> of my work at TU Berlin and University of Twente:

The starting point is the following: Current research suggests that the concept of Circular Economy has enormous potential to contribute to sustainable development. At the same time, it also shows that the concept faces challenges in its realization. The basis for a Circular Economy is the exchange of data and information about products and materials throughout the supply chain. Blockchain technology has been proposed as a possible solution to overcome the current obstacles.

My **<u>goal</u>** now is to find out
a) which **factors lead to companies being early adopters** in pilot projects
b) which **factors lead to the fact that companies do not yet find an application** for the technology or what it would take for this technology to be applied.
After all, this is a very new, unproven technology that is also very costly.

During this interview, I would like to **cover three fields**. I would like to discuss factors in the context of the **technology** itself, in the context of the **corporate structures**, and in the context of the **corporate environment** (according to the TOE framework).

At this point, I would like to briefly clarify that **no names or companies will be mentioned**. If you agree, I would just mention the industry, the size of the company and your position (differentiation sustainability, innovation management, Blockchain expert, circularity department, etc.). Lastly, the question: **<u>may I record this interview?</u>**

Beforehand, I would like to ask you three introductory questions to have an overview of the sample of interview partners and companies:

1) Which approaches/projects or even business models towards a Circular Economy are currently being followed in your company?

2) Does Blockchain play a role in this context? Are there already applications?

3) How do you assess your own knowledge of this technology?

Before we jump into the structured interview, I have one rather open question for you:

Blockchain is not yet widely used in your business. What are the first 1-2 reasons that come to mind when you want to justify this?

Then I would like to get into the main part of the interview.

This is structured as follows: I briefly summarize the current state of research on a factor and then ask you to comment in relation to your company. Or have 2-3 more specific questions. You are also welcome to skip questions if you can't or don't want to say anything about it.

Technology

The technological context includes the technical capabilities, complexity, difficulty, and availability of the innovation being considered for application.

1) Compatibility

Two things emerge from the literature:

a) The integration of Blockchain into existing systems is a barrier. The technology entry threshold is very high, it requires new software, and hardware.
Can you assess the situation in your company? Is there already digital support for information exchange or similar? If yes, what kind and to what extent?

b) Beyond the IT structure in the company, the real world must be connected with the digital world. The quantity and quality of materials must be fed into the system. Industry 4.0 technologies can be linked for this purpose. For example, Blockchain with the Internet of Thing (IOT), where materials or products are tracked automatically.
How do you currently record what is, when and where, and in what quantity? Is information tracked, or how is it shared in the supply chain?

2) Technical capabilities

From the literature:

(a) **Blockchain is a decentralized, trust-independent network that allows data assets to be used across the supply chain**. Blockchain offers security and speed in this regard. It also provides a high level of transparency, as all transactions are accessible to all members. This offers improved access, enhanced visibility, traceability for important resources. **However, it is also discussed that the technology is not yet fully mature**. Also, trust in a completely new technology is not shared across the board. Caused by the risks associated with cryptocurrencies like Bitcoin, the reputation is not spotless either.
What is your assessment with regard to your company? Can you invest in a technology that is not fully mature? How do you assess the capabilities of the technology for your industry/business?

3) Complexity

The technology promises to **reduce the complexity** of processes. For a Circular Economy, billions of data are exchanged and materials are traced. With Blockchain, this can happen much faster and automated, with high transparency. The **complexity of the technology** itself, however, can be daunting. Its exact functionality is not self-explanatory.
How do you assess the complexity of the technology and how does that go together with the already high complexity of moving towards a Circular Economy?

4) Availability

It is clear from the literature: Blockchain needs to become more accessible, and that is a big challenge.
Let's assume there are to be initial tests with Blockchain technology in your company. What would be the first steps?

Organisation

The organizational context includes factors and issues related to the internal concerns of the company. So management support, costs, corporate culture, resources and the business model of the company.

1) Costs

Adapting Blockchain technology comes with **high costs for setup, development and data maintenance**. Accordingly, the initial investment is very high. Not only is the switch to closed-loop and carbon neutrality costly, but so is setting up the technology. On the other hand, the use of the technology **promises to increase efficiency** in linking stakeholders and ensure cost and time savings. To do this, **stakeholders can share the costs.**
Who do you see as responsible for bearing the costs of the technology, is cost sharing among several actors feasible, or how does this play out in current projects? How do you estimate the relative advantage for your company?

2) Resources

According to literature, there is a lack of comprehensive understanding of Blockchain in companies, which blocks its implementation. In addition, the **need for expertise and experts is increasing**. There is a **lack of standards and appropriate methods** and tools for implementing Blockchain technology and measuring sustainability performance in organizations.
How do you assess the situation in your company? Did it need training or new staff? Did you cooperate with a service provider or consultant? How do you assess the situation in the future?

3) Corporate culture

The introduction of Blockchain technology changes or transforms the current organizational culture. The introduction can mean a major change in all aspects of an existing company. A large number of stakeholders are involved, there may be conflicting goals between the different stakeholders, intermediaries at different levels may be eliminated, uncertainty hinders acceptance.
How do you assess the corporate culture or the departmental culture in the CE area with regard to openness to change. What influence would a changeover to a decentralized digital system have on the corporate structure?

4) Circular Economy Driver

One challenge for companies is tracing and identifying the origin as well as the supply chain of products. Blockchain enables the reconciliation of data located in different SCs, improves security, and captures all information in real time. **The benefits of such activities are that they lead to economic-environmental "win-win" situations created by eco-efficiency measures.** If there are no business and economic benefits to CE Blockchain linkage, the latter stakeholder group is unlikely to push for adoption.
Do you see the technology as high risk or do you see it as an opportunity in the longer term?

5) Top Management Support

According to the literature, the lack of management buy-in is a barrier. This barrier exists in risk-averse companies, where the risks of a new technology can affect the organization.
Does your company consider itself a pioneer or a follower when it comes to innovation? Does this apply to Blockchain as well? To what extent did top management influence whether Blockchain was adopted? How much say does the sustainability department or Circular Economy project leaders have in this?

Environment

Environmental factors include factors related to the legal environment, industry characteristics, market competition, inter-firm linkages, and customer demand.

1) Industry

From a product design perspective, current approaches that are not CE-oriented in many cases result in products that are difficult to disassemble, reuse, and recycle.
How suitable do you think Blockchain is for your industry or sector? Are there products in the industry that cannot be integrated into a Circular Economy?

2) Competition

The industry's practices can lead to imitation effects among competitors. After some early adopters are successful, others will follow.
Is there already a visible impact of the technology in the industry? Do you see applications of the technology among your competitors? Do you also see the adoption of the technology as a competitive advantage?

In interorganizational systems, **the question of confidentiality and privacy** often arises. Companies are skeptical about sharing their information because they view information as a competitive advantage. However, without **information sharing and cooperation**, there is no Circular Economy.
How do you see that? Can sharing internal company information also be seen as a risk?

3) Dependency - information exchange

According to literature, **convincing all stakeholders to share information is a challenge**. Some stakeholders are not very tech-savvy, and operating the Blockchain-based system is not easy for them. Supply chain **participants may have different privacy needs and policies** regarding information and data. **Cultural and geographic differences** among supply chain partners may hinder the adoption of Blockchain technology.
What is your assessment in relation to your company? Do you have any experience or assessment of how your supply chain is doing in terms of contributing and using information?

4) Regulatorien und Richtlinien

Government regulations do not yet fully support Blockchain technology. **Gaps in government regulation** over what to measure and how to measure it are hindering the transition to Blockchain systems. **However, regulators may also introduce recycling rates or carbon pricing**, making a technology that can track material composition, origin, energy use, etc. and **prove it without falsification attractive.**
What is your take on this? Is a lack of regulations a hurdle? Is Blockchain also used as an audit tool in your company?

5) Customers

Blockchain data sets help to monitor the quality and quantity of manufactured products and **provide evidence to the customer.**
The use of cyber-physical systems that determine material composition and quality can assist in matching supply and demand and marketing secondary raw materials. However, companies also need to **ensure that their investments in sustainable processes and new technology such as Blockchain are rewarded by their customers.**
What's your take on this? How is customer demand for greener products shaping up? How do you assess its use as a means against "greenwashing"?

_____

Finally, one last quite open question:

What would need to happen for your company to seriously consider adopting this technology?

Thank you very much!

Appendix 7: Interview Guide (Early-adopter)

____

Interview Guide - Early-Adopter

Interview partner:
Company:

Thank you for your time!

Relevance and aim of my work at TU Berlin and University of Twente:

The starting point is the following: Current research suggests that the concept of Circular Economy has enormous potential to contribute to sustainable development. At the same time, it also shows that the concept faces challenges in its realization. The basis for a Circular Economy is the exchange of data and information about products and materials throughout the supply chain. Blockchain technology has been proposed as a possible solution to overcome the current obstacles.

My **goal** now is to find out
a) which **factors lead to companies being early adopters** in pilot projects
b) which **factors lead to the fact that companies do not yet find an application** for the technology or what it would take for this technology to be applied.
After all, this is a very new, unproven technology that is also very costly.

During this interview, I would like to **cover three fields**. I would like to discuss factors in the context of the **technology** itself, in the context of the **corporate structures**, and in the context of the **corporate environment** (according to the TOE framework).

At this point, I would like to briefly clarify that **no names or companies will be mentioned**. If you agree, I would just mention the industry, the size of the company and your position (differentiation sustainability, innovation management, Blockchain expert, circularity department, etc.). Lastly, the question: **may I record this interview?**

Beforehand, I would like to ask you three introductory questions to have an overview of the sample of interview partners and companies:

1) Which approaches/projects or even business models towards a Circular Economy are currently being followed in your company?

2) Does Blockchain play a role in this context? Are there already applications?

3) How do you assess your own knowledge of this technology?

Before we jump into the structured interview, I have one rather open question for you:

Company XY is one of the so-called early adopters, implementing first applications of Blockchain technology with pilot projects. What are the first 1-2 motivations that come to mind that you see as relevant for Company XY to adopt?

Then I would like to get into the main part of the interview.

This is structured as follows: I briefly summarize the current state of research on a factor and then ask you to comment in relation to your company. Or have 2-3 more specific questions. You are also welcome to skip questions if you can't or don't want to say anything about it.

Technology

The technological context includes the technical capabilities, complexity, difficulty, and availability of the innovation being considered for application.

1) Compatibility

Two things emerge from the literature:

(a) **Integrating Blockchain** into existing systems is a hurdle. The technology entry barrier is very high, new software, and hardware are needed. **Can you assess the situation in your company? How is information shared alongside or before the Blockchain application? How big do you see the hurdle to connect/replace existing systems with Blockchain?**

b) Beyond the IT structure in the company, **the real world must be connected with the digital world**. The quantity and quality of materials must be imported into the system. Industry 4.0 technologies can be linked for this purpose. For example, Blockchain with the Internet of Thing (IOT), where materials or products are tracked automatically.
Before Blockchain, how was it tracked what is where, when, and in what quantity? How was information "tracked" throughout the supply chain? Are other Industrie 4.0 technologies already being used in addition to Blockchain technology?

2) Technical capabilities

From the literature:

(a) **Blockchain is a decentralized, trust-independent network that allows data assets to be used across the supply chain**. Blockchain offers security and speed in this regard. It also provides a high level of transparency, as all transactions are accessible to all members. This offers improved access, enhanced visibility, traceability for important resources. **However, it is also discussed that the technology is not yet fully mature**. Also, trust in a completely new technology is not shared across the board. Caused by the risks associated with cryptocurrencies like Bitcoin, the reputation is not spotless either.
What is your assessment with regard to your company? Can you invest in a technology that is not fully mature? How do you assess the capabilities of the technology for your industry/business?

3) Complexity

The technology promises to **reduce the complexity** of processes. For a Circular Economy, billions of data are exchanged and materials are traced. With Blockchain, this can happen much faster and automated, with high transparency. The **complexity of the technology** itself, however, can be daunting. Its exact functionality is not self-explanatory.
How do you assess the complexity of the technology and how does that go together with the already high complexity of moving towards a Circular Economy?

4) Availability

Stemming from the literature, it is clear that Blockchain needs to become more accessible, and that is a big challenge.
Your company has already implemented pilot projects and gained experience with the technology. Can you provide some insight into what the first steps looked like? Was there a cooperation, an offer, funding or was the technology developed in-house?

Organisation

The organizational context includes factors and issues related to the internal concerns of the company. So management support, costs, corporate culture, resources and the business model of the company.

1) Costs

Adapting Blockchain technology comes with **high costs for setup, development and data maintenance**. Accordingly, the initial investment is very high. Not only is the switch to closed-loop and carbon neutrality costly, but so is setting up the technology. On the other hand, the use of the technology **promises to increase efficiency** in linking stakeholders and ensure cost and time savings. To do this, **stakeholders can share the costs.**
Who do you see as responsible for bearing the costs of the technology, is cost sharing among several actors feasible, or how does this play out in current projects? How do you estimate the relative advantage for your company?

2) Resources

According to literature, there is a lack of comprehensive understanding of Blockchain in companies, which blocks its implementation. In addition, the **need for expertise and experts is increasing**. There is a **lack of standards and appropriate methods** and tools for implementing Blockchain technology and measuring sustainability performance in organizations.
How do you assess the situation in your company? Did it need training or new staff? Did you cooperate with a service provider or consultant? How do you assess the situation in the future?

3) Corporate culture

The introduction of Blockchain technology **transforms the current organizational culture**. The introduction can mean a major change in all aspects of an existing company. A large number of stakeholders are involved, there can be **conflicting goals** between the different stakeholders, middlemen at different levels could be eliminated, **uncertainty hinders acceptance.**
How do you assess the corporate culture or for the departmental in the Circular Economy area with regard to openness to change? Did the transition to the decentralized digital system have an impact on the corporate structure yet? How do you assess the situation in the future?

4) Circular Economy Driver

One challenge for companies is tracing and identifying the origin as well as the supply chain of products. Blockchain enables the reconciliation of data located in different SCs, improves security, and captures all information in real time. **The benefits of such activities are that they lead to economic-environmental "win-win" situations created by eco-efficiency measures.** If there are no business and economic benefits to CE Blockchain linkage, the latter stakeholder group is unlikely to push for adoption.
Do you see the technology as high risk or do you see it as an opportunity in the longer term?

5) Top Management Support

According to the literature, the lack of management buy-in is a barrier. This barrier exists in risk-averse companies, where the risks of a new technology can affect the organization.
Does your company consider itself a pioneer or a follower when it comes to innovation? Does this apply to Blockchain as well? To what extent did top management influence whether Blockchain was adopted? How much say does the sustainability department or Circular Economy project leaders have in this?

Environment

Environmental factors include factors related to the legal environment, industry characteristics, market competition, inter-firm linkages, and customer demand.

1) Industry

From a product design perspective, current approaches that are not CE-oriented in many cases result in products that are difficult to disassemble, reuse, and recycle.
How suitable do you think Blockchain is for your industry or sector? Are there products in the industry that cannot be integrated into a Circular Economy?

2) Competition

The industry's practices can lead to imitation effects among competitors. After some early adopters are successful, others will follow.
Is there already a visible impact of the technology in the industry? Do you see applications of the technology among your competitors? Do you also see the adoption of the technology as a competitive advantage?

In interorganizational systems, **the question of confidentiality and privacy** often arises. Companies are skeptical about sharing their information because they view information as a competitive advantage. However, without **information sharing and cooperation**, there is no Circular Economy.
How do you see that? Can sharing internal company information also be seen as a risk?

