DOCTORAL THESIS

Digitalisation for the Circular Economy: Blockchain, Service Design, and the Greening of Digital Processes

Vera Gerasimova

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VERA GERASIMOVA

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TALLINN UNIVERSITY OF TECHNOLOGY
School of Business and Governance
Department of Business Administration
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Supervisor: Prof. Gunnar Prause
School of Business and Governance
Tallinn University of Technology
Tallinn, Estonia

Co-supervisor: Prof. Wolfgang Gerstlberger
School of Business and Governance
Tallinn University of Technology
Tallinn, Estonia

Opponents: Prof.ssa Lucia Marchegiani
Department of Business Economics
Roma Tre University
Rome, Italy

Prof. Per Servais
School of Business and Economics
Department of Management
Linnaeus University
Växjö, Sweden

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Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology, has not been previously submitted for doctoral or equivalent academic degree.

Vera Gerasimova

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Digitaliseerimine ringmajanduse toetamiseks: plokiahel, teenusedisain ja digitaalsete protsesside keskkonnahoidlikumaks muutmine

VERA GERASIMOVA

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Contents

List of Publications

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Author's Contribution to the Publications

Contribution to the papers in this thesis are:

I The author independently developed the research idea, conducted the study, analysed the findings, and wrote the entire paper.

II Took the lead in literature review, data collection and analysis and paper writing.

III Took the lead in literature review, data collection and analysis and paper writing.

IV Took the lead in literature review, data collection and analysis and paper writing.

Introduction

Concepts of sustainability increasingly inform government policy and action plans, business models, and academia. Linear "take–make–dispose" production and consumption patterns have been identified as unsustainable because they rely on finite resources, generate excessive waste, and lead to pollution (Ellen MacArthur Foundation, 2019). The circular economy (CE), by contrast, aims to close the loop by slowing, narrowing, and closing cycles of resource use through longer product lifecycles and by maximising the utility and value of products before recovering materials and regenerating new ones (Kirchherr et al., 2017; Korhonen et al., 2018). However, the transition to CE at scale has proven highly complex and slow. It requires multiple interconnected interventions spanning technological development, market mechanisms, policy and regulation, and consumer behaviour. Therefore, an aligned multi-level socio-technical shift across production systems, supply-chain configurations, and consumption patterns is required to develop an effective CE model (Kalmykova et al., 2018; Millar et al., 2019). However, current evidence suggests that CE practices remain unevenly applied across industries and regions. In particular, incomplete data, limited traceability of resources, and fragmented or poorly interoperable systems constrain the scalability of CE practices. A lack of agreed standards and limited coordination between institutions also present barriers to mainstreaming CE practices (Geissdoerfer et al., 2017; Kristoffersen et al., 2020). In this dissertation, "multi-level" refers to interactions between individual actors and organisations at the micro level, value-chain ecosystems at the meso level, and institutional and regulatory systems at the macro level.

In parallel, the digital transformation of industries, often framed as Industry 4.0 or Industry X.0 (Accenture, 2017), has created new opportunities for integrating advanced technologies such as artificial intelligence (AI), the Internet of Things (IoT), and blockchain into sustainability agendas (Bellavista et al., 2021). Increasingly, scholars and policymakers emphasise the "twin transition," in which digitalisation and sustainability are pursued as mutually reinforcing processes (European Commission, 2021). Digital technologies can support CE through product tracking, predictive maintenance, new business models, and consumer engagement (Chauhan et al., 2022). Yet empirical insights into how such technologies can be systematically embedded in CE practices remain limited (Schöggl et al., 2023; Perotti et al., 2024, Lakatos et al., 2026). This doctoral thesis is positioned within this discussion, with a particular focus on the "Greening of Digital Processes." This approach highlights the integration of sustainability objectives into digitalisation strategies, rather than viewing digitalisation solely as a means of improving efficiency and productivity (Liao et al., 2023; Rosati et al., 2024). Positioned at the intersection of CE and Industry X.0, this perspective sheds light on how digital infrastructures and services can be reoriented to enable regenerative design, circular material flows, and more sustainable consumption patterns (Rejeb et al., 2025; Hariyani et al., 2024; Falcke et al., 2024; Aivazidou et al., 2025). In this dissertation, the Greening of Digital Processes (GDP) is used as the analytical lens for explaining how digitalisation can drive circular economy implementation through blockchain-enabled infrastructures and Service Design.

