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Blockchain for the circular economy: Theorizing blockchain's role in the transition to a circular economy through an empirical investigation

Moritz Böhmecke-Schwafert[1] | Marie Wehinger[1] | Robin Teigland[2]

[1]Institute of Technology and Management, Technical University Berlin, Germany
[2]Chalmers University of Technology, Gothenburg, Sweden

Correspondence
Moritz Böhmecke-Schwafert, Technical University Berlin, Straße des 17, Juni 135, Berlin D-10623, Germany.
Email: moritz.boehmecke-schwafert@tu-berlin.de

Abstract

Blockchain is increasingly lauded as an enabler of the transition to a circular economy. While there is considerable conceptual research and some empirical studies on this phenomenon, scholars have yet to develop a theoretical model of blockchain's role in this transition. Grounded in the sustainability transition literature, this paper addresses this gap through the following research question: What role does blockchain play in the transition to a circular economy? Following an abductive approach, we conducted interviews with ground-level experts implementing blockchain innovations for the circular economy across Europe and the United States. Through a thematic analysis, we derived a theoretical model of the relationships among (1) drivers and barriers of the transition to a circular economy, (2) blockchain innovation for the circular economy, (3) technical challenges of blockchain, and (4) the circular economy. While blockchain plays a moderating role, interviewees considered it only an infrastructural resource rather than a panacea.

KEYWORDS
blockchain, circular economy, innovation, sustainability, transition

1 | INTRODUCTION

Irreversible environmental change, biodiversity loss, and the depletion of essential resources are increasingly catastrophic threats to human well-being (Geels, 2011; Köhler et al., 2019; Rockström et al., 2009). Recent reports by the Intergovernmental Panel on Climate Change and the UN Environment's Sixth Global Environmental Outlook have shown that society is facing a climate emergency, and planetary boundaries are increasingly under severe pressure (Ekins et al., 2019; IPCC, 2021). Systemic change is essential to halt continued resource extraction and reduce emissions caused through human activity (Geels, 2011).

The circular economy (CE) is gaining traction as a potential solution to reduce these threats (Prieto-Sandoval et al., 2018). The goal of the CE is to transition from today's linear economic model to a closed-loop economy based on resource regeneration and ecosystem restoration (Ghisellini et al., 2016; Murray et al., 2017). A plethora of studies suggest that the CE will lead to significant economic benefits, and conceptual research has identified numerous drivers and barriers to the transition (e.g., Suchek et al., 2021). In addition to changes in consumer behavior, design approaches, and material choices, innovation is viewed as a promising avenue to the CE (de Jesus et al., 2018; Geissdoerfer et al., 2017; Kalmykova et al., 2018).

In this context, blockchain has received increasing attention from scholars and practitioners alike as a potential catalyst for the transition to a CE. Blockchain can facilitate new business models and a new era of transparency and, perhaps most importantly, generate economies of trust, thereby potentially transforming prevailing economic and institutional systems (Adams et al., 2018; Kouhizadeh, Sarkis, & Zhu, 2019). Recent studies have explored blockchain's role in environmental sustainability with different foci: supply chain sustainability (Agrawal et al., 2021; Francisco & Swanson, 2018; Kouhizadeh, Sarkis, & Zhu, 2019), product-service systems (Vogel et al., 2019), product deletion (Kouhizadeh, Sarkis, & Zhu, 2019), and the CE in general (Eikmanns, 2018; Faber & Jonker, 2019; Upadhyay, Laing, et al., 2021).

More recent research has found that blockchain can support the CE's three principles of reduce, reuse, and recycle. Blockchain-based supply chain management systems can facilitate traceability in complex supply chains (Agrawal et al., 2021; Venkatesh et al., 2020) and increase responsible buying behavior by providing accurate information (Saberi et al., 2019). In waste management, blockchain can support waste exchange platforms and recycling schemes through smart contracts (Khadke et al., 2021). Moreover, blockchain can support the use of renewable energies through peer-to-peer energy trading platforms and source verification systems (Herweijer et al., 2018; Yildizbasi, 2021).

Research investigating blockchain innovation for the CE, however, comprises primarily conceptual research and few empirical studies. As a result, scholars have yet to develop a theoretical model of blockchain's role in this transition. This is not too surprising as the phenomenon has appeared just within the past few years, and there are few operational implementations across the globe (Böckel et al., 2021). To fill this gap, we developed the following research question: What role does blockchain play in the transition to a CE?

To address our research question, we turned to the sustainability transition research, which focuses on dynamic, co-evolutionary, multi-actor processes affecting economic development and social or environmental spheres (Smith et al., 2010). In particular, we draw on the literature investigating the drivers and barriers of a transition to a CE in addition to the relevant blockchain literature. Following an abductive approach, we conducted a thematic analysis incorporating data from interviews with ground-level experts working on operational blockchain innovations for the CE (blockchain CE innovation) across Europe and the United States. On the basis of the unanticipated empirical findings and new theoretical insights as our study progressed (Dubois & Gadde, 2002), we developed and refined current theory regarding the transition to a CE.

Our study makes three contributions. First, we contribute to the extant sustainability transition and CE research with a theoretical model of blockchain's role in the transition to a CE that we derived from a thematic analysis of our interview data. To the best of our knowledge, this model is the first to suggest relationships among the following concepts: (1) drivers and barriers of the transition to a CE (CE drivers and barriers), (2) blockchain innovation for the CE (blockchain CE innovation), (3) technical challenges to blockchain, and (4) the CE. In particular, our findings suggest that blockchain CE innovation plays a moderating role between CE drivers and barriers and the CE, primarily by strengthening technical drivers while reducing market barriers. We also find that CE drivers and barriers directly influence blockchain CE innovation both negatively and positively. Emerging from our analysis, we further found that general technical challenges of blockchain negatively influence blockchain CE innovation, thereby weakening blockchain's moderating role. Our theoretical model of blockchain's moderating role in the transition to a CE can thus serve as the basis for future deductive research.

Second, our study contributes to the blockchain literature as it moves beyond previous conceptual research of potential blockchain applications based on anecdotal or secondary data and provides a more comprehensive empirical study based on primary data of operational ground-level blockchain innovation for the CE. Findings suggest that while blockchain plays a moderating role as noted above, many interviewees considered it only an infrastructural resource that could be replaced by other technologies rather than a panacea for the CE. Finally, we discuss the implications of our study for practitioners and policymakers on how to leverage the potential of this emerging technology for the imperative transition to a CE.

This paper is structured as follows. In the next section, we present the theoretical background and provide an overview of the relevant literature. In Section 3, we describe our research methodology before presenting our findings and theoretical model in Section 4. Section 5 discusses our results in light of theory and practice before concluding our paper in Section 6.

2 | THEORETICAL BACKGROUND

2.1 | The circular economy

The CE concept is rooted in general systems theory and industrial ecology (Andersen, 2007; Geissdoerfer et al., 2017). The concept is receiving significant attention from policymakers, firms, and researchers alike as it offers a practical framework for sustainable development (Ghisellini et al., 2016; Murray et al., 2017). Instead of the linear economy paradigm (i.e., take, make, dispose) that focuses on continuous growth, the CE postulates a closed-loop that operates within the planet's ecological limits (Ghisellini et al., 2016; Merli et al., 2018). While various definitions and models exist, we define the CE as an "industrial economy that is restorative or regenerative by intention and design" (Ellen MacArthur Foundation, 2013).

The CE literature articulates three main principles: reduce, reuse, and recycle (Kirchherr et al., 2017). Reduction mandates minimizing energy, raw material, and waste input by optimizing production efficiency and promoting less consumption (Ghisellini et al., 2016; Su et al., 2013). This includes promoting eco-efficient production processes, lighter and more compact products, and a minimalistic lifestyle (Ghisellini et al., 2016). Reusing refers to using a product or component again in its original form or with little enhancement or change for the same purpose (Ellen MacArthur Foundation, 2013). This principle entails the maximization of product lifecycles, promotion of consumer demand for used products, take-back incentives, and firms' use of waste or by-products (Ghisellini et al., 2016; Su et al., 2013). Recycling aims to reduce virgin material input (Su et al., 2013). Barriers to recycling are natural limits (entropy law), the complexity of products and materials, material abuse (Stahel, 2013), and additional required energy (King et al., 2006). Finally, renewable energy should replace fossil fuels to support a resilient circular system (Ellen MacArthur Foundation, 2013; Ghisellini et al., 2016; Korhonen et al., 2018).

While the concept is still evolving, the CE generally requires increased involvement from numerous stakeholders and a common ground for its implementation (Ghisellini et al., 2016). Two primary implementation approaches for the CE have emerged: (1) top-down approaches driven by government policy (Kalmykova et al., 2018) and (2) bottom-up approaches driven by enterprises, environmental organizations, and civil society (Ghisellini et al., 2016; Lieder & Rashid, 2016). Policies to drive the transition to a CE are manifold, such as a reduction of taxes on renewable resources. In addition, educational programs and public campaigns can help raise awareness for the CE.

CE research has found that innovation can improve product quality and extend product lifecycles, enable new circular business models (Lieder & Rashid, 2016; Mont, 2002; Vogel et al., 2019), and facilitate systemic integration (de Jesus & Mendonça, 2018). Relevant innovation concepts include eco-innovation, green innovation, environmental innovation, and sustainable innovation, which are used interchangeably in the literature (Díaz-García et al., 2015).

The transition to a CE has been studied through a sustainability transition lens (de Jesus & Mendonça, 2018; Jackson et al., 2014; Jurgilevich et al., 2016; Lazarevic & Valve, 2017). Sustainability transition research focuses on socio-technical systems, such as energy, transport, or production and consumption systems (Köhler et al., 2019; Markard et al., 2012), and emphasizes that transition is not a linear process aimed at achieving maximum profits. Instead, it is a dynamic, co-evolutionary, multi-actor process affecting economic development and social or environmental spheres (de Jesus et al., 2018; Smith et al., 2010). Sustainability transition requires active policy involvement, and institutional support as sustainability is viewed as a collective good while few incentives exist for private actors to engage in such transitional processes (Geels, 2011; Köhler et al., 2019; Markard et al., 2012).

2.2 | Drivers and barriers of a transition to a CE

Within the sustainability transition research, considerable studies have focused on the drivers and barriers of a transition to a CE. These drivers and barriers can include financial, governmental, market-related, and cultural aspects (Govindan & Hasanagic, 2018; Kirchherr et al., 2018; Rizos et al., 2016; Tura et al., 2019; Upadhyay, Laing, et al., 2021). A review of the drivers and barriers by de Jesus and Mendonça (2018) distinguished between “softer” (institutional/regulatory, social/cultural) and “harder” (technical, economic/financial/market) factors. They concluded that the transition to a CE is mainly hampered by harder factors, such as the lack of available technological solutions and financial barriers including high investment costs and linear lock-ins. In contrast, softer factors, such as effective public policies, awareness of environmental issues among consumers, and demand for environmental-friendly products, drive the transition (de Jesus & Mendonça, 2018). Prieto-Sandoval et al. (2018) highlighted the importance of innovation for a transition to the CE by demonstrating how eco-innovation determinants (regulation and policy, supply-side actions, and demand-side requirements) apply to the CE concept. Their review found that regulation and policy support the legal foundation to strengthen circular supply while consumers (demand side) are described as crucial for accepting eco-innovation and driving the transition through their changed behavior (Prieto-Sandoval et al., 2018). Additionally, Cainelli et al. (2020) accentuated the crucial role of public policy and demand-side factors as innovation drivers. Their quantitative analysis of EU manufacturing and service company data showcased that environmental policy and demand-pull factors are instrumental in driving clean technology adoption. Finally, Kirchherr et al. (2018) conducted an empirical study on the barriers to the CE based on 208 survey respondents and 47 expert interviews in the EU and concluded that cultural barriers are the primary obstacle.

We synthesize this literature on drivers and barriers of a transition to a CE (CE drivers and barriers) in Table 1. We find that despite a general agreement on the primary categories (technical, economic/financial/market, institutional/regulatory, social/cultural), the literature has primarily been conceptual and has produced varying results regarding the respective relevance of CE drivers and barriers.

2.3 | Blockchain

Initially appearing in 2008 in a white paper, blockchain combines several well-proven technologies: decentralization, consensus, immutability of data entries, and cryptographic security (Tschorsch & Scheuermann, 2016; Vogel et al., 2019). First, blockchain is a decentralized technology that stores transaction data in so-called blocks, chronologically linked in a blockchain (Yli-Huumo et al., 2016). Every time a new transaction is conducted, it is added to the chain and linked to the previous block (Yli-Huumo et al., 2016). Instead of centrally storing transaction records, the technology operates in a distributed manner with a ledger of transactions stored on all nodes participating in the network (Zheng et al., 2017). Hence, the ledger is available to all network participants, making blockchain technology more transparent than traditional databases in which all information is controlled by one party (Yli-Huumo et al., 2016). Second, a consensus mechanism ensures data consistency in such a distributed system (Zheng et al., 2017). Forged transactions cannot be recorded on the blockchain, thereby eliminating the need for a trusted third party to validate transactions (Yli-Huumo et al., 2016). A public ledger is only updated if network participants reach a consensus; however, consensus mechanisms vary significantly between specific blockchain applications. Third, records on a blockchain are immutable, preventing previously verified transactions to be modified (Hofmann et al., 2018). The concepts of immutability and consensus ensure the data integrity and security of blockchain technology (Hughes et al., 2019; Yli-Huumo et al., 2016). Finally, public-key cryptography provides the data security of ledger entries. The existence of public keys and

TABLE 1 Drivers and barriers of the transition to a circular economy

		CE drivers	CE barriers	References
Harder factors	Technical	Availability of technologies that facilitate resource optimization, remanufacturing and regeneration of by-products as input to other processes, development of sharing solutions with superior consumer experience and convenience	Inappropriate technology, lag between design and diffusion, lack of technical support and training	de Jesus and Mendonça (2018)
	Economic/financial/market	Related to demand-side trends (rising resource demand and consequent pressures resource depletion) and supply-side trends (resource cost increases and volatility, leading to incentives towards solutions for cost reduction and stability)	Large capital requirements, significant transaction costs, high initial costs, asymmetric information, uncertain return, and profit.	Rizos et al. (2016), Prieto-Sandoval et al. (2018), Govindan and Hasanagic (2018), de Jesus and Mendonça (2018), Kirchherr et al. (2017), Tura et al. (2019), Cainelli et al. (2020), Upadhyay, Laing, et al. (2021).
Softer factors	Institutional/regulatory	Associated with increasing environmental legislation, environmental standards and waste management directives	Misaligned incentives, lacking a conducive legal system, deficient institutional framework	Rizos et al. (2016), Prieto-Sandoval et al. (2018), Govindan and Hasanagic (2018), de Jesus and Mendonça (2018), Kirchherr et al. (2017), Tura et al. (2019), Cainelli et al. (2020), Upadhyay, Laing, et al. (2021).
	Social/cultural	Connected to social awareness, environmental literacy and shifting consumer preferences (e.g., from ownership of assets to service models)	Rigidity of consumer behavior and businesses routines	Rizos et al. (2016), Prieto-Sandoval et al. (2018), Govindan and Hasanagic (2018), de Jesus and Mendonça (2018), Kirchherr et al. (2017), Tura et al. (2019), Upadhyay, Laing, et al. (2021).

private keys for each user enables secure and pseudo-anonymous validation of transactions (Preikschat et al., 2020). Moreover, a one-way cryptographic hash function and timestamp ensure the unique identification of a block (Zheng et al., 2017).

Scholars argue that blockchain can significantly impact socio-technical systems on various levels and domains (Crosby et al., 2016; Iansiti & Lakhani, 2017). While Bitcoin and its underlying blockchain technology have already transformed significant aspects of the financial market (see, e.g., Teigland et al., 2018), it also has the potential to influence the prevailing global economic, legal, and political structures (Preikschat et al., 2020). Besides providing a trusted system of records for transactions, blockchain facilitates decentralized applications through smart contracts (Crosby et al., 2016; Yli-Huumo et al., 2016). Smart contracts automatically evaluate pre-defined requirements and self-execute determined terms of agreements, which substitutes the need to verify transactions through a trusted third party (Crosby et al., 2016). Since the technology is still relatively nascent, empirical research on its implications for societal, political, and economic structures is scarce (Beck et al., 2017; Hughes et al., 2019). For a more comprehensive overview of blockchain technology, we refer to Crosby et al. (2016) and Zheng et al. (2017).

2.4 | Blockchain innovation for a transition to a CE

While blockchain innovation has been lauded as an enabler of the CE through its application within the three principle areas of reuse, reduce, and recycle (e.g., Upadhyay, Mukhuty, et al., 2021), extant research is primarily conceptual. Upadhyay, Laing, et al. (2021) conducted a literature review of the role of blockchain for the CE and noted on a more general level that the technology can reduce transaction costs and carbon footprints and improve performance and communication. Possible blockchain applications for the CE fall primarily under five categories: supply chain transparency (e.g., Agrawal et al., 2021; Narayan & Tidström, 2020; Saberi et al., 2019; Shojaei et al., 2021; Venkatesh et al., 2020; Vogel et al., 2019), waste management (Khadke et al., 2021; Kouhizadeh, Zhu, & Sarkis, 2019), sharing economy (e.g., Kouhizadeh, Sarkis, & Zhu, 2019), renewable energy (Andoni et al., 2019; Wu & Tran, 2018; Yildizbasi, 2021), and incentivization of sustainable behavior (Herweijer et al., 2018; Khadke et al., 2021; Saberi et al., 2019).

Vogel et al. (2019) highlighted several blockchain characteristics enabling these application areas: secure data records, public data transmission, immutability, and decentralization. Immutability and tamper-proof data records on a blockchain can significantly increase the tracking and transparency of supply chains and raise customer awareness of a product's manufacturing process (Saberi et al., 2019; Vogel et al., 2019). Blockchain-based supply chains can provide accurate real-time information on material and product flows, and waste management applications can enable efficient recycling and reutilization of resources. The benefits of these areas of blockchain applications are transparency and traceability of product components and materials (Kouhizadeh, Sarkis, & Zhu, 2019). Reverse logistics is required for the repair, remanufacturing, and recycling of products and can benefit from an extension of supply chain transparency based on blockchain beyond the point of consumption (Bekrar et al., 2021). Additionally, blockchain supports sharing economy platforms, eliminating the need for a trusted third party and reducing the need to rely on intermediaries to ensure information trustworthiness, such as user ratings (Kouhizadeh, Sarkis, & Zhu, 2019).

As for renewable energy, blockchain can facilitate energy source verification systems (Herweijer et al., 2018), and disintermediation and smart contracts can enable peer-to-peer energy trading between individual (solar) energy producers and consumers (Andoni et al., 2019; Eikmanns, 2018; Herweijer et al., 2018). However, existing legal frameworks in some countries prohibit specific applications, such as peer-to-peer energy trading (Andoni et al., 2019). Blockchain can improve investment in renewable energies and carbon market platforms by mitigating current market inefficiencies, such as double counting or information asymmetries (Herweijer et al., 2018; Wu & Tran, 2018). Lastly, blockchain can attribute value to things (e.g., plastic waste) that are currently wasted but that could be of economic value (Herweijer et al., 2018), thereby incentivizing responsible behavior among individuals and organizations (Eikmanns, 2018; Khadke et al., 2021; Le Sève et al., 2018).

Table 2 categorizes the blockchain literature across the three CE principles. In summary, we find that the extant literature tends to focus on potential blockchain applications on a conceptual level, primarily using secondary data rather than analyzing primary empirical data collected from operational blockchain CE innovations (e.g., Eikmanns, 2018; Saberi et al., 2018; Upadhyay, Mukhuty, et al., 2021).

2.5 | Technical challenges to blockchain

While blockchain holds potential for a transition to a CE, our literature review revealed that the technology is rife with more general technical challenges, regardless of whether it is used for the transition to a CE or for some other area. The high energy consumption of many blockchain applications poses a significant challenge (Faber & Jonker, 2019; Herweijer et al., 2018; Kouhizadeh, Sarkis, & Zhu, 2019; Le Sève et al., 2018; Yli-Huumo et al., 2016). Bitcoin network's annual emissions in 2018 were argued to be comparable to those of Sri Lanka or Jordan (Stoll et al., 2019), thus mainstream adoption of traditional proof-of-work-based blockchain applications might have negative environmental consequences (Herweijer et al., 2018). Security is also an issue, and several significant manipulation and fraud cases have occurred, e.g., DAO hack (Hofmann et al., 2018). These cases are not directly associated with blockchain technology but with flaws in additional software layers of decentralized applications (Preikschat et al., 2020). Other technical challenges are high development costs, limited scalability, the complex usability of decentralized applications, the often required stable and fast internet access, and limited digital literacy (Andoni et al., 2019; Herweijer et al., 2018;

TABLE 2 Blockchain applications supporting circular economy's three principles

Application	Examples and References	CE principle
Supply chain transparency and traceability	Improved transparency through tamper-proof, distributed data records can impact consumer behavior and drive more firms to responsible production (e.g., less hazardous chemicals; less emissions) (Kouhizadeh, Zhu, & Sarkis, 2019; Saberi et al., 2019; Vogel et al., 2019) Ability to track complex supply chains/products' lifecycle and their sustainability (Agrawal et al., 2021; Herweijer et al., 2018; Narayan & Tidström, 2020) Reutilizing and reusing products requires complete product and material information (Kouhizadeh, Sarkis, & Zhu, 2019; Shojaei et al., 2021; Wang et al., 2020)	Reuse Recycle
Waste management	Smart contracts to improve recycling efficiency (Herweijer et al., 2018) Waste exchange platforms (Khadke et al., 2021; Kouhizadeh, Sarkis, & Zhu, 2019) Reverse logistics (Bekrar et al., 2021; Kouhizadeh, Sarkis, & Zhu, 2019)	Reuse Recycle
Sharing economy	Sharing platform provision (no third party, trustworthy information) (Kouhizadeh, Sarkis, & Zhu, 2019)	Reduce Reuse
Renewable energy	Peer-to-peer energy trading (Andoni et al., 2019; Wu & Tran, 2018; Yildizbasi, 2021)	Reduce Reuse Recycle
Incentivization of sustainable behavior (examples)	Incentivizing individuals to recycle through token rewards (Khadke et al., 2021; Saberi et al., 2019) Plastic cleanup incentive mechanisms (Herweijer et al., 2018)	Reduce Reuse Recycle

Note: CE principles cannot be completely differentiated from each other as interdependencies exist. Hence, the applications might also have an influence on other CE principles.

Le Sève et al., 2018; Preikschat et al., 2020; Yli-Huumo et al., 2016). In addition, the so-called oracle problem constitutes a technical challenge that has been increasingly recognized in the literature (Caldarelli, 2020). Oracles are the means of communication between blockchain and the physical world, and unlike blockchain nodes, they are centralized and must be trusted (Caldarelli, 2020). A final technical challenge is the lack of standards and a high level of technological heterogeneity among terminology standards (Ingram et al., 2016).

2.6 | Research question

In summary, our literature review revealed that scholars have yet to develop a theoretical model of the role that blockchain plays in the transition to a CE as this phenomenon is still nascent and research has been primarily conceptual with few empirical studies. To truly understand the potential of this emerging technology, it is imperative that we investigate the relationships among CE drivers and barriers, blockchain CE innovation, technical challenges to blockchain, and the CE. Thus, we have developed the following overarching research question to guide our investigation:

RQ: What role does blockchain play in the transition to a CE?

3 | METHODOLOGY

To address our research question, we followed an abductive approach. This approach is appropriate when the phenomenon has a high degree of novelty and the aim is to investigate the underlying variables and their relationships (Coffey & Atkinson, 1996; Dubois & Gadde, 2002). An abductive approach allows for theory refinement rather than new theory generation or theory testing (Dubois & Gadde, 2002; Reichertz, 2004). The approach comprises identifying a particular phenomenon and then relating this to broader concepts through systematic combining, moving back and forth between the literature and the empirical data (Coffey & Atkinson, 1996; Dubois & Gadde, 2002). This approach allowed us to investigate blockchain's role in the transition to a CE from a broader sustainability transition perspective and to thereby derive a theoretical model of the relationships among the relevant concepts (Dubois & Gadde, 2002). Figure 1 details our research approach.

3.1 | Data collection

In line with the abductive approach, we applied theoretical sampling to select experts in the relevant subject domain (Coyne, 1997). In contrast to purposeful sampling, where a fixed sample is selected a priori (Conlon et al., 2020), theoretical sampling is a "method of data collection based on concepts derived from data" (Corbin & Strauss, 2008, p. 134) and is "more of a continuous process than a separate stage in the study, resulting in a preset sample on which data collection is based" (Dubois & Gadde, 2002, p. 559).

In our first round of data collection, we conducted extensive desk research and expert consultation on blockchain CE innovations to identify organizations across the globe active in this area. We then

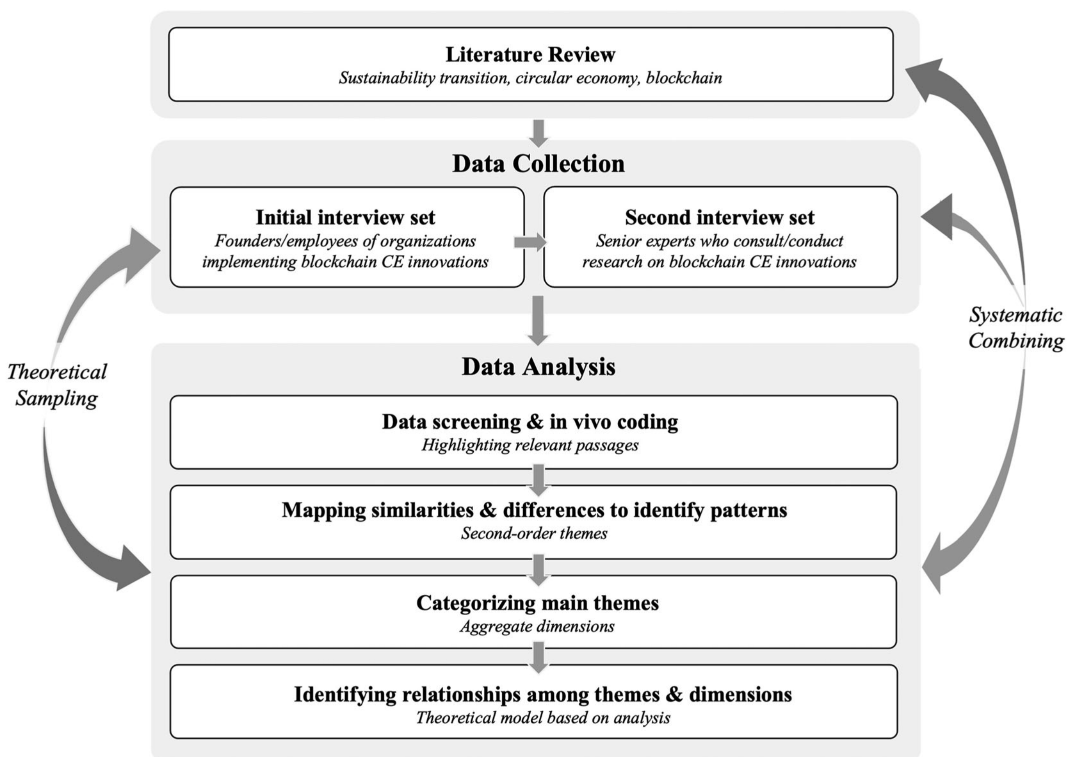

FIGURE 1 Our abductive research approach

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selected 13 interviewees based on two criteria. First, the experts had to be founders or senior employees of organizations that were currently involved in blockchain innovation that enabled or supported the CE in its main principles of reduce, reuse, and recycle. We also included organizations working with the clean energy principle. Second, the experts had to be actively involved in implementing blockchain CE innovation on the ground. The initial experts were from organizations developing blockchain innovations for waste-related applications, supply chain solutions, and renewable energy applications. While some organizations were well-established, the majority were in an early operational stage. The organizations were located in Germany, Greece, Netherlands, Norway, Sweden, the United Kingdom, and the United States.

The analysis of our first set of interviews through open coding and theory-data matching revealed that these interviewees focused primarily on their own organization's perspective and generally avoided critically expressing problems or challenges they were facing. To address this potential interviewee bias and take a more holistic approach, we extended our initial sample to include additional experts from the blockchain CE innovation domain. We again conducted extensive desk research and expert consultation and selected five further experts based on our identified categories and concepts (Corbin & Strauss, 2008; Urquhart et al., 2010). However, we modified the two criteria above and excluded founders and employees who were working with blockchain innovation as part of their own organization's business. Thus, while this second set of experts did not work for organizations implementing their own blockchain solutions, the interviewees were actively working on one or more ground-level blockchain CE innovations at other organizations. This set included individuals who were consultants for organizations implementing blockchain CE innovation, researchers affiliated with blockchain research institutes, and an associate working for a blockchain development agency. They came from Austria, Germany, and the United States. The perspectives and experiences of the second set of interviewees were, therefore, more diverse, more objective and provided an excellent counterbalance to the initial interviewees.

TABLE 3 Overview of interviewees

First set of interviews

No.	Length	Position	CE area	Organization type	CE activity	CE principle/implementation
1	44 min	Founder, CEO	Waste	Private	Incentivization of plastic cleanups	Recycle/pilot projects
2	1 h 4 min	Consultant	Waste	Private	Incentivization of plastic cleanups	Recycle/operating
3	48 min	Project manager	Waste	NGO	Open platform for plastic CE	Recycle/pilot projects
4	57 min	Founder, CTO	Waste	Private	Deposit scheme, incentivization	Recycle/testing
5	55 min	Co-founder, CEO	Supply chain	Private	Digital twin for products/materials	Recycle/pilot projects
6	43 min	Co-founder	Supply chain	Private	Fashion supply chain traceability	Recycle/operating
7	41 min	Co-founder	Supply chain	Private	Supply chain platform	Recycle/pilot projects
8	57 min	Co-founder	Supply chain	Private	Fashion supply chain traceability	Recycle/pilot projects
9	32 min	Co-founder, CEO	Supply chain	Private	Second-hand market for fashion items	Reuse/pilot projects
10	1 h 6 min	Founder, CEO	Energy	Private	Operating system renewables	Renewable energy/pilot projects
11	49 min	Co-founder, CEO	Energy	Private	Carbon offset platform	Carbon offsets/demo version
12	1 h 18 min	Founder	Energy	Private	Solar energy incentivization	Renewable energy/operating
13	56 min	Co-founder, director	Energy	Private	Tracking system for renewable energy	Renewable energy/operating

Second set of interviews

No.	Length	Position	Area	Organization type
14	1 h 3 min	Research employee	Consulting/research	Registered association
15	49 min	Project lead	Consulting	Private
16	47 min	Professor	Research	Academic institute
17	50 min	Research employee	Research	Non-profit
18	58 min	Project associate	Development agency	Private

In total, we conducted 18 semi-structured interviews with an average duration of 53 minutes (Table 3) during a 3-month period. Interviewees were contacted via email or LinkedIn, and interviews were conducted via Skype. Audio records and transcripts were carefully maintained and stored. We discussed amongst ourselves the concepts and relationships emerging from our ongoing analysis of the interview data throughout the interview process, leading to a constant back and forth between data collection and our thematic analysis (Dubois & Gadde, 2002). We reached theoretical saturation after 18 interviews when we could no longer derive any additional or different conceptual patterns from the interview data, and the identified concepts and key themes continuously re-emerged (Charmaz, 2006).

3.2 | Data analysis

An abductive approach requires literature immersion before delving into the data analysis (Timmermans & Tavory, 2012). Hence, we drew on the literature on the CE and in particular drivers and barriers to the transition in Table 1, blockchain innovations supporting the CE in Table 2, and the technical challenges to blockchain to compare, match, and extend our data. We used the qualitative analysis software MAXQDA to code the data. The coding process followed the approach of Gioia et al. (2013), which particularly emphasizes the importance of qualitative rigor. We first screened transcripts and highlighted relevant passages. After that, we applied in vivo coding to the transcripts. This resulted in numerous codes, which we then consolidated by mapping the similarities and differences. We continuously moved from our empirical material, even collecting more data during the second set of interviews, to theory and then back again. In this manner, we could identify patterns and thematic focus areas and compare them to existing theory and findings from our literature review. This "double fitting" (Timmermans & Tavory, 2012) of data and theory led to the final formulation of our second-order themes. We further categorized these themes and mapped them onto aggregate dimensions from our analytical framework, thereby revealing relationships among our core concepts. Figure 2 shows the second-order themes and the aggregate dimensions.

To secure the trustworthiness of our data and the credibility of our findings, we continuously reflected on our abductive approach

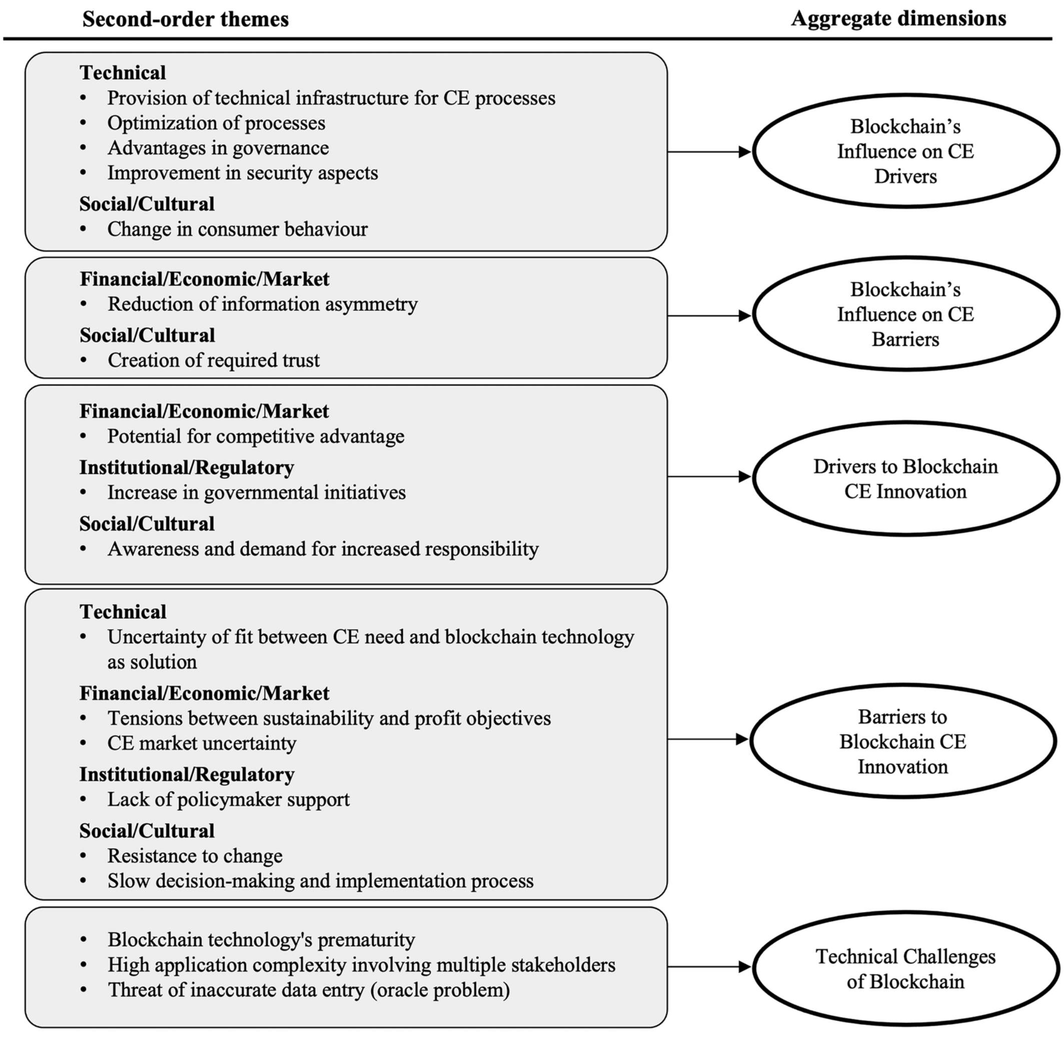

FIGURE 2 Second-order themes and aggregate dimensions

and followed advice by qualitative researchers, e.g., Dubois and Gadde (2002), Elo et al. (2014), and Gioia et al. (2013). Theoretical sampling enabled us to acknowledge biases in our initial sampling and to conduct further data collection until we reached theoretical saturation. We encouraged interviewees to speak freely and informed them that their responses and any derived findings would be anonymized. Multiple co-authors participated in the open coding process, and we openly discussed emerging themes while challenging assumptions and initial findings and reflecting on any personal biases. While we used rich, thick verbatim interview extracts in our analysis, we repeatedly revisited the semi-structured audio recorded interviews to ensure that the final themes stayed true to the interviewees' original accounts. Finally, we continuously moved from our empirical material to theory and then back again while scrutinizing the trustworthiness of every phase of our data collection and analysis process. In this manner, we strived for triangulation to ensure the convergence of our findings and to reduce the risk of bias and increase the confirmability of our results (Connelly, 2016).

4 | FINDINGS

Our analysis suggested a set of relationships among our core concepts, which we used as the basis for our theoretical model. Below, we present first a simplified model highlighting the primary relationships among our core concepts (Figure 3) and then at the end of this section a more granular model summarizing second-order themes and aggregate dimensions (Figure 4).