3) Dependency - information exchange

According to literature, **convincing all stakeholders to share information is a challenge**. Some stakeholders are not very tech-savvy, and operating the Blockchain-based system is not easy for them. Supply chain **participants may have different privacy needs and policies** regarding information and data. **Cultural and geographic differences** among supply chain partners may hinder the adoption of Blockchain technology.
What is your assessment in relation to your company? Do you have any experience or assessment of how your supply chain is doing in terms of contributing and using information?

4) Regulatorien und Richtlinien

Government regulations do not yet fully support Blockchain technology. **Gaps in government regulation** over what to measure and how to measure it are hindering the transition to Blockchain systems. **However, regulators may also introduce recycling rates or carbon pricing**, making a technology that can track material composition, origin, energy use, etc. and **prove it without falsification attractive.**
What is your take on this? Is a lack of regulations a hurdle? Is Blockchain also used as an audit tool in your company?

5) Customers

Blockchain data sets help to monitor the quality and quantity of manufactured products and **provide evidence to the customer.**
The use of cyber-physical systems that determine material composition and quality can assist in matching supply and demand and marketing secondary raw materials. However, companies also need to **ensure that their investments in sustainable processes and new technology such as Blockchain are rewarded by their customers.**
What's your take on this? How is customer demand for greener products shaping up? How do you assess its use as a means against "greenwashing"?

_____

Finally, one last quite open question:

In your opinion, what needs to happen for Blockchain technology to be widely used within the company in the long term?
(All a question of time, there are still hurdles, initially a different focus, etc.)?

Thank you very much!

Appendix 8: Cross-Case Generalizing findings on barriers and facilitators

Agenda

Sub-Factor	Cases where the factor was mentioned
High technology threshold	A B C D F

Mentioned in 7-8 cases
Mentioned in 5-6 cases
Mentioned in 3-4 cases
Mentioned in 1-2 cases

Barriers

TECHNOLOGY

Compatibility

Integration Challenges	A B C D F
High technology threshold	D
Data transmission challenge	A E F G H

Technical Capabilities

Immaturity	C D
Security and privacy concerns	A
No mechanisms against Fraud	C D F G

Complexity/ difficulty

Lack of Interoperability of BC systems	G
High complexity of system design	C

Availability

Accessability and complexity	C D
Ownership and application	B C F G H

ORGANIZATIONAL

Perceived cost

Unclear relative advantage	A C E G H

Data driven organizational culture

Resistance to change	C
Adjustment effort	A C D G

Personnel

Lacking new Personnel	D F
Unskilled existing Personnel	B C

Top Management Support

Lack of management commitment and support	C

Industry type

Property rights	G

Application

Challenging BC design descisions	A E G H

CE design decisions

Challenging business development	A B C D E F G H

ENVIRONMENTAL

Competitive pressure

Not reaching a critical mass	C D E
Fierce competition	E
Lack of CE-oriented products	C F

Cooperation

Inhibition through Codependency	B C D E F G H
Alignment challenges	B C D F H
Integrity concerns	B H
Lack of collaboration	B

Government regulation

Lack of regulations	A C D F G H
Laws as roadblock	A B G
Lack of incentives	A D F

Standards

Lack of common standards	A B C D F G H

Customer pressure

Lack of demand and awareness	A C D F

Facilitators

TECHNOLOGY

Technical Capabilities

Consensus mechanisms	A B C E F G H
Data availability	A

Complexity/ difficulty

Complexity reduction	A B D F H

ORGANIZATIONAL

Perceived cost

Cost saving	C F

Industry type

Reputation	A B
Cross-company application	D

ENVIRONMENTAL

Competitive pressure

Imitation effect	D

Cooperation

Cost sharing	B F H

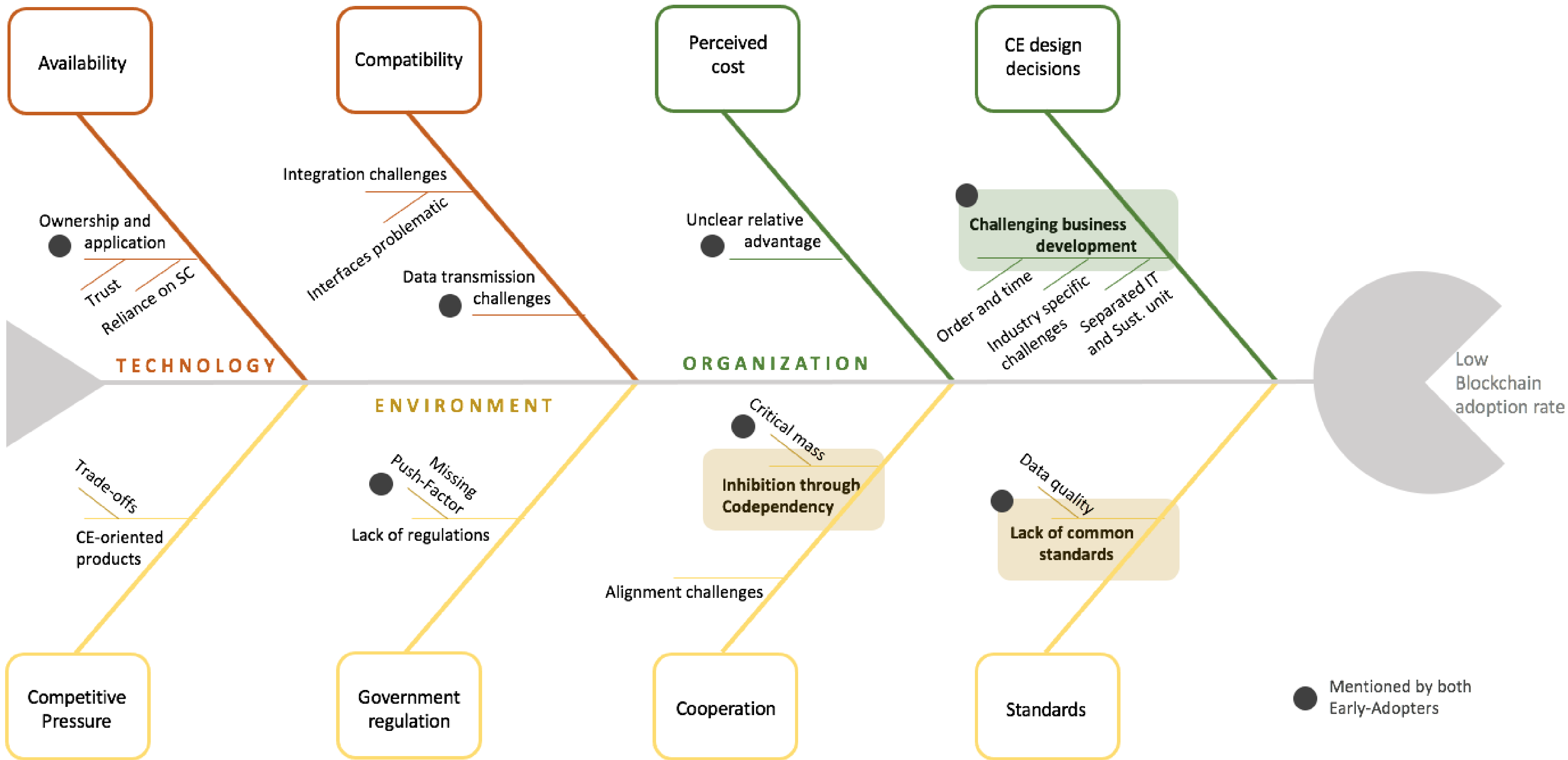
Government regulation

Compliance and audit	A C F G H

Customer pressure

Ensure product quality	A B C D H

Appendix 9: Cross-Case analysis - Additions from the case studies



Appendix 10: Cross-Case comparison with Literature review

Agenda

Marked Green = There is consens between literature and cases
[B] = Consens over a **B**arrier → Is a barrier that has been mentioned in the literature as well as in the case
[BA] = Consens over a **B**arrier with an **A**dditional aspect/ persepctive
→ Is a barrier that has been mentioned in the literature as well as in the case,
BUT an additional Factor regarding this barrier has been added in the interview

[F] = Consens over a **F**acilitator → Is a barrier that has been mentioned in the literature as well as in the case
[FA] = Consens over a **F**acilitator with an **A**dditional aspect/ persepctive
→ Is a facilitator that has been mentioned in the literature as well as in the case,
BUT an Additional Factor regarding this barrier has been added in the interview

Marked Blue = There are discrepancies between literature and cases
[X] = Discrepancy between literature and case
[XA] = Additional aspect to why this is seen differently in pratice

White
- nothing specifically mentioned about the point

Technological context										
Factor-Category	B/F	Sub-Factors	Non-Adopter						Early-Adopter (Pilot)	
			Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H
Compatibility	B_T1	Integration challenges	[B] Integration Challenges [BA] Tranferring historical data [BA] Interfaces problematic	[B] Integration challenges	[B] Integration Challenges [BA] Interfaces problematic	[B] Integration challenges	[X] Compatibility feasible	[B] Integration challenges [BA] Interfaces problematic		
	B_T2	High technology entry threshold	[XA] Digital transformation already underway		[XA] Kick-Off to digital transformation	[B] High technology entry threshold			[X] Easy handling	
	B_T3	Data transmission challenge	[B] Data transmission challenge		[XA] Digital Twin		[B] Data transmission challenge	[B] Data transmission challenge [BA] Digital Twin	[B] Data transmission challenge	[B] Data transmission challenge
	F_T1	Combination with other technologies								
Technical Capabilities	B_T4	Immaturity	[XA] Proactive development	[XA] Proactive development	[B] Immaturity	[B] Immaturity		[X] Immaturity		[XA] Proactive Development
	B_T5	Security and privacy concerns	[XA] Security measures against security gaps			[XA] Security measures against security gaps		[XA] Security nowhere given [XA] Security measures against security gaps	[X] No security concerns	
	B_T6	Critical public image	[X] Not perceived as risky	[XA] Perceived as chance		[XA] Perceived as chance				
	B_T7	No mechanism against fraud			[B] No mechanism against fraud	[B] No mechanism against fraud		[B] No mechanism against fraud	[B] No mechanism against fraud	
	B_T8	Undesirable features								
	F_T2	Consensus mechanisms	[F] Consensus mechanisms	[F] Consensus mechanisms	[F] Consensus Mechanism		[F] Consensus mechanisms	[F] Consensus mechanisms	[F] Consensus mechanisms	[F] Consensus mechanisms [FA] Tocenizing [FA] Smart contracts
	F_T3	Data availability	[F] Data availability		[X] No such high demands on data					
Complexity/ difficulty	B_T9	Lack of Interoperability of BC systems							[B] Lack of Interoperability of BC systems	
	B_T10	High complexity of system design	[X] Managable complexity of system design	[X] Managable complexity of system design [XA] Entry-level complexity	[B] High complexity of system design			[X] Managable complexity of system design		[XA] Entry-level complexity
	F_T4	Complexity reduction	[F] Complexity reduction	[F] Complexity reduction		[F] Complexity reduction	[X] Complexity too high	[F] Complexity reduction		[F] Complexity reduction
Availability	B_T11	Accessability and complexity	[XA] Openness to initiate	[XA] Openness to initiate	[B] Accessability and complexity	[B] Accessability and complexity	[XA] Several ways to access		[XA] Access via start up	
	B_T12	Ownership and application	[XA] Big players as shapers	[B] Ownership and application [BA] Big players as shapers [BA] Reliance on SC [BA] Divergent demands of the industries	[B] Ownership and application [BA] Reliance on SC			[B] Ownership and application [BA] Long term planning uncertainty [BA] Reliance on SC	[B] Ownership and application [BA] Trust [BA] UX	[B] Ownership and application [BA] Trust

Organizational context										
Factor-Category	**B/F**	**Sub-Factors**	**Case A**	**Case B**	**Case C**	**Case D**	**Case E**	**Case F**	**Case G**	**Case H**
			Non-Adopter						**Early-Adopter (Pilot)**	
Perceived cost	B_O1	**High costs**	[XA] Revenue issue instead of cost issue				[XA] Costs not a killer argument			
	B_O2	**Unclear relative advantage**	[B] Unclear relative advantage		[B] Unclear relative advantage		[B] Unclear relative advantage [BA] BC as Business case		[B] Unclear relative advantage	[B] Unclear relative advantage
	F_O1	**Cost savings**			[F] Cost savings			[F] Cost savings		
Data driven organizational culture	B_O3	**Resistance to change**	[X] Agile organizational culture [XA] Openness to technology [XA] Co-designer for change	[XA] Co-designer for change [XA] Change Management [XA] Experience [XA] Openness to technology	[B] Resistance to change		[X] Agile organizational culture		[XA] Openness to technology	[XA] Change Management
	B_O4	**Adjustment effort**	[B] Adjustment effort		[B] Adjustment effort	[B] Adjustment effort		[X] Decentralized organization	[B] Adjustment effort	[XA] Application-dependent
Personell	B_O5	**Lacking new personell**	[X] Inhouse capacitites being built up			[B] Lacking new personell		[B] Lacking new personell	[XA] No new personell needed	[XA] Application-dependent
	B_O6	**Unskilled existing personell**	[X] Skilled IT unit	[BA] Lack of knowledge/ awareness	[BA] Lack of Knowledge/ awareness	[X] Skilled IT unit	[X] Skilled personell	[X] Skilled IT unit	[X] Skilled IT unit	[X] Skilled IT unit
Resources	B_O7	**Lack of resources**	[XA] Available ressources as big player							
Top management support	B_O8	**Lack of management commitment and support**	[X] Mgmt as a driver [XA] Generation Change [XA] Top Mgmt support	[X] Top Management Support	[B] Lack of management commitment and support	[X] Top management support	[X] Top Management Support	[X] Top management support		[X] Top Management Support
Industry type	B_O9	**Property rights**							[B] Property rights	[XA] Technology Capabilities
	F_O2	**Reputation**	[F] Reputation	[F] Reputation						
	F_O3	**Cross-company application**			[X] Cross-company application	[F] Cross-company application				
Application	B_O10	**Challenging BC design descisions**	[B] Challenging BC design decisions [BA] First step challenge [BA] Strategic relevance				[B] Challenging BC design descisions [BA] Industry specific challenges [BA] Question of necessity		[B] Challenging BC design descisions	[B] Challenging BC design descisions [BA] Business Model Development [BA] Implementation [BA] Question of necessity
CE design decisions	B_O11	**Challenging business development**	[B] Challenging business development	[B] Challenging business development [BA] Separated IT and Sust. unit [BA] Order and time	[B] Challenging business development [BA] CE nonprioritized [BA] Lack of self drive [BA] Separated IT and Sust. unit [BA] Order and time	[B] Challenging business development [BA] Relevance for action [BA] Separated IT and Sust. unit	[B] Challenging business development [BA] Order and Time	[B] Challenging business development [BA] Industry specific challenges [BA] Order and Time	[B] Challenging business development [BA] Industry specific challenges [BA] Change of competitive landscape	[B] Challenging BC design descisions

Environmental context										
Factor-Category	B/F	Sub-Factors	Case A	Case B	Case C	Case D	Case E	Case F	Case G	Case H
			Non-Adopter						Early-Adopter (Pilot)	
Competitive pressure	B_E1	Undesired Codependency								
	B_E2	Not reaching a critical Mass	[XA] First mover advantage	[XA] First mover advantage	[B] Not reaching a critical Mass [BA] First follower	[B] Critical mass	[B] Not reaching a critical Mass			
	B_E3	Fierce competition					[B] Fierce competition	[X] Voluntary data provision		
	B_E4	Lack of CE-oriented products			[BA] No competitive products [BA] Trade-Offs			[BA] LCA [BA] Trade-offs		
	F_E1	Imitation effect				[FA] Knowledge Transfer	[XA] Value chain specific			
Cooperation	B_E5	Inhibition through Codependency		[B] Inhibition through Codependency	[B] Inhibition through Codependency	[B] Inhibition through Codependency	[B] Inhibition through Codependency [BA] Trust [BA] Critical Mass	[B] Inhibition through Codependency	[B] Inhibition through Codependency [BA] Critical Mass	[B] Inhibition through Codependency [BA] Critical Mass
	B_E6	Alignment challenges		[B] Alignment challenges [BA] Global Alignment challenges	[B] Alignment challenges	[B] Alignment challenges		[B] Alignment challenges		[B] Alignment challenges
	B_E7	Resistance	[XA] Technology Diffusion rules							
	B_E8	Integrity concerns		[B] Integrity concerns						[B] Integrity concerns
	B_E9	Lack of collaboration	[XA] Survival of the fittest	[BA] Lack of collaboration [BA] Diverging instead of converging				[XA] No levering		
	F_E2	Cost sharing	[XA] Profit sharing	[F] Cost sharing				[FA] Selling system	[F] Cost sharing	[FA] Business model
Government regulation	B_E10	Lack of regulations	[B] Lack of regulations [BA] Missing Push-Factor		[B] Lack of regulations [BA] Missing Push-Factor	[B] Lack of regulations [BA] Missing Push-Factor		[B] Lack of regulations	[B] Lack of regulations [BA] Missing Push-Factor	[B] Lack of regulations [BA] Missing Push-Factor
	B_E11	Laws as roadblock	[BA] Competition Law	[BA] Regulations as roadblock					[B] Laws as roadblock	
	B_E12	Lack of incentives	[B] Lack of incentives			[B] Lack of incentives		[B] Lack of incentives		
	F_E3	Compliance and audit	[F] Compliance and audit [FA] Auditing Workflow		[F] Compliance and audit [FA] Auditing Workflow			[F] Compliance and audit	[F] Compliance and audit	[F] Compliance and audit [FA] Auditing Workflow
Standards	B_E13	Lack of common standards	[B] Lack of common standards	[B] Lack of common standards [BA] Lack of international standards	[B] Lack of common standards [BA] Data quality	[B] Lack of common standards		[B] Lack of common standards	[B] Lack of common standards	[B] Lack of common standards [BA] Data quality
Customer pressure	B_E14	Lack of demand and awareness	[B] Lack of demand and awareness [BA] Conventional Is cheaper [BA] Customer is price-driven	[XA] B2B Customer driven [XA] Increasing demand	[B] Lack of demand and awareness	[B] Lack of demand and awareness	[X] Demand and awareness is present	[B] Lack of demand and awareness	[X] Demand is present	[X] Demand is present
	F_E4	Ensure product quality	[F] Ensure product quality	[F] Ensure product quality	[F] Ensure product quality	[F] Ensure product quality		[X] Focus on tracking downstream		[F] Ensure product quality

Appendix 11: All factors Case A

Barriers

T/O/E	Factor-Category	Sub-Factor
T	Compatibility	Integration challenges (Tranferring historical data, Interfaces problematic)
		Data transmission challenge
	Technical Capabilities	Security concerns (but security measures against security gaps)
O	Perceived cost	Unclear relative advantage
	Data driven organizational culture	Adjustment effort
	Application	Challenging BC design decisions (First step challenge, Strategic relevance)
	CE design decisions	Challenging business development
E	Government regulation	Lack of regulations {Missing Push-Factor}
		Laws as roadblock (Competition Law)
		Lack of incentives
	Standards	Lack of common standards
	Customer pressure	Lack of demand and awareness (Conventional Is cheaper, Customer is price-driven)

Facilitators

T/O/E	Factor-Category	Sub-Factor
T	Technical Capabilities	Consensus mechanisms
		Data availability
	Complexity/ difficulty	Complexity reduction
O	Industry type	Reputation
E	Government regulation	Compliance and audit (Auditing Workflow)
	Customer pressure	Ensure product quality

Appendix 12: All factors Case B

Barriers

T/O/E	Factor-Category	Sub-Factor
T	Compatibility	Integration challenges
	Availability	Availability (Big players as shapers, Reliance on SC, Divergent demands of the industries)
O	Personnel	Lack of knowledge/ awareness
	CE design decisions	Challenging business developmen,(Connecting IT and Sustainability, Order and time)
E	Cooperation	Copedependency
		Alignment challenges (Global Alignment challenges)
		Integrity concerns

		Lack of Collaboration (Diverging instead of converging)
	Government regulation	Regulations as roadblock
	Standards	Lack of common standards (Lack of international standards)

Facilitators

T/O/E	Factor-Category	Sub-Factor
T	Technical Capabilities	Consensus mechanisms
	Complexity/ difficulty	Complexity reduction
O	Industry type	Reputation
E	Cooperation	Cost sharing
	Customer pressure	Ensure product quality

Appendix 13: All factors Case C

Barriers

T/O/E	Factor-Category	Sub-Factor
T	Compatibility	Integration Challenges (Interfaces problematic)
	Technical Capabilities	Immaturity
		No mechanism against Fraud
	Complexity/ difficulty	High complexity of system design
	Availability	Accessability and complexity
		Ownership (Reliance on SC)
O	Perceived cost	Unclear relative advantage
	Data driven organizational culture	Resistance to change
		Adjustment effort
	Personnel	Lack of Knowledge/ awareness
	Top management support	Lack of management commitment and support
	CE design decisions	Challenging business development (Nonprioritized business development, Lack of self drive, Connecting IT and Sustainability, Order and time)
E	Competitive pressure	Critical Mass (First follower)
		Lack of CE-oriented products (No competitive products, Trade-Offs)
	Cooperation	Inhibition through Codependency
		Alignment challenges (Data quality)
	Government regulation	Lack of regulations (Missing Push-Factor)
	Standards	Lack of common standards
	Customer pressure	Lack of demand and awareness

Facilitators

T/O/E	Factor-Category	Sub-Factor
T	Technical Capabilities	Consensus Mechanism
O	Perceived cost	Potential cost savings
E	Government regulation	Auditing Workflow
	Customer pressure	Ensure product quality

Appendix 14: All factors Case D

Barriers

T/O/E	Factor-Category	Sub-Factor
T	Compatibility	Integration challenges
		High technology entry threshold
	Technical Capabilities	No mechanism aginst Fraud
		Immaturity
	Availability	Accessability and complexity
O	Data driven organizational culture	Adjustment effort
	Personnel	Lacking new Personnel
	CE design decisions	Challenging business development (Relevance for action, Connecting IT and Sustainability)
E	Competitive pressure	Critical mass
	Cooperation	Inhibition through Codependency
		Alignment challenges
	Government regulation	Lack of regulations (Missing Push-Factor)
		Lack of incentives
	Standards	Lack of standards
	Customer pressure	Lack of demand and awareness

Facilitators

T/O/E	Factor-Category	Sub-Factor
T	Complexity/ difficulty	Complexity reduction
O	Industry type	Cross-company application
E	Competitive Pressure	Knowledge Transfer
	Customer pressure	Ensure product quality

Appendix 15: All factors Case E

Barriers

T/O/E	Factor-Category	Sub-Factor
T	Compatibility	Data transmission challenge
O	Perceived cost	Unclear relative advantage (BC as Business case)
	Application	Industry specific challenges (Question of necessity)
	CE design decisions	Challenging business development (Order and Time)
E	Competitive pressure	Critical Mass
		Fierce competition
	Cooperation	Cooperation (Trust, Critical Mass)

Facilitators

T/O/E	Factor-Category	Sub-Factor
T	Technical Capabilities	Consensus mechanisms

Appendix 16: All factors Case F

Barriers

T/O/E	Factor-Category	Sub-Factor
T	Compatibility	Integration challenges (Interfaces problematic)
		Data transmission challenge (Digital Twin)
	Technical Capabilities	No mechanism against Fraud
	Availability	Ownership and application (Long term planning uncertainty, Reliance on SC)
O	Personnel	Lacking new Personnel
	CE design decisions	Challenging business development (Industry specific challenges, Order and Time)
E	Competitive pressure	Lack of CE-oriented products (LCA, Trade-offs)
	Cooperation	Inhibition through Codependency
		Alignment challenges
	Government regulation	Lack of regulations
	Standards	Lack of common standards
	Customer pressure	Lack of awareness

Facilitators

T/O/E	Factor-Category	Sub-Factor
T	Technical Capabilities	Consensus mechanisms
	Complexity/ difficulty	Complexity reduction
O	Perceived cost	Cost savings
E	Cooperation	Selling system
	Government regulation	Compliance and audit

Appendix 17: All factors Case G

Barriers

T/O/E	Factor-Category	Sub-Factor
T	Compatibility	Data transmission challenge
	Technical Capabilities	No mechanism against Fraud
	Complexity/ difficulty	Lack of Interoperability of BC systems
	Availability	Ownership and application (Trust, UX)
O	Perceived cost	Unclear relative advantage
	Data driven organizational culture	Adjustment effort
	Industry type	Property rights
	Application	Challenging BC design descisions
	CE design decisions	Challening business development (Industry specific challenges, Change of competitive landscape)
E	Cooperation	Inhibition through Codependency (Critical mass)
	Government regulation	Lack of regulations (Missing Push-Factor)
		Laws as roadblock
	Standards	Lack of common standards

Facilitators

T/O/E	Factor-Category	Sub-Factor
T	Technical Capabilities	Consensus mechanisms
E	Cooperation	Cost sharing
	Government regulation	Compliance and audit

Appendix 18: All factors Case H

Barriers

T/O/E	Factor-Category	Sub-Factor
T	Compatibility	Data transmission challenge
	Availability	Ownership and application (Trust)
O	Perceived cost	Unclear relative advantage
	Application	Challenging business development (Business Model Development, Implementation, Question of necessity)
E	Cooperation	Codependency (Critical Mass)
		Allignment challenges (data quality)
		Integrity concerns
	Government regulation	Lack of regulations (Missing Push-Factor)
	Standards	Lack of common standards

Facilitators

T/O/E	Factor-Category	Sub-Factor
T	Technical Capabilities	Consensus mechanisms
	Complexity/ difficulty	Complexity reduction
O	Cooperation	Cost sharing (Business model)
	Government regulation	Compliance and audit (Auditing Workflow)
E	Customer pressure	Ensure product quality