MASTER

The contribution of blockchain to circular business models in the manufacturing industry

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Master thesis

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Abstract

The circular economy is gaining popularity in the manufacturing industry as a solution to the challenges of the planetary crises that the current economic system is facing. However, transitioning to a circular economy requires manufacturing businesses to eliminate product end-of-life and reconfigure their value chain. As a result, business models are being disrupted and aim for a broader definition of value from the perspective of multiple stakeholders by preserving or recovering value from materials and products. The blockchain is receiving wide recognition for supporting the transition to a circular economy as it can help businesses improve the collaboration and trust required in the production of circular products. However, a concrete contribution of blockchain to circular business models is lacking. This thesis proposed reference blockchain blueprints depicting the generic set of actors and their characteristics to guide the development of blockchain-enabled circular business models in the manufacturing industry. Following a design science research approach, a systematic literature review is performed to develop the initial reference blockchain blueprints according to the service-dominant business model radar. Subsequently, validation and utility interviews were performed to improve the model. These proposed reference blockchain blueprints were validated on feasibility and viability.

Preface

This thesis inspired me a lot with the two emerging topics that found my interest: blockchain and circular economy.

I worked very hard to achieve the finishing of my master thesis. A topic which is quite new and innovative. It was a big experience working on my own challenging project the last year. Therefore, I would like to thank a few people.

First of all, I would like to thank Banu Aysolmaz for giving me the opportunity to do my graduation project in her research group. Your knowledge and enthusiasm gave me new insights and motivation for this project. Thank you for all the discussions and conversations we had about my innovative subject. Second, I would like to thank Oktay Türetken for all the interesting meetings we had about my project. Furthermore, I really appreciate your feedback during and about my thesis.

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A special thanks goes to Jelmer and Laura from Sabic, who guide and supervised me throughout my project. You took the time for me and questioning critical questions about blockchain and business models. Thank you for all your feedback and time, and good luck with all your future work!

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1. Introduction

The planetary crises (i.e., climate change, pollution, and biodiversity loss) have become a growing concern for businesses around the globe. These crises drive the transition to more sustainable sociotechnical systems and empower businesses towards innovative and efficient use of resources to contribute to a healthy planet for the future (Geissdoerfer et al., 2017; IPCC, 2021; Köhler et al., 2019). Researchers and policymakers claim that the circular economy concept is a potential solution to combat the planetary crises (Prieto-Sandoval et al., 2018) and practitioners started investigating this concept as it promises economic prosperity within ecological limits (Kirchherr et al., 2017; Murray et al., 2017). The circular economy is “an economic system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes” (Kirchherr et al., 2017). Therefore, businesses need to reconfigure their value chain to guarantee that products do not have end-of-life when transitioning to a circular economy (Hazen et al., 2020).

The circular economy concept disrupts existing business models as it goes beyond the product creation. Focal businesses transitioning to a circular economy remove their linear take-make-waste approach and introduce a closed-loop value chain (Geissdoerfer et al., 2017; Suchek et al., 2021). Although the circular economy concept disrupts existing businesses, it could harmonize economic growth with current environmental pressures (Merli et al., 2018). The European Commission (2020) estimated that a shift towards the circular economy in Europe could increase the gross domestic product by 0.5% and create approximately 700.000 jobs by 2030. Furthermore, companies that spend high costs on materials (i.e., manufacturing companies) could reduce the overall costs and remove dependency on commodity price fluctuation (Ellen MacArthur Foundation, 2013; EUROPEAN COMMISSION, 2020). In contrast to the circular economy, the traditional linear economy is under pressure due to exposure to price volatility, increasing resource demand by the growth of population and wealth, and environmental challenges (De Angelis et al., 2018; Morone & Yilan, 2020). Therefore, next to the environmental pressures for transitioning to a circular economy, economic benefits could further empower this transition.

Conceptual studies on circular economy that emphasize its drivers and corresponding economic benefits indicate that several critical barriers cause manufacturing businesses to be reluctant to transition to a circular economy (Suchek et al., 2021). Common barriers that cause this reluctance include inefficient waste management practices, low consumer comprehension of sustainable practices, and lack of environmentally friendly value chain design approach for products (Babbitt et al., 2018; Fehrer & Wieland, 2021; Kirchherr et al., 2018). Technological innovations could be a solution to overcome these barriers and are essential in transitioning to a circular economy (de Jesus et al., 2018; Kalmykova et al., 2018).

Digital technologies are frequently mentioned in supporting the transition to a circular economy (Cagno et al., 2021; Lopes de Sousa Jabbour et al., 2018). In this context, blockchain is widely mentioned by scholars and practitioners as a critical enabler for transforming and advancing the circular economy. Nakamoto (2008) introduced the technology blockchain for its usability based on the fundamental attributes: Decentralization, consensus, the immutability of data entries, and cryptographic security. Although blockchain technology is used for several practices, the underlying structure of blockchain technology is created as an auditing tool to guarantee the credibility of time-stamping (Haber & Stornetta, 1991). Hence, the fundamental attributes of blockchain can be translated into circular economy practices such as transparency, reliability, traceability, and real-time information sharing (Aslam et al., 2021). Seebacher & Schüritz (2017) define blockchain as "*a distributed database which is shared among and agreed upon a peer-to-peer network*." Recent studies have proven the supportive role of blockchain in the circular economy, for instance, by facilitating traceability in complex supply chains and accurate information sharing (Agrawal et al., 2021; Saberi et al., 2019).

Blockchain integration is based on the underlying business model, which determines the goal for implementation and commercialization to generate economic value for companies (Chesbrough & Rosenbloom, 2002; Zott et al., 2011). Circular business models (CBMs) describe business models suited for the circular economy focusing on slow, narrow, and close resource loops to create economic value (Geissdoerfer et al., 2018). Accordingly, Böhmecke-Schwafert et al. (2022) argue that blockchain could be a moderator by strengthening drivers and mitigating barriers in the transition toward a circular economy. Despite these theoretical findings supporting the benefits of blockchain, empirical evidence on the contribution of blockchain to companies for their CBMs are scarce (Alexandris et al., 2018; Böckel et al., 2021; Böhmecke-Schwafert et al., 2022; White, 2017). Moreover, a systematic overview of the contribution of blockchain to CBMs is lacking. Several papers touch upon the potential use cases of blockchain in the manufacturing industry and highlight their corresponding benefits (e.g., Gong et al., 2022; Khadke et al., 2021; Steenmans & Taylor, 2018). However, the current research on blockchain applications for circular economy practices lacks oversight of the use cases and the characteristics of the corresponding CBM.

Circular economy is particularly important in the manufacturing industry as it can lead to cost reduction through maximizing resource efficiency, while reducing unsustainable production and improving resilience to resource price volatility (Lieder & Rashid, 2016; OECD, 2022). The manufacturing industry is dependent on the supply of raw materials for product creation. As a result, this industry is increasingly under pressure due to its linear economy approach causing unsustainable production and increased solid waste generation (Lieder & Rashid, 2016; OECD, 2022). Because the raw materials from earth are finite, increased competition for these limited materials increases market price volatility (Lieder & Rashid, 2016). In contrast, the circular economy concept could yield higher profits and reduce the costs of materials (Ellen MacArthur Foundation, 2013). The circular economy concept is receiving wide recognition in the manufacturing industry to cope with these challenges.

However, transitioning to a circular economy in the manufacturing industry requires collaboration between businesses (Lieder & Rashid, 2016). The preserving or recovering of value from materials and products is vital to the success of circular economy, and a collaborative business model should be developed to realize this within the manufacturing industry. Since this industry comprises complex networks and a competitive environment, information technology, and especially blockchain, is mentioned as a significant moderator to enable this transition (Böhmecke-Schwafert et al., 2022; Lieder & Rashid, 2016). Thus, blockchain could significantly contribute to the adoption of a circular economy in the manufacturing industry to cope with the challenges of a linear economy.

1.1 Research Problem and Objective

The blockchain phenomena started to receive wide recognition only recently to support the circular economy concept within the manufacturing industry. Hence, literature on this subject is nascent for academia and practice and comprises mainly conceptual and empirical case studies (Adams et al., 2018; Böckel et al., 2021; Kouhizadeh et al., 2019; Upadhyay et al., 2021). Since manufacturing companies are reluctant to transition to a circular economy given several critical barriers, blockchain can be a tool to mitigate these barriers and remove the reluctance to transition towards a circular economy. However, concrete studies highlighting contribution of blockchain to a CBM are lacking (Kouhizadeh et al., 2020). Identifying the contribution of blockchain to CBMs could encourage companies to adopt blockchain to overcome barriers in transitioning to a circular economy. Therefore, this thesis aims to identify the contribution of blockchain as an enabler for the circular economy concept in the manufacturing industry, specifically targeting the underlying collaborative business model.

The main *objective* of this thesis is to identify how blockchain can contribute to CBMs for companies that intend to operate or expand their circular economy practices in the manufacturing industry. Accordingly, this thesis will develop a solution artifact, which will be referred to as the *reference blockchain blueprint* in the remainder of this report. The reference blockchain blueprint can guide companies to develop their concrete CBMs by taking the blueprint as a reference. The implementation of blockchain for circular economy practices can reduce adoption reluctance to a circular economy for practitioners. This thesis is among the first to create overview of blockchain use cases for the circular economy in the manufacturing industry. Hence, it aims to fill the literature gap to give concrete guidance on the value implementation of blockchain for CBMs from a multiple-stakeholder perspective. Thus, the following research question addresses the gap in the literature:

"How can blockchain contribute to circular business models for companies operating in the manufacturing industry?"

To guide this thesis and to answer the main research question, five sub-questions are developed and answered in corresponding order. The first and second sub-questions are answered through a literature background research, whereas the third sub-question is researched through a systematic literature review (SLR). The fourth sub-question is answered through validity interviews with field experts. Finally, the fifth sub-question is answered through evaluation interviews with practitioners.

SQ1: *What characterizes circular business models, and how do they differ from linear business models?*

SQ2: *Which business model framework is most suitable for defining circular business models?*

SQ3: *How do circular business models for blockchain applications in the manufacturing industry look like?*

SQ4: *How does the literature on blockchain-enabled circular business models differ from practice?*

SQ5: *How feasible & viable is a blockchain-enabled circular business model in practice?*

1.2 Research Methodology

The research methodology for this thesis is followed according to the design science research approach (Hevner et al., 2004). First, a thorough and rigorous systematic literature is conducted to extract data on blockchain characteristics and circular business models of blockchain applications in the manufacturing industry. Following the grounded theory approach (Strauss & Corbin, 1990), the initial reference blockchain blueprint is developed based on the systematic literature review results. Validation interviews with field experts are performed to validate and complement the reference blockchain blueprint, and evaluate the utility of the blueprint based on the technology acceptance model (Venkatesh & Davis, 2000). Following that, the final version of the reference blockchain blueprint is created based on the feedback gathered from the first set of interviews. The final version is evaluated based on interviews with petrochemical industry practitioners to determine the feasibility and viability in practice.

1.3 Thesis Outline

This thesis is structured as follows. First, Section 2 elaborates on the background literature by providing an extensive literature overview of the concepts of blockchain, business models, and circular economy central to this study and the related work. In Section 3, the research design is described according to a design science research process by Peffers et al. (2007) for the proposed artifact. Section 4 describes a rigorous and reproducible SLR on blockchain applications for circular economy practices in the manufacturing industry to extract information on blockchain characteristics and SDBM/R elements. The extracted information from the SLR is synthesized and used to develop the initial reference blockchain blueprint in Section 5. In section 6, evaluation interviews are conducted and discussed to validate and assess the utility of the initial reference blockchain blueprint. In Section 7, the proposed reference blockchain blueprint is discussed. Subsequently, Section 8 performed evaluation interviews with petrochemical industry practitioners to assess the feasibility and viability of the proposed reference blockchain blueprint. Finally, this thesis concludes by describing the theoretical contribution and practical implications, limitations, and future research in Section 9.

2. Background and Related Work

This section elaborates upon the concepts central to this study. These concepts are *circular economy, blockchain, business model, blockchain for a circular economy, business model concept, and service-dominant business model radar.*

2.1 Circular Economy

The concept of circular economy is widely recognized, yet existing literature lacks consensus on a definition for this concept (Alhawari et al., 2021; Kirchherr et al., 2017). Although several studies use various keywords to define the critical elements of circular economy, the circular economy approach mainly emphasizes economic prosperity and the improvement of environmental quality (Geissdoerfer et al., 2017; Kirchherr et al., 2017; Lieder & Rashid, 2016). The concept differs from sustainability as it does not integrate the social equity term in its approach, yet the society does benefit from these environmental improvements. This study follows the definition of Kirchherr et al. (2017) who defined *circular economy* as “An economic system that replaces the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes.” Since this thesis definition is grounded on a systematic analysis of existing circular economy definitions, it is most suitable for a generalizable definition of circular economy (Alhawari et al., 2021; Kirchherr et al., 2017). However, Siderius & Zink (2022) emphasized that the circular economy concept is still at a crossroad for a rebranding on the business level or forcing true systematic change. Figure 1 shows that the linear economy is driven by market efficiency, which incentivizes behaviour from a market perspective and is always based on costs. In contrast, technical efficiency focuses on solutions guided by system, science, and technology solutions to realize the full potential of a functional circular economy (Siderius & Zink, 2022). Therefore, the four core characteristics of market economies determine the incentives and structures of an economy system in realizing the systematic change of a circular economy.

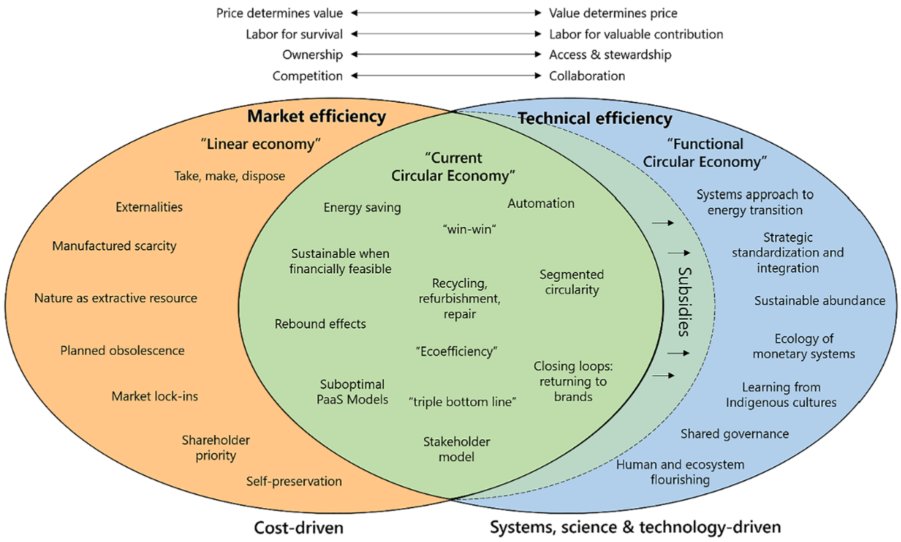

Figure 1: Market efficiency versus technical efficiency in realizing a circular economy (Siderius & Zink, 2022)

Scholars targeting the circular economy context refer to principles for transitioning towards a circular economy. To guide practitioners towards a circular economy, several frameworks have been developed. McKinsey (2016) developed the ReSOLVE framework, which depicts strategies to incorporate the circular economy concept into practice. The ReSOLVE framework aims to represent circular business opportunities for companies. According to Rosa et al. (2019), the ReSOLVE framework is used for the majority of classification methods of circular business models in studies. Another well-known framework is the 4R framework, which is developed to depict the core principles of the circular economy. The 4R framework for circular economy consists of reducing, reusing, recycling, and recovering and is prioritized according to a hierarchy (Kirchherr et al., 2017, 2018; Vermeulen et al., 2018). These principles (or imperatives) are grounded by the circular economy definition of Kirchherr et al. (2017). Furthermore, these principles guide the Waste Framework Directive developed by the European Commission (n.d.) to establish an order of preference for managing and disposing of waste.

The 4R framework is more suited to the characteristics of the manufacturing industry and can address the huge challenges this industry faces. This 4R framework is categorized on a hierarchical level and depicts how each individual principle can guide to address the difficulties of transitioning to the circular economy in the manufacturing industry (Kirchherr et al., 2017). Although the ReSOLVE framework is used for most classification methods (Rose et al., 2019), the 4R framework tends to be more concrete for the manufacturing industry, as demonstrated by the Waste Framework Directive. Therefore, the 4R framework is chosen in this thesis since it better suits the circular economy in the manufacturing industry.

2.2 Blockchain

Blockchain received wide recognition through the study of Nakamoto (2008) for its usability based on the following fundamental attributes: Decentralization, consensus, the immutability of data entries, and cryptographic security. However, general interest in blockchain only started to increase exponentially at the end of 2015, with its peak at the end of 2017 (Google Trends, 2022). Although blockchain originates from the financial sector (Lee & Shin, 2018; Nakamoto, 2008), it could offer various benefits in many other industries (White, 2017). For instance, it may revolutionize how companies do business with each other (i.e., interaction and transactions). An explanatory definition of blockchain by Seebacher & Schüritz (2017), building on the fundamental attributes of Nakamoto (2008), is as follows: "*A blockchain is a distributed database, which is shared among and agreed upon a peer-to-peer network. It consists of a linked sequence of blocks, holding timestamped transactions secured by public-key cryptography and verified by the network community. Once an element is appended to the blockchain, it cannot be altered, turning a blockchain into an immutable record of past activity*." Since this definition accurately captures the underlying technology of blockchain, it is used as the central definition for this thesis.

To be able to digest the underlying mechanisms of the blockchain phenomena, it is crucial to understand the general concept of a blockchain. Although blockchain implementations can have their own data fields, blocks require having a block header and block data. The block header consists of metadata to link the sequence of hash codes across the blockchain. Whereas the block data consists of any transaction submitted to the blockchain network. The transaction data from participants in the network are transformed into blocks that are chronologically connected in a chain of blocks, a so-called blockchain. The blockchain is initiated by the genesis (or reference) block and new blocks are linked to the previous block when it complies with the established rules of the platform and after validation of the network (Yaga et al., 2018). This process is illustrated in Figure 2.

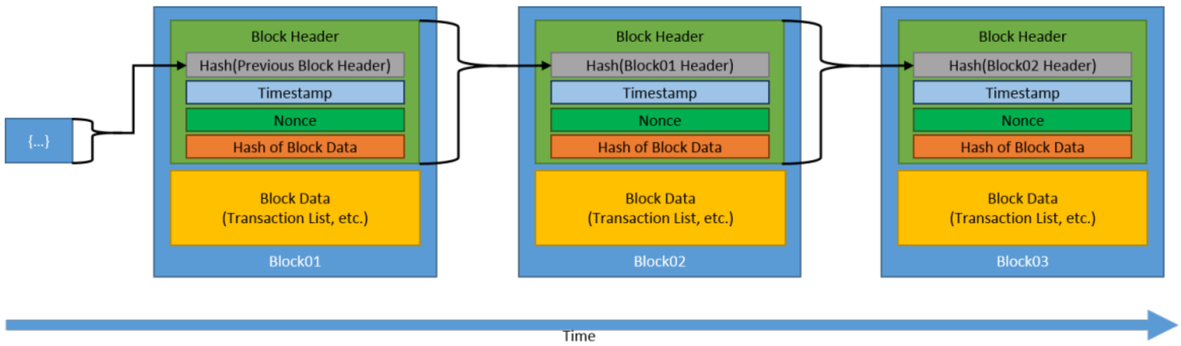

Figure 2: Generic chain of blocks (Yaga et al., 2018)

To understand the blockchain phenomena and its underlying mechanisms, it is important to elaborate on the fundamental attributes discussed earlier in this report as defined by Nakamoto (2008). The attribute *decentralization* refers to an environment that does not require a third-party organisation to control the transactions and data. Moreover, it refers to a network configuration with multiple authorities for control and decision-making (Yaga et al., 2018; Yli-Huumo et al., 2016). These blockchain networks are permissionless and permissioned (Lin & Liao, 2017; Yaga et al., 2018). The permissionless, referred to as the public blockchain, is a decentralized network accessible to anyone, where users can execute or read transactions freely. Contrary to this, the permissioned blockchain requires adequate permission to join and perform transactions on the network, resulting in a lower degree of decentralization. This permissioned blockchain can be divided into a private- or consortium blockchain (Dib et al., 2018). Since businesses require a certain degree of trust among network participants, the permissioned blockchain is most applicable and will be the main focus of this thesis. From a circular economy perspective, permissioned blockchain is also preferred as energy-intensive consensus mechanisms over the permissionless blockchain type.

Table 1: Blockchain classification (adapted from Dib et al. (2018))

	Network types		
Blockchain type	Public	Consortium	Private
Blockchain network	Permissionless	Permissioned	Permissioned
Decentralization level	Highly-decentralized	Decentralized	Centralized
Transaction validation	Miner	A list of authorized users	A central authority

The *consensus mechanism* and *immutability* attributes maintain the data integrity of the blockchain for all participants (Hughes et al., 2019). The *consensus mechanism* attribute for a blockchain comprises of predefined protocols to guarantee that all network participants agree on the state of the distributed ledger. Since only authorized users are allowed on the permissioned blockchain, counterfeit transactions should be discovered by verifying users and not transmitted into the blockchain (Yaga et al., 2018; Yli-Huumo et al., 2016; Zheng et al., 2017). Various consensus mechanisms exist and significantly differ for blockchain applications in practice. After approval of the integrity of a transaction, the transaction is stored on the blockchain network. These verified transactions stored on the blockchain network are secured and prevented from modification on a later stage according to the *immutability* attribute. However, permissioned blockchain networks could allow a clause for misconduct to adapt a transaction accordingly (Hofmann et al., 2018; Yaga et al., 2018; Yli-Huumo et al., 2016).

Cryptographic security is important in realizing a permissioned blockchain as it provides data security and authenticity by using pairs of keys (i.e., public and private keys) among authorized users. The *cryptographic* function is built on a mathematical algorithm defined as a one-way function, transmitting confidential information into public information for particular users (Preikschat et al., 2021; Yaga et al., 2018). Moreover, confidential information is only visible to authorized users (i.e., those with a private key) but allowing unauthorized users (i.e., those with a public key) to receive public information is extremely difficult to compute the input.

Next to the fundamental attributes of blockchain, *smart contracts* are essential for blockchain applications in businesses as they can automate workflows or trigger subsequent actions. Smart contracts are predetermined rules with strict implementation conditions before transactions are conducted and recorded on the blockchain (Luu et al., 2016; Mohanta et al., 2018). Moreover, smart contracts govern business transactions by setting protocols for self-executing and verifying transactions in digital form. These protocols are vital to creating a blockchain platform, as linking the information is critical in validating the transactions (Kumar et al., 2017). Since this thesis focuses on the manufacturing industry, smart contracts form an essential part of the blockchain platform.

Lastly, it is important to mention when blockchain is preferred over other information technology systems. The main characteristic of blockchain is trust, which distinguishes it from other information technology systems (Centobelli et al., 2021; Upadhyay et al., 2021). A certain level of trust among stakeholders is generated by the attributes of blockchain (i.e., decentralization, consensus, immutability, and (cryptographic) security) as defined by Nakamoto (2008). However, blockchain is not a one-size-fits-all solution for circular economy practices but requires specific applications or circumstances to reach its full potential (Kouhizadeh et al., 2020). The current literature mentioned that blockchain is recommended when one of the following scenarios is present (Ajwani-Ramchandani et al., 2021):

- Transactions require a precise and immutable data record between multiple stakeholders, which an independent third party could not guarantee.
- The potential for conflicting motivations and interests exists.
- Tampering with the data record forms a risk.
- An independent third party to maintain integrity is not available or preferred.

2.3 Blockchain for a Circular Economy

The blockchain phenomena has received wide recognition and interest from the industry to drive manufacturing companies toward a circular economy (Carson et al., 2018; Okorie et al., 2018). Since the circular economy focuses on reducing, reusing, recycling, and recovering materials and goods, the circular economy aims at a broader notion of value from a multiple-stakeholder perspective. Blockchain could support these underlying principles of a circular economy by creating transparency and trust among businesses operating in a circular value chain (R. Adams et al., 2018; Kouhizadeh et al., 2019; Upadhyay et al., 2021). According to Kouhizadeh et al. (2022), the raw material or durable goods industry could yield the most support from blockchain and its underlying capabilities. Therefore, researchers and practitioners have started investigating blockchain in a circular economy context.

Studies highlighted the usage of blockchain for several applications in a circular economy context. Most of these studies emphasize traceability and transparency for products among circular value chains. For instance, a blockchain could track products' lifecycle and measure their environmental footprint among the entire value chain (Agrawal et al., 2021; Narayan & Tidström, 2020; Shou & Domenech, 2022). Furthermore, it could bring transparency via a secured and trusted distributed database on corporate social responsibility across value chains or industries to drive more sustainable behavior (Kouhizadeh et al., 2020; Saberi et al., 2019). Next, creating more awareness among an industry could lead to accurate waste management for manufactured goods and facilitate the reuse of products via product passwords (Gong, Xie, et al., 2022; Magrini et al., 2021). These specific blockchain applications, therefore, indicate the usefulness of a blockchain system for stimulating the circular economy in the manufacturing industry. Accordingly, Böhmecke-Schwafert et al. (2022) theorized the role of blockchain in transitioning toward a circular economy and argued that blockchain could act as a moderator.

Although there is a consensus on the applicability of blockchain for a circular economy among scholars, the blockchain adoption rate by companies for circular economy practices is low (Wolf et al., 2022). It could be implicated that a blockchain is only a pre-programmed tool for sharing data that requires an underlying vision and strategy for businesses to govern their operations. Böckel et al. (2021) highlight the nascent research field in academia and practice and that current research is primarily based on conceptual and qualitative case studies. As a result, it remains questionable whether blockchain could be adapted to transition toward a circular economy, and many studies emphasize the need for more research in this area (Esmaeilian et al., 2020; Kouhizadeh et al., 2020), especially on empirical case studies or practical experiments (Tang et al., 2022).

2.4 Business Model Concept

The business model concept became prevalent in the mid-1990s during the rise of the internet (Zott et al., 2011). It acted as a mediator between technology and its potential for economic value (Chesbrough & Rosenbloom, 2002). Hence, information technology implementation and commercialization depend on an organization their business model. However, a consensus on the definition of the business model concept among scholars is lacking (Massa et al., 2017). Multiple studies have compared various definitions and corresponding business model components (Birkinshaw & Ansari, 2015; Zott et al., 2011). A well-known and highly cited definition of a business model formulated by Teece (2010) is *"a business model articulates the logic, the data and other evidence that supports a value proposition for the customer, and a viable structure of revenues and costs for the enterprise delivering that value."* This definition aligns with the definition of business models by Osterwalder & Pigneur (2010): *"The business model is the rationale of how an organization creates, delivers, and captures value."* These definitions form the basis of the business model concept and are necessary to guide the discussion on CBMs.

2.4.1 Circular Business Models

The value perception for a CBM represents a broader notion of value through strategic decisions on economic prosperity and environmental quality of a product or service in the economic system (Clift & Druckman, 2015; van Renswoude et al., 2015). Moreover, the CBM refers to business models suitable for circular economy practices focusing on “slow, narrow, and close resource loops” (Geissdoerfer et al., 2018). Hence, perceptions of the value of CBMs differ majorly from linear business models. Thus, companies focusing on circular economy practices remove the end-of-life cycle and aim at a broader notion of value from a multi-stakeholder perspective (Lüdeke-Freund et al., 2019; Massa et al., 2017).

Scholars have introduced frameworks to design CBMs by integrating the circular economy principles or characteristics. The current literature on business model creation in a circular economy remains immature. Researchers captured the mainstream body of literature and argued that existing frameworks for creating CBMs refer to the practical use of the Business Model Canvas, ReSOLVE framework, or a hybrid form of both (Lopez et al., 2019; Rosa et al., 2019). However, the ReSOLVE framework only depicts circular economy strategies for businesses, and the Business Model Canvas considers cross-organizational relations from a focal organization's perspective (Turber et al., 2015). Moreover, it could be argued that these existing framework designs are built on the principles of a linear economy and focus on an organization-centric approach. Creating a collaborative business model that captures value from a multiple-stakeholder perspective is vital to realize a systematic change in the system. Therefore, it could be argued that the CBMs built on the traditional business model frameworks do not suit the purpose of this study.

The emphasis for a functional circular economy transitioning the economic system requires collaboration from a multiple-stakeholder perspective. A mental model that best suits this multiple-stakeholder approach and aims at a broader notion of value is the service-dominant (S-D) logic (Vargo & Lusch, 2004; Vargo, 2021). The S-D logic proposed by Vargo & Lusch (2004) emerged as an alternative mindset to the prevailing goods-dominant logic. The S-D logic emphasizes value creation from a broader view of economic and social exchange rather than the production and exchange of manufactured goods (Vargo et al., 2020; Vargo & Lusch, 2004). This logic aligns with the principles of a circular economy, focusing on a broader notion of value and an integrated customer-focused solution co-created among multiple actors. The emphasis is on the value-in-use, which refers to the actual value a solution could offer to the customer (Ostrom et al., 2010; Vargo & Lusch, 2016). Moreover, the S-D logic argues that economic activities conceptualize as a service-for-service exchange among actors in a network. This logic could go beyond circularity, creating a “service ecosystem” of vast network actors collaborating according to institutional arrangements (Vargo, 2021). Therefore, the S-D logic is a representative logic to support the circular economy and its corresponding CBM.

2.4.2 Business Model Design

The previous section elaborated on the requirements for a suitable CBM for this thesis. The paper of Szopinski et al. (2022) highlights that not many business modeling frameworks originated for the sustainability (or circular economy) domain. Thus, it is argued that business model frameworks should depict the S-D logic by focusing on the perception of value creation from a multiple-stakeholder perspective. The following business model frameworks that are built on the S-D logic are discussed and elaborated upon: The Service Business Model Canvas and the Service-Dominant Business Model Radar (Turetken et al., 2019; Zolnowski et al., 2014).

The Service Business Model Canvas proposed by Zolnowski et al. (2014) depicts the traditional Business Model Canvas for all network actors separately. It does not emphasize a co-created value required to realize a CBM. Moreover, the model is inherent to the Business Model Canvas, focusing on an organization-centric approach for multiple businesses working in a network. The Service-Dominant Business Model Radar (SDBM/R) proposed by Turetken et al. (2019) does facilitate the co-creation of value among network actors for a particular customer segment. Next to these S-D logic characteristics, the SDBM/R is a method to facilitate a collective analysis and evaluation and is easily understandable and communicative (Szopinski et al., 2022). Therefore, the best suitable business model framework is the SDBM/R, which will be used in this thesis and elaborated on in the following paragraph.

2.4.3 Service-Dominant Business Model Radar

The SDBM/R aims to depict value co-creation through collaborative processes with network stakeholders (Turetken & Grefen, 2017). The SDBM/R is built on the service-dominant logic and is defined by Turetken et al. (2019) as a "representation of the way in which a network of organizations, including the providers and customers, co-creates a value for the customer through a solution-oriented service and generates revenue and benefits for all network partners." The SDBM/R consists of a central hearth with four concentric layers. The hearth of the SDBM/R, depicted by the network value proposition, represents the actual value a solution could offer to the customer. The first concentric layer focuses on the value proposition representing the contribution of a single actor toward the network value proposition. Second, co-production activity specifies the specific actor's task in realizing the value proposition towards the network value proposition solution. Third, costs and benefits focus on the financial and nonfinancial gains or pains for actors based on the network value proposition. Fourth, the SDBM/R is divided into slices to represent co-creation actors. These actors can be divided into four separate categories: focal organization(s), core partner(s), enriching partner(s), and customer(s). The focal organization initiates the business model innovation and actively participates in developing the value-in-use solution. The core partner plays an essential role in co-creating the value-in-use solution and actively participates in the solution development, whereas the enriching partner only enhances the value-in-use solution. Furthermore, the customer represents the concrete contribution of the value-in-use for which it is appropriated. The SDBM/R template used in this thesis is shown in Figure 3.

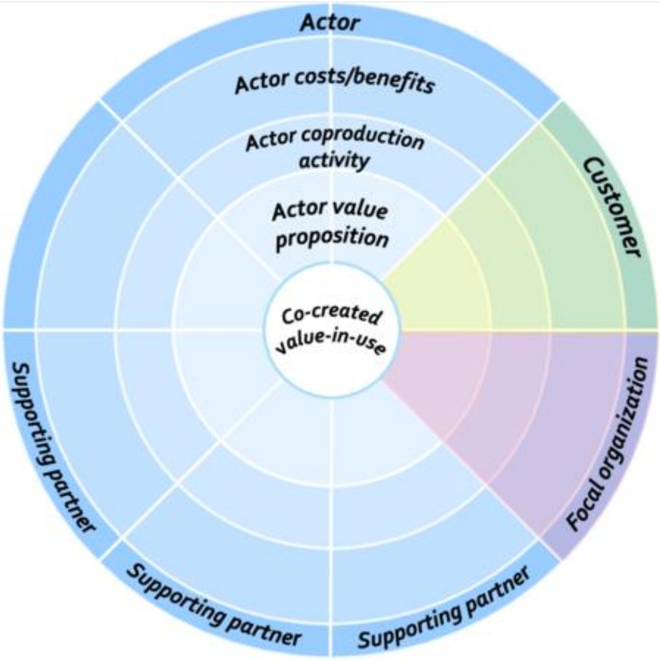

Figure 3: Service-dominant business model radar (Turetken et al., 2019)

2.5 Related Work on Blockchain for Circular Economy

Blockchain received wide recognition from researchers and practitioners to enable a transition to a circular economy in the manufacturing industry. Although a consensus has been reached on the ability of blockchain to support a circular economy (Böckel et al., 2021; Wolf et al., 2022), existing literature remains nascent and is primarily based on conceptual research and qualitative case studies (Böckel et al., 2021). Several studies have investigated potential blockchain use cases for a circular economy in a manufacturing industry focusing on traceability and transparency (Centobelli et al., 2021; Shou & Domenech, 2022), waste management activities (Hristova, 2022; Khadke et al., 2021), and incentivization of sustainable behaviour (Ajwani-Ramchandani et al., 2021). Although these studies focus on blockchain for circular economy practices in the manufacturing industry, most of these studies differ in terms of their use cases. Since many studies emphasize the need for more empirical case studies or practical experiments on this subject (Esmaeilian et al., 2020; Tang et al., 2022), this thesis depicts an overview of all use cases for circular economy practices in the manufacturing industry. This overview of blockchain use cases can guide companies to identify the possibilities of blockchain for their business needs.

An attempt to depict an overview of blockchain applications for a sustainable supply chain is made by Kouhizadeh & Sarkis (2018). This review significantly advanced the knowledge on the potential of blockchain, as literature on blockchain was then scarce. Esmaeilian et al. (2020) researched the potential of blockchain and industry 4.0 for sustainable supply chains. Although it also investigates industry 4.0, this study categorizes and discusses blockchain capabilities that support sustainability in a supply chain separately. However, the emphasis of this study is on environmental quality and not on the economic prosperity required for a circular economy. Therefore, this thesis differs by focusing on a combination of economic prosperity and environmental quality and solely focusing on the manufacturing industry.

Next to potential blockchain applications, many papers emphasized the drivers and barriers of blockchain for a circular economy. Researchers argue that blockchain could mitigate barriers for transitioning to a circular economy, yet it remains a tool heavily dependent on underlying vision and strategies (Esmaeilian et al., 2020). As a result, many studies emphasize the need for research to identify how blockchain can contribute to a CBM (Alexandris et al., 2018; Böckel et al., 2021; Böhmecke-Schwafert et al., 2022; White, 2017; Wolf et al., 2022). Böhmecke-Schwafert et al. (2022) argue that blockchain should be established as part of the business processes required for a CBM. Therefore, this thesis aims to identify how blockchain could contribute to the underlying business processes of CBMs.

3. Research Design

This section depicts an overview of the research design and elaborates on the research activities performed in this thesis to address the research objectives. As described in the introduction, the main goal is to guide companies in designing CBMs that integrate blockchain applications. Since the design science research (DSR) methodology aims to create an innovative and purposeful artifact intended to solve a problem domain (Hevner et al., 2004), this methodology best suits the research objective of this thesis. This thesis uses the DSR process of Peffers et al. (2007) to create the reference blockchain blueprint. The individual stages, as depicted in Figure 4, are described and elaborated upon in the remainder of this section.

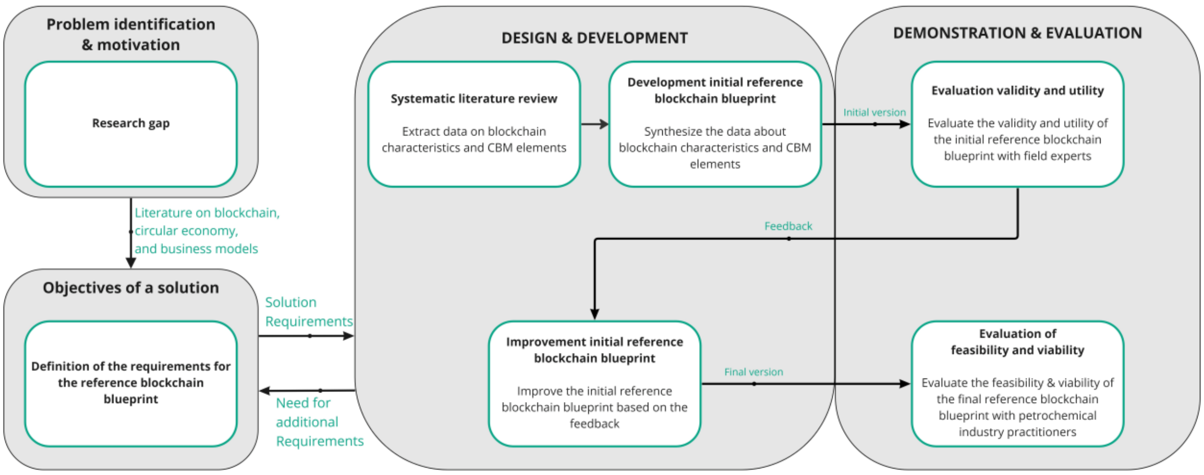

Figure 4: Research process

3.1 Problem Identification & Motivation

The first stage of the DSR process is problem identification and motivation. Since this research must contribute to a specific research gap, this step is the foremost criterion for the success of the DSR process (Gregor & Hevner, 2013). The problem description and corresponding research gap are identified and described in Section 1 of this thesis. As a result, this research is initiated via a problem-centred approach to develop the blockchain blueprint (Peffers et al., 2007).

3.2 Definition of the Requirements

The second stage aims to define solution requirements that must guide the development of the artifact. Identifying these solution requirements explicates the research scope and enhances the validity and completeness of the artifact. However, additional requirements could be determined during the design & development stage, making this stage an iterative process.

The reference blockchain blueprint includes a reference business model for blockchain applications related to the circular economy in the manufacturing industry. Since the circular economy is based on the service-dominant logic and aims for a broader notion of value, the reference blockchain blueprint should depict the value co-creation from the perspective of multiple stakeholders. As a result, the reference blockchain blueprint should include the generic stakeholders in the manufacturing industry, along with their characteristics and value contribution. The structure of the reference blockchain blueprint should depict the value from a network-centric approach and represents the value of a service-based solution. Therefore, requirements to accommodate the structure of the reference blockchain blueprint are defined as:

R1: *The proposed reference blockchain blueprint should depict value creation from a network-centric perspective.*

R2: *The proposed reference blockchain blueprint should take a co-created value perspective.*

The reference blockchain blueprint is built on the circular economy and blockchain concepts. To specify the scope of the circular economy, the principles of reducing, reusing, recycling, or recovering should be embedded in the reference blockchain blueprint. In addition, the blockchain differs in terms of attributes and should be further specified for the reference blockchain blueprint. Since the permissioned blockchain (i.e., private- or consortium blockchain type) is most applicable for businesses (Dib et al., 2018), the artifact incorporates characteristics of these blockchain types.

R3: *The proposed reference blockchain blueprint should include value elements related to the circular economy principles.*

R4: *The proposed reference blockchain blueprint should include the characteristics of a permissioned blockchain.*

The objective of the reference blockchain blueprint is to provide an overview of the actors that participate in the realization of blockchain for circular economy practices in the manufacturing industry. Hence, the reference blockchain blueprint should depict an overview of the actor groups required for this business model design. The participation per actor group in this blueprint is justified based on a value proposition to show how each of the individual actors contribute to the realization of this business model design. Furthermore, the proposed reference blockchain blueprint should include the costs and benefits per actor in monetary or non-monetary value. Therefore, requirements to illustrate the actor groups and their attributes in the business model realization are defined as:

R5: *The proposed reference blockchain blueprint should describe generic actor groups and their role in realizing the business model design (i.e., network actors and actor categorization).*

R6: *The proposed reference blockchain blueprint should describe the support of each actor group in the realization of the co-created value (i.e., actor value proposition).*

R7: *The proposed reference blockchain blueprint should describe costs and benefits per actor group in monetary or non-monetary value (i.e., actor costs and benefits).*

3.3 Design and Development

The design & development stage is responsible for building the reference blockchain blueprint according to the defined solution requirements. This stage determines the reference blockchain blueprint its functionality and method of use to address the problem description of this thesis (Hevner et al., 2004; Peffers et al., 2007). The design and development of the proposed reference blockchain blueprint is separated into two subsequent steps. The initial reference blockchain blueprint is derived from the SLR, and it is validated and complemented by a series of field expert interviews to develop the final reference blockchain blueprint.

This thesis performed an SLR to research existing blockchain applications for circular economy practices in the manufacturing industry. This SLR applied a rigorous, reproducible approach for identifying, evaluating, and synthesizing all existing literature relevant to the research question to gain comprehensive insights (Fink, 2019). The solution requirements, as defined in section 3.2, govern the scope of the SLR and the design and development of the initial reference blockchain blueprint. Therefore, to guide the SLR, the research area is defined as: "*What blockchain applications for circular economy practices in value chains related to the manufacturing industry exist, and how can they contribute to circular business models?"* The SLR is performed according to the methodology from Kitchenham & Charters (2007), followed by the data extraction and synthesizing according to the concept-centric approach by Webster & Watson (2002). The proposed initial reference blockchain blueprint is derived from the final set of studies obtained from the SLR, as described in Section 4.1. These studies are thoroughly analysed from iteratively developed categories related to blockchain characteristics and SDBM/R elements, as elaborated on in 4.2, for extracting and synthesizing. The results from the extracting and synthesizing data are used to develop the initial reference blockchain blueprint to guide companies in designing blockchain-enabled CBMs.

The proposed reference blockchain blueprint was developed according to a grounded theory approach (Strauss & Corbin, 1990). Following the iterative process suggested by the grounded theory approach (Strauss & Corbin, 1990), the reference blockchain blueprint is developed through two subsequent semi-structured interview rounds. The semi-structured interviews for both rounds were guided by the initial reference blockchain blueprint, and the methodology suggested by Kvale (2007) was followed. In total, 14 semi-structured interviews were conducted in two rounds for this thesis as shown in Table 2. The first round of interviews was conducted with six field experts who played an active role in a blockchain pilot. This round of interviews primarily served the goal of validating and improving the initial reference blockchain blueprint. Furthermore, this round of interviewees evaluated the utility of the proposed reference blockchain blueprint. The second round of interviewees was performed with eight petrochemical industry practitioners working in the circular economy domain and are familiar with blockchain. This second round of interviews aimed to measure the feasibility and viability of the proposed reference blockchain blueprint.

Table 2: Set of interviews per sample group.

Interview number	**Company category**	**Job title**	**Years of experience**	**Business modeling level**	**Blockchain level**	**Duration**
First set of interviews: Field experts						
1	Raw material producer	Business development manager	4	N/A	N/A	59 min
2	Raw material producer	Business developer	3	N/A	N/A	59 min
3	Blockchain provider	Business development manager	4	N/A	N/A	55 min
4	Chemical producer	Lead blockchain pilot	3	N/A	N/A	62 min
5	Chemical producer	Lead Technology & Innovation	12	N/A	N/A	68 min
6	Blockchain provider	CEO	6	N/A	N/A	57 min
Second set of interviews: Petrochemical Industry Practitioners						
7	Converter	Technology development manager	20	Competent	Expert	61 min
8	Chemical	Leader circular economy	15	Competent	Competent	58 min
9	Converter	Senior Nature Project Manager	10	Competent	Expert	60 min
10	Converter	Vice president R&D	30	Expert	Expert	63 min
11	Waste management company	Manager Product development	8	Expert	Novice	67 min
12	Brand owner	Packaging Sustainability Manager	13	Expert	Novice	56 min
13	Waste management company	Projectmanager recycling & waste	1	Expert	Competent	64 min
14	Raw material producer	Senior specialist sustainability	5	Competent	Competent	60 min

3.4 Demonstration & Evaluation

The final stage of the DSR is on demonstrating and evaluating the proposed reference blockchain blueprint. This stage is vital to prove whether the artifact works for its designed purpose on validity and utility in a realistic environment (Hevner et al., 2004; Venable et al., 2016). The proposed reference blockchain blueprint is evaluated on utility with field experts during the first interview round according to the Technology Acceptance Model (TAM). In addition, evaluation interviews performed with petrochemical industry practitioners measure the feasibility and viability of the proposed reference blockchain blueprint.

The utility of the proposed reference blockchain blueprint is evaluated according to the constructs of the TAM (Davis, 1989; Venkatesh & Bala, 2008). The TAM consists of three constructs, namely perceived ease of use, perceived usefulness, and intention to use, to identify the acceptance of the proposed reference blockchain blueprint. This evaluation on utility is only performed with field experts from interview round 1 because they have actively participated in the design of business models for blockchain on circular economy practices. The acceptance of the proposed reference blockchain blueprint is evaluated according to the constructs of TAM as depicted in Table 12.

The proposed reference blockchain blueprint is evaluated by petrochemical industry practitioners from interview round 2. This proposed reference blockchain blueprint is assessed according to its feasibility & viability. The feasibility determines the accessibility to resources and capabilities for each actor in the blueprint design to operationalize the business model design. The viability aspect measures the ability of the business model design to have benefits that outweigh the costs for each network actor (Gilsing et al., 2021; Gilsing et al., 2020). Robustness is removed from the scope because practical experience on blockchain for circular economy practices in the manufacturing industry is nascent.

4. Systematic Literature Review

The SLR summarizes blockchain applications for circular economy practices in the manufacturing industry and their corresponding characteristics related to a CBM. This section aims to answer SQ4: *How do circular business models for blockchain applications in the manufacturing industry look like?*

4.1 Systematic Literature Review Process

The SLR process is performed according to the methodology of Kitchenham & Charters (2007) and the concept-centric approach for data extraction and synthesizing of Webster & Watson (2002). The methodology adopted for this thesis is shown in Table 3 and described per step in this sub-section. To enhance the output for constructing the blockchain blueprint, the research question and pre-defined solution requirements are considered in answering the steps.

Table 3: Guideline on the Systematic Literature Review (Kitchenham & Charters, 2007)

Phase	Steps
Planning the review	1. Identification of the need for a review 2. Specifying the research question for SLR 3. Developing a review protocol 4. Identification of research
Conducting the review	5. Conduct initial search 6. Eliminate duplicate studies 7. Relevance check on title, abstract, and keywords 8. Review full-text of potentially relevant studies 9. Forward and backward citation on the final sample 10. Data extraction and monitoring 11. Data synthesis
Reporting the review	12. Specifying dissemination mechanisms 13. Formatting the main report 14. Evaluating the report

The first stage, planning the review, is necessary to validate the need and specify the direction for an SLR (Kitchenham & Charters, 2007). This stage contains three steps in preparation for the review. The first step is identifying a need to conduct an SLR. This step is thoroughly discussed in Section 3.3.1 and is not elaborated on in this section. Step two is creating an appropriate research question to guide the SLR. The scope of the SLR focuses on blockchain applications related to circular economy practices for value chains in the manufacturing industry. Therefore, the research question for the SLR is formulated as follows: "*What blockchain applications exist for circular economy practices in the manufacturing industry, and how can they contribute to circular business models?*"

The third step focuses on the development of the review protocol. The review protocol includes scoping the database selection, search string, and inclusion and exclusion criteria. The fourth step is an iterative process that determines whether the review protocol could assess relevant articles and obtain relevant primary studies prior conducting the initial search. The data source selection is discussed in the review protocol. Although this study aims to ensure relevant and high-quality scientific articles with peer-reviewed articles, grey literature will be considered for a complete search (Garousi et al., 2019; Levy & Ellis, 2006). The grey literature will contribute to the low numbers of literature, and the synthesis of findings from practice and academia would further contribute to the results (Garousi et al., 2019). However, only tier one grey literature will be included to maintain a qualitative and effective SLR and avoid incomplete or irrelevant findings. A comparison of the different grey literature combinations is shown in Figure 55. Hence, the databases that will be used for this study include Scopus and Web of Science libraries for peer-reviewed articles and Google Scholar for grey literature. Additionally, the specialized database AISeL from the academic community of information systems will be included. This combination would tackle the contribution of blockchain on CBMs from a broader perspective (Garousi et al., 2019).

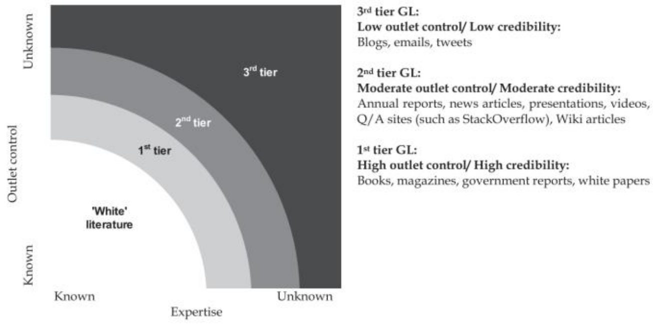

Figure 5: Shades of grey literature (Adams et al., 2017)

Next to the database selection, the search string is developed according to major search terms and iterative pilot searches. This iterative process identifies the search string that could align best with the scope of the research area to fit with the identified research gap. To develop a good search string, the focus is on three major search terms: blockchain, circular economy, and manufacturing. These are the main concepts and are central to this study. Accordingly, several search string combinations have been tested. As a result, the following keyword combination was used in this study: *(blockchain OR "block-chain") AND ("circular economy" OR "closed loop supply chain" OR "green supply chain" OR "circular supply chain")* in the title, abstract, and keywords. This search string is set broad to cover all potential blockchain applications for circular economy practices in a manufacturing value chain. Hence, the inclusion and exclusion criteria ensured the selection of articles. However, important to note is that the grey literature database Google Scholar yielded too many results. Since Google Scholar is a generalized search engine, it is necessary to develop new selection criteria and only the first 200 results are reviewed (Adams et al., 2017).

The inclusion and exclusion criteria are introduced in the review protocol to ensure that only articles relevant to the scope are included in this thesis. An overview of the inclusion and exclusion criteria is shown in Table 4 and elaborated on in this paragraph. The first inclusion criterion focuses on the existence of a blockchain application or use cases. This criterion is most important because studies should report on a specific application or use case of blockchain to identify the network value proposition it offers. The second inclusion criterion requires blockchain applications or use cases to focus on at least on ore more of the circular economy principles (i.e., reduce, reuse, recycle, & recover) as depicted in the 4R framework (Kirchherr et al., 2017). The third inclusion criterion is introduced to scope the focus on the manufacturing industry. According to Sahoo et al. (2022), blockchain is thoroughly investigated in the following four sectors: food, healthcare, manufacturing, and infrastructure. To make more concrete conclusions, the emphasis of this study is on companies operating in the manufacturing industry (e.g., automotive, textile, chemical, and more). However, food production (or agriculture) is a separate category for blockchain, thus, excluded from this study. Studies that do not explicitly mention the focus of the blockchain application on the manufacturing industry but do focus on this area are still included and referred to as “value chain” in the application area.

The fourth inclusion criteria are set on peer-reviewed articles and grey literature tier 1 articles as defined by Adams et al. (2017). Moreover, this study only includes journal articles, conference papers, and grey literature, it includes books, magazines, government reports, or white papers. The fifth inclusion criteria is on articles that are written in English. The sixth and last inclusion criteria is on articles published between 2017 and 2022. Although blockchain started to receive attention in 2008, the adoption of blockchain for the circular economy in the manufacturing industry only started to receive interest from 2017 onwards.

Several exclusion criteria are developed further to ensure the selection of relevant articles for this paper. The first exclusion criterion is set for articles that do not focus on business purposes or suggest blockchain applications for future research. The second exclusion criterion is for papers that only focus on technical details of blockchain. The third criterion is set on excluding blockchain applications or use cases embedded with industry 4.0 technologies. Nevertheless, studies incorporating Industry 4.0 technologies but discussing and elaborating on blockchain applications or use cases separately are not excluded. The fourth and last criterion removes articles built up on secondary sources (e.g., literature reviews, systematic reviews, or meta-analyses).

Table 4: Systematic literature review protocol based on Kitchenham & Charters (2007).

Review protocol	Protocol definition for this master thesis study
Research question	What blockchain applications for circular economy practices in value chains related to the manufacturing industry exist, and how can they contribute to circular business models?
Database selection	Scopus, Web of Science, AISeL, and Google Scholar
Search terms	(blockchain OR "block-chain") AND ("circular economy" OR "closed-loop supply chain" OR "green supply chain" OR "circular supply chain")
Inclusion criteria	Include only studies that depict a blockchain application or use case Include only studies that aim at least one or more of the circular economy principles Include only studies that focus on the manufacturing industry Include only studies from journal publications, conference proceedings, or grey literature tier 1 Include only studies written in English Include only studies published between 2017 and 2022
Exclusion criteria	Exclude studies that do not focus on business purposes or state blockchain for future research Exclude studies that only focus on the technical details of blockchain Exclude studies that focus on blockchain applications embedded with Industry 4.0 technologies Exclude studies that only contain of secondary sources

The second stage, conducting the review, discusses the selection method of the articles found during the literature search. The initial search of the SLR is performed in step five. Steps six, seven, and eight focused on guiding the review unbiased. The seventh step refined the study selection by reviewing the title, abstract, and keywords. The ninth step identified relevant articles through forward and backward citations. Step ten examined the selected sample by highlighting findings and insights relevant to the research area. The analysis step is guided by an open coding approach, determining the relevant findings by an ‘excerpt’ to synthesize the findings into a concept matrix. Step eleven focused on synthesizing all relevant data by incorporating the ‘excerpt’ into concepts to retrieve insights.

The SLR protocol and its refinement steps are shown in Figure 6. The initial search from the selected databases retrieved 510 studies (as of 30 September 2022) distributed as 184 from Scopus, 126 from WoS, 200 from Google Scholar, and none from AISeL. After removing the duplicates, 283 studies remained for the first screening and second review based on pre-defined criteria as defined in the review protocol depicted in Table 4. The first screening focuses on title, abstract, and keywords, leaving 115 studies that subsequently are reviewed based on their full text, leading to 27 studies. Subsequently, a forward and backward search is performed for these studies until no new potential studies are identified. This search only retrieved three new studies, which the nascent research stage and a specific scope of the manufacturing industry could explain, resulting in a final dataset of 30 studies for extraction and synthesizing in the next section.

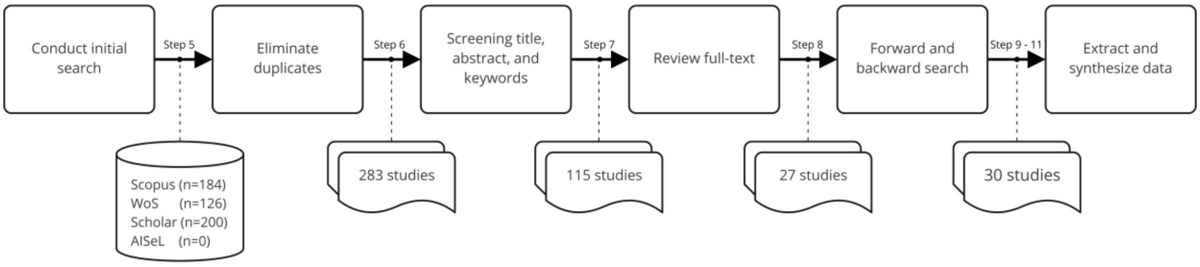

Figure 6: Refinements steps conducting the SLR procedure and resulting numbers of articles.

4.2 Development of the Concept Matrix

The classification model and its corresponding concept matrix were developed according to an iterative process in the extraction phase of the SLR review process. The classification model, as shown in Figure 7, depicts the categories used for extracting and synthesizing the selected studies in the concept matrix. The classification model is categorized into three main categories: *research characteristics*, *CBM characteristics, and blockchain characteristics*. These main categories and sub-categories are described in Table 5 and elaborated upon in this sub-section.

The *research characteristics* classification aims to identify the general characteristics of a published study on *publication type*, *research type*, and *research method*. Each study is grouped into one of the sub-categories for the categories in the research characteristics classification. The *publication type* is included to identify peer-reviewed, white papers, or grey literature tier 1 as defined by Adams et al. (2017). The *research type* (Wiener et al., 2020) and *research method* (Collins et al., 2021) are used for studies in this research domain. The *research type* is adopted from the paper of Wiener et al. (2020) and depicts how studies generated knowledge for their research purpose based on the three research types conceptual, empirical, and literature review. The research method described by Collins et al. (2021) is used in this SLR to depict the data collection methodologies of primary studies.

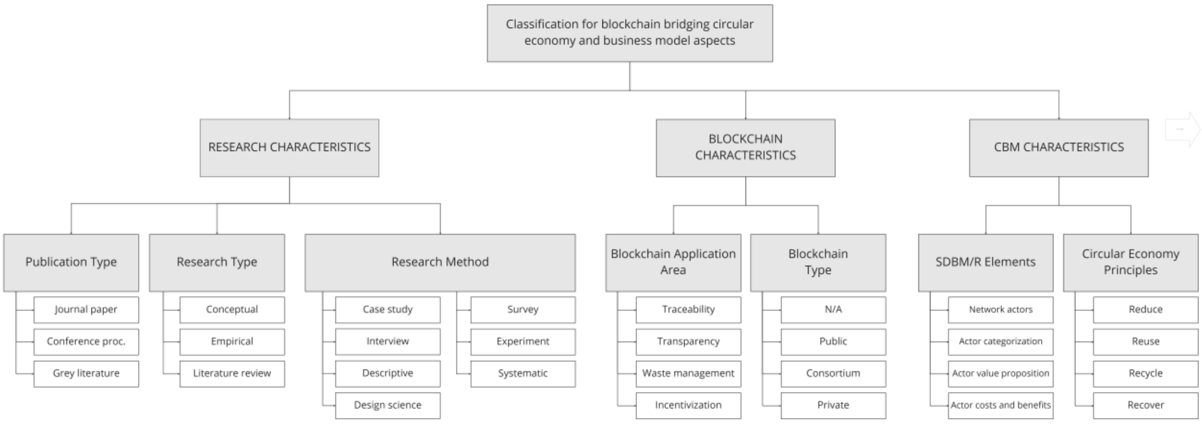

Figure 7: Classification model

The *blockchain characteristics* category is divided into *blockchain application area and blockchain type*. The *blockchain type* is essential to identify as it could determine the accessibility and usability of a blockchain platform. This SLR used the blockchain types defined by Dib et al. (2018) to categorize the applications as public, consortium, or private blockchain type. The studies are listed into one of the sub-categories based on which *blockchain type* the application or use case is operating.

The *blockchain application area* is developed according to the categorization of Böhmecke-Schwafert et al. (2022). Böhmecke-Schwafert et al. (2022) categorized blockchain applications in a circular economy according to the following categories: traceability & transparency, waste management, incentivization, renewable energy, and sharing economy. During the extraction and synthesizing phase, it was found that not all applications did apply to this categorization. This thesis introduced traceability and transparency as individual categories and removed the renewable energy and sharing economy as they are irrelevant to the manufacturing industry. The blockchain applications per study are categorized based on keywords into one or more sub-categories: *traceability*, *transparency*, *waste management*, and *incentivization*. Next to categorizing these blockchain applications, these applications are clustered according to keywords into more specific blockchain use cases. Therefore, this classification identifies the most common blockchain application category and depicts their corresponding blockchain use cases.

The *CBM characteristics* classification focuses on discovering the characteristics related to the *SDBM/R elements* and *circular economy principles*. The *SDBM/R elements* category represents the core elements defined by Turetken et al. (2019) for creating a business model. These core elements specify the information required for the development of an SDBM/R representing the contribution of blockchain to CBMs. The studies retrieved from this SLR used for data extraction and synthesis represent a blockchain application, which is considered the network value proposition for this thesis. These network value propositions are depicted according to the blockchain application area in this thesis. This category identifies the core elements covered in each study and can be situated in one or more of these sub-categories. Each of these sub-categories are further specified in detail. For example, the sub-category *network actors* depicts whether studies involve network actors in their blockchain application or use case and notes each actor represented in a particular study. Therefore, the following core elements required for the design steps are introduced in the concept matrix: *network actors*, *actor value propositions*, *actor categorization*, and *actor cost and benefits*.

The *circular economy principles* category comprises the principles *reduce*, *reuse*, *recycle* and *recover* as defined by the of the 4R framework of Kirchherr et al. (2017) for transitioning to a circular economy. This category identifies how blockchain applications or use cases could contribute to the principles by categorizing them into one or more of the sub-categories *reduce*, *reuse*, *recycle*, and *recover*. As a result, this category highlights how studies identify the contribution of blockchain with respect to the circular economy principles in the manufacturing industry.

Table 5: Classification of categories for concept matrix

CLASSIFICATION, **categories** & sub-categories		Category & sub-category definition
RESEARCH CHARACTERISTICS	**Publication Type**	***Spectrum of publication types, as defined by Gourasi et al. (2019), is classified into white papers (i.e., published journals & conference proceedings) and grey literature tier 1.***
	Journal	*The published journal aims at a specific discipline or study by researchers, professors, or other experts.*
	Conference	*A conference proceeding is intended for a conference and could be published in a conference proceeding.*
	Grey literature (T1)	*The scope is set on grey literature tier 1, including books, magazines, government reports, & white papers.*
	Research Type	***The research type describes the methodology of knowledge generation based on the research types in the information system domain as described by Wiener et al. (2020) on conceptual, empirical, & literature review.***
	Conceptual	*Conceptual studies have developed a blockchain application for specific purposes on available information on a specific topic.*
	Empirical	*Empirical studies conclude from blockchain applications based on observation and experimentation in a practical setting.*
	Literature review	*Literature review studies aim to understand the applicability of a blockchain system to a particular area of study.*
	Research Method	***The research method describes the techniques utilized in studies for data collection and analysis in the information system domain, as Collins et al. (2021) described in a case study, interview, descriptive, design science, survey, and experiment.***
	Case study	*A case study examines a particular case (or cases) in a realistic environment.*
	Interview	*Obtain knowledge based on a series of questions from the interviewee.*
	Descriptive	*Systematically and accurately describing a blockchain application and its characteristics in a circular economy.*
	Design science	*Development and validation of an innovative artifact for a specific research objective.*
	Survey	*Questionnaire for participants of the study to identify opinions or behaviour aspects of a person.*
	Experiment	*Experimental setting includes one or more variables under controlled conditions that can be manipulated to test hypotheses or identify outcomes.*
BLOCKCHAIN CHARACTERISTICS	**Blockchain application area**	***Classification of blockchain applications adapted from Böhmecke-Schwafert et al. (2022) to categorize traceability, transparency, waste management, and incentivization.***
	Traceability	*Categorizes blockchain applications that trace the circularity of materials and products or environmental performance metrics to enable a circular economy (Böhmecke-Schwafert et al., 2022).*
	Transparency	*Blockchain applications to empower visibility among value chain- or industry partners on the circularity of production processes and products (Kouhizadeh & Sarkis, 2018). This is a separate blockchain application category as it clearly defines what information businesses will be transparent about and to whom (Agrawal et al., 2021; Kumar et al., 2017).*
	Waste management	*Aims to extend the end-of-life by accurate waste management practices according to a blockchain application (Böhmecke-Schwafert et al., 2022).*
	Incentivization	*Enable or empower incentivization possibilities to improve circular economy practices (or sustainable behavior) during products their lifespan (Böhmecke-Schwafert et al., 2022).*
	Blockchain Type	***The blockchain applications can be permissioned and permissionless resulting in three different types of blockchain types. The blockchain types are based on the definition by Lin and Liao (2017) on public, consortium (or hybrid) and private blockchain types.***
	Not Available (N/A)	*The blockchain application in a particular study does not specify a blockchain type.*
	Public Blockchain	*Is an open blockchain-platform that is accessible for everyone, and users can freely conduct transactions and participate in the process of getting consensus (Lin & Lao, 2017). This blockchain type is fully decentralized as no one is the owner of the system.*
	Consortium	*Is mostly used for blockchain applications for businesses and is a combination of open and private information. This blockchain type provide access only to pre-selected participants, which are often*

	Private Blockchain	*verified in advance, and each participant has equal power as consensus is build among businesses (Lin & Lao, 2017). This type of blockchain is semi-decentralized as it requires some authority of businesses. "Node will be restricted, not every node can participate this blockchain, has strict authority management on data access" (Lin & Lao, 2017).*
CBM CHARACTERISTICS	**SDBM/R elements**	***The CBM for this thesis is based on SDBM/R that depicts value co-creation through collaborative processes with network stakeholders (Turetken et al., 2019). The main elements are used in the categorization to extract and synthesize data essential for realizing a reference blueprint. Important to note is that selected studies depict a blockchain application area as a network value proposition.***
	Network actors	*Depicts whether the study represents one or multiple actors required in the realization of a blockchain application (Turetken et al., 2019).*
	Actor categorization	*Describe the role of actors deduced from the main text or use case in the realization of a specific blockchain application according to the categorization of Turetken et al. (2019) on focal organization, core partner, enriching partner, or the customer.*
	Actor value proposition	*Identify the contribution of a single actor in the realization of the network value proposition that is realized with the blockchain application depicted in the study (Turetken et al., 2019).*
	Actor costs and benefits	*Representing the costs and benefits types from a particular blockchain application on monetary and non-monetary levels (Turetken et al., 2019).*
	Circular economy principles	***Dimensions of circular economy practice according to the 4R framework hierarchy as defined by Kirchherr et al. (2017) prioritizing the CE principles on reducing, reusing, recycling, and recovering of materials and products.***
	Reduce	*Focus is on the minimalization, reduction, and prevention of the earth its natural resources (Kirchherr et al., 2017)*
	Reuse	*Focus is on reusing products by removing waste streams based on a closed-loop for repairment or refurbishment (Kirchherr et al., 2017).*
	Recycle	*Focus is on actual recycling practices, such as the remanufacturing of products from waste materials (Kirchherr et al., 2017)*
	Recover	*Focus on an accurate incineration of waste (Kirchherr et al., 2017)*

4.3 Systematic Literature Review Results

This sub-section elaborates on the studies retrieved from the review process based on the classification as presented in the concept matrix. The classification model shown in Figure 7 represents the categories and corresponding sub-categories incorporated in the concept matrix depicted in Table 6. This matrix incorporates the categories *research characteristics*, *CBM characteristics*, and *blockchain characteristics* for each of the 30 studies identified in the SLR. Since these results are used to develop the initial blockchain blueprint, each of the sub-categories describe their contribution in the last paragraph.

4.3.1 Publication Type

The distribution of research by kind of publication is as follows: 19 journal publications, seven grey literature, and four conference papers. This high amount of journal publications is explained by the database selection, only focusing on Google Scholar to include grey literature next to the peer-reviewed studies (i.e., Scopus, Web of Science, and AISeL). The sample of studies for blockchain applications related to circular economy practices in the manufacturing industry are explored to identify the knowledge generation and their data collection methodologies. This review highlights the nascent field of blockchain for circular economy practices in the manufacturing industry. Publications on this subject only started in 2018 and received broad interest from 2020 and onwards.

4.3.2 Research Type & Method

The knowledge generation and research objectives of studies are identified based on their study type. The research type includes 17 conceptual studies, compared to eight empirical and five literature studies. As a result, most academic investigations on blockchain for a circular economy are conceptual in nature and are based on accessible knowledge on this subject. Furthermore, it is interesting to note that empirical research has doubled in 2022.

The data collection techniques used for analysis are categorized according to the research methods commonly used in the information systems domain. The descriptive approach is the most common, with 17 studies describing the characteristics of blockchain and its applicability to circular economy practices in the manufacturing industry. The case study method focuses on a particular case or multiple cases in a realistic environment, is another common approach represented by 15 studies. Despite the fact that these case studies depict a realistic environment, they are primarily focusing on a conceptual study and are qualitative in nature. The SLR results show an increase of empirical studies targeting a case study.

This review highlights a considerable number of conceptual studies compared to empirical studies. Furthermore, it demonstrates that the majority of studies are descriptive in nature. The empirical studies in this domain are only based on case studies. These findings confirm the nascent research field of studies on blockchain applications for circular economy practices in the manufacturing industry. The findings align with the claim of Böckel et al. (2021), stating that studies for a blockchain in a circular economy is a nascent research field and mainly comprises conceptual studies.

Table 6: Concept matrix

		Classification for Blockchain Applications and CBMs																											
		RESEARCH CHARACTERISTICS												BLOCKCHAIN CHARACTERISTICS								CBM CHARACTERISTICS							
		Publication Type			Research Type			Research Method						Blockchain Type				Blockchain Application Area				SDBM/R Elements				Circular Economy Principles			
		Journal paper	Conference proceeding	Grey literature	Conceptual	Empirical	Literature review	Case study	Interview	Descriptive	Design science	Survey	Experiment	N/A	Public	Consortium	Private	Traceability	Transparency	Waste management	Incentivization	Network actors	Actor categorization	Actor value proposition	Actor costs and benefits	Reduce	Reuse	Recycle	Recover
S1	Ajwani-Ramchandani et al. 2021	x			x				x	x		x		x							x	x	x	x	x	x		x	
S2	BASF & Deloitte, 2020			x		x		x								x*		x	x	x		x			x	x	x	x	
S3	Cale, 2022		x		x			x							x*			x	x		x	x			x		x		
S4	Centobelli et al. 2021Oropallo E., Se	x			x			x									x	x	x			x	x		x		x	x	
S5	Chaudhuri et al., 2022	x				x		x									x	x			x	x			x			x	
S6	Chen & Jin, 2021	x			x						x					x*		x	x	x	x	x	x		x		x	x	
S7	Chen & Ogunseitan, 2021	x			x					x						x		x	x	x	x	x			x		x	x	
S8	Chidepatil et al., 2020	x			x					x						x*		x	x	x	x	x						x	x
S9	Dindarian & Chakravarthy, 2020			x		x		x		x				x				x	x	x	x	x	x		x		x	x	x
S10	Eikmanns, 2018			x			x			x				x				x	x		x				x	x	x	x	
S11	Eshghie et al., 2022	x			x					x					x			x	x	x		x	x				x	x	
S12	Esteban et al., 2022			x		x		x								x		x	x			x			x		x	x	
S13	Glass Technology Forum, 2021			x		x				x				x				x	x						x		x	x	
S14	Gonçalves et al., 2021	x			x			x		x						x*		x	x			x					x	x	
S15	Gong, Wang et al., 2022b	x			x			x		x				x				x	x	x	x	x			x			x	
S16	Gong, Xie et al., 2022a	x				x		x						x				x	x	x	x	x			x			x	
S17	Hristovo, 2022		x		x					x					x	x		x		x		x	x		x		x	x	
S18	Khadke et al., 2021	x			x					x					x			x	x		x				x		x	x	
S19	Kouhizadeh & Sarkis, 2018	x					x			x				x				x	x	x	x	x			x	x	x	x	
S20	Kouhizadeh et al., 2020	x					x	x						x				x	x		x	x		x	x	x	x	x	
S21	Kuae et al., 2021		x			x		x								x		x	x	x	x	x		x	x		x	x	
S22	Mastos et al., 2021	x				x		x		x						x		x	x			x	x						x
S23	Narayan & Tidström, 2020	x			x					x				x				x	x						x	x			
S24	Rusinek, et al., 2018			x	x			x								x	x	x	x			x	x	x	x	x	x	x	x
S25	Shou & Domenech, 2022	x			x			x	x							x*		x	x	x	x	x	x	x	x	x	x		
S26	Soldatos et al., 2020		x		x			x		x						x*		x	x	x		x	x	x	x		x		
S27	Steenmans & Taylor, 2018			x			x				x			x				x			x					x		x	
S28	Steenmans et al., 2021	x			x					x				x				x	x		x						x	x	x
S29	Upadhyay et al., 2021	x					x			x				x				x	x						x	x	x		
S30	Wang et al., 2020	x			x						x					x*		x	x	x		x			x	x	x	x	
		19	4	7	17	8	5	15	2	17	3	1	0	12	4	13	3	29	26	14	17	23	10	6	24	11	22	24	5

4.3.3 Blockchain Type

The sub-category *blockchain type* determines which is best suited for blockchain applications related to circular economy practices in the manufacturing industry. This is guiding the underlying characteristics of the proposed reference blockchain blueprint.

In the *blockchain type* category, 13 studies comprise a consortium blockchain and three studies a private blockchain, while only four studies focus on a public blockchain. This validates the preference for a permissioned (i.e., consortium or private) blockchain from a business perspective in the manufacturing industry. Besides businesses requiring trust among network participants, the significant amount of energy and computationally expensive consensus mechanisms required for public blockchains forms a significant barrier to applying it for circular economy practices (Kouhizadeh & Sarkis, 2018; Soldatos et al., 2020). However, this burden of energy consumption for consensus mechanisms for public blockchains is identified and not deemed acceptable for applications in the circular economy. Therefore, public blockchain platforms need to switch to less energy consuming consensus mechanisms (Eshghie et al., 2022).

The studies show that a consortium blockchain is most appropriate as it combines the characteristics of a private blockchain for trust and consensus mechanisms that do not require much energy consumption while offering public information required for the circular economy. The applicability of this blockchain type is supported by the numerous blockchain applications, as depicted in Table 7. A consortium blockchain could, for instance, store confidential information only accessible for auditing purposes (Esmaeilian et al., 2020; Saberi et al., 2019) and offer transparency on the circularity of a product to the public on one blockchain platform (Shou & Domenech, 2022). Thus, blockchain should be implemented on industry level instead of value chain level to yield the most benefits from blockchain applications.

Another remarkable insight is the lack of information on the blockchain type for blockchain applications. Twenty studies did not identify the underlying blockchain type for their application, while eight studies of this sample could be identified based on its application by the researcher. Although blockchain not being a one-size-fits-all solution for all circular economy practices (Kouhizadeh et al., 2020), consensus on an appropriate blockchain type is necessary for future research. Therefore, the initial version of a blockchain blueprint should be guided by the consortium type, regulated by a group of companies.

4.3.4 Blockchain Application Area

The blockchain application area category distinguishes studies their blockchain application into one or more sub-categories representing an application area: traceability, transparency, waste management, and incentivization. Grouping the studies into one or more of these sub-categories identified the most common blockchain application area in this domain. These blockchain applications present in the studies are thoroughly analyzed and clustered according to keywords into a specific use case, as described in Section 4.2. The sub-categories for each blockchain application area category and corresponding blockchain use cases are depicted in Table 7 and explained in this section. The most common *blockchain application areas* deduced a generic network value proposition used for the development of the initial reference blockchain blueprint.

Table 7: Blockchain services for circular economy practices in the manufacturing industry

Blockchain use cases for circular economy practices in a manufacturing industry		
Blockchain application		SLR source #
UC1	Traceability	
UC1.1	Enable a trail of critical data (e.g., design, material origin, material quality, production processes, composition, and its movement among partners) according to uniform transactions in a chain of custody during the production of circular products on a decentralized blockchain ledger.	S2, S3, S4, S5, S6, S7, S9, S10, S11, S12, S13, S14, S15, S17, S18, S19, S21, S24, S25, S26, S28
UC1.2	Simplify the mass balancing approach to ensure that circular product outflow does not exceed the inflow of renewable or recycled materials on a decentralized blockchain ledger.	S25
UC1.3	Recording or modification of transactions on a blockchain must be signed by nodes (i.e., users of blockchain) to guarantee its existence and link it with a company or its representative.	S4, S6, S12, S15, S29
UC1.4	Authenticate products (and their components) to record their usage and assess its condition.	S3, S18, S20, S30
UC1.5	Digital twin in the form of a token representing a physical asset in the real world, depicting its economic value and governing ownership.	S11, S23
UC2	Transparency	
UC2.1	Enable an accurate and more efficient life cycle assessment for circular products.	S3, S4, S11, S14, S15, S18, S19, S20, S24, S25
UC2.2	Increase the efficiency of procedural auditing required for the production of circular products on a decentralized blockchain ledger.	S6, S12, S13, S14, S19, S25, S29
UC2.3	Enable and automate sustainability reporting systems for corporations on their environmental impact.	S18, S19, S21, S25, S28, S29, S30
UC2.4	Creation of product passports according to a unique digital identity for circular products.	S6, S9, S10, S11, S13, S15, S18, S21, S26, S27
UC2.5	Establish a single decentralized blockchain ledger to facilitate the supply and demand of renewable and recycled materials for the production of circular products.	S8, S26, S30
UC3	Waste management	
UC3.1	Enable data access on product compositions to improve the accuracy of waste handling related to disassembling of products or extracting materials.	S6, S9, S15, S17, S19, S26, S28, S30
UC3.2	Promote the life extension of products by supporting secondary markets on reuse or finding a new use for products.	S6, S11, S25, S30
UC3.3	Support and enable producers to be held responsible for their products (i.e., extended producer responsibility) along the entire lifecycle, including end-of-life management.	S16, S21, S25, S27
UC4	Incentivization	
UC4.1	Stimulate environmentally friendly behavior on a blockchain-based incentivization system, rewarding consumers actively or passively in the form of tokens.	S1, S5, S6, S7, S9, S15, S16, S18, S28
UC4.2	Attract consumers interest in second-hand products by providing information on product history and condition.	S3, S7, S9, S19, S20, S24, S25
UC4.3	Increase the regulatory efficiency of governments to examine if companies comply with regulations related to circular economy practices and enable effective penalization for companies that break the rule.	S1, S6, S10, S19
UC4.4	Stimulate awareness for consumers on environmentally friendly behavior in their consumption.	S9, S18, S24, S25

4.3.4.1 Traceability

The *traceability* aspect is vital for a circular economy and a key enabler of the blockchain. Stakeholders generate information on the production of circular products and upload proof documents on the blockchain to prove its circularity. The data from *traceability* enable *transparency* on a blockchain and indirectly stimulate the application areas of *waste management* and *incentivization*. The sub-category *traceability* is used in 29 studies and is clustered into five specific blockchain use cases.

First, use case UC1.1 represents the use of blockchain to enable a trail of critical data according to uniform transactions in a chain of custody during the production of circular products (Shou & Domenech, 2022; Centobelli et al., 2022; Dindarian Chakravarthy, 2020). It involves the use of blockchain to trigger transactions in chronological order during the production of circular products. These transactions require information and proof documents from stakeholders on their production process, which the following stakeholder verifies in the production process. The information required in these transactions differs per blockchain application. For instance, it could document material origin & quality, production processes & emissions (Kouhizadeh & Sarkis, 2018), product compositions

(Centobelli et al., 2022; Upadhyay et al., 2021) and record the physical movement (Bhubalan et al., 2022).

Second, use case UC1.2 focuses on a blockchain-enabled mass balancing approach that ensures that circular product outflow does not exceed renewable or recycled material inflow. This use case does not require substantial upfront investments in new production lines (Shou & Domenech, 2022). However, it does not record critical information possible with UC1.1.

Third, use case UC1.3 refers to the recording and modification of transactions on a blockchain that must be signed by nodes (i.e., users of a blockchain) to guarantee the existence of its data and link it with a company or its representative. Stakeholders sign their transaction to enable its execution on a blockchain and trigger a new transaction at the subsequent stakeholder in the value chain. As a result, transactions related to the circular economy are traced back to the responsible company to prevent and minimize counterfeit information such as greenwashing (Centobelli et al., 2022; Upadhyay et al., 2021; Esteban et al., 2022).

Fourth, use case UC1.4 involves the authentication of products (and their components) to record their usage and assess their condition. This use case can apply to individual durable products (Cale, 2022; Wang et al., 2020) or batches of fast-consumer goods such as plastic bottles (Bhubalan et al., 2022; Khadke et al., 2021). To authenticate these products, a blockchain-generated QR code is generated for these products. Companies can track these authenticated products on a blockchain, assess their usage cycle, or determine its condition level (Cale, 2022; Kouhizadeh et al., 2020).

Fifth, use case UC1.5 includes the definition of a digital twin in the form of a token representing a physical asset in the real world, depicting its economic value and governing ownership. These tokens circulate within a blockchain and keep track of ownership and trade history in the real world (Narayan & Tidstrom, 2020; Eshgie et al., 2022).

As represented in almost all of the studies, traceability is defined as an inherent characteristics of the blockchain. The use cases are combined into one specific definition to create a generic network value proposition for the initial reference blockchain blueprint for traceability. This traceability network value proposition can guide the evaluation interviews with field experts and is defined as: “relative ease to trace material- and environmental footprint data for circular products on a consortium blockchain.”

4.3.4.2 Transparency

Traceability refers to the ability to track information in blockchain applications based on the submission of proof documents and completed transactions. Completing transactions related to traceability enables transparency by allowing users on the blockchain to exchange this information, which contains separate use cases that blockchain could offer to companies. The sub-category *transparency* is used in 26 studies and is always incorporated with the sub-category of *traceability*.

First, use case UC2.1 focuses on enabling an accurate and more efficient life cycle assessment for circular products. This use case involves benchmarks on the environmental impact of a product from a holistic view based on the aggregation of data during the production process (Shou & Domenech, 2022; Centobelli et al., 2022; Kouhizadeh et al., 2020). The ability for accurate and actual life-cycle assessment increases if products retrieve an individual QR-code to provide recycling rates and their degradation behavior (Gong et al., 2022; Khadke et al., 2021). Another opportunity for this use case is to highlight production processes that have most impact on the environment during product creation (Shou & Domenech, 2020; Rusinek et al., 2018).

Second, use case UC2.2 focuses on increasing the efficiency of procedural auditing required for the production of circular products on a decentralized blockchain ledger. Since all the transactions are irreversible after recording and verifying by a value chain stakeholder, the auditing procedure becomes more accurate and increases in efficiency (Esteban et al., 2022; Goncalves et al., 2021; Dindarian & Chakravarthy, 2020). Furthermore, it creates one decentralized ledger containing all relevant information required to perform an audit (Eikmanns, 2018). Kouhizadeh & Sarkis (2018) even argue that third-party audits may not be needed as transactions and their corresponding documentation are continuously updated, evaluated, and verified. This auditing use case could also enhance the approval of permits or other certifications (Dindarian & Chakravarthy, 2020)

Third, use case UC2.3 aims to enable and automate reporting systems for companies on their environmental impact. This use case entails benchmarks for sustainability practices of companies and enables supplier monitoring with a more secure development or selection criteria (Esmailian et al., 2020; Shou & Domenech, 2022). This use case can help companies to lower the risk of greenwashing and contributes to the environmental impact.

Fourth, use case UC2.4 is on the creation of a product passport for circular products according to a unique digital identity. This unique digital identity is generated by a blockchain (i.e., QR-code, watermarking, or other methods) and must represent a passport for a physical asset. This product passport contains information, such as the composition and authenticity of products, to offer transparency to the market (Forum, 2021). Hence, this use case enables transparency for consumers on the repairability index of a product (Steenmans et al., 2021) and offers vital information for more accurate waste management practices (Chen & Jin, 2021; Dindarian & Chakravarthy, 2020; Khadke et al., 2021). However, information on the accurate composition of the product is often kept private as companies perceive this information as confidential (Dindarian & Chakravarthy, 2020).

Fifth, use case UC2.5 involves matching supply and demand for renewable and recycled materials for the production of circular products. Manufacturing companies require a continuous inflow of renewable and recycled materials for their production processes. Hence, this use case involves the use of a decentralized blockchain ledger that provide information on the availability of renewable or recycled materials required to maintain production across the manufacturing industry (Chidepatil et al., 2020; Soldatos et al., 2020). The decentralization of blockchain increases the information velocity, and this real-time data minimizes the bullwhip effect among a value chain (Wang et al., 2020).

Similar to the blockchain application area traceability, blockchain applications or corresponding use cases related to transparency are included in the majority of the studies. As a result, transparency can also be considered as an inherent characteristic of the blockchain and is also represented in the reference blockchain blueprint. To summarize the blockchain application area transparency and their corresponding use cases, the corresponding network value proposition to guide the interviews is defined as: “customized data sharing for circular product creation with authorized users on a consortium blockchain.”

4.3.4.3 Waste Management

The *waste management* sub-category is vital for the circular economy as it can extend the end-of-life of a product or its materials. Use cases falling under this sub-category are only defined in 14 studies and is incorporated with the categories traceability and transparency. Therefore, this thesis argues that the sub-category *waste management* is a subsequent step of the sub-categories *traceability* and *transparency*, as it depends on available information based on a unique digital identity of a product on the blockchain.

First, use case UC3.1 enables data access on product compositions to improve the accuracy of waste handling. This use case involves the disassembly of components or extraction of materials from products acknowledged to be at the end-of-life for reusing, recycling, or recovering (Wang et al., 2020; Chen & Jin, 2021). Providing waste management companies with information on the composition of a product can significantly empower the efficiency of waste segregation (Dindarian & Chakravarthy, 2020; Soldatos et al., 2020; Hristova, 2022). For products with a unique digital identity listed to its owner, illegal waste dumping could be prevented (Steenmans et al., 2021; Kouhizadeh & Sarkis, 2018).

Second, use case UC3.2 on promoting the life extension of products by supporting secondary markets. This use case involves the extension of authenticated and verified products or components on a blockchain for reusing and recycling practices (Shou & Domenech, 2022; Wang et al., 2020). Manufacturers or brand owners communicate with consumers for product recovery at the end of life to remanufacture or resell (Chen & Jin, 2021; Dindarian & Chakravarthy, 2020).

Third, use case UC3.3 enables producers to be held responsible for their products along the entire lifecycle, including end-of-life management. This use case supports the potential of policies to govern the extended producer responsibility to the brand owner and the producers (Kuae & Machado, 2021; Steenmans & Taylor, 2018). This extended producer responsibility stimulates producers to adhere to circular economy practices (Gong et al., 2022).

4.3.4.4 Incentivization

Incentivization for a circular economy on a blockchain aims to stimulate the sustainable behavior of stakeholders. The sub-category *incentivization* is described in 17 studies and depicts four use cases.

Similar to the sub-category *waste management*, the majority of studies combine incentivization with the sub-categories *traceability* and *transparency*.

First, use case UC4.1 is about stimulating environmentally friendly behavior on a blockchain-based incentivization system. This use case involves an active rewarding system in the form of digital tokens stimulating environmentally responsible behavior for consumers (Chaudhuri et al., 2022; Chen & Ogunseitan, 2021; Dindarian & Chakravarthy, 2020; Khadke et al., 2021). Such an active incentivization mechanism can be appointed to business-to-business or business-to-consumer target sectors (Gong et al., 2022a; Gong et al., 2022b). For developing countries, this could stimulate entrepreneurial behavior in waste management collection facilities (Gong et al., 2022a). Therefore, companies operating this use case on a blockchain can transfer the waste stream from a cost-centered approach to a profit-oriented value stream.

Second, use case UC4.2 entails attracting consumers' interest in second-hand products. Blockchain can remove the lack of information for used products, enabling a refurbished product market by determining its product history (Kouhizadeh et al., 2020; Kouhizadeh & Sarkis, 2018; Dindarian & Chakravarty, 2020; Shou & Domenech, 2022) and remove the distrust of consumers (Chen & Ogunseitan, 2021). This use case could also involve manufacturers collecting and returning their registered products or components for a quality inspection and subsequent repair or refurbishment (Cale, 2022). Another opportunity for the manufacturers is to use industrial symbiosis to minimize further waste (Kouhizadeh & Sarkis, 2018).

Third, use case UC4.3 involves the increase in regulatory efficiency and more effective penalization practices of governmental organizations on regulations related to the circular economy. More accurate and real-time circular product creation information could significantly improve a governmental organization's regulatory efficiency (Chen & Jin, 2021; Ajwani-Ramchandani et al., 2021; Kouhizadeh & Sarkis, 2018). Since a circular economy heavily depends on information transparency, blockchain could create a system of incentivization and penalization to govern circular activities (Ajwani-Ramchandani et al., 2021; Chen & Jin, 2021). This use case might even entail the adoption of tax levels on circular economy practices for businesses. However, this requires the implementation of blockchain on an industry level.

Fourth, use case UC4.4 involves blockchain to stimulate consumer awareness of environmentally friendly behavior. This use case includes the use of blockchain to facilitate environmentally friendly consumption by providing information on the sustainable metrics of a product or depicting its composition and inherent risks (Dindarian & Chakravarthy, 2020; Shou & Domenech, 2022; Khadke et al., 2021). As a result, consumers are more engaged with circular activities and might create a feeling of being a part of the circular economy system,

4.3.5 SDBM/R Elements

SDBM/R elements describe results on *network actors*, *actor categorization, actor value proposition*, and *actor costs and benefits*. The network actors and actor categorization are described for blockchain applications in general, while the actor value proposition and actor costs and benefits are divided and solely described for traceability and transparency. As stated in Section 4.2, the network value proposition is not included as a sub-category because it is represented by the blockchain application area. As a result, the blockchain application area category discovered that the sub-categories *traceability* and *transparency* are present in the majority of the blockchain applications. Since the sub-categories *traceability* and *transparency* are inherent of the blockchain, they are used to guide the network value propositions for the reference blockchain blueprints.

4.3.5.1 Network Actors

This section is used to describe the sub-category *network actors* and aims to identify studies involving actors functioning in their blockchain applications. From the SLR results, 23 studies fit into this sub-category and are thoroughly investigated to cluster actors into an actor group. In these studies, we have identified 10 actor groups as listed in Table 8. This table distinguishes actors that are integrated into the blockchain (x) and actors that only have access to public information on the blockchain (a). Since this thesis focuses on companies operating solely in the manufacturing industry, logistics and distributors are out of the scope. The actors retrieved from the studies are applicable to the initial reference blockchain blueprint for traceability and transparency as they are depicted in the majority of the studies.

The most frequent actors in blockchain applications are the recycler and waste management businesses, as depicted in 19 studies. The recycler represents the recycling facilities and supplies raw materials for the (intermediary) manufacturing companies. However, accurate waste collection and segregation are necessary to perform these recycling activities. The waste management business is the stakeholder that accurately collects and segregates waste. The manufacturing company is depicted in 18 studies and manufactures finished goods and products for consumption. The brand owner is depicted as part of the blockchain in 13 studies. This actor category markets the final product under their brand name and pledges the circularity of their products. The consumer represents the buyer and user of the circular product the brand owner sells. The consumer is represented in the blockchain application of 13 studies. However, the majority of studies only state that the consumer can access information on the circularity of products from the blockchain. Furthermore, the intermediate manufacturer is used in blockchain applications as they require intermediate manufacturing processes for the final manufacturing of a product. These stakeholders all form the core actors of a value chain in the manufacturing industry and are common in a blockchain application.

Next to the actual value chain stakeholders, several supportive roles are depicted. A blockchain provider creates the blockchain platform. Although blockchain platforms need to be developed for usage, only six studies highlight a blockchain provider as a network actor. Furthermore, six studies refer to an auditor for circular economy practices. This actor also includes non-governmental organizations (NGOs) whose goal is to validate circularity claims for products. Another supportive role, as mentioned in the background literature, is the governmental body, as they can accelerate and support the transition towards a circular economy with legislation. The governmental body is included in six studies, mainly focusing on regulations for environmentally friendly behavior. Lastly, the consortium group is only mentioned in one study that emphasizes the collaboration of companies in an industry to diffuse the adoption of blockchain.

Table 8: Actor groups

	Ajwani-Ramchandani et al., 2021	BASF & Deloitte, 2020	Cale, 2022	Centobelli et al., 2021	Chaudhuri et al., 2022	Chen & Jin, 2021	Chen & Ogunseitan, 2021	Chidepatil et al., 2020	Dindarian & Chakravarthy, 2020	Eshghie et al., 2022	Esteban et al., 2022	Gonçalves et al., 2021	Gong, Wang et al., 2022b	Gong, Xie et al., 2022a	Hristovo, 2022	Kouhizadeh & Sarkis, 2018	Kouhizadeh et al., 2020	Kuae et al., 2021	Mastos et al., 2021	Rusinek, et al., 2018	Shou & Domenech, 2022	Soldatos et al., 2020	Wang et al., 2020	
Recycler	x	x		x	x	x		x	x		x	x	x	x	x	x		x	x	x	x	x	x	19
Waste management company	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x		x	x		x	x		19
Manufacturer	x	x		x			x	x	x	x	x	x		x		x	x	x	x	x	x	x	x	18
Brand owner	x	x	x			x	x		x	x			x	x				x			x	x	x	13
Consumer	x	A	x			x	x	A	A	A				x	A					A	A		A	13
Intermediate manufacturer		x										x		x		x	x	x		x	x	x	x	10
Blockchain provider					x				x	x				x						x	x			6
Auditors / NGO	x								x	x		x					x				x			6
Governmental body	x		x						x		x			x			x							6
Consortium group																	x							1

x = Integrated in the blockchain; A = Access to information but not part of the blockchain

Based on their functioning and how frequently they appear in the SLR studies, the actors included in the initial reference blockchain blueprints for traceability and transparency are chosen. The results show that blockchain applications typically include all parties involved in the value chain of the manufacturing industry, from producing goods to closing the loop. As a result, the blockchain blueprint includes representation for the waste management company, recycler, intermediate manufacturer, manufacturer, and brand owner. Although the blockchain provider is only mentioned six times in the blockchain blueprint, it is essential for creating a blockchain and must be included. Similar is the auditor (or NGOs), as they are usually included in studies to oversee companies their claims of circularity. Although the consumer is a crucial actor as well, studies frequently only cover this actor when discussing information requests. The governmental body and consortium group are not included in the blockchain blueprint as they do not have direct impact in the functioning of a blockchain application for the circular economy.

4.3.5.2 Actor Categorization

The sub-category actor categorization follows up on the generic *network actors* as listed in Table 8 and determines the roles in the business model design: customer, focal organization, core actor, and enrichment actor (Turetken et al., 2019). Only ten studies argued to a certain extent on the categorization for one or more actors in a blockchain. Despite the generic network value proposition and corresponding use cases differ for traceability and transparency, they are closely related and operate on the same blockchain platform. Therefore, the actor categorization of the generic network actors in this thesis are assumed to be applicable for traceability and transparency. The SLR results showed only six studies that argued on the categorization for one or more actors.

Targeted customer

The SLR results identified the lack of a specific categorization for the role of customer in the blockchain applications. A possible explanation is the collaborative nature of the circular economy and blockchain, which remain the focus on value from a multiple-stakeholder perspective. However, Shou & Domenech (2022) argue that the brand owner is the link between upstream- and downstream value chain and pledges the circularity of a product to its consumers. Furthermore, the willingness of producers to share data on a blockchain depend on the relationship between a brand owner and its value chain (Shou & Domenech, 2020). Therefore, the brand owner in this thesis is considered as the customer for the initial reference blockchain blueprints.

Focal organization

The focal organization is depicted as the blockchain provider in this thesis for the initial reference blockchain blueprints. Several blockchain application examples show blockchain platforms governed by a blockchain provider (Dindarian & Chakravarthy, 2020; Shou & Domenech, 2022). Other businesses are governed by the consultation of blockchain experts on the implementation of a blockchain (Shou & Domenech, 2022). Although brand owners could influence suppliers and manufacturers to join the platform and share data, they do not orchestrate the development of a blockchain platform. Other studies stated that it could be a single large corporate organization operating as network orchestrator (Kuae et al., 2022) or a consortium group that develops and diffuse it across the industry (Kouhizadeh et al., 2020).

Core partners

All value chain participants must be involved in order to create an actual closed-loop on blockchain, as discussed in the network actors sub-category. As a result, the recycler, intermediate manufacturer, manufacturer and waste management company are designated as core actors in the value chain. Their information related to circular product creation and proper waste management are essential for blockchain to stimulate the circular economy (Ajwani-Ramchandani et al., 2021; Steenmans & Taylor, 2018). The blockchain provider and auditor (or NGOs) are crucial in the development of blockchain for the circular economy and are represented as core actors in the blueprint, despite the fact that this is not stated explicitly in the studies.

4.3.5.3 Actor Value Proposition

The sub-category *actor value proposition* aims to define how the actor contributes to the network value proposition, referred to the blockchain application in this thesis. Since actor co-production activities emphasize on high-level activities to realize the *actor value proposition*, the actor co-production activities are deduced from this sub-category. Noteworthy is that only six studies describe the components of an actor vital to realize this network value proposition. These studies are examined to improve the components for each actor as listed in Table 8 and elaborated upon in this section. To clarify the value proposition of actors representative in a blockchain application, a distinction is made on value chain actors and more supportive roles.

The value chain actors consist of the actor recycler, (intermediary) manufacturer, brand owner, and waste management company. The recycler, also referred as the supplier of materials, creates the hash value for renewable or recycled materials by uploading information and corresponding proof documents on the blockchain (Centobelli et al., 2021; Rusinek et al., 2018; Shou & Domenech, 2022). Since these recycled or renewable materials are used during circular product creation and proper waste management, the recycler creates the genesis block. However, a verification step is required on the waste received to guarantee its circularity for the initial hash value or subsequent circular loop of material (Shou & Domenech, 2022; Kouhizadeh & Sarkis, 2018).

The next actor is the (intermediary) manufacturer which performs a verification on the circularity (e.g., origin, recycling process) of the materials received from the recycler (Rusinek et al., 2018; Kouhizadeh & Sarkis, 2018). The (intermediary) manufacturer also collects sustainability data and proof documents during the creation of a circular product (or component), and then upload this information onto a blockchain (Dindarian & Chakravarthy, 2020). It is noteworthy that the manufacturer is responsible for creating a unique digital identity for a physical asset on the blockchain as the first step in product authentication (Rusinek et al., 2018). After the manufacturer, the brand owner is the next actor in the value chain. Their main goal is to ensure that circular products with their brand name comply with regulations and standards by validating the information provided by the manufacturer (Shou & Domenech, 2022). As a result, brand owners promotes and market their circular products.

The waste management company is considered as a part of the value chain as they play an important role in closing the loop in a circular economy. A closed-loop in the manufacturing industry is enabled by waste collection to extend the life of materials (Ajwani-Ramchandani et al., 2021; Hristova, 2022). Proper waste segregation can distinguish recyclable, renewable, or reusable waste from non-reusable waste. This information can be uploaded to the blockchain for circulation in the value chain (Mastov et al., 2021).

The consumer, blockchain provider, auditors or NGOs, and governmental bodies are the actor that support the blockchain application for the circular economy. In order to promote the circular economy, the consumer plays the role of buyer and user of a circular product (Rusinek et al., 2018). However, the consumer only has access to information on a blockchain to encourage sustainable purchasing behavior. The blockchain provider develops the blockchain application and might grant access to new nodes (i.e., user of blockchain) joining the blockchain (Centobelli et al., 2021; Rusinek et al., 2018). Lastly, the auditors or NGOs validate product circularity claims, and governmental bodies can provide incentives (Ajwani-Ramchandani et al., 2021).

4.3.5.4 Actor Costs & Benefits

The sub-category *actor costs & benefits* specifies the costs and benefits for each actor in a blockchain application for their circular economy practices. Since the related costs and benefits for traceability and transparency differ, this sub-category separates the costs and benefits from each other. In total, 23 SLR studies describe on the costs and benefits of traceability or transparency in their blockchain application. These studies are thoroughly researched in order to identify keywords on potential costs and benefits, and to which network value propositions they apply to. These keywords are translated into specific costs and benefits through an iterative process for traceability and transparency and assigned to network actor as listed in Table 8. Although some of the cost and benefits are shared by traceability and transparency, they are separated because their descriptions might differ. Table 9 depicts the identified cost and benefit groups for the initial reference blockchain blueprint of traceability, while Table 10 depicts transparency.

Table 9: Costs and benefits for traceability

Traceability			
Costs & Benefits	Applicable to actor group(s)	Description	SLR source nr.
Decentralized ledger (+)	All (except blockchain provider)	Circulate verifiable transaction history data on circular product creation among nodes and ensure data integrity on a single ledger without needing a third party.	S2, S6, S9, S12, S13, S19, S22, S23, S30
Tamperproof ledger (+)	All (except blockchain provider)	Prevent fraudulent transactions on an immutable data record as authorized nodes sign transactions that can be traced back.	S6, S15, S23
Increased trust (+)	All (except blockchain provider)	Nodes must adhere to the self-executing contract (i.e., smart contract) agreed between value chain actors and allow companies to cooperate in the verification process during circular product creation.	S3, S4, S20
Reduced administration cost (+)	All (except blockchain provider)	Increased efficiency in acquiring, storing, and confirming or updating transactions among nodes in circular product creation on a decentralized ledger reduces the need for resources and saves cost and time.	S4, S6, S9, S12, S20, S30
Reduced manual work (+)	Recycler, Intermediate manufacturer, Manufacturer, Brand owner, Waste management company	Harmonizing and verifying data exchange from different systems among nodes into one single decentralized blockchain ledger significantly increases the efficiency of process monitoring and reduces the need for manual registration.	S4, S7, S24
Accurate documentation (+)	All (except blockchain provider)	Standardized transaction formats (i.e., smart contracts) are pre-programmed, unified data collection and verification methods that resolve uncertainty on information for transactions among nodes in the circular product creation.	S2, S4, S6, S9
Accelerate auditing procedure (+)	Auditor / NGO	Significantly increases the efficiency in certification and validation by harmonizing data related to circular product	S3, S4, S9, S12, S19, S23, S24.

		creation and providing access to auditors (e.g., NGOs) to query the relevant data required for the auditing procedure.	
Unique value proposition (+)	Brand owner	The relative ease, compared to segmented systems, to record critical data in the circular product creation and claim a product its circularity.	S5, S19, S30
Regulatory compliance (+)	Recycler, Intermediate manufacturer, Manufacturer, Brand owner, Waste management company	Support regulatory compliance by recording all relevant information.	S9, S25, S12
Development cost (-)	Recycler, Intermediate manufacturer, Manufacturer, Brand owner, Waste management company	Implementation of a traceability system on blockchain is time-consuming and costly.	S5, S30
Training costs (-)	Recycler, Intermediate manufacturer, Manufacturer, Waste management company	Training is required to operate the blockchain and correctly use a blockchain	S5
Confidential information (-)	Intermediate manufacturer, Manufacturer, brand owner	Reluctance in sharing information related to production processes or product compositions	S9
Maintenance cost (-)	All	A blockchain has maintenance costs for the users of blockchain as they are shared among participants	S12
Operation cost (-)	Recycler, Intermediate manufacturer, Manufacturer, Brand owner, Waste management company	Gathering data on the production processes and upload information and proof documents on blockchain, and verification of transactions as receiver.	S25

Table 10: Costs and benefits for transparency

Transparency			
Cost & Benefit groups	Applicable to actor group(s)	Description	SLR source nr.
Decentralized ledger (+)	All (except blockchain provider)	Circulate verifiable transaction history data on circular product creation among nodes and ensure data integrity on a single ledger without needing a third party.	S2, S6, S9, S12, S13, S19, S22, S23, S30
Tamperproof ledger (+)	All (except blockchain provider)	Prevent fraudulent transactions on an immutable data record by identifying how each node is related to the aggregated data in the circular product creation.	S6, S15, S23
Increased trust (+)	All (except blockchain provider)	Nodes must adhere to the self-executing contract (i.e., smart contract) agreed between network actors building trust on the information within and between actors in the blockchain	S3, S4, S20
Information accessibility (+)	Recycler, Intermediate manufacturer, Manufacturer, Brand owner	Increased efficiency in accessing information related to circular product creation by eliminating the need for a centralized authority.	S4, S18, S22, S23, S24, S25
Information disclosure (+)	Recycler, Intermediate manufacturer, Manufacturer, Brand owner, Waste management company	Easily disseminate circular product creation information by customized data sharing without a centralized authority.	S4, S18, S19, S20
Accurate documentation (+)	All (except blockchain provider)	Smart contracts (i.e., pre-determined rules and conditions) require full information before execution and data verification by the receiver, which significantly increases the trustworthiness of data.	S2, S6, S8, S9, S18, S19, S23, S24
Decreased information asymmetry (+)	Recycler, Intermediate manufacturer, Manufacturer, Brand owner, Waste management company	Real-time information sharing among value chain actors on a decentralized ledger reduces information asymmetry, thereby improving the understanding of the circular materials and products for operations in the value chain.	S6, S9, S20
Improved material identification (+)	Waste management company	Facilitate product information for a more efficient and effective waste collection and segregation.	S9, S15
Increased waste-to-value (+)	Waste management company	Stimulate development of secondary markets and maintain material value through a higher degree of transparency on waste.	S2, S9, S15, S24, S25
Unique value proposition (+)	Brand owner	Blockchain-empowered circular products enhance brand value and increase the perceived value of consumers buying circular products.	S2, S5, S21
Waste management figures (+)	Auditor / NGO, governmental body	Accurate waste management figures on collecting, recycling, and disposing of waste materials.	S5, S18
Regulatory efficiency (+)	Governmental body	Increased regulating efficiency for quick investigation and penalizing, reducing governance costs.	S1, S6, S12
Development cost (-)	All (except blockchain provider)	Implementation of a transparency system on blockchain is time-consuming and costly.	S5, S30
Eliminate power (-)	All (except blockchain provider)	Increased transparency and automated execution of contracts result in less power for negotiation.	S20

Maintenance cost (-)	All	A blockchain has maintenance costs for the users of blockchain as they are shared among participants.	S12

4.3.6 Circular Economy Principles

The category *circular economy principles* identified how extant literature on blockchain applications for circular economy practices contributes to the principles of reduce, reuse, recycle, and recover in the manufacturing industry. Each of the studies included in this SLR focused on a specific circular economy principle as defined by Kirchherr et al. (2017), including 30 studies. The majority of these studies focused on recycling with 24 studies, followed by reuse with 22 studies, and reduce and recover with 11 and 5, respectively. An explanation for the high amount of studies focusing on recycling and recovering is the tangible asset. These principles are measurable to an extent and could be assigned with explicit use cases and potential costs and benefits. The principle reduce with blockchain in a circular economy could be stimulated due to the collaborative nature of these domains. However, this principle is less discussed due to intangibility of these figures. The principle recover is only discussed in a few studies as the emphasis of these studies is on a closed-loop value chain.

5. Initial Reference Blockchain Blueprints

This section aims to develop the initial reference blockchain blueprints in accordance with the solution requirements identified in Section 3.2. The initial artifact is developed according to the findings retrieved from the SLR results on blockchain characteristics and SDBM/R elements. Since the initial artifact derived from the SLR results will be validated and improved in the subsequent sections, only the design and development steps are described and elaborated upon shortly.

The underlying structure of the initial reference blockchain blueprint is depicted in the form of a SDBM/R as described in Section 2.4, depicting value from a network-centric perspective and co-creating value with multiple stakeholders. This satisfies the first (R1) and second (R2) requirements of the artifact. Furthermore, each of the studies focus at least on one of the principles of reduce, reuse, recycle, and recover to depict value related to the circular economy in the initial artifact. Hence, the third (R3) requirement is fulfilled. Furthermore, the initial artifact integrates potential value elements related to the permissioned blockchain. Moreover, the insights configured into the initial artifact correspond to the capabilities and boundaries of the permissioned blockchain. Thus, satisfying the fourth (R4) requirement.

As described in the SLR protocol, the blockchin application area depict the network value proposition of identified blockchain applications related to the circular economy. In accordance to the SLR results, the most common blockchain applications in a circular economy focus on traceability and transparency. These two network value propositions differ as traceability refers to the ability to generate data on circular product creation, while transparency refers to the visibility and accessibility of information among actors on a blockchain. Therefore, this thesis creates two reference blockchain blueprints to be able to give more concrete information on the contribution to CBMs. However, except for the differences in costs and benefits, these reference blockchain blueprints are very similar in terms of network actors and associated roles, and actor value proposition.

The generic actor groups and their associated roles for the initial artifacts are identified through the SLR results and included based on there functioning. As a result, the initial artifacts included the actors waste management company, recycler, intermediate manufacturer, manufacturer, and brand owner are incorporated in the blockchain blueprint. Furthermore, the blockchain provider is included as they develop the network and auditor (or NGOs) are involved to oversee companies their circularity claims. These actors are categorized according to the actor roles as defined by Turetken et al. (2019). In the blueprint, the brand owner is perceived to be the customer and the blockchain provider represents the orchestrator of the blockchain. The remaining actors involved in the blockchain blueprint are depicted as the core actors. The inclusion of these actor groups and associated roles fulfill the fifth (R5) requirement of the artifact.

The actor value proposition and co-production activity are depicted for each of the generic actors represented in the initial artifacts. The actor value proposition is retrieved from the SLR, and the co-production activity is deduced from this actor value proposition by the researcher. Hence, the initial artifacts satisfy the sixth (R6) requirement of the initial artifacts. The costs and benefits are depicted separately for the initial artifact of traceability and transparency, and indexed in Table 9 and Table 10 respectively. Meaning that the costs and benefits are specified for each actor, satisfying the seventh (R7) requirement. This results in the initial blockchain blueprint for traceability as shown in Figure 8, and transparency as depicted in Figure 9.

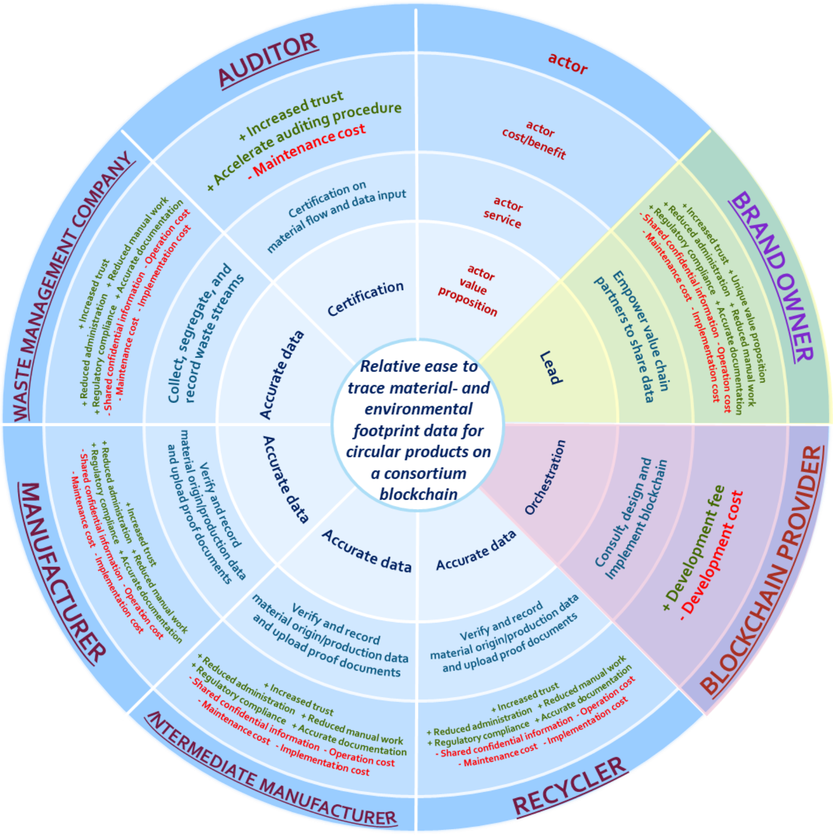

Figure 8: Initial blockchain blueprint – Traceability

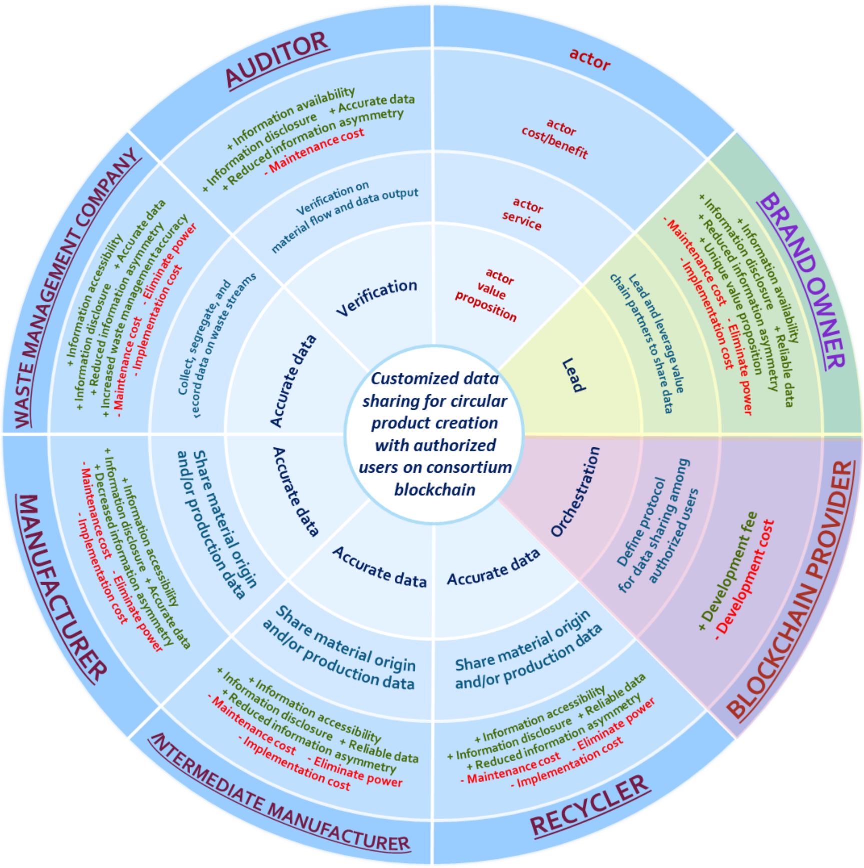

Figure 9: Initial blockchain blueprint – Transparency

6. Evaluation of Validity and Utility

This section aims to validate, improve, and evaluate the utility of the initial reference blockchain blueprints derived from literature by practice. Since CBMs for blockchain are lacking, these blueprints are developed by synthesizing and extracting blockchain- and core business model elements from publications. According to empirical semi-structured interviews information from the literature on established blueprints is validated and extended by field experts. The results from the semi-structured interviews are used to develop the proposed reference blockchain blueprints.

As described in previous sections, the extant literature on CBMs for blockchain applications in the circular economy is lacking. This research further explores the initial reference blockchain blueprints derived from literature with professionals which are knowledgeable about this subject domain and considered as field experts in this thesis. The consultation of field experts is suitable for qualitative research as they can provide valuable insights and validate extant literature (Creswell, 2014; Kvale, 2007). Hence, these field expert interviews build on the derived initial reference blockchain blueprints and assess whether they are conceptually valid in practice. Furthermore, the set of interviews can expand the knowledge base in this domain and enable the exploration of new core elements for the proposed reference blockchain blueprints. Although focus group interviews could have been used as an alternative research method for this thesis, interviews were conducted separately with each interviewee due to time and planning constraints. The guideline of Kvale (2007) for semi-structured interviews is followed and described in the following sections.

6.1 Selection of Participants

The first step in the guideline of Kvale (2007) is selecting participants for the semi-structured interviews. This step is important for determining how participants' characteristics and expertise can add value to this research, as the extraction of right information depends on the interviewees (Creswell, 2014; Kvale, 2007). The participants selected for this validity evaluation interview are actively engaged in a blockchain pilot initiated by SABIC, one of the largest diversified petrochemical companies operating globally (SABIC, 2021). SABIC created a pilot by deploying a blockchain-enabled digital platform with value chain partners in the petrochemical industry to integrate a mass balance approach. This mass balance approach adds circular materials, also known as feedstock in the petrochemical industry, at the beginning of the value chain and allocates them to the final product. Their ultimate goal is to establish digital traceability on feedstock in circular packaging, along with increased transparency throughout the value chain. Because the objective of this pilot is to determine the potential value of blockchain for circular economy practices in the petrochemical industry, these pilot participants are considered field experts and are deemed suitable candidates for this validity evaluation.

The blockchain pilot comprises of four companies operating in the petrochemical industry. This industry produces products from renewable and recycled feedstocks and is a subset of the manufacturing industry. As a result, the generic network actors defined in the initial reference blockchain blueprint are translated into functional roles depicting the petrochemical industry, as shown in Figure 10. The blockchain pilot involved four network actors during the process of writing this thesis. These actors include the raw material producer, chemical producer, converter, and blockchain provider. Despite the absence of the brand owner and waste management company, this pilot aims to enhance the circulation of renewable and recycled materials.

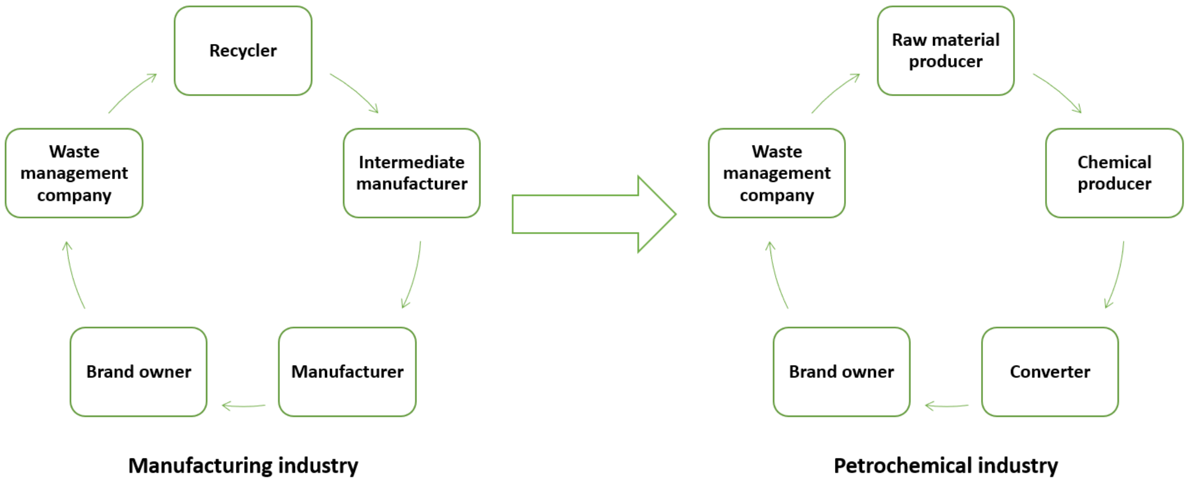

Figure 10: Network actors for the petrochemical industry

According to Creswell (2014) the minimally acceptable amount of interviews is six. This number of interviews align with the findings of Guest et al. (2006), which discovered that with six interviews a total of 94% of the information was extracted while 12 interviews retrieved 97% of the information. Therefore, the researcher aimed to integrate two field experts per company represented in the blockchain. This ensures reliable and valid answers related to the specific network actors in the artifact. The researcher approached the field experts via an invitation email, which is depicted in Appendix B: Invitation interview 1. This invitation email addressed the objective of this research, length and procedure of the interview session, and a request for participation on a specific date. In the event of no response, several reminder emails have been sent. Six field experts agreed to participate in an interview session as a result of this invitation procedure, representing two field experts for the network actors raw material product, chemical producer, and blockchain provider. Despite several emails, the researcher was unable to schedule an interview session with field experts representing the converter in the blockchain pilot. However, this is still within the boundaries of the minimally acceptable amount of interviews (Creswell, 2014; Guest et al., 2006). As a result, the first round of interviews on the evaluation of validity and utility represents a total of six field experts, as defined in Table 2.

6.2 Designing Interview Protocol

Semi-structured interviews with field experts are conducted in a structured manner by establishing and adhering to an interview protocol. The interview protocol includes a guideline for conducting an interview with pre-defined topics and corresponding questions (Kvale, 2007). This protocol serves as a checklist to ensure that all topics are covered during the interview, and follow-up questions are used to gain a deeper understanding of the interviewees' perspectives. For instance, field experts are asked to elaborate on their response and provide examples. The topics in the interview protocol are defined in further detail in terms of their purpose and the rationale for inclusion. The following paragraphs summarize the topics covered in the interview protocol for the first interview round, as shown in Appendix E: Interview round 1E.

Topic 1 (INTRODUCTION) aims to give a brief introduction on the background of the interviewer, the purpose of this thesis, and an overview of the objective for the interview session. Next, the confidentiality rules are discussed, and the interviewer explicitly mentions the anonymization of data retrieved from the interview sessions. Thereafter, the interviewer and interviewee agree on the confidentiality reasons and the recording is started.

Topic 2 (BACKGROUND) focus on the professional background of the interviewee and the company. This topic serves a dual purpose as it identifies the expertise and knowledge of an interviewee on this subject domain and specifies the reasoning of the interviewee on a particular subject. The identification of expertise and knowledge is vital to ensure reliable and valid answers. Furthermore, it is vital to have a mutual understanding on the subject to avoid confusion between the interviewee and interviewer during the interview session (Myers & Newman, 2007). Only questions related to their expertise to circular economy and business modelling were discussed for field experts actively participating in the identification of blockchain in the petrochemical industry. The questions on this topic are easy for the interviewee to get familiar with the subject, which is supposed to establish trust between the interviewee and interviewer (Kallio et al., 2016).

Topic 3 (BLOCKCHAIN) questions focus on the characteristics of blockchain. Since the blockchain characteristics depicted from background literature and SLR results are inherent to the reference blockchain blueprint, validation with field experts is critical for practical applicability. To validate blockchain decisions derived from the background literature and SLR results in the initial reference blockchain blueprint, generic questions related to blockchain type and blockchain application area are integrated. The questions related to blockchain type are depicted in question 4, 5, and 6. However, questions related to the blockchain application area are incorporated in topic 4 when introducing the initial reference blockchain blueprint.

Topic 4 (REFERENCE BLOCKCHAIN BLUEPRINT) questions primarily concern the evaluation of correctness of the proposed reference blockchain blueprint by field experts. This topic starts with a brief introduction of the SDBM/R, which is the underlying structure of the proposed reference blockchain blueprint. Questions related to this topic validate and improve the extant of literature based on the knowledge and experience from the field experts. Therefore, the findings from the literature are shown during the interview and used to guide the conversation. For each of the layers in the initial reference blockchain blueprint, a separate slide is depicted to narrow the focus to this specific value element. The first question relates to the blockchain application area, verifying the network value proposition for the proposed reference blockchain blueprints of traceability and transparency. Subsequent questions in this topic focus on validating and improving the initial reference blockchain blueprint. The validation and complementation is guided by the approach of Gilsing et al. (2021) on evaluating service-dominant business model core elements value network, value capture, value architecture, and value proposition. These are closed questions to verify if the reference blockchain blueprint is built in adherence to the S-D logic (Gilsing et al., 2021; Gilsing et al., 2020), which characterizes the underlying structure required for blockchain and circular economy. However, the initial blockchain blueprint is deduced from literature and is built in adherence to these premises by following the business model design steps of Turetken et al. (2019). Therefore, open questions are formulated from these structural validity questions as represented in Table 13, to validate and complement core business elements for the proposed reference blockchain blueprint from practice. The formulated open questions related are guided in this interview protocol by the design steps of an SDBM/R as defined by Turetken et al. (2019) to validate and complement the network value proposition & targeted customer, determining the actors and their roles, and determining cost and benefit types. This could determine if design decisions based on the SLR are valid or require alteration or complementation for the practical application of the blockchain blueprint.

Topic 5 (TECHNOLOGY ACCEPTANCE MODEL) represents a questionnaire built on the core constructs of the TAM by Venkatesh & Bala (2000) which originated from Davis (1989). In this thesis, the core variables perceived of use, perceived usefulness, and intention to use were used to assess the utility of the proposed reference blockchain blueprint. For the purpose of this thesis, the statements for each of these questions related to the constructs have been modified accordingly. The defined statements were evaluated by the field experts using a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Several statements have been reversed and are denoted with (*) to avoid repetitive responses. The statements are closed questions and no feedback is received on their responses due to time constraints. The questionnaire specified for this research related to these constructs are depicted in Table 12.

Topic 6 (CONCLUDING) concludes the interview session and determines potential next steps in accordance with the interviewee. Based on the preferences of the interviewee, a transcript of the interview session is sent or a summary of the core findings.

6.3 Data Analysis

This step describes the coding approach used in this thesis to analyze the data retrieved from the semi-structured interviews (Kvale, 2007). The study of Gilsing et al. (2018) showed the development of a reference model based on the grounded theory approach. This method can be used to derive a theory based on the collection and analysis of empirical data (Strauss & Corbin, 1990). The grounded theory approach can build upon existing knowledge and can be combined with a SLR (Charmaz, 2014). Therefore, the proposed reference blockchain blueprint was developed according to the grounded theory approach.

The grounded theory approach was performed in the following order. First, the results derived from the SLR are used to categorize the network actors, actor roles (also referred to as actor categorization), and actor costs and benefits, and blockchain. Furthermore, additional findings from the interviews are assigned to each of these categories. Second, given the iterative process of the grounded theory, it was possible to verify new insights in the subsequent interviews. For instance, the benefit validation premium fee was highlighted by the first interviewee and verified in subsequent steps. Since the number of interviewees was relatively small and the open coding is guided by the SLR, the transformation to axial coding was relatively simple. Third, the transformation from axial coding to focus coding is performed to identify the generic categories identified in the model. These results are described and discussed upon in Section 6.4.

6.4 Results and Discussion

This sub-section discusses the results that were identified by the field experts to validate and complement the initial reference blockchain blueprints as shown in Section 5. This section is structured as follows. First, the characteristics of blockchain for circular economy are described. Second, the SDBM/R elements are elaborated upon. Third, the utility of the reference blockchain blueprint is evaluated by field experts.

6.4.1 Blockchain characteristics for circular economy

This section is only for validation to strengthen some assumptions on blockchain and does not contribute to the improvement of the reference blockchain blueprint. According to the literature section, blockchain is considered as a great enabler of the circular economy concept in the manufacturing industry. To comply with the requirements of the circular economy, companies must gather data on circular metrics as evidence for the product its circularity. As a result, companies are searching for digital information systems that could best apply to these requirements. The interviewees confirm that blockchain is a good candidate for a circular economy and is best illustrated by Interviewee 6 "*there is* *a very good fit between the characteristics of blockchain and circularity initiatives in general because these initiatives need transparency and shared recordkeeping between companies*."

6.4.1.1 Level of implementation

The interviewees discuss their perspectives on the use of blockchain applications and the level of implementation related to circular economy practices. As discussed in the SLR, the blockchain is not a one-size fits all application, and the implementation depends on the specific use case and the purpose of the company (Kouhizadeh et al., 2020). Since almost all use cases on circular economy practices in the manufacturing industry requires participants of the entire closed-loop value chain, blockchain adoption on industry level would yield most benefits. However, interviewees 1 - 4, and 6 states that a blockchain application should be initiated at the value chain level with the ultimate goal of industry adoption. The statement, as defined by Interviewee 6, best summarizes this as "*The role of NGOs and non-profits in terms of issuing certifications or authenticating data for other players will be reduced and reduced as blockchain implementations get stronger and stronger*." Adopting the blockchain on an industry level can empower the paradigm shift towards a circular economy by removing the fragmentation of value chains on circular product creation. Interviewee 5 furthering this statement: "*it depends on the use case, but probably at the industry level, the support and the number of applications are more likely, and it allows you to finance a blockchain platform as an industry*."

6.4.1.2 Blockchain type

Blockchain is not a one size-fits all application, and its purpose is determinant for the most suitable blockchain type. The SLR results identified that the consortium blockchain type is widely used for circular economy practices in the manufacturing industry. From the six pilot participant interviewees, four interviewees (3 – 6) were able to answer their thoughts on the most suitable blockchain type in this domain. The general consensus (3 – 6) of the interviewees is that the consortium blockchains are depicted as most suitable. The main reasons provided for this consensus are related to the transparency of data. Interviewee 3 argued, for example, that the consortium is best suited for " *allowing companies to bring transparency while maintaining control over the data and not opening all data to a broad audience*." Interviewee 4 believes that "*as a company you would like to have some control over the distribution of your information*." In comparison to the consortium blockchain, integration of stakeholders from various industries is the challenging part of a public blockchain. According to interviewee 6, "*a public blockchain with users from various industries have different use cases and require another business model*." This argument assumes that the value and cost of using the blockchain are not distributed equally, which is possible for the consortium blockchain. Based on these arguments, consortium blockchain is considered to be the most suitable blockchain type for the manufacturing in the current situation. However, interviewee 3 and 6 emphasize that this general consensus may change in the future because the technology still has a lot of room for improvement.

6.4.2 Practice-based circular business model core elements

This section presents the core business model elements that were discovered during the field expert interviews. First, the network actors and actor categorization are elaborated on. Second, the actor value proposition and corresponding co-production activities are described. Third, the costs and benefits are discussed upon separately for traceability and transparency.

6.4.2.1 Network actors and actor categorization

The network actors and their related actor categorization in the initial reference blockchain blueprint are validated and complemented by field experts. As depicted in Section 5, the initial reference blockchain blueprint show similarities in terms of network actors and actor categorization. Thus, the following interview results are applicable to traceability and transparency. The field experts first elaborated upon the inclusion or exclusion of network actors for the proposed reference blockchain blueprint that interacts on the same hierarchy level to co-create value as a service (Gilsing et al., 2021). Furthermore, the field experts discuss the categorization of these actors in the proposed reference blockchain blueprint. Therefore, the inclusion or exclusion of network actors is discussed per actor categorization for the targeted customer, focal organization, core partners, and enrichment partner (Turetken et al., 2019).

Targeted customer

According to Shou & Domenech (2022), brand owners link upstream- and downstream value chains and pledge the circularity of their product. As a result, the brand owner is argued to be the targeted customer for traceability & transparency. Interviewees 1, 2, and 3 acknowledge that the brand owner is a key customer for blockchain traceability, which aligns with the statement of Shou & Domenech (2022). For instance, interviewee 1 states that the "*ability to prove that circularity is probably most valuable to them.*" However, it is found during the interviews that the brand owner is not the only targeted customer of the blockchain. The interviewees (1 – 6) state that all stakeholders in the manufacturing industry could utilize opportunities from blockchain and should not solely depict the brand owner as a targeted customer. Interviewee 6 argues that "*blockchain is an environment where everyone is a potential customer, building a model or different models where different players are the customer*." A similar statement is made by each of the interviewees for the reference blockchain blueprint related to transparency. This means that depending on the design of the blockchain application, each stakeholder in the manufacturing industry could be the customer of the business model design for traceability and transparency. Therefore, the customer representing any stakeholder in the manufacturing industry is introduced into the proposed reference blockchain blueprint as the targeted customer.

Focal organization

Following the SLR results, the blockchain provider is designated to be the focal organization (Dindarian & Chakravarthy, 2020; Shou & Domenech, 2022) in the initial blockchain blueprint for traceability and transparency. Although this is supported by interviewees 2 and 5, they mainly refer to the facilitating role of blockchain providers in the blockchain application. This facilitating role of blockchain could be illustrated by interviewee 1 as "*the blockchain provider can implement the system, link all the dots, and in the end provide the benefits to the users*." Interviewees 1, 3, 4, and 6 claim that the blockchain provider serves only as a facilitator and not as the initiator or orchestrator of the business model design. They reason that representatives in the industry should initiate this business model design for blockchain applications. This finding aligns with the statement of Kouhizadeh et al. (2020) that introduces a consortium that develops and diffuses the blockchain across the industry. Given the collaborative nature of a circular economy, this business model design requires a group of stakeholders who jointly define the purpose and boundaries of the blockchain application. This is illustrated by interviewees 3 and 5: "*We as blockchain provider are in the seat and trying to create the necessity, but we are not deciding. This could be for instance a group of stakeholders in the industry*" and "*So in my opinion, this will always be driven by a consortium which defines the goal of the blockchain and its boundaries, and also who will participate and what role*." Therefore, according to the evaluation interview results the blockchain orchestrator is defined as the focal organization, and it consists of a group of industry representatives for the proposed reference blockchain blueprints traceability and transparency.

Core actors

The core actors in the blockchain blueprints traceability and transparency for this case study are the raw material producer, chemical producer, converter, brand owner, waste management company and NGO. Overall, each of the interviewees (1 – 6) agreed on the importance of involving actors in the development of a blockchain application for the circular economy. However, several interviewees referred to the exclusion of the NGO and potential core actors that might need to be included in the blockchain blueprint.

The interviewees 3, 5, and 6 claims that the NGO is not a core actor in the realization of this business model design. The ultimate goal of a blockchain initiative for the circular economy is that the issuing of certification by third parties disappears. This is best represented by interviewee 6 "*It's almost to say that these sustainability claims are by default, authenticated because of how that blockchain design was created, because of how they were introduced, how they were issued*." Furthermore, all interviewees (1 – 6) state that the NGO does not have to be included in the blockchain. This is defined by interviewee 4 as "*you could have NGOs actively verify on blockchain or you could just have them* *query the data and then do their own assessment outside the blockchain platform*.” They are referring to the fact that, while the NGO is still required to verify these sustainability claims in the short term, including them in the blockchain is not required.

Interviewees 3, 5, and 6 discussed the possible inclusion of the consumers in the reference blockchain blueprint for traceability and transparency. Their reasoning is primarily focused on consumer behaviour for circular products, which are critical for realizing a circular economy. This is best illustrated by interviewee 5 “*to some extent, we discussed that the ultimate goal, probably when we're doing product traceability and it will be applicable also in the transparency piece, is for the consumer to have that trust on being able to trace back that product or see its footprint*.” For the time being, the demand for circular products is based on the influence of consumers who purchase circular products. However, the scope for this thesis is on the manufacturing industry and the creation of a blockchain-enabled CBM. Since the consumer does not actively contribute in the realization of this blockchain-enabled CBM, this actor is not integrated in the proposed reference blockchain blueprint.

Some interviewees mentioned additional actors that might suit the purpose of the blockchain blueprint. The governmental organization was identified as a potential actor for the blockchain blueprint related to traceability by interviewees 2, 3 and 5. Their reasoning is that governments could legislate circular behaviour and enforce companies in the petrochemical industry to share data on circular product creation. This could stimulate the adoption of blockchain for circular economy practices. This statement is depicted by interviewee 3 “*stronger regulation can enforce companies to share this kind of data and stimulate blockchain adoption*.” However, because the governmental organization does not actively contribute to the network value proposition of the blockchain blueprint for traceability and transparency, it is not included.

Enrichment actors

The interviewees 3, 4 and 6 explicitly mentioned the integration of a system integrator as an enrichment partner for the blockchain blueprint related to traceability and transparency. This system integrator focuses on data automation between companies their individual enterprise resource system and the blockchain. Hence, it should automate the data sphere between individual enterprise resource systems as argued by Interviewee 6 “*Companies have their own system and they connect those systems to the blockchain design, right? Because that reduces either double input or exports and imports of data*.” Despite the fact that the system integrator is an important part of realizing this blockchain platform, this actor does not contribute on the same transactional hierarchy level and is not included in the proposed artifact.

6.4.2.2 Actor value proposition and actor co-production activity

This section validated and improved the actor value proposition in the proposed reference blockchain blueprints traceability and transparency. Furthermore, the actor co-production activity is deduced from the actor value proposition. In accordance with the SLR results and derived findings from the first set of interviews, the actor value proposition for each actor show similarities for the reference blockchain blueprints traceability and transparency. Hence, this section describes how each actor contributes to the proposed reference blockchain blueprints traceability and transparency.

Upstream suppliers & manufacturers

According to the SLR findings, the raw material producer, chemical producer, and the converter have similar actor value propositions. The SLR findings state that these actors have to provide accurate data on their decoupled production processes (e.g., material origin, environmental footprint, carbon emissions) in the creation of circular products. The interviewees (1 – 6) agreed upon the similarities in the value creation of the upstream suppliers & manufactures in realizing the network value proposition traceability and transparency. Upstream suppliers & manufacturers' actor value proposition for the traceability and transparency blockchain blueprints is to provide accurate data on circular materials and sustainability metrics from their processes on the blockchain.

This actor value proposition is realized by verifying and recording information. The verifying phase ensures that raw materials and environmental processes from previous actors in the value chain satisfy the standards required for a circular economy. While the recording phase focuses on uploading this data to comply with these standards. This is confirmed by all interviewees and is best illustrated by Interviewee 6: "*Exactly, they have a verifying role next to sharing accurate data. So they need to have accurate data themselves, but they need to make sure that they're receiving accurate data from their suppliers*." It is worth noting that the type of data on circular product creation is no different from before blockchain implementation. However, traceability and transparency are offered by blockchain in a different format. Interviewee 5 states, "*The type of data we're providing is not different if blockchain would not have been there, but blockchain allows us to have a digital platform with traceability and transparency embedded in it and information doesn't change in that sense*."

Brand owner

The brand owner is perceived as the link between upstream- and downstream value chain, and their main contribution is to pledge the circularity of a product to its consumers (Shou & Domenech, 2022). Despite the fact that brand owners might act as an intermediary in the value chain, interviewees 3 - 6 do not consider the brand owner as the authority to pull traceability and transparency in circular product creation. Although the brand owners would like to push their suppliers to share all this data, they are not able to lead the traceability and transparency of data. This is best illustrated by the statement of interviewee 3 "*they are willing to hear about how we can get all this data, but they do not have the arms to force their suppliers to give them all the data*." Instead, the interviewees 3 – 6 argued that brand owners are driving the request for traceability and transparency. As concluded by interviewee 4 "*I think* *the brand owner would be the one demanding traceability or in that sense driving the request for traceability*." The interviewees 3 – 6 referred back on the actor value proposition for transparency

Waste management company

The waste management company is an important network actor in the realization of the circular economy. Although they have a similar role as the upstream suppliers & manufacturers, their actor value proposition is a little bit different. According to the literature, their actor value proposition is to provide accurate information on their waste to realize these CBMs. The interviewees 1 and 2 claimed that this actor value proposition is correctly defined and is illustrated by interviewee 2 "*it is essential that they segregate the waste and record this information as these waste streams can have contamination of quality*." The actor value proposition on accurate data is applicable for traceability and transparency.

Blockchain provider

The blockchain provider has a separate role for traceability and transparency. The traceability part is focusing on the development of a blockchain platform consisting a traceability system (Centobelli et al., 2021; Rusinek et al., 2018). Furthermore, they are guiding the data preparation and authorize access to new blockchain users regarding the transparency system (Centobelli et al., 2021; Rusinek et al., 2018). Interviewees 3 and 6 agree that the phrasing of the actor value propositions for traceability and transparency are correct.

Blockchain orchestrator

The blockchain orchestrator is introduced in the proposed reference blockchain blueprint as the focal organization by interviewees 1, 3, 4, and 6. In accordance with their answer, the actor value proposition for traceability is to orchestrate the consortium blockchain by defining the purpose and objectives of the blockchain. This statement is depicted by interviewee 4 as "*They are deciding what is going to be traced, how it's going to be traced, and what contribution is required from every participant*", followed by interviewee 3 "*We as blockchain providers don't have the decision to initiate this kind of product, but industry stakeholders can see the value and initiate a blockchain system*." A similar actor value proposition applies for transparency, which is focused on defining the requirements and standards for data sharing.

Customer

Similar to the blockchain orchestrator, the customer is introduced to the proposed reference blockchain blueprint. The blockchain application could yield opportunities for several stakeholders, dependent on the purpose and use of the blockchain. However, as stated by all interviewees (1 – 6) the blockchain applications should be adopted on industry level. As illustrated by interviewee 5 "*the support and* *number of applications are more likely, and it allows you to finance a blockchain platform as an industry*." Hence, the main actor value proposition of these customers is to stimulate adoption of the proposed reference blockchain blueprint.

6.4.2.3 Actor costs and benefits

The specified costs and benefits identified through the SLR, as shown in Table 9 and Table 10, are validated and complement through interviews with field experts to ensure the practical implications. As described in Section 4.3.3.4, some costs and benefits related to traceability and transparency can be very similar. As a result, sub-groups are defined and classified as traceability & transparency, traceability, and transparency. Furthermore, an overview table making this distinction is needed for all elements. According to the interview protocol, field experts only discuss the costs and benefits of their own actor group or those they are able to answer. An overview of the costs and benefits retrieved from the interviews is depicted in Table 11 and explained in this section.

Table 11: Validated and improved costs and benefits for the proposed reference blockchain blueprint

	VALIDATED																	IMPROVED					
	Decentralized ledger (+)	Tamperproof ledger (+)	Increased trust certification scheme (+)	Accurate documentation (+)	Development cost (-)	Maintenance cost (-)	Unique value proposition (+)	Reduced manual work (+)	Regulatory compliance (+)	Training costs (-)	Confidential information (-)	Information accessibility (+)	Reduced transaction costs (+)	Decreased information asymmetry (+)	Improved material identification (+)	Increased waste-to-value (+)	Eliminate power (-)	Consultant costs (-)	Cost of resources (-)	Consultation fee (+)	Operation fee (+)	Material differentiation (+)	Validate premium fee (+)
Related to traceability & transparency	x	x	x	x	x	x	x											x	x	x	x		
Related to traceability								x	x	x	x											x	
Related to transparency												x	x	x	x	x	x						x
Interviewee 1 (Raw material producer)							n/a											n/a	n/a	n/a	n/a		
Interviewee 2 (Raw material producer)							n/a											n/a	n/a	n/a	n/a		
Interviewee 3 (Blockchain provider)															n/a	n/a						n/a	
Interviewee 4 (Chemical producer)															n/a	n/a		n/a	n/a	n/a	n/a		
Interviewee 5 (Chemical producer)															n/a	n/a		n/a	n/a	n/a	n/a		
Interviewee 6 (Blockchain provider)															n/a	n/a						n/a	
Included in Reference Blockchain Blueprint	x	x	x	x		x	x	x	x			x	x	x	x	x		x	x			x	x

n/a = not able to answer (no expertise)

<u>Traceability & transparency</u>

The following costs and benefits are categorized into the sub-category of traceability & transparency, showing many similarities. This is confirmed by the interviewees during the validation interviews.

Decentralized ledger & tamperproof ledger

The decentralized & tamperproof ledger are considered as inherent characteristics of the blockchain by the interviewees (1 – 6) and should be integrated into the model.

Increased trust certification scheme

The increased trust benefit group is valued by interviewees 1, 2, 4 and 5 as important for the blockchain platform. However, according to interviewee 4 and 5, the term "increased trust" should be defined further because they mentioned "*It is not necessarily trust in general, but it increases trust in the fact that the certification scheme works,*" and "*In a market with a lot of competition, you cannot assume that every player in the market would act in a fully ethical manner. … Blockchain could extent the level of trust based on the confirmity of consensus*." To further specify the meaning of "increased trust" in the proposed reference blockchain blueprint, it is defined as "increased trust in certification scheme."

Accurate documentation

The accurate documentation could be a benefit for the proposed reference blockchain blueprint by all interviewees (1 – 6). Their reasoning is primarily focused on transaction formats, or smart contracts as defined in this thesis, that require the necessary information before they can be executed. Interviewee 5 illustrates an overall example that best represents this reasoning from all actors as "*blockchain could increase the streamline of documentation, because it's only going to accept a certain type of data to be entered for the transaction or workflow to proceed*." Therefore, the "accurate documentation" benefit group is included.

Development and maintenance costs

Overall, everybody agrees on the implementation and maintenance costs for the blockchain platform. The interviewees 1, 2, 4, and 5 argued that these implementation costs have to be paid as a collective in order to make it successful. In agreement with this statement, interviewees 2 and 5 state the following "*I believe that the success of the blockchains would be built on the fact that everybody realizes the value and everybody is paying,*" and "*it's another IT system, but I don't see any organization willing to sponsor an application that benefits multiple parties so it will only work in a consortium kind of way.*" The implementation and maintenance costs are applicable to all the stakeholders using the blockchain and is integrated into the proposed reference blockchain blueprint.

Unique value proposition

Although each of the interviewees (3 – 6) agreed on the benefit of a unique value proposition for the brand owner, the perceived value of this benefit group differs. The interviewees 3, 5, and 6 refer to the unique value proposition for the brand owner because they can convey an offering that proves the circularity of a product with actual data. According to interviewee 3 "*blockchain enables brand owners to track all this information and convey a message to position themselves as a circular business.*" In contrast, interviewee 4 refers to the unique value proposition as a potential marketing value, yet it does not create a unique value proposition solely for your company. The argument being: "*I would say it is really a marketing value, but as soon as it's not new technology anymore I do not agree that it's a benefit.*" Based on the interviewees' responses, blockchain for circularity solutions in the manufacturing industry is considered as a unique value proposition only in the short term. Assuming that this blockchain could distinguish circular products from fossil products, the unique value proposition is considered a benefit for brand owners in the proposed reference blockchain blueprint for traceability and transparency.

IMPROVED: Consultation fee and operation fee

According to the interviewees 3 and 6, the blockchain provider receives a consultation fee for the development or operation fee for the maintenance costs. The blockchain provider actor receives a fee for the development and implementation of the blockchain platform in the form of a consultation fee. However, in addition there is a consultation fee based on operating the services of the blockchain for the clients. This is best described by interviewee 3 as "*when you have developed and implemented such a blockchain platform, you end-up focusing more on an operating fee rather than consultation fee.*" Therefore, the "consultation fee" and "operation fee" are included in the proposed reference blockchain blueprint for traceability and transparency.

IMPROVED: Cost of resources and consultant costs

Several costs are required for the operation of the blockchain platform. According to the interviewees 3 and 6 these costs can be further defined into consultant cost, infrastructure costs, and R&D costs. This is best illustrated by interviewee 6 as "*our two main costs are related to the digital resources which are about infrastructure and R&D costs and consultant costs. But these consultant costs should become less of an impact as the implementation is very similar."* Therefore, the costs related to the blockchain provider are distinguished into "Cost of resources" and "Consultant costs" and included in the proposed reference blockchain blueprint.

<u>*Traceability*</u>

The following costs and benefits are related to the reference blockchain blueprint of traceability.

Reduced manual work (Reduced administration)

Interviewees 1, 2, 4 and 5 agree upon the reduced administration costs. Although the circular economy in general requires more activity handling for transparency in product creation, blockchain has the potential to significantly reduce manual work in administration. The interviewees 4 and 5 demonstrate this by saying "*if you have a single ledger for administration the latest version of every document is available without sending back and forth hundreds of emails*" and "*when we try to quantify the benefits of our pilot, the reduction of the manual work was clearly one of the benefits that we listed.*" According to findings of the interviews, the answers are more focused on reducing manual labour than on lowering overall administrative costs. As a result, the "reduced manual work" better illustrates this specific benefit group for blockchain related to the circular economy.

Regulatory compliance

The benefit "regulatory compliance" refers to how blockchain can support companies to comply with regulation. Some interviewees do not consider this as a benefit of the blockchain system as they always must comply with the regulations. In contrast, interviewees 3, 4, and 6 do agree on this benefit and especially elaborate on the damage it could bring to companies when they are not compliant to regulations. This is best illustrated by interviewee 6 "I think it can ensure regulatory compliance for companies as it's less human error, but I question whether compliance can be much better." Hence, the regulatory compliance is introduced in the proposed reference blockchain blueprint.

Training costs

Except for interviewee 2, all of the interviewees stated that there are no training costs associated with this blockchain platform. Interviewee 2 only referred to the training costs in the short term by stating "*when setting up this new system also involves additional training for the operational users of the staff in the short term*." The interviewees 1, and 3 – 6 reason that the blockchain should be a plug and play system that does not require significant training costs. More important is that blockchain should be interoperable with companies their enterprise resource systems to automate and streamline these processes. This is best illustrated by Interviewee 6 referring to "*in the end blockchain is part of the solution, and blockchain is the one that connect those enterprise resource systems from individual actors in the blockchain design.*" Therefore, in agreement with the interviewees it is assumed that the blockchain should not require training costs.

Confidential information

The interviewees (1 – 6) all agree that sharing confidential information is definitely not a cost and should be removed from the proposed reference blockchain blueprint. Besides the fact that the information tracked on blockchain for circular economy is already partially public, confidential information is not public and is managed accordingly. This so-called confidential information could be shared with suppliers or customers, but is very much dependent on the blockchain application. This is best depicted by the interviewees 1 and 4 as "*this blockchain allows you to manage whatever information you want to share or that you consider as confidential*" and "*it's already semi-public information that you share and in case you're sharing any confidential information you will not share it with any other than your customers or suppliers*." However, according to interviewee 5 the integration of stakeholders in the pilot is that people are not sure how much confidential information would be shared. Therefore, the sharing of confidential information is not perceived as a cost from the interviewees and is removed from the proposed reference blockchain blueprint.

IMPROVED: Material differentiation

Another benefit group for traceability according to Interviewee 4 and 5 is the inclusion of material differentiation. This is illustrated by Interviewee 4 as "*for us this traceability would allow us to differentiate, for instance, in pricing between renewable and circular feedstock or different types of circular polymers.*" This benefit is applicable to the upstream value chain actors. As a result, this specific benefit is included for the chemical producer as a potential benefit.

IMPROVED: Downstream traceability

Noteworthy is that interviewees 1 and 2 consider downstream traceability of their materials and feedstocks as a valuable asset of blockchain. This allows the upstream suppliers to identify how the product is being used and where it is being end. Interviewee 1 argued this argumentation as "*I would like to know where my raw material is going to end up which could provide me with information on the usage of our materials.*"

<u>*Transparency*</u>

The following costs and benefits are related to the reference blockchain blueprint of transparency.

Information accessibility

The interviewees (1 – 6) agreed on the inclusion of information accessibility as a benefit for the reference blockchain blueprint of transparency. This argumentation is best illustrated by interviewee 4 "*in general the information is already there but the blockchain makes it much easier to access this information*." Thus, information accessibility is included in the reference blockchain blueprint.

Reduced transaction costs (information disclosure)

Although some of the interviewees disagree with the naming, all the interviewees (1 – 6) agreed that the underlying meaning is a benefit of blockchain. This is best referred to by interviewee 5 as "*the blockchain platform can easily disseminate information, however this is also possible with other systems. The actual benefit is reducing the costs related to these transactions*." Interviewees 1 and 4 made similar statements. As a result, information velocity is renamed to reduced transaction costs.

Decreased information asymmetry

Overall, the decreased information asymmetry is confirmed by each of the interviewees as a potential benefit of blockchain for the circular economy (1 – 6). As depicted by Interviewee 2 "*a circular economy is only enabled when you have information symmetry on the sustainability metrics of materials and products*." Interviewee 4 confirms the potential benefit of decreased information asymmetry for a circular economy from an industry perspective, but he explicitly states that it could negatively impact commercial benefit for businesses. Interviewee 4 argued "*the whole idea behind doing business and receiving a commercial benefit in the market is information asymmetry. So it might be beneficial for* *one but not beneficial for another, what does it do to my business model in general?*” Because the circular economy aims at a broader definition of value and requires collaboration from multiple stakeholders, it is assumed in this thesis that decreased information asymmetry is considered as a benefit. Therefore, the benefit is included in the proposed reference blockchain blueprint.

Improved material identification and *increased waste-to-value*

According to the SLR results, the waste management company benefits from improved material identification and increased waste-to-value. Since the waste management company was not included in the pilot, the interviewees were unable to validate these benefits. However, the benefits are included in the proposed reference blockchain.

IMPROVED: Validate premium fee

The validation of a premium fee is recognized as an important benefit of the blockchain and is mentioned as an additional benefit for transparency by interviewees 1, 4, 5, and 6. According to the interviewees, circularity solutions come with extra costs compared to non-circular products and blockchain can validate these price differences. Hence, the "validate premium fee" can provide more tangible data of a circular product. This is argued by the interviewees 4 and 6 as "*next to the differentiation in premiums, transparency on circularity of materials or products allows you to validate this premium fee*" and "*Consumers do not just buy the product, they are buying the reduced environmental impact and blockchain can validate this premium. That's at least as it stands today.*" Therefore, the benefit "validate premium fee" is added to the reference blockchain blueprint for transparency.

6.4.3 Evaluation of utility

As discussed in Section 6.2, the utility of the reference blockchain blueprint is evaluated by field experts during the end of the interview by closed-questions on a 5-point Likert Scale. Although the main purpose of the first set of interviews with field experts was on validating and improving the reference blockchain blueprint, a thorough discussion is held with the researcher for each of the embedded value elements. Therefore, the evaluation of utility for the reference blockchain blueprint is representative for upcoming users' of the proposed reference blockchain blueprint.

The utility is evaluated according to the core constructs of TAM to identify the acceptance of the designed reference blockchain blueprints (Davis, 1989; Venkatesh & Davis, 2000). The TAM is commonly used in the information systems field for empirical studies through their set of statements to determine the usefulness and its ease of use. In addition, Turetken et al. (2019) use this method to evaluate the SDBM/R, indicating that it is an appropriate method for evaluating the utility of the reference blockchain blueprint according to the TAM constructs. To identify the utility of the reference blockchain blueprint, the three constructs of TAM are used: Perceived usefulness, perceived ease of use, and intention to use (Davis 1989). Perceived usefulness refers to the users' perception on the utility of the designed artifact to increase the efficiency for the user. The perceived ease of use depicts users' believe on the use of an artifact that is free from physical or mental effort. Finally, the intention to use describes how users' intends to use the proposed artifact, which is determined by the perceived usefulness and ease of use. This thesis used four statements for perceived usefulness and ease of use, and two for intention to use, in accordance with the study of Turetken et al. (2019) by following the work of Venkatesh & Davis (2000). The results for each set of statements are presented in Table 12 and provide positive results for each of the constructs.

Table 12: Utility statements (Adapted from Venkatesh & Davis (2000))

Construct	Code	Statement	1	2	3	4	5
Perceived usefulness	PU1	I think this Reference Blockchain Blueprint provides an effective solution to guide companies in designing blockchain related circular business models.				4	2
	PU2*	The Reference Blockchain Blueprint would be difficult for users (colleagues, stakeholders, etc.) to understand.		1		1	4
	PU3*	Using the Reference Blockchain Blueprint would make it more difficult to communicate the blockchain-related circular business model to other stakeholders.			1	2	3
	PU4	Overall, I found the Reference Blockchain Blueprint useful.			1	1	4
Perceived ease of use	PE1	Learning to use the Reference Blockchain Blueprint to guide companies in designing blockchain related circular business models would be easy for me.		1		3	2
	PE2*	I found the structure of the Reference Blockchain Blueprint unclear and difficult to understand.			2	2	2
	PE3	It would be easy for me to become skillful at using the Reference Blockchain Blueprint to guide companies in designing blockchain related circular business models.			2	3	1
	PE4*	Overall, I found the Reference Blockchain Blueprint difficult to use.			1	3	2
Intention to use	IU1	I would use this Reference Blockchain Blueprint to guide companies in designing blockchain related circular business models in the future.		1		2	3
	IU2*	I would not intent to use Reference Blockchain Blueprint to guide companies in designing blockchain related circular business models in preference to another approach.			1	3	2

(*) statements are provided in negative form, and their outcomes are reversed in the table.

7. Final Reference Blockchain Blueprint

The proposed reference blockchain blueprint for designing blockchain-enabled CBMs in the manufacturing industry is described in this section. This section is divided in the following four sections to elaborate on the structure and use of the reference blueprint. First, the development of the reference blockchain blueprint is described according to the defined solution requirements. Second, the actor groups and their associated roles are elaborated upon. Third, the practical implications of the reference blockchain blueprint for users are described.

7.1 Design and Development of the Reference Blockchain Blueprint

The proposed reference blockchain blueprints that serve as guide to develop blockchain-enabled CBMs for traceability and transparency are depicted in Figure 11 and Figure 12, respectively. Each of these blueprints are depicted in the form of an SDBM/R, which creates value from a network-centric perspective by co-creating value with multiple stakeholders. Hence, the first (R1) and second (R2) requirements of the artifact are fulfilled by the underlying structure and characteristics of an SDBM/R.

The characteristics of the concepts circular economy and blockchain have been embedded into the design of the artifact to make it more applicable to a practical setting. First, the researcher argued that the circular economy principles of the 4R framework by Kirchherr et al. (2017) are best suited to the manufacturing industry and determined the inclusion of value elements related to the reference blockchain blueprint. As a result, the artifact comprises value elements related to the principles reduce, reuse, recycle, and recover, satisfying the third (R3) requirement of the artifact. Second, blockchain configurations could differ in terms of applications and attributes, which affects the potential value elements of the artifact. In accordance with the extant literature, the permissioned blockchain is most suitable for the manufacturing industry (Dib et al., 2018). Hence, the potential value elements of the reference blockchain blueprint correspond to the capabilities and boundaries of the permissioned blockchain, satisfying the fourth (R4) requirement of the artifact.

As mentioned at the beginning of this section, the reference blockchain blueprint is built on the underlying structure of the SDBM/R. This reference blockchain blueprint provides guidance for each of the SDBM/R layers: network actors and actors categorization, actors value proposition, actors co-production activity, and actors costs and benefits. The generic actor groups were identified, and characteristics of the roles they play were elaborated on and depicted in the outer ring of the reference blockchain blueprint. The inclusion of these generic network actors and associated roles satisfy the fifth (R5) requirement of the artifact. This serves as a guide for users when designing blockchain-enabled CBMs to identify the relevant actor groups that could be included to realize the network value proposition.

Next, for each of the identified generic network actors, the actor value proposition is determined and represented in the first layer, which describes the concrete support of individual actor groups in the realization of this network value proposition. However, to further specify this actor value proposition for each actor group, a concrete co-production activity is deduced from the actor value proposition and included in the second layer of the blueprint. This co-production activity elaborates on generic activities that enable the generic actor value proposition. Hence, the sixth (R6) requirement of the artifact is fulfilled with the actor value proposition and associated co-production activities. In addition, the actors costs and benefits are specified in terms of monetary or non-monetary value that could be expected when participating in this CBM design. These costs and benefits are specified to each generic network actor, hence, fulfilling the seventh (R7) and last requirement of the artifact.

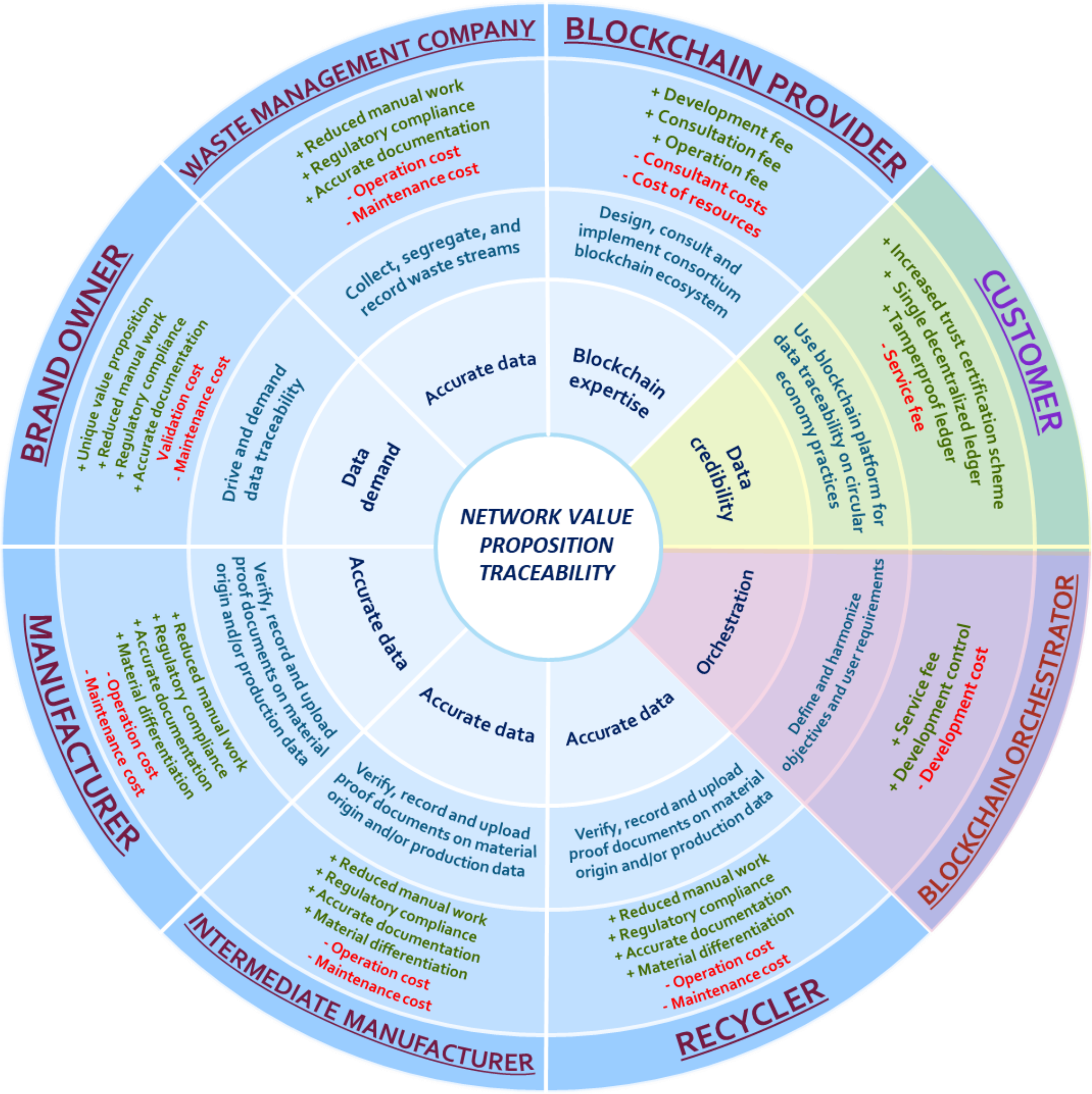

Figure 11: Proposed Blockchain Blueprint - Traceability

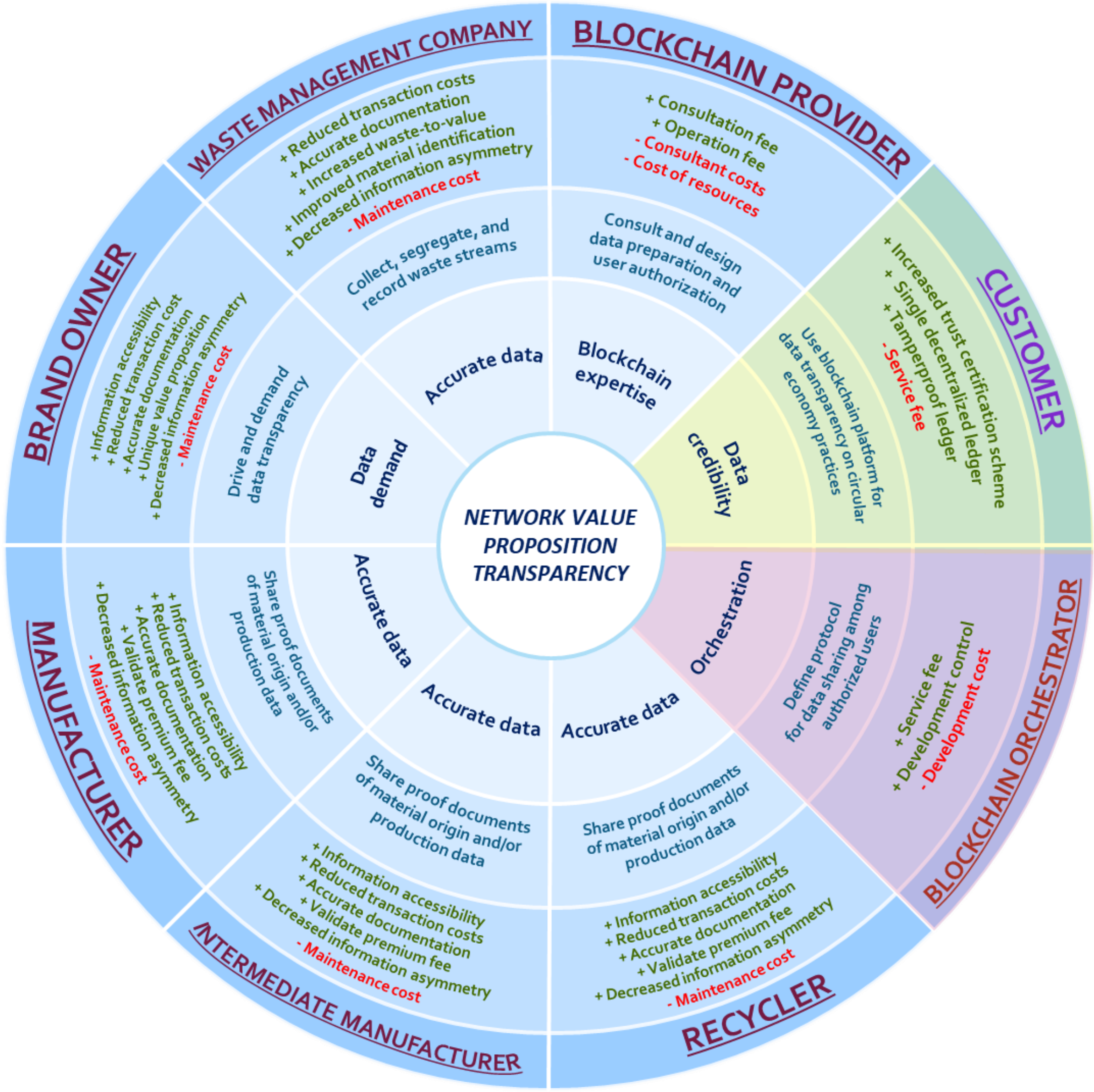

Figure 12: Proposed blockchain blueprint - Transparency

7.2 Actor Groups in Reference Blockchain Blueprint

This section describes each of the actor groups and the associated role in the reference blockchain blueprints traceability and transparency.

Customer

The customer is represented as the user of the network value proposition and is an essential actor in service-dominant business models. The customer is the actor to which the network value proposition is appropriated. Blockchain-enabled CBMs should always include a customer and ensure that the network value proposition is catered to this customer. The role of the customer is to create data credibility by actively participating on the blockchain platform. The customer in this blueprint can be concretized as a business, non-governmental organization, or governmental body who wants to participate in the blockchain platform or use it as a servic e to gain insights. This customer does not solely depict these actors from a higher level, but can also be specified towards more specific user groups (e.g., a sustainability department, production department, procurement department, or technology department). It might also be an organization that acts on behalf of the customer. For example, consider a multinational corporation that wants to use blockchain to improve traceability and transparency in the production of circular products related to their brand.

In accordance with the field expert interviews, the customer is the one who is financing the blockchain platform as a collective. The targeted customer is dependent on the blockchain application (or use case), and the customer pays a certain amount of costs for the use of the blockchain platform. In addition, the customer contribute to the network value proposition by participating on the blockchain platform according to their own generic actor.

Blockchain orchestrator

The blockchain orchestrator is the focal organization and is the initiator of the reference business model. This actor is responsible for defining the purpose and objective for a specific network value proposition on the blockchain platform. The blockchain orchestrator can be concretized as a consortium or multi-stakeholder model, which can comprise of businesses, non-governmental organizations, governmental bodys, and research institutions. According to the interviewees, the blockchain orchestrator should consist of a good representation of a specific sector or industry to reflect the needs and interests of the industry. The purpose of the blockchain orchestrator is to jointly decide on the requirements and boundaries of the network value proposition for establishing the interfaces between actor participants. This actor is in close contact with the blockchain provider to ensure the feasibility of the network value proposition. The blockchain orchestrator is driven primarily by achieving a shared objective. However, it should be compensated for the development of a blockchain platform.

Recycler

The inclusion of a recycler in the business model design is important to recover materials from waste according to proper processing and treatment techniques. Circular economy activities require preserving and recovering materials or goods in the manufacturing industry. The recycler for this blueprint can be concretized as, but not limited to, a recycling facility or waste treatment center that focuses explicitly on processing waste into circular materials. Hence, the role of the recycler is to provide circular materials in the industry that comply with the required specifications of the intermediate manufacturer or manufacturer. For the recycler, it is often important to verify the waste stream from the waste management company. Similar to the intermediate manufacturer and manufacturer, the main benefit appropriated for this actor is the accessibility of information, accurate documentation, and reduced manual work or transaction costs. These benefits come with the cost of operations such as tracing information and costs for the expenses of maintenance for the blockchain.

Intermediair manufacturer

The intermediate manufacturer can be characterized as an intermediate producer or an intermediate supplier who perform a preliminary processing step on circular materials and serves as input for the final manufacturer. As such, the intermediate manufacturer is an important actor in this business model design. The intermediate manufacturer needs to provide accurate information on the quality and origin of the intermediate materials or goods to comply with the specifications demanded from the manufacturer of the final good. In order to do that, they must verify the quality of the raw materials retrieved from the recycler. Similar to the recycler and manufacturer, the main benefit appropriated for this actor is the accessibility of information, accurate documentation, and reduced manual work or transaction costs. These benefits come with the cost of operations such as tracing information and costs for the expenses of maintenance for the blockchain.

Manufacturer

The manufacturer in this business model design is the final actor for the upstream value chain and produces or assembles the final circular product. This actor is concretized as a manufacturing company or original equipment manufacturer who develops the final circular product in accordance with the defined quality standards. This production could be at the request of a brand owner or for their own purposes. The main contribution of the manufacturer to the business model design is to provide accurate data on the production process and proof documents on the quality and origin of the final circular product. In some business model designs focusing on a certain level of product authenticity, the manufacturer also creates an unique digital identity for the circular products. The product authentication identifier could be beneficial for the brand owner, as well as for the waste management company to perform more accurate waste segregation. Similar to the recycler and intermediate manufacturer, the main benefit appropriated for this actor is the accessibility of information, accurate documentation, and reduced manual work or transaction costs. These benefits come with the cost of operations such as tracing information and costs for the expenses of maintenance for the blockchain.

Brand owner

The brand owner is the link between the upstream- and downstream actors in the value chain and pledges the circularity of a product. This brand owner is characterized as an organization that markets a circular product on their own brand label, which could include, but not limited to, large corporations, small-medium enterprises, or entrepreneurs. According to the interviews, this party is often seen as the most interested party in this business model design as it needs to ensure that circular products with their brand name comply with regulations and standards. To contribute to this specific business model, the main contribution of the brand owner is to drive the request of circular product creation data. As this network value proposition contributes to the traceability and transparency of data, the main benefit for the brand owner is a unique value proposition, accurate documentation, and reduced manual work and transaction costs. In contrast, the costs for the brand owner in this solution are based on validation- and maintenance costs.

Waste management company

The waste management company serves the purpose of collecting and sorting waste in this business model design. Hence, including this actor in the business model design is key to determining the waste value stream. The waste management company concretize any actor in the waste management stage, such as a waste collector or waste segregator. This actor in the business model is important in most cases because it differentiates recyclable, renewable, or reusable waste from non-reusable waste. Given the network value proposition, the support of the waste management company provides accurate waste collection and segregation for circulation in the value chain. The corresponding costs and benefits focus on non-monetary values. However, the value of transparency can enable them to increase the waste-to-value and improve material identification. The costs in this business model design are based on operation- and maintenance costs.

Blockchain provider

The blockchain provider is a vital element in the business model design and involves the design and development of the blockchain platform. This actor is responsible for the design and consultation of the blockchain platform and acts as a facilitator. Moreover, the blockchain provider concretizes actors with blockchain expertise for developing these applications. This blockchain platform development is performed in collaboration with the blockchain orchestrator. For this specific actor, the costs and benefits are focused on monetary value. According to the interviews, benefits for the blockchain provider are related to the consultation fee for the development of the blockchain platform and the operation fee for maintenance. In contrast, the costs are based on resources for developing and maintenance.

7.3 Practical Implications of the Reference Blockchain Blueprint

The proposed reference blockchain blueprint can facilitate users to design blockchain-enabled CBMs in the manufacturing industry. First, the users can identify the generic actor groups that could contribute to the realization of the network value proposition related to traceability and transparency. Users can categorize stakeholders into one of the actor groups based on the characteristics during the design of a blockchain-enabled CBM. It is important to note that stakeholders can function in different actor groups, performing multiple roles in the business model design. Since each of these actor groups have a generic actor value proposition and associated co-production activity, users can determine how these descriptions apply for each of the actors groups in the business model design and specify them accordingly. Similarly, users can determine whether each of the costs and benefits are applicable to the generic actor groups or adapt it according to their specific business model design.

8. Evaluation of Feasibility and Viability

This section assesses the proposed reference blockchain blueprint by practitioners in the petrochemical industry. This evaluation step is performed the further concretize and motivate the operationalization of the artifact in practice. The design science research approach requires the evaluation of the proposed reference blockchain blueprint in practice (Hevner et al., 2004). Although the reference blockchain blueprint is not operational, a business model evaluation based on stakeholder predictions could be performed (Mateu & Escribá-Esteve, 2019). Hence, the reference blockchain blueprint is evaluated for feasibility and viability with petrochemical industry practitioners active in the circular economy domain. These evaluations assess to what extent the reference blockchain blueprint could be used to guide the design of blockchain-enabled CBMs.

8.1 Selection of participants

Following a similar approach as Section 6, this set of interviews is performed according to the guideline of Kvale (2007). In contrast to the first set of interviews with field experts described in Section 6.1, the second interview round focuses on petrochemical industry practitioners. Hence, the actors as depicted in Figure 10 are applicable for this interview round. To maintain a high quality of information retrieved from the interviews, it is important to identify suitable interviewees for this thesis. Therefore, the following three criteria are predefined and ensure that the interviewee is a good candidate for this research:

1. The interviewee should work at a company that complies with the characteristics of the generic actor roles as defined in the proposed reference blockchain blueprint.
2. The interviewee should be knowledgeable on the concepts of blockchain and circular economy.
3. The interviewee should work in a role related to the circular economy domain.

In agreement with the predefined criteria, a list of potential candidates for the second round of interviews in this thesis is formed together with SABIC. The list comprises of interviewee candidates working at companies that fit the requirements for the blockchain pilot initiated by SABIC. Each interviewee candidate is contacted via email, as depicted in Appendix F: Interview invitation . In case of no response, two reminder emails have been sent. This resulted in a total of eight petrochemical industry practitioners, as described in Table 2.

8.2 Designing interview protocol

In line with the method of Kvale (2007) as described in Section 6.2, this interview protocol serves as a guide for the semi-structured interviews with the petrochemical industry practitioners. These semi-structured interviews allows the research to ask follow-up questions to gain a deeper understanding of the interviewees' perspectives. The following topics are considered in this interview round, and elaborating on the purpose and rationale for inclusion. The topics for the second round of interviews with petrochemical industry practitioners is described below, and the interview protocol is depicted in Appendix G: Interview round 2.

Questions related to topic 1 (INTRODUCTION), topic 2 (BACKGROUND), topic 3 (BLOCKCHAIN), and topic 5 (CONCLUSION) are similar to the first interview round and is described in Section 6.2.

Topic 4 (REFERENCE BLOCKCHAIN BLUEPRINT) evaluates the feasibility and viability of the proposed reference blockchain blueprints. This topic starts with a brief introduction to the SDBM/R. Then, evaluation questions proposed by Gilsing et al. (2021) related to feasibility and viability are used to evaluate the reference blockchain blueprints in practice. The questions related to feasibility & viability are asked in open questions, and the researcher interprets the potential response of the answer. First, the quality attribute feasibility is measured. Feasibility focuses on technical performance and is based on the accessibility of resources and capabilities to operationalize the business model design (Gilsing et al., 2021). Furthermore, it aims to highlight potential barriers that may arise during the implementation and the level of trust in the business model design. Since the circular economy and blockchain require a high level of collaboration and should operate on a blockchain platform, the question related to communication and resource interfaces is not required. The evaluation questions related to feasibility are depicted in Table 14.

Viability as a quality attribute is more business performance related and aims to focus on the perceived costs and benefits for each actor participating in creating the network value proposition (Gilsing et al., 2021). Since the benefits must outweigh the costs for each actor, a key driver is business model participation. It focuses on whether the costs and benefits are reliable and can be quantified in terms of monetary and non-monetary costs and benefits. Moreover, it determines the acceptability based on strategic goals and motivation for actor participation. The evaluation questions related to viability are depicted in Table 15. The last quality attribute is robustness, which captures the uncertainty on the previous quality attributes viability and feasibility (Gilsing et al., 2021). Although it is crucial to identify how its uncertainty could influence the quality attributes mentioned above, blockchain remains in its nascent stage. Hence, this attribute might be an essential step when the blockchain blueprint could be implemented and assessed by other studies.

8.3 Results and discussion

The outcome of the evaluation interviews on the feasibility and viability of the reference blockchain blueprints are discussed in this section.

8.3.1 Results Feasibility

The feasibility evaluation of the reference blockchain blueprints focuses on the availability of resources for actors to operationalize the business model design. Since traceability and transparency operate on a similar blockchain platform, the feasibility applies to both proposed reference blockchain blueprints. As discussed in Section 8.2, three sub-questions related to feasibility are developed to determine the feasibility of the artifact. The topics to evaluate the feasibility of the reference blockchain blueprint are the accessibility of resources for performing co-production activities, technological and legal barriers, and trust between actors.

8.3.1.1 Accessibility of Resources to Realize the Actor Value Proposition

This section describes the accessibility to resources for realizing the actor value proposition required for the network value proposition. Overall, the interviewees (7 – 14) noted that they have access to the resources to fulfil the co-production activity required for the actor value propositions to operationalize the business model design. Even though the resources are in place, some actors refer to a few constraints. Nevertheless, the accessibility of resources is perceived as high for the reference blockchain blueprint.

First, some interviewees (9, 10, and 14) argued that smaller companies do not have expensive enterprise resource planning systems that store all the data required for these circularity solutions to pull it into the blockchain, as they often still work with Excel sheets. Interviewee 10 illustrated this best "*at some point in time, brand owners obligate suppliers and manufacturers to deliver circularity information of product, but especially for the smaller this will be extra manual labor for the accounting department to transfer data and fill the blockchain.*" Hence, implementing blockchain for smaller (intermediary) manufacturers could become a burden instead of an enrichment.

Second, the printing of an identifier, such as a QR-code, on packaging solutions was found to require significant upfront costs. Interviewee 7 argued that adding the printing feature can open a wide range of solution dimensions for the (intermediate) manufacturer, but the implementation heavily depends on costs. This is best illustrated as "*the ultimate goal is to have packaging that communicate information related to the circularity solution for the consumer, but in the end it is all about how much it costs. Our industry [fast-moving consuming goods] you look at solutions which are a cent or lower for every package, should we integrate an identifier on individual products or per tray with 12* *packages? I would suggest the latter one.*” This finding raises the question of whether products could be provided with an individual identifier necessary to provide circular solutions.

Another noteworthy finding is the misalignment between the brand owner and other actors in the blockchain blueprint according to interviewee 12. The interviewee representing the brand owner state that they are willing to pay a premium for recycled content. However, according to the brand owner he is not in the seat to drive and demand circularity solutions. This is argued by interviewee 12 as “*we do create demand, but I do not see us as brand owner demanding it, we are part of the objective to more sustainable practices and usage of recycled content.*” In contrast, other interviewees do consider the brand owner as the one demanding these circularity solutions in the manufacturing industry. For instance, interviewee 9 stated “*The demand is coming from brand owners, as they are the ones being exposed to consumer concerns. We provide solutions for them to talk about emissions, circularity, and material origin for them to create a narrative.*” Hence, it might be that the brand owner is not able to drive the adoption of blockchain for suppliers and manufacturers operating in their value chain.

8.3.1.2 Presence of Technological and Legal Barriers

The interviewees elaborated upon several technological and legal barriers that hamper the operationalization of the business model design. Considering the amount of technological- and legal barriers hampering the operationalization of the business model design, the perceived feasibility is low. However, this could be explained by the nascent field of blockchain.

Lack of interoperability with existing ERP systems for data automation

Interviewees 7, 8, 10, 11, 13, and 14 argued that the interoperability of blockchain with existing enterprise resource systems is a potential technological barrier. Reasoning from the results of these interviews, it is stated that blockchain should not become a platform that runs in parallel with existing enterprise resource systems. Moreover, blockchain must be interoperable with different systems to pull the data automatically and remove the manual input. This is best illustrated by interviewee 8: "*if the blockchain could automatically pull the data from our [ERP] system, it would be excellent, but if it is just another parallel system that needs to be provided with data, it becomes a hurdle.*” Because this business model design requires collaboration between different companies in the industry, it is argued by interviewees that blockchain should be compatible with various ERP systems. As depicted by interviewee 10 “*all different ERP systems need to be prepared for this so that they can extract the data immediately into the blockchain, it will happen automatically afterward, every month, every week, every day, every hour, if you like.*” In summary, the interviewees consider this technological barrier vital to the success of a blockchain ecosystem.

Assurance and credibility issues

Another potential technological barrier is the risk of blockchain providers in the market who do not fully understand the industry in which they operate, as described by interviewees 8 – 10. Several blockchain providers are operating in the market and are offering solutions to the customer or industry. However, to implement a blockchain platform it is necessary to understand the need of the value chain or industry to assure a credible claim from a business-to-business perspective. This is best depicted by interviewee 8 as "*I recognize from the market that start-ups are operating in the market and do not fully understand the industry and its information required. This is a risk as they focus on nice and shiny dashboards but it lacks the assurance of credible claims.*" Furthermore, interviewee 9 questioned the verification of performance of physical data on the blockchain. This is stated as "*you would be able to transmit data, but you always have to get the data in the system and I don't see that technology could verify performance on the ground.*" Therefore, a potential technological barrier is the assurance of credibility claims on the blockchain platform.

Misunderstanding the functioning of blockchain

From the perspective of interviewee 7, the biggest bottleneck of a blockchain solution is the lack of people in understanding the functioning of blockchain. The reasoning from interviewee 7 is that people simply do not trust the solution. This is best illustrated as "*blockchain application is a mystery and they are not trusting such a solution since their experience is that every automated solution can be cracked somehow*." Therefore, before you can convince people to join a blockchain platform, it is vital to explain the working of blockchain.

Lack of legislation on decentralized ownership

The decentralized ownership of blockchain is recognized as a legal barrier according to the interviewees 7, 8, 10, 11, 13, and 14. This decentralization offered through a blockchain platform differs from an enterprise resource system of a company. Transactions stored on a blockchain are distributed across each of the participants, while individual enterprise resource systems are stored in a centralized database. Although blockchain could control sensitive business data from users, it is stored on a blockchain and interviewees refer to the lack of legal protocols for ownership. For instance, interviewee 13 referred to an earlier project on watermarking which showed a similar constraining on the question of who is the owner of this data. This is represented by interviewee 13 as "*the major issue of this project, which is also very much related to blockchain, is based on who is owner of the data and what are the consequences if this fall into the wrong hands*." This requires additional consideration in the design of blockchain-enabled CBMs until a governmental body resolves this issue.

8.3.1.3 Existence of Trust Between Actors

The idea of implementing a blockchain application for circular economy practices is to establish trust between actors in the design of a CBM. Overall, the trust between actors in the industry related to circular economy practices is low. This level of trust is currently created by an external auditing certification scheme on which all stakeholders rely. According to the interviewees, blockchain could replace the level of trust created by an auditor and improve the integrity of these certification schemes. This is best illustrated by interviewee 8 and 9 as "*blockchain gives trust in general because it's sort of an unchangeable set of information going through the value chain*" and "*it gives you more integrity about the transactions and it enables us to store information on origin, climate impacts, and more…*" Some interviewees, however, question the integrity of the actual data stored on the blockchain. As illustrated by interviewee 9 "*You know what is the tricky part. How do you actually get credible climate data or where and what type of waste was originally used?*" Nevertheless, this might be resolved by a stringent protocol to enable trust. Therefore, trust between actors is assumed to be high in this business model design.

8.3.2 Results Viability

The evaluation of viability is related to the perceived costs and benefits for each actor participating in the business model design. These interview questions related to viability identified the acceptability of actors representative in the artifact. As discussed in Section 8.2, three sub-questions related to viability are developed to determine the viability. The topics to evaluate the viability are the measurability of costs and benefits, benefits outweigh the costs, and equal balance of costs and benefits.

8.3.2.1 Measurability of Costs and Benefits

The measurability of costs and benefits are depicted below for the blueprints traceability and transparency. Although the costs and benefits for each blueprint show many similarities, the blueprint differ and are described separately.

Traceability

In general, the costs and benefits associated with the traceability blueprint are considered measurable for each actor. Several patterns were identified from the interviews and further discussed. The operation costs for recording data are perceived as measurable, but most actors argued that you always have operation costs and they do not differ much from the costs we have today. This also applies to the reduced manual work benefit for actors in the value chain. Some interviewees assume that the benefit of reduced manual work is only measurable if the industry has a single decentralized system in place and requires an automated process.

The benefits of improved material identification and increased waste-to-value for the waste management company showed some interesting findings. Overall, interviewees 11 and 13 agreed upon the measurability of these two benefits but recognized the following constraints. Improved material identification could facilitate waste segregation processes, but it is not appropriate for mixed waste streams such as domestic waste. For instance, present sorting lines for mixed waste cannot always guarantee the segregation of waste to maintain the quality required for manufacturing processes. This could be the case if waste is separated at the source prior to collection and dedicated sorting lines are built for this specific type of waste. Furthermore, the interviewees 11 and 13 provided a similar reason for the increased waste-to-value benefit. The increased waste-to-value benefit is enabled by waste stream transparency through source separation prior to collection to maintain quality and maximize waste value.

Transparency

The interviewees (7 – 14) agreed on the measurability of the costs and benefits related to the transparency blueprint. Therefore, no patterns in the measurability of these costs and benefits that required further discussion were discovered.

8.3.2.2 Benefits Outweigh the Costs

The interviewees (7 – 14) confirmed that the potential benefits for the reference blockchain blueprint for traceability and transparency outweigh the costs for participating in the business model design. The general argument is that present circular economy efforts demand traceability and transparency, but the benefits of the reference blockchain blueprints could further support this requirement. Moreover, the blockchain is perceived as a platform that could increase the credibility and reduce the costs of CBMs. However, the interviewees 7 – 10, 13, and 14 explicitly mention that this based on the assumption that ERP systems are automated with the blockchain and blockchain is integrated on an industry level.

8.3.2.3 Equal Balance of Costs and Benefits

First of all, the interviewees considered the balance of costs and benefits similar to the blueprints traceability and transparency. The balance of costs and benefits from the actors in the value chain is perceived as moderate for the reference blockchain blueprint.

Interviewees 7 – 10, 11, 13, and 14 specifically mentioned the burden for this reference blockchain blueprints for actors in the upstream value chain, while the brand owner would profit the most. Nevertheless, some actors still perceive the inequality of costs and benefits as the brand owner is not covering all these costs, while actors in the value chain are trying to maximize their benefits. This inequality is best depicted by interviewee 10 as "*It does not work if everyone is only there to maximize their profits, otherwise the entire circular economy paradigm does not work*." Another constraint in the balance of costs and benefits according to interviewees 7, 10, and 14, some actors require more handling and input than others and these efforts should be rewarded equally. This is best represented by interviewee 7 as "*the efforts on what information you're providing, would be on one side very high and on the other side very low. This should be based on the efforts which must be handled by the industry,* *for sharing according to the efforts with a percentage table*.” Next to these costs and benefits, each actor might have a different motivation such as profit maximization or brand image. Hence, some actors still argue the balance of costs and benefits in this business model design.

9. Conclusion

In this section, the implications of the results for the solution requirements are discussed. This section consists of a summary of the research approach, the contribution to research and practice, and the limitations and future work of this thesis.

9.1 Research summary

Even though the blockchain concept is receiving wide recognition from researchers and practitioners to support the transition to a circular economy, the extant literature lacks an overview of the contribution of blockchain to circular business models (CBMs). The lack of a definition for the contribution of blockchain to CBMs causes reluctance to use blockchain to overcome barriers to transitioning to a circular economy. Therefore, the research objective of this thesis aimed to develop and evaluate a reference business model to facilitate the design of blockchain-enabled CBMs, in particular the reference blockchain blueprint.

The literature highlights that the characteristics of CBMs differ significantly from linear business models, while not many business modeling frameworks originated for the circular economy (or sustainability) domain. Since the CBM depicts a broader notion of value from the perspective of multiple stakeholders, it is found that the underlying characteristics are aligned with the service-dominant (S-D) logic. The S-D logic addresses the co-creation among network actors, including the customer, rather than the production and exchange of goods. Hence, the business model frameworks should depict the S-D logic inherent to the business model design as it facilitates co-created value among network actors. Thus, the service-dominant business model radar (SDBM/R) is most appropriate for depicting CBMs and is used to map the proposed reference blockchain blueprint.

The proposed reference blockchain blueprint is developed and evaluated using a design science research (DSR) approach performing multiple steps. First, a systematic literature review is performed on studies describing blockchain applications for circular economy practices in the manufacturing industry. The findings of this SLR retrieved 30 studies, and a thorough analysis was performed on blockchain characteristics and SDBM/R elements to develop the initial reference blockchain blueprint. The results showed that traceability and transparency are the most common blockchain application areas in the circular economy. Therefore, two reference blockchain blueprints are created to give more detailed information on their contribution to CBMs. The SLR studies showed numerous similarities in terms of value elements for the SDBM/R. Except for expected costs and benefits, these reference blockchain blueprints are similar regarding network actors and associated roles, actor value propositions, and co-production activities derived from the SLR.

The initial reference blockchain blueprints were validated and improved with field expert interviews. Several patterns were identified, and some improvements were made to the reference blockchain blueprints. First, the auditor is not considered a core actor as it is not required to participate on the blockchain platform. The customer and blockchain orchestrator were integrated into the reference blockchain blueprint based on the findings. Therefore, the proposed reference blockchain blueprints listed eight generic network actors: a customer, a blockchain orchestrator, a recycler, an intermediate manufacturer, a manufacturer, a brand owner, a waste management company, and a blockchain provider. Another noteworthy enhancement is the modification of the actor roles targeted customer and focal organization. The interviewees argued that the targeted customer could be any stakeholder in the manufacturing industry and not solely the brand owner. While the focal organization should be representatives in the industry to diffuse the blockchain across the industry. For the actor value proposition and deduced actor co-production activity, a modification is made for the brand owner as it does not take the lead in implementing traceability and transparency in blockchain applications. Instead, the brand owner is driving the demand for traceability and transparency. Besides, in total three costs and benefits were invalid, and seven were complemented. Furthermore, the utility of the reference blockchain blueprints was evaluated during the end of the field expert interviews and showed positive results.

The final step in the demonstration and evaluation step of the DSR for proposed reference blockchain blueprints is an assessment on the predicted operationalization in practice with practitioners. This demonstration revealed several challenges that can hinder the operation of the reference blockchain blueprint. First, the actors in the business model design perceived the accessibility to resources and existence of trust as high. However, the depicted technological and legal barriers can hamper the operationalization and are perceived as low related to the feasibility of the business model design. For instance, a critical technological barrier is the lack of interoperability with existing ERP systems, and a significant legal barrier is the lack of decentralized ownership legislation. The viability for the proposed reference blockchain blueprints traceability and transparency in terms of measurability of costs and benefits and benefits outweigh the cost is high. In contrast, the appropriated balance of costs and benefits is perceived as moderate for viability. This is explained by the inbalance of operation costs in the business model design among participating value chain actors. However, because blockchain is an emerging concept for the circular economy, its feasibility and viability will change over time.

9.2 Research contributions

The integration of blockchain and circular business models (CBMs) into synthesized reference blockchain blueprints is the primary theoretical contribution of this thesis. Currently, the literature in the research domain of blockchain and circular economy lacks an overview on the contribution of blockchain to CBMs. This gap is solved by the design of the reference blockchain blueprints specified for blockchain-enabled CBMs in the manufacturing industry. Even though actors can vary for business model designs, the artifact solution can be used to determine the configuration of blockchain-enabled CBMs for research purposes. Thus, the reference blockchain blueprints can serve as a foundation for research on blockchain-enabled CBMs.

For business purposes, the reference blockchain blueprints can serve as a guide to practitioners in the manufacturing industry on how to develop a blockchain-enabled CBM for future blockchain applications. Next to the guide, the proposed artifact can depict the actors required for the business model design and support decision-making. Hence, it can serve as a starting point for practitioners to design more rapidly a blockchain-enabled CBM appropriate for an industry or sub-industry.

9.3 Limitations and future work

This thesis presents some limitations that were applicable to this research approach. The first limitation of this research is the relatively small sample of interviews conducted to evaluate the validity and utility. The reference blockchain blueprint derived from the SLR is validated and improved based on only six interviews and could limit the generalizability of the artifact. This issue is mitigated to some extend considering the knowledge of interviewees on blockchain, circular economy, and business models based on their active participation in the blockchain pilot. This defines the second limitation as the field experts operated into a blockchain pilot and some work at the same company, occurring the potential problem of being biased. However, the field experts work in different departments and have different backgrounds and expertise.

The initial reference blockchain blueprints represent in total seven generic actors, while only three actors are represented during the interviews. Since the validation and improvement of the reference blockchain blueprint are conducted only with three of the seven generic actors, a possibility exists that the findings are skewed toward these interviewees. However, the relatively short timespan of this thesis and the selective group of participants with the required knowledge made it difficult to map each of the generic actors in the artifact multiple times. Besides, the second round of interviews with eight practitioners evaluated the feasibility and viability of their generic actor in the artifact to support the findings.

Another limitation of this thesis is that the proposed reference blockchain blueprint for the manufacturing industry is validated and improved according to field experts operating in the petrochemical industry. Since the petrochemical industry for manufacturing petroleum products shares many characteristics with the manufacturing industry, generic actor roles and characteristics can be defined accordingly to this industry. Therefore, the petrochemical industry is a good representation of this industry and can be generalized to the manufacturing industry.

This thesis provides some suggestions for future research. The extent literature showed little research on blockchain-enabled CBMs in general. The proposed reference blockchain blueprints in this thesis can serve as starting point for future research on blockchain-enabled CBMs in the manufacturing industry. Therefore, it is necessary to investigate further the blueprint within other businesses operating in the manufacturing industry. The researchers could build on this study by using one or a combination of defined use cases, as depicted in Table 7, to depict the network value proposition for their collaborative business model design. In addition, according to the feasibility and viability of the current reference blockchain blueprint, some critical points are identified and require further investigation.

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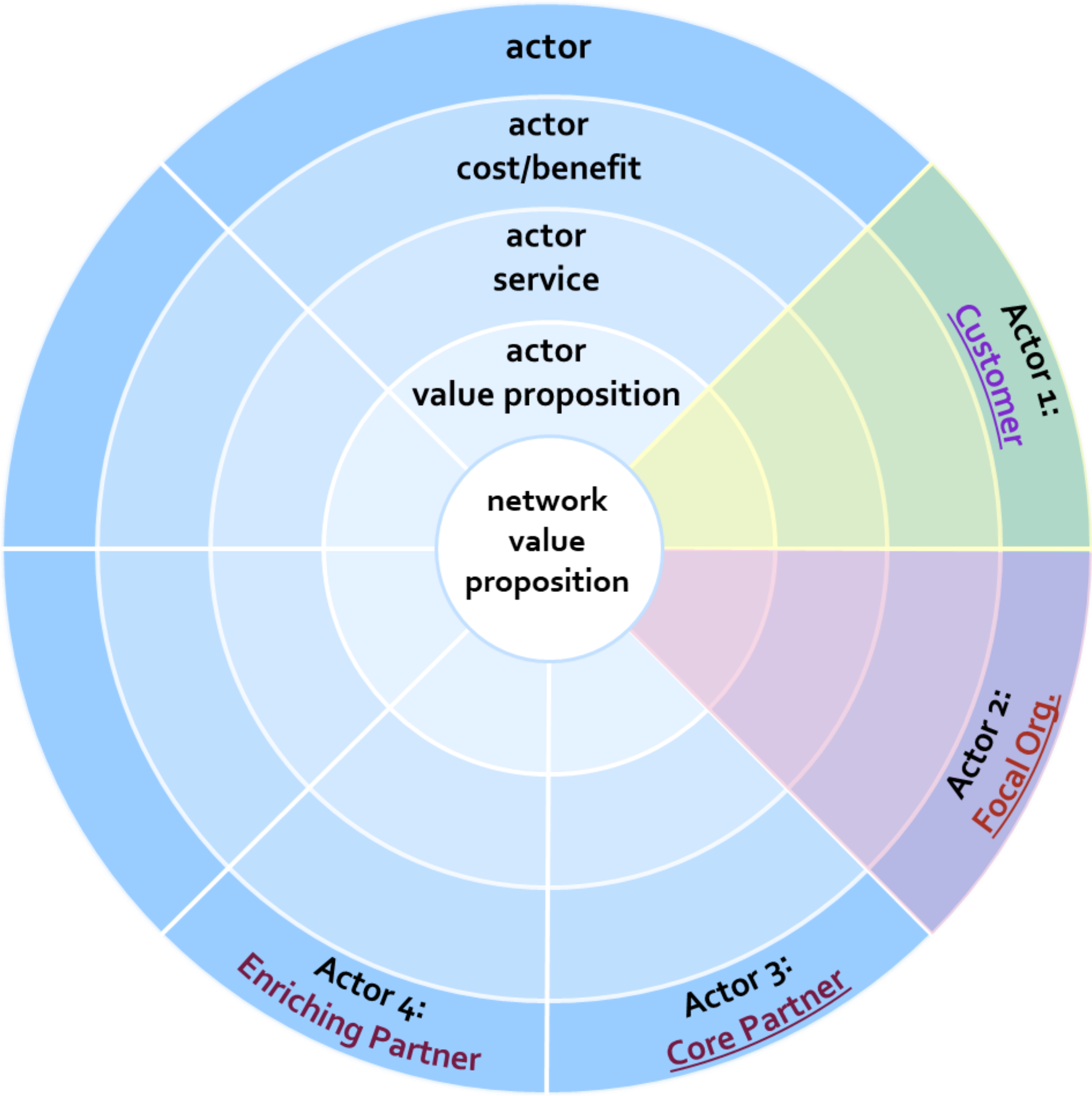
11. Appendix

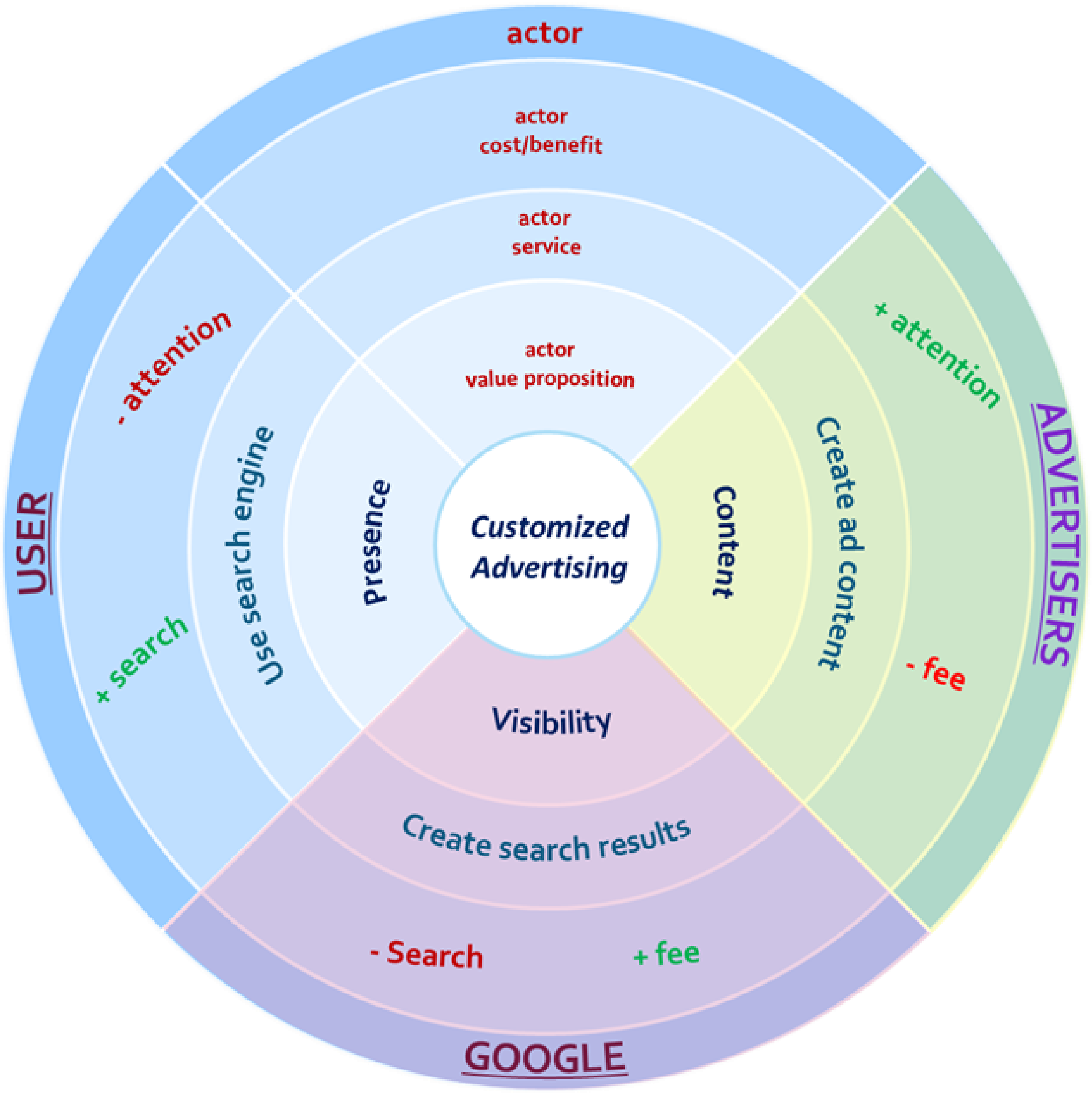
Appendix A: Introduction interview sessions

The service-Dominant Business Model Radar



EXAMPLE:

Google Search Engine Business Model



Appendix B: Invitation interview 1

Subject: Blockchain to support circular economy practices in the petrochemical industry

Dear Sir/Madam,

My name is Luke Tonnaer, and I am an MSc student in Innovation Management at the Technical University of Eindhoven. Along with SABIC, I am working on my master thesis to identify the contribution of blockchain on circular business models. With this mail, I would like to invite you for a 60 minutes interview on the subject.

This thesis will develop a blockchain business model blueprint that could guide companies in recognizing how blockchain can contribute to their circular business model. Since you participated in the blockchain pilot initiated by SABIC, I would like to validate some blockchain business propositions. Would you be willing to support me by participating in an interview?

Please feel free to contact me by email (luke.tonnaer@sabic.com) in case you have any questions. Thank you in advance.

I am looking forward to your reply!

Best regards,
Luke Tonnaer

Appendix C: Structural validity for evaluation of validity

Table 13: Questions for evaluation of validity

	Structural validity questions	Evaluation of validity questions
Value Network	Does the SD-BMD consist of at least three actors?	NOT APPLICABLE – derived from the SLR
	Is the customer an explicit actor in the SD-BMD?	Q9: From your perspective, how does the customer (in this case …) contribute to this network value proposition?
	Does each actor interact with at least one actor in the SD-BMD?	NOT APPLICABLE – derived from the SLR
	Do all actors in the SD-BMD iteract on the same level of hierarchy	Q12: Based on your experience, is there an actor not in the radar that could (or should) contribute to this network value proposition?
Value Proposition	Can the expected value-in-use follow from the set of actor value propositions?	Q13: Do you agree on the actor value proposition, actor service, and actor costs- and benefits applicable to your company?
	Does the expected value-in-use match or address the needs of the customer?	Q11: Do you agree on the role of actors and their corresponding actor value proposition in realizing the network value proposition?
Value Architecture	Does each actor value proposition realistically result from its deployed operant and operand resources?	Q13(A): Start with your actor value proposition, is this correctly defined?
	Does the service offering of the SD-BMD enable or support the value creation process of the customer?	Q13(B): Do you align with the description for your service in realizing the network value proposition?
Value Capture	Does each actor in the SD-BMD have at least one cost and one benefit listed?	NOT APPLICABLE – derived from the SLR
	Are all costs and benefits as a result of exchange reciprocally listed in the SD-BMD?	Q13(C): Do you agree on the costs- and benefits for your company? Q13(D): From your experience of the SABIC blockchain pilot, could you elaborate on the cost- and benefit types for the brand owner?

Appendix D: Structural validity for evaluation of validity

Table 14: Evaluation questions on feasibility

	Questions:	
Evaluation of feasibility	To what extent does each actor in the SD-BMD have access to its listed operant and operand resources?	How would you describe the feasibility of this network value proposition according to the actor value proposition and co-production activity for your specific actor?
	To what extent are communication and resource interfaces present between actors in the SD-BMD?	NOT APPLICABLE
	To what extent are legal and technological barriers present towards implementation of the SD-BMD?	Could you elaborate on potential technological barriers in realizing this network value proposition? How about legal barriers?
	To what extent does trust or mutual understanding exist between actors in the SD-BMD?	To what extent does trust exist between actors in realizing this network value proposition? Could you elaborate on your answer why this is the case?

Table 15: Evaluation questions on viability

	Questions:	
Evaluation of viability	To what extent can the costs and benefits per actor in the SD-BMD be measured or quantified?	Could you elaborate on the measurability of costs and benefits for each actor in this network value proposition?
	To what extent do the costs and benefits per actor in the SD-BMD satisfy strategic goals of each actor?	Would you argue that benefits outweigh the costs for each of these actors?
	To what extent can the costs and benefits realistically be balanced per actor?	How would you describe the balance of costs and benefits among each of the actors, are they equally divided and could you elaborate on why you think it is (not) balanced?

Appendix E: Interview round 1

TOPIC 1 (INTRODUCTION)

Objective & setup of the interview

The objective of this interview is to gain insights into the contribution of blockchain to circular business models within the petrochemical industry. We will focus on the contribution of blockchain to your company and its circular business model. We will also elaborate on the contribution of a circular business model to value chain partners within the petrochemical industry. The emphasis will be on your experience from participating in the blockchain pilot. **Therefore, your answers should reflect your experience with the blockchain pilot.**

Introduction to Thesis

The circular economy concept focuses on reducing, reusing, recycling, and recovering materials and goods. Many businesses started investigating the circular economy concept as it promises economic prosperity within ecological limits. Moreover, businesses that focus on circular economy practices remove end-of-life products and aim at a broader notion of value from a multiple-stakeholder perspective. Therefore, businesses operating in the circular economy are shifting from delivering business products to a solution-oriented service for the customer.

Blockchain is widely mentioned as an enabler for the circular economy as it can track and monitor materials and goods circulating in the value chain. Blockchain integration could bring transparency in a circular value chain and trust among the participants based on the underlying characteristics of decentralization, consensus mechanism, and immutability of the blockchain. However, a concrete business model for blockchain in a circular economy context is missing. Thus, this thesis depicts blockchain's contribution to circular business models from a multiple-stakeholder perspective.

Interview questions:

Before we start with the interview questions, I would like to mention that the insights gained from this interview will only be used for my thesis and will be treated with care. Important to note is that business-related information will be anonymized. I want to ask if you allow me to record the conversation and transcribe it afterward. If you want, I can send you the transcript for approval before processing the interview results for my thesis.

Topic 2 (BACKGROUND)

1. What is your current position within the organization you are working for?
    a. How many years of experience do you have in this position?

    b. Have you been working on blockchain projects with brand owners?
2. Could you elaborate on how your role is related to the circular economy?
3. How is your role related to the development of business models?

Topic 3 (BLOCKCHAIN)

4. Which blockchain type do you consider most suitable for its applicability in the petrochemical value chain, and could you elaborate why?
    a. How would you consider the applicability of a public blockchain for a value chain?
5. What would be the most suitable consensus mechanism for a consortium blockchain?
6. Should a blockchain platform be implemented on value chain- or industry level?

TOPIC 4 (REFERENCE BLOCKCHAIN BLUEPRINT)

7. How do you consider the relevance of this network value proposition for the circular economy?
8. Do you agree that for this network value proposition the XXX is the right targeted customer?
9. From your perspective, how does the customer (in this case …) contribute to this network value proposition?
10. The CSS is an description on high-level for activities of the customer actor and its interaction with other partners for the Blockchain Circular Business Model Blueprint. Can you read the corresponding Customer Service Scenario and does it relate to this network value proposition?
11. Do you agree on the role of actors and their corresponding actor value proposition in realizing the network value proposition?
    a. Focal organization; (why this is / is not the initiator for this network VP?)
    b. Core partners; (why this is / is not a core partner for this network VP?)
    c. Enriching partners;
12. Based on your experience, is there an actor not in the radar that could (or should) contribute to this network value proposition?
    a. Which role would this actor conduct in realizing this network value proposition?
13. Do you agree on the actor value proposition, actor service, and actor costs- and benefits applicable to your company?
    a. Start with the value proposition, is this correctly defined?
    b. Do you align with the description for your service in realizing the network value proposition?
    c. Do you agree on the costs- and benefits for your company?
    d. From your experience of the SABIC blockchain pilot, could you elaborate on the benefits- and cost types for the brand owner?
14. Would you like to comment on any other findings from this SDBM/R?

Topic 5 (TECHNOLOGY ACCEPTANCE MODEL)

15. Based on our conversation related to the Reference Blockchain Blueprint and its applicability, could you rate each of the following statements on a Likert scale from 1 (strongly disagree) to 5 (strongly agree)?

Topic 6 (CONCLUSION)

Appendix F: Interview invitation 2

Subject: Blockchain to support circular economy practices in the petrochemical industry

Dear Sir/Madam,

My name is Luke Tonnaer, and I am an MSc student in Innovation Management at the Technical University of Eindhoven. Along with SABIC, I am working on my master thesis to identify the contribution of blockchain on circular business models. With this mail, I would like to invite you for a 60 minutes interview on the subject.

This thesis will develop a blockchain business model blueprint that guides companies in recognizing how blockchain could contribute to their circular business model. Moreover, it will consist of a template with specific blockchain use cases for the circular economy and a corresponding set of guidelines based on theoretical- and empirical research. Therefore, I would like to validate blockchain business propositions with partners in the industry. Would you be willing to support me by participating in an interview?

If you have any questions, please get in touch with me by email (luke.tonnaer@sabic.com). Thank you in advance.

I am looking forward to your reply!

Best regards,
Luke Tonnaer

Appendix G: Interview round 2

TOPIC 1 (INTRODUCTION)

Introduction to Thesis

Businesses started investigating the circular economy concept as it promises economic prosperity within ecological limits. This concept focuses on reducing, reusing, recycling, and recovering materials and goods. The circular economy aims at a broader notion of value from a multiple-stakeholder perspective. Therefore, businesses shift from the delivery of products to a solution-oriented service for the customer.

Blockchain is widely mentioned as an enabler for the circular economy as it can trace the material origin and environmental footprint of products in the entire value chain. Blockchain integration could bring transparency in a circular value chain and trust among the participants based on the underlying characteristics of decentralization, consensus mechanism, and immutability of the blockchain. However, a concrete business model for blockchain in a circular economy still needs to be developed. Therefore, this thesis created the Blockchain Circular Business Model Blueprint to recognize the value of blockchain applications for circular business models. This so-called Blockchain Blueprint aims at traceability, value chain transparency, and product transparency.

"A blockchain is a distributed database, which is shared among and agreed upon a peer-to-peer network. It consists of a linked sequence of blocks, holding timestamped transactions secured by public-key cryptography and verified by the network community. Once an element is appended to the blockchain, it cannot be altered, turning a blockchain into an immutable record of past activity."

Objective & setup interview:

The objective of this interview is to gain insights into the contribution of blockchain to circular business models within the petrochemical industry. Next to some general questions on blockchain for a circular economy, this interview will evaluate the Blockchain Circular business Model Blueprint according to its feasibility, viability, and robustness.

Interview questions:

Before we start with the interview questions, I would like to mention that the insights gained from this interview will only be used for my thesis and will be treated with care. Important to note is that business-related information will be anonymized. I want to ask if you allow me to record the conversation and transcribe it afterward. If you want, I can send you the transcript for approval before processing the interview results for my thesis.

TOPIC 2 (BACKGROUND)

1. What is your current position within your organization? Could you elaborate on that in two sentences.
    a. Years of experience?
2. How familiar are you with business modeling for circular economy practices?
3. How familiar are you with the term blockchain?
    a. *Test blockchain knowledge 1*: What do you consider when hearing blockchain?
    b. *Test blockchain knowledge 2*: What keywords do you relate to a blockchain application in the value chain?

TOPIC 3 (BLOCKCHAIN)

4. How could a blockchain platform support the development and progression of a circular economy within your industry?
5. How do you envision a suitable blockchain platform?
    a. Implementation on value chain/industry level?
    b. Who should initiate a blockchain platform?
6. Would your organization be willing to participate in a blockchain platform initiated by a consortium group?
    a. Requirements to participate on such a blockchain platform?
7. Do you consider the ISCC certification scheme sufficient to enable a circular economy? Why?
    a. Could you elaborate on how blockchain can support the ISCC certification scheme?

TOPIC 4 (REFERENCE BLOCKCHAIN BLUEPRINT

The Blockchain Circular Business Model Blueprint is built on a systematic literature review and validated and complemented with participants in a blockchain pilot. Good to note: the consortium blockchain is recognized as the most suitable blockchain platform at this moment for the petrochemical industry and is a central part of the business model.

Due to time constraints, I do want you to read the CSS. I just want to show you a quick example of how this blockchain blueprint is accompanied with a (shortened) CSS to further explain the goal and how each actor is contributing in realizing this.

Reference Blockchain Blueprint: Traceability

8. How could traceability for products among circular value chains according to a consortium blockchain support circular economy practices for your organization?
    a. Sustainable solutions it could offer?
    b. Is the origin of renewable-/circular feedstock important? Why?

Feasibility

9. How would you describe the feasibility this network value proposition according to the resources and capabilities for your specific actor?
10. Could you elaborate on potential technological barriers in realizing this network value proposition? And how about legal barriers?
11. To what extent does trust exist between actors in realizing this network value proposition?

Viability

12. Could you elaborate on the measurability of costs and benefits for each actor in this network value proposition?
13. Would you argue that benefits outweigh the costs for each of these actors?
14. How would you describe the balance of costs and benefits among each of the actors, are they equally divided and could you elaborate on why you think it is (not) balanced?

Reference Blockchain Blueprint: Transparency

15. How could a transparency among value chain partners for circular product creation support circular economy practices for your organization?

Repeat questions on its feasibility (9, 10, and 11) & viability (12, 13, and 14)

TOPIC 5 (CONCLUSION)