Our findings suggest that blockchain CE innovation has a moderating effect on the relationship between CE drivers and barriers and

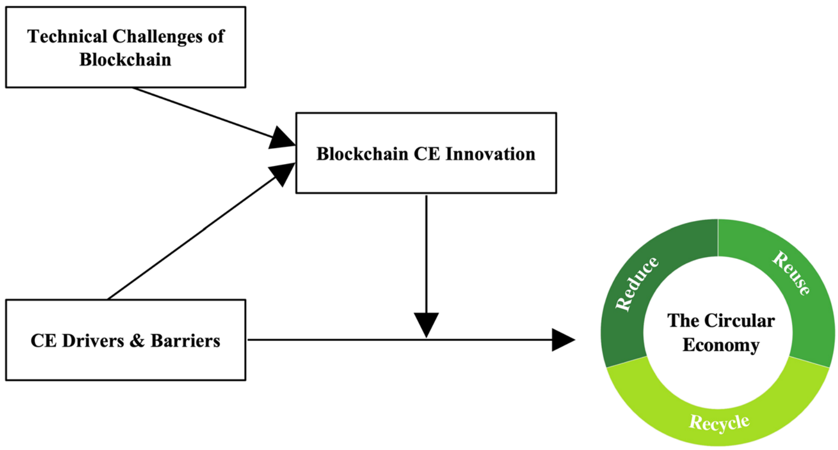

FIGURE 3 Simplified model of blockchain's role in CE transition [Colour figure can be viewed at wileyonlinelibrary.com]

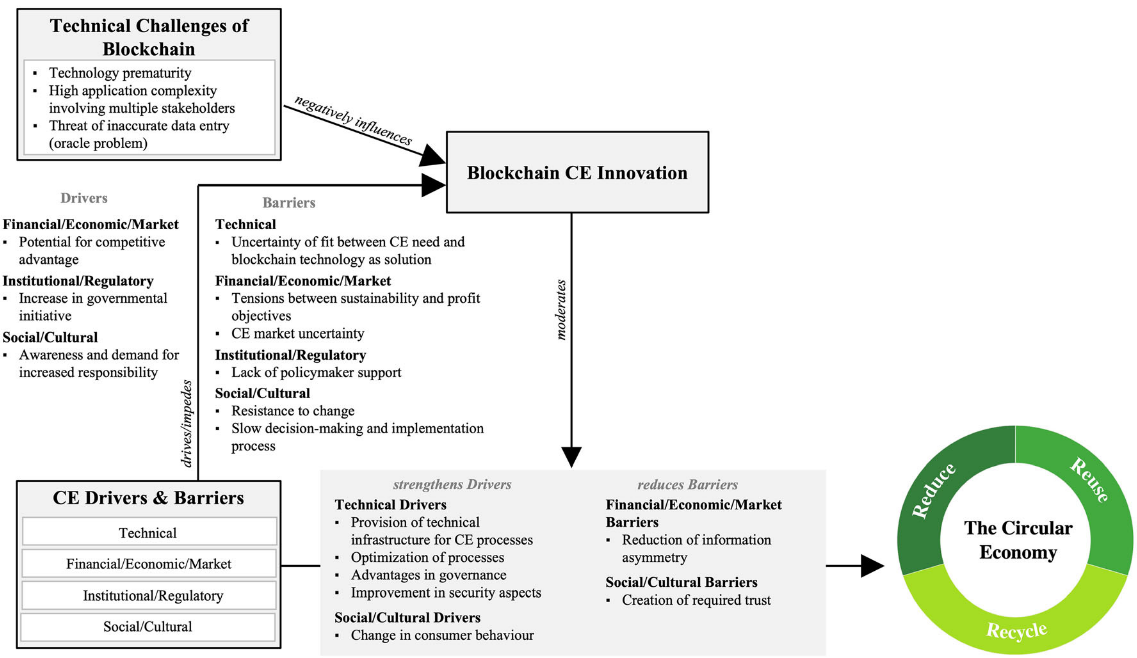

FIGURE 4 Granular model of blockchain's role in CE transition [Colour figure can be viewed at wileyonlinelibrary.com]

the CE. In other words, blockchain CE innovation can both reinforce CE drivers and reduce CE barriers. Furthermore, some CE drivers and barriers can also have a direct effect on blockchain CE innovation. However, technical challenges to blockchain can also indirectly influence a transition to the CE through their direct negative impact on blockchain CE innovation. Below, we discuss our results in more detail.

4.1 | Blockchain CE innovation acts as a moderator

4.1.1 | Blockchain CE innovation strengthens CE drivers

Our analysis suggests that blockchain CE innovation significantly strengthens CE *technical drivers* through the following aspects. First, blockchain is viewed as a tool that *provides a technical infrastructure for CE processes*. Interviewees mentioned that blockchain offers a platform for the CE ecosystem as it facilitates physical and non-physical transactions. This aspect demonstrates that the technology itself does not take a direct role in the CE transition, but instead has a supporting role, as stated by an interviewee:

> The technology is one that enables you to build infrastructures so that you can, for example, ship containers without having to fly freight papers around (…), or so that you can trace supply chains without the need for some form of surveilling authority that you do not want. But it is ultimately an infrastructure that enables me to do other things.

Second, blockchain CE innovation *optimizes CE processes*. Experts mentioned smart contracts that can automate decentralized processes, cost-sharing, and payment processes among platform participants (e.g., tokenization). In addition, the technology's open-source character facilitates the interaction of different stakeholders. Third, the *governance structure* of blockchain enables transactions that do not require a trusted intermediary for monitoring and authorization. This contrasts with existing supply chain initiatives aiming to advance the CE that often do not scale because their centralized technological solutions hinder information sharing. Also, stakeholders can embed the rules of engagement in smart contracts to avoid conflicts and enable extensive cooperation.

Fourth, blockchain provides *improvement in security* aspects as it is a complete record of data transactions on a distributed ledger, thereby enabling fraud detection and improving transaction traceability. Several interviewees mentioned the immutability paradigm of blockchain and highlighted that data entries cannot be modified after they are recorded on a blockchain, as one interviewee noted here:

> It was important not to do the whole thing with a simple SQL, where in the end any kind of data can be manipulated afterward, but to use the blockchain so that the data is collected directly from the value chain and cannot be manipulated afterward.

The ability to uniquely identify transactions avoids problems such as double-spending or copying, which can also play a crucial role in the traceability and accountability of transactions.

In addition, our results suggest that blockchain CE innovation positively influences CE *social/cultural drivers*. Several interviewees argued that blockchain CE innovation *changes consumer behavior* by incentivizing sustainability activities, such as the proper recycling of waste. While similar mechanisms already exist (e.g., Germany's deposit bottle scheme), the digitization of these through the blockchain was argued to enable "individual value creation" and "dynamic economic rewards" on a global basis.

4.1.2 | Blockchain CE innovation reduces CE barriers

Interviewees noted the lack of information availability as a primary CE barrier. As blockchain CE innovation improves information provision and transparency, it *reduces current information asymmetries*. Producers can document information from each part of the supply chain process on a blockchain. Moreover, producers can provide information on specific materials and products, which is a condition for recyclability. Further, consumers can consider transparent information for materials and production processes stored on the blockchain in their buying decisions. Solutions also aim to enable brands to benchmark their supply chain's status. In addition to information provision, interviewees highlighted the value of improved transparency through blockchain CE innovation as this interviewee noted:

> And at the moment, I believe that for the circular economy, transparency is key. Because everybody needs to know and trust what's happening.

Blockchain CE innovation can also reduce CE *social/cultural barriers* through *creating trust*. One interviewee noted, "When we are talking about sustainability efforts, especially ones that are driven by cultural change, the trust and credibility is the most important part." Blockchain's immutability paradigm and decentralized nature enable trust between contracting parties. Interviewees stated that blockchain CE innovation extends trust from within a small group of stakeholders to many. Others mentioned that it replaces the necessity to trust each other. Either way, the experts were of the opinion that an essential aspect of blockchain's potential is its ability to create trust that is required for CE, as supported by this interviewee:

> I think the important part about blockchain is not actually the technology; it's about the trust that it facilitates between humans. And the technology is just the way that it does that. I mean, that has always been the way that I've thought about it.

4.2 | CE drivers and barriers influence blockchain CE innovation

Our analysis also suggests that CE drivers and barriers can either directly foster or impede blockchain CE innovation. In terms of CE drivers, we found that the *financial/economic/market driver* fosters blockchain CE innovation. Our analysis shows that using blockchain for marketing purposes, such as the potential benefit from a "positive image effect," drives blockchain CE innovation. This driver can be summarized by a company's aim to *gain a competitive advantage*, resulting in higher revenues and profits. Particularly in commodity markets, it is difficult to prove sustainable material sourcing. Small, sustainable firms can differentiate themselves using blockchain solutions for market signaling.

Further, the CE *institutional/regulatory driver* (e.g., environmental legislation) can play a significant role in driving blockchain CE innovation through various *governmental initiatives*. Public CE funding supports the development of blockchain applications, and increasing environmental regulations assert pressure on firms. Our analysis suggests that one motive for organizations is to be ahead of the market regarding environmental conditions or regulations. One interviewee stated, "A lot of brands that are […] approaching us right now are just trying to be prepared for an impending regulation that may come up anytime." Our analysis suggests that in particular the EU's activities have been deemed productive for the CE as one interviewee noted, "The EU has done a good job in opening its innovation arms."

Finally, CE *social/cultural drivers*, such as a *general increase in CE awareness and demand for increased responsibility*, can drive blockchain CE innovation. Interviewees showed different perceptions, however, ranging from the positive opinion that it is "very obvious kind of, yeah, it's growing very fast […]" to a more pessimistic judgment that "the only thing that has been achieved in the last ten years is actually an awareness of the problems." Moreover, interviewees described end consumers as a driving force of blockchain CE innovation. An example is individuals donating money for plastic collection initiatives who then demand transparency about how their financial support is used.

We also found that all four CE barriers can directly influence blockchain CE innovation. *Technical barriers* were less related to specific difficulties but rather more to a general *uncertainty as to whether blockchain truly fits circular economy needs*. Interviewees were concerned that the technology alone is not sufficient despite its inherent potential. One interviewee noted, "It's just the technology. A lot of people, they see it as the solution for everything. That's definitely not it." The interviewee further explained that providing information about products or materials will not have any impact if the product itself cannot be dismantled. This is in line with the interviewees' tenor about the necessity for organizations and individuals to actively shape the potential of CE principles and the use of blockchain to fulfill them. A considerable number of interviewees specifically questioned the fit of blockchain solutions for CE implementations and raised concerns that other technological solutions might be more applicable, e.g., traditional databases. For example, one interviewee noted, "If blockchain did not exist, could we do this? Yes, we could," while another interviewee stated, "It just makes it easier. I hate to say that (…) we can do it with other technologies." A few interviewees also argued that several blockchain CE innovation projects do not have coherent arguments about why they have chosen this technological approach. However, some interviewees stated that they regarded blockchain as superior to other technologies or approaches.

Our study also finds that *tensions between sustainability and profit objectives* is a *market barrier* that hinders blockchain CE innovation and constitute a systemic gap between actors that want to drive sustainable development and others that predominantly aim to generate profits. This originates from competitive behavior and a lack of cooperation among CE market actors. Some interviewees also argued that the uncertainty of revenues and suitable business models complicate adopting blockchain CE innovation. Several challenges intensify this dilemma. For instance, there is considerable complexity in defining value propositions for every involved organizational actor, as one interviewee noted, "That is, of course, a social problem, for the time being, you have to see quite clearly that the individual company does not necessarily benefit from it yet."

The ambiguity between advancing sustainable development while simultaneously seeking profits is related to another *market barrier*, *CE market uncertainty*. Early-stage markets are characterized by uncertainty concerning future developments, as noted by one interviewee, "There is also this problem where if you have a lot of different approaches for the same problem, in the end, there is no clear way to move forward." Several interviewees noted intense competition between CE initiatives and, as a result, very little collaboration.

When it comes to *institutional/regulatory barriers*, our analysis shows that a ***lack** of policymaker support* creates challenges for organizations implementing blockchain CE innovation. A lack of funding and relevant regulations reduces the potential progress of the innovation. Multiple interviewees agreed that governments are not doing enough to foster the application of blockchain to the CE principles. One interviewee stated, "Because the responsibility for the circular economy lies first and foremost with society, politics would have to push much harder to accelerate such solutions." Interviewees discussed the lack of policymaker commitment to innovation and the need for more CE-related regulation, such as an increased obligation for firms to ensure product recyclability or improved transparency of electronic consumer good composition. Additionally, blockchain innovations in the energy sector seem hindered by existing regulations (e.g., peer-to-peer trading).

As for the *social/cultural barrier*, our findings suggest that firms' *resistance to change* and *slow decision-making and implementation processes* hinder blockchain CE innovation. Interviewees commented that companies often lack motivation to undertake the necessary investments. Developing blockchain CE innovation requires the willingness to establish it as part of business processes and a profound desire to contribute to sustainable development, including the motivation to provide financial and human resources to implement relevant applications. However, a prevailing finding in our study was that organizations were not ready to change their culture or existing operations, such as shifting their business model or decentralizing their organization. One interviewee described this in the following way:

> It's just that the decision-making on implementing is slower than expected, like way slower. So, for the plastics companies, for instance, we have been working on a contract now for half a year. And it's not that they do not want it. It's just that every time there's this new question.

4.3 | Technical challenges to blockchain negatively influence blockchain CE innovation

Our analysis also revealed three primary technical challenges to blockchain: premature blockchain solutions, highly complex applications involving multiple actors, and threat of inaccurate data entry known as the oracle problem. These three challenges negatively influenced blockchain CE innovation and therefore indirectly weakened blockchain's moderating role in the transition to a CE.

The consensus among interviewees was that *blockchain technology is premature*, and most solutions are still in a very basic research and early development phase. The majority of interviewees agreed, however, that the technology would become better in the future. Many of the technical problems, such as scalability or privacy concerns, are related to public blockchains, and some interviewees noted these could be overcome by deploying private blockchains at the expense of, for example, anonymity. Another issue relates to a lack of consensus as to which blockchain solutions should be developed. For example, opinions differed on the token economy and whether a blockchain solution is really necessary. Whereas one interviewee noted how some initiatives “create this artificial demand for the token that does not actually have any real demand,” another portrayed a token economy as essential.

Additionally, interviewees repeatedly mentioned the problem of high energy consumption. However, they did not consider it as a significant challenge because it would be solved in the future, e.g., through other consensus mechanisms. For example, one interviewee stated, “I mean the energy example, I'm a bit tired of it because this killing argument is always used.”

Second, blockchain solutions tend to be *highly complex applications involving multiple actors*. The transparency of blockchain solutions comes at the cost of collecting and sharing data among organizations and even the public. Our analysis indicates that the protection of confidential information and the reluctance to share data with others represents a significant challenge, especially when implementing blockchain solutions for supply chains. Many firms require maintaining confidentiality to protect their competitive advantage. One interviewee stated, “Simple data collection for brands and simple data sharing for suppliers, but without compromising the business confidentiality, that would be the key value proposition.”

Furthermore, the complexity of blockchain challenges organizations with data fatigue and limited technical capacities, as another interviewee stated, “Decentralized applications require an incredible amount of technical savviness.” However, interviewees partially disagreed on the notion of complexity of decentralized applications, and some interviewees argued that usability is no different from other technological solutions.

Third, a significant technical challenge is the *threat of inaccurate data entry*, which refers to the oracle problem. As blockchain solutions are not solely digital but connected to the physical world, a reliant gateway between relevant physical assets and the digital system is required. For example, a blockchain supply chain application requires information about the provenance of products. Hence, data from the physical world (e.g., from a human or sensor) are necessary. One interviewee exemplified this in the following statement:

> And that physical to digital relationship is a problem that goes beyond just supply chain; like that's one of the fundamental problems with pretty much everything blockchain-related is that it's a piece of solely digital technology that is desperately trying to interact with the real world.

This issue deals with the difficulty of ensuring that no malicious or incorrect data from the physical world are submitted to the blockchain. Blockchain innovations seek to minimize this risk using sensors for data input or scans of existing certificates (e.g., about materials). However, as mentioned by one interviewee, “Whether the certificate itself (…) is authentic or not is done by the certifying body,” and it cannot be verified by the blockchain application. Therefore, the interviewees agreed that current blockchain technology is not entirely secure from fraud or human error. Developing a blockchain innovation that overcomes the physical-digital relationship hurdle was regarded as a major challenge to the development of blockchain for the CE.

Below is our granular model we developed based on our analysis in which we have included all concepts, aggregate dimensions, and second-order themes.

5 | DISCUSSION

The implications of our findings are threefold. We contribute (1) to the sustainability transition and CE literature through deriving a theoretical model of blockchain's moderating role in the transition to a CE, (2) to the blockchain literature through an empirical investigation of blockchain innovation for the CE based on primary data across several organizations and countries, and (3) to practitioners and policymakers through implications for blockchain's role in the transition to a CE.

5.1 | Theoretical model of blockchain's role in the transition to a CE

Our study contributes to the sustainability transition and CE literature through a theoretical model relating CE drivers and barriers, blockchain CE innovation, technical challenges to blockchain, and the CE. To the best of our knowledge, this study is the first to derive a theoretical model of blockchain's role in the transition to a CE based on a thematic analysis of empirical data. Our findings suggest that blockchain CE innovation *indirectly* supports the transition to a CE by playing a moderating role instead of a direct role. Our more granular findings suggest that blockchain CE innovation strengthens technical and social/cultural drivers while mitigating financial/economic/market and social/cultural barriers.

CE drivers and barriers were also found to directly influence blockchain CE innovation in both a negative and positive manner. For example, our study further accentuates the need to mitigate financial/economic/market barriers, such as tensions between profit and sustainability objectives (Kouhizadeh, Zhu, & Sarkis, 2019) and insufficient market demand (Cainelli et al., 2020), in order to encourage further blockchain CE innovation. In terms of social/cultural barriers, our study supports the work by Kouhizadeh, Sarkis, and Zhu (2019) in the case of blockchain CE innovation in particular and by Kirchherr et al. (2018) for the CE in general as we find that companies' resistance to change and slow decision-making and implementation processes impede blockchain CE innovation.

Furthermore, we find that more general technical challenges to blockchain *indirectly* impact the transition to a CE as they can decelerate blockchain CE innovation. This supports previous eco-innovation and CE literature, which emphasizes technology-related obstacles (de Jesus & Mendonça, 2018) and technical difficulties, such as the energy issue (Herweijer et al., 2018; Kouhizadeh, Zhu, & Sarkis, 2019; Le Sève et al., 2018).

5.2 | Blockchain within the CE context

We also contribute to the blockchain literature by providing an empirical investigation of blockchain's role in the transition to a CE. As this phenomenon has a very high level of novelty, the majority of the literature to date is conceptual and primarily based on secondary data. Our study provides a deeper understanding of the role that this digital innovation has in developing an infrastructure for the CE. This is in line with the work by several scholars who proposed that blockchain might help to develop an infrastructure for the CE ecosystem, e.g., de Jesus et al. (2018); Kouhizadeh, Sarkis, and Zhu (2019), Limata (2019), and Prieto-Sandoval et al. (2018). However, our findings also echo other scholars' views that the technology alone cannot be a panacea for shifting to a closed-loop economy (de Jesus et al., 2018). Instead, a robust multidimensional approach from several stakeholders (e.g., organizational change) is necessary, and the technology only holds a supporting, moderating role.

While our findings indicate that blockchain CE innovation strengthens technical drivers, there is considerable uncertainty about the exact fit between the technological requirements for CE applications and blockchain. We suggest two reasons. On the one hand, there is a general concern that the technology alone is insufficient to enable the CE, which can be related to the finding that blockchain CE innovation has an indirect moderating influence. On the other hand, the interviewees' perception that blockchain is not always inherently superior to different technological approaches contributes to general uncertainty and, sometimes, even skepticism about the potential of blockchain CE innovation (Chowdhury et al., 2018).

While interviewees discussed several general technical challenges of blockchain, they were of the opinion that these will fade as blockchain matures in the future, which follows Yli-Huumo et al.'s (2016) insights. However, one significant challenge was the oracle problem that has previously been discussed in the blockchain literature but not specifically in the case of blockchain CE innovation (Caldarelli, 2020). As no perfect solution for this challenge will likely be developed within the near future, the risk of incomplete and inaccurate data entries on the blockchain can impede blockchain CE innovation since most blockchain CE innovations require a link to the physical world.

5.3 | Implications for practitioners and policymakers

We derive four recommendations for practitioners and policymakers. First, blockchain CE innovation is a multi-actor driven endeavor, and the resulting complex ecosystems and diverse stakeholders complicate innovation development. Therefore, we recommend establishing interdisciplinary teams (e.g., behavioral economists, sustainability experts, and policymakers) and collaboration among different actors in a pilot project or industry consortium in order to create a common understanding of the technology's potential and challenges. Second, a fundamental pillar is education about blockchain and the CE to avoid skepticism and increase knowledge of the technology's potential among organizations and policymakers. Also, education about blockchain is crucial to improve decision making regarding the fit of blockchain for the specific CE use case so that organizations do not expend unnecessary resources and time falling for the "sheer hype of blockchain." Third, to address the oracle problem, increasing automation of processes and the technological convergence with Internet-of-Things technologies (e.g., sensors and RFID chips) can reduce the risk of inaccurate data entry while additional external data sources (e.g., GPS) can be harnessed to triangulate data entries.

Lastly, our findings also stress the importance of appropriate policies to enable the CE. Our study supports previous literature that has identified regulations on data protection and the energy sector as barriers to blockchain innovation (Andoni et al., 2019; Herweijer et al., 2018). While scholars tend to emphasize the crucial role of policy to drive the CE (de Jesus & Mendonça, 2018; Ghisellini et al., 2016; Kalmykova et al., 2018; Upadhyay, Mukhuty, et al., 2021), our study revealed that interviewees were of the opinion that policymakers are not doing enough to support the transition. Regulations may need to be revised to account for the decentralized nature of blockchain technology, which includes the definition of jurisdictional responsibilities (Andoni et al., 2019; Herweijer et al., 2018) or facilitation of data protection compliance (Andoni et al., 2019; Saberi et al., 2019). Therefore, for blockchain to achieve its potential in enabling the CE, policymakers should focus on regulations and standards governing smart contracts and blockchain adoptions (Upadhyay, Mukhuty, et al., 2021).

6 | LIMITATIONS AND CONCLUSIONS

This study is subject to the inherent limitations of qualitative research. First, our findings are based on specific blockchain CE innovations (primarily reuse and recycle), their development status (primarily pilot), the type of initiative (primarily bottom-up), and the interviewees' narratives that depend on their background and personal convictions. Hence, contextual findings might emerge. Second, the co-authors' personal experiences, knowledge, and moods could have influenced the expert interviews and the coding process. Third, even though the findings have been discussed along prior insights in the domain, the generalizability of these findings is limited, and further empirical analysis is required, especially beyond Europe and the United States.

In conclusion, this study contributes to the sustainable transition and CE literature along with the blockchain literature by developing a theoretical model of blockchain's role in the transition to a CE. To the best of our knowledge, this study is the first to empirically investigate the relationships among relevant CE and blockchain concepts and to derive a theoretical model based on a thematic analysis of empirical data. Our finding suggests that while blockchain plays a moderating role, it is not a universal solution to the CE. Our theoretical model provides a basis for future research as scholars could test hypotheses on the suggested relationships through methods such as surveys or experiments. Moreover, future research could investigate blockchain-enabled business models to help identify short- and long-term economic benefits and solve the trade-off between profitability and environmental sustainability. Also, potential policy recommendations supporting and regulating CE blockchain innovation demand further investigation.

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