The interplay between digital transformation and circularity has become an increasingly prominent topic of discussion over the last decade (Kristoffersen et al., 2020; Rejeb & Simske, 2023). However, current research remains fragmented across disciplinary silos (Shojaei et al., 2021; Alves et al., 2022; Ranta et al., 2021; Bücker et al., 2025; Camacho-Otero et al., 2018; Greene et al., 2024). In particular, the literature often highlights blockchain's potential for transparency and traceability but provides limited insight into how blockchain-driven circular economy solutions are actually implemented, scaled, and embedded in practice. This dissertation focuses on four such processes: (1) governance and regulatory alignment, including standards, legal clarity, and accountability; (2) ecosystem coordination and data-sharing routines across value-chain actors; (3) the translation of traceability and automation into circular business model innovation, including value propositions and incentives; and (4) Service Design processes that shape usability, trust, and stakeholder participation. Taken together, these processes help explain why many blockchain-for-CE solutions remain at the pilot stage and why the conditions for scaling remain unclear. However, existing research does not sufficiently explain how these elements interact in practice to enable or constrain the scaling of blockchain-enabled circular economy solutions.

Whereas engineering and computer science studies often emphasise technical feasibility (Shojaei et al., 2021; Alves et al., 2022), management and sustainability studies tend to focus on business models and governance mechanisms (Ranta et al., 2021; Bücker et al., 2025), and social science research highlights user practices and institutional frameworks (Camacho-Otero et al., 2018; Greene et al., 2024). The limited integration of these perspectives constrains a holistic understanding of how digital technologies can accelerate CE transitions.

Blockchain can be seen as representative of both the opportunities and the frictions that arise in digital–green integration. It was chosen as the primary focus of this dissertation because it exemplifies a digital technology that entails both significant risks and considerable potential. Blockchain offers opportunities to improve transparency and coordination across stakeholders while also giving rise to important technical, organisational, and governance risks and trade-offs. As such, it provides a useful case through which to develop broader understandings of digital–green transitions. In itself, blockchain enables decentralised, immutable, and transparent records of transactions (Saberi et al., 2019; Sunny et al., 2020). This infrastructure is particularly relevant to several CE challenges, especially traceability of materials, certification of sustainably sourced inputs, and verification of product lifecycles (Saberi et al., 2019). In practice, blockchain technology has been applied to support CE-related business models such as product-as-a-service models, deposit-return and take-back systems, digital product passports, and circular supply-chain platforms (Casino et al., 2019; Upadhyay et al., 2021). However, adoption remains slow, as progress has been hindered by systemic challenges such as underdeveloped infrastructure, the high energy requirements of some blockchain applications, a lack of interoperability standards, organisational reluctance to share control, and end-user unfamiliarity with the technology (Kouhizadeh et al., 2021; Upadhyay, 2021). Furthermore, blockchain pilots related to CE have often remained small in scale and have not progressed into conventional operations due to unclear governance arrangements, regulatory uncertainty, and implementation costs (Rejeb et al., 2023).

Current literature (Böckel et al., 2021; Rejeb & Zailani, 2023; Upadhyay et al., 2021) does not sufficiently emphasise the importance of Service Design and human-centred innovation approaches in ensuring that blockchain-enabled CE solutions are usable, accessible, and socially acceptable. Without integrating these dimensions, technical advances risk remaining underutilised. Service Design emphasises stakeholder collaboration and human-centred usability testing in order to tailor solutions to user needs and institutional constraints (McAloone & Pigosso, 2018). Therefore, the critical research gap lies not only in understanding blockchain's technical capacity for CE, but also in examining the socio-technical processes that enable its adoption, scaling, and institutionalisation.

Given this gap, the core aim of this dissertation is to develop a conceptually grounded and empirically tested framework that explains how digitalisation, especially blockchain-enabled infrastructures, can either support or impede CE implementation when viewed through the Greening of Digital Processes (GDP) perspective. This aim is addressed through four interrelated research questions (RQ1–RQ4), which examine the impacts of blockchain-enabled circular economy solutions on (1) supply-chain transparency, efficiency, and circularity; (2) circular economy business model innovation; (3) adoption and scaling within institutional and regulatory contexts; and (4) the role of Service Design in enabling adoption and scalability. This thesis uses a qualitative multiple-case study research design (Eisenhardt, 1989; Yin, 2018), supplemented by expert interviews and document analysis. Three distinct cases were selected for the study, representing a range of sectors, from large-scale infrastructure to consumer products, and encompassing diverse levels of technological advancement and stakeholder involvement. Comparison across these dimensions helps identify common challenges, enabling factors, and distinct outcomes.

The blockchain applications examined in this research involve major CE stakeholders, including technology developers, supply-chain actors, policymakers, and end users. By situating blockchain within the broader digital–green transition discussion, this dissertation does not treat blockchain as a standalone technical solution, but rather as a socio-technical innovation whose implementation depends on institutional, cultural, and market conditions.

Accordingly, the thesis addresses the following research questions:

RQ1: How do blockchain and smart contracts shape transparency, efficiency, and circularity in circular economy supply chains?

RQ2: How does blockchain support business model innovation in blockchain-enabled circular economy solutions?

RQ3: How do institutional and regulatory conditions enable or constrain the adoption and scaling of blockchain-enabled circular economy solutions?

RQ4: How does Service Design shape the adoption and scalability of blockchain-enabled circular economy solutions?

These research questions are interrelated, yet each addresses a distinct aspect of how blockchain-enabled CE solutions create, mediate, and scale sustainability outcomes. RQ1 examines how blockchain and smart contract technologies influence transparency, efficiency, and circularity in CE supply chains. RQ2 investigates how blockchain-enabled CE solutions enable or reshape business model innovation. RQ3 examines which institutional and regulatory factors enable or constrain the adoption and scaling of blockchain-enabled CE solutions. Finally, RQ4 explores how Service Design facilitates adoption and scaling through the user-centred configuration of technical and institutional building blocks, as well as stakeholder alignment. Together, these four questions enable the study to contribute not only to multiple strands of academic research, but also to ongoing policy discussions and practice-oriented efforts by businesses, policymakers, and designers concerned with digital–green integration and the effective adoption of blockchain-enabled CE solutions.

Across the cases studied, the technical robustness of blockchain and smart contract technologies did not appear to be the dominant constraint on scaling. Rather, scaling was more likely where governance arrangements and Service Design translated ledger-based traceability into (i) enforceable accountability, (ii) trusted data stewardship, and (iii) low-friction stakeholder buy-in. The findings suggest that projects stalled less because of technological immaturity than because institutional arrangements for decision-making and value creation did not adapt to the requirements of blockchain's shared immutable infrastructure. This analytical logic is reflected in RQ1–RQ4, which together address the technological, business-model, institutional, and service-design conditions shaping the scaling of blockchain-enabled circular economy solutions.

Figure 1 summarises this alignment between the aim, research questions, empirical focus areas, and the publications.

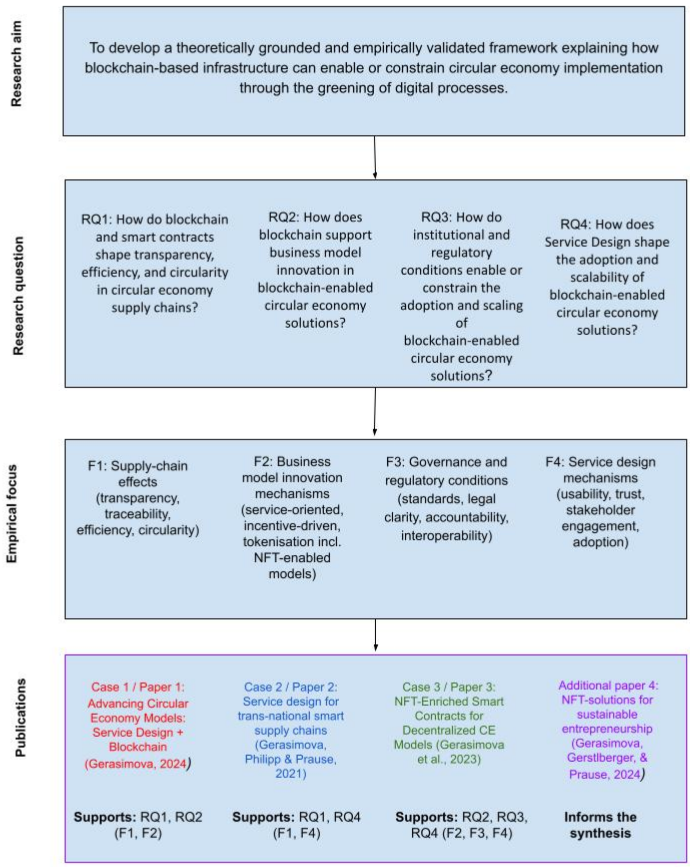

Figure 1. Alignment of Research Aim, Questions, Empirical focus areas, and Publications. Source: Author's own elaboration.

This dissertation contributes to both theory and practice. Theoretically, it contributes to three areas of literature. First, by expanding and empirically testing an emerging framework of blockchain-enabled CE business models, the study provides an in-depth understanding of how blockchain can support the closing, slowing, and narrowing of resource loops through greater transparency, traceability, and tokenisation. In doing so, it advances academic research on the circular economy. Second, by specifying the institutional, regulatory, and organisational preconditions under which digital technologies, and blockchain in particular, do or do not enable CE implementation, the study enriches the literature on twin transitions. Third, the study offers an integrated socio-technical framework that explains how technical architectures, business models, Service Design, and governance arrangements relate to one another and collectively affect sustainability outcomes. In this way, it helps to overcome the fragmentation present in previous work on the greening of digital transformation.

More specifically, the conceptual novelty of the framework lies in moving beyond existing circular economy and digitalisation models, which typically treat traceability technologies, business model change, governance conditions, and user adoption as separate dimensions. This dissertation theorises them instead as interdependent elements of a single multi-level socio-technical configuration: blockchain functions as enabling infrastructure, but in the cases studied, circular outcomes were most evident where governance arrangements provided institutional legitimacy and Service Design translated technical capabilities into usable and trusted practices. The framework therefore advances current theory by specifying the conditions under which blockchain contributes to circular economy implementation, particularly in settings where lifecycle data, multi-actor coordination, and user participation are central.

For practice, the findings provide a strategic guide for industry stakeholders and policymakers by offering evidence-based recommendations for overcoming adoption barriers and leveraging blockchain as a catalyst for CE.

By positioning blockchain not merely as a tool, but as part of a socio-technical system, this research also contributes to a more nuanced understanding of the twin transition. It highlights the conditions under which digital technologies can genuinely support sustainability goals, rather than reinforce existing inefficiencies or create new forms of exclusion.

The remainder of the thesis is organised into five chapters. Chapter 1 reviews the literature on circular economy, blockchain, digital–green integration, and Service Design, and develops the conceptual framework. Chapter 2 outlines the research methodology and case study design. Chapter 3 presents the empirical findings and analysis. Chapters 4 and 5 then discuss the theoretical and practical implications, highlight the dissertation’s contributions and limitations, and offer directions for future research.

Abbreviations

CE	Circular Economy
NFTs	Non-Fungible Tokens
STS	Socio-Technical Systems
BMI	Business Model Innovation
RQ	Research Question
AI	Artificial Intelligence
EU	European Union
GDP	Greening of Digital Processes
SD	Service Design
SME	Small and Medium-Sized Enterprise
DPPs	Digital Product Passports
ISO	International Organization for Standardization
IoT	Internet of Things
GDPR	General Data Protection Regulation
CSRD	Corporate Sustainability Reporting Directive
ESRS	European Sustainability Reporting Standards
UX	User Experience
ROI	Return on Investment

1 Literature Background and Analytical Framework

This chapter is structured to move from background literature toward the analytical framework used in the dissertation. It first reviews the conceptual foundations of circular economy implementation and Service Design as a lens for adoption and stakeholder alignment. It then consolidates prior blockchain scholarship specifically in circular economy contexts, integrates prior blockchain research into the evidence base that shapes the empirical analysis. The chapter concludes with a synthesis of these strands into an integrated analytical framework guiding the study's research questions and cross-case interpretation.

1.1 Theoretical Foundations

The aim of this dissertation is to study how blockchain technologies and Service Design can facilitate and scale CE transitions and circular business models. To respond to this question, the dissertation draws on two complementary theories: Socio-Technical Systems (STS) Theory and Business Model Innovation (BMI) Theory. By synthesising both a system-level and process-level view, these theories have been influential in sustainability transitions research for explaining the interplay of technological, organisational, and behavioural changes across innovation processes (Geels, 2002; Markard et al., 2012). STS has commonly been used in this research to understand the systemic characteristics of change, while BMI theory is used to investigate firm-level innovation and value-creation mechanisms (Zott et al., 2011). By merging them into a single framework, this work offers an integrated perspective on blockchain adoption and Service Design in a CE context, accounting for how circular innovations are situated within a socio-technical ecosystem that co-evolves over time.

Service Design has been recognised both as a practical methodological toolbox for improving services and as a theoretical perspective on socio-technical change, emphasising user participation and co-design (Blomkvist et al., 2010; Sangiorgi, 2011). A more recent stream of scholarship has also explored its role in service ecosystems and systemic innovation (Koskela-Huotari et al., 2016; Stickdorn et al., 2018). In this dissertation, Service Design is treated both as an approach to working with stakeholders and users, and as a theoretical perspective on how usability, co-creation, and participatory processes mediate the adoption of complex digital technologies such as blockchain.

1.1.1 Socio-Technical Systems (STS) Theory

STS theory has long emphasised the mutual dependence between technological, organisational, and social aspects of production and innovation (Trist & Bamforth, 1951; Geels, 2002; Rip & Kemp, 1998; Markard et al., 2012). In STS, transitions are conceptualised as multi-level processes that are both material and social—they are not caused solely by individual technologies or scientific breakthroughs but by the interactions of infrastructures, institutions, markets, and user practices. CE can be considered a socio-technical transition in this sense, as it simultaneously represents an infrastructural shift (new tools and methods to track, share, and recover resources), a market and governance challenge (new forms of regulation, incentives, and value creation), and a cultural and behavioural shift (new ways of product use and sharing) (Smith et al., 2005).

The STS perspective on blockchain adoption and CE allows blockchain to be viewed not as an isolated technology but as a socio-technical infrastructure for multi-actor record-keeping and tracking that is likely to influence how different social actors interact, such as firms with customers or customers with recyclers. Digital ledgers and digital product passports may, for instance, change product usage or traceability practices, while smart contracts may automate or streamline previously manual or relationally embedded processes. At the same time, these innovations may not scale without appropriate Service Design and attention to their usability and adoption in consumer-facing systems and applications. Blockchain is thus one socio-technical element of circular transitions, whose overall success depends on systemic change. STS provides the theoretical grounding for this dissertation's focus on the value and scalability of Service Design in supporting CE and blockchain adoption.

1.1.2 Business Model Innovation (BMI) Theory

BMI theory focuses on how firms and organisations innovate the logic of value creation, delivery, and capture (Teece, 2010; Bocken et al., 2014; Zott et al., 2011). As many business models in the linear economy have been based on the throwaway, short-term use of goods and resources, CE almost by definition involves business model change. Firms may move from product sales to product-as-a-service, leverage shared-use platforms, or offer incentivised take-back systems to customers (Pieroni et al., 2019).

Blockchain is often described as a powerful enabler of BMI because it supports the decentralisation of processes and information, as well as the transparency, recording, and automation of interactions (De Giovanni, 2022; Böhmecke-Schwafert et al., 2022). It can facilitate the creation of peer-to-peer marketplaces or circular platforms; digital product identities that are easily accessible, visible, and trusted; digitally mediated interactions between suppliers and consumers; and service contracts that are automatically executed when specific conditions are met. Such innovations can enable key elements of CE business models, including multi-actor collaboration, consumer engagement, shared use, and traceability.

1.1.3 Integration of STS and BMI Perspectives

In sum, by combining STS and BMI theoretical perspectives, this dissertation develops a foundation for understanding blockchain adoption in CE from both the perspective of the value created and the process through which it is generated. STS helps to show how blockchain-enabled solutions can be embedded within a complex, co-evolving socio-technical CE ecosystem, while BMI theory highlights the firm-level value propositions of blockchain for scaling circular business models and driving innovation (Pieroni et al., 2019; Böhmecke-Schwafert et al., 2022). These two approaches are complementary and together provide the theoretical basis for the analysis of case data across different levels of analysis.

In terms of the relationship between the theoretical framework and the empirical strategy of the dissertation, it is noted that all three case studies are situated at the intersection of blockchain features and capabilities on one hand, and Service Design activities on the other (Carayannis et al., 2022). As such, they illustrate not only the technical affordances of blockchain and its societal implications (Saberi et al., 2019; Rejeb et al., 2023) but also how it can be combined with specific design principles and market mechanisms to scale CE and circular business models (Kristoffersen et al., 2021; Rosa et al., 2020). The data collected serve to verify the theoretical propositions derived from STS and BMI—particularly the logic and process of value creation and capture (Geels, 2002; Teece, 2010). The case evidence, as well as its interpretation in the dissertation, is thus rooted in these theoretical foundations.

To conclude, literature reviewed in this chapter is not discussed as three isolated bodies of literature. Rather, they are inputs into one analytical lens: circular economy literature defines the 'what' of the implementation problem space, Service Design literature provides understanding of the 'why' and 'how' of stakeholder alignment and adoption mechanisms; finally, blockchain literature informs 'how' specifically digital traceability and governance enable or constrain circular value creation. Taken together, these elements define constructs and relationships operationalised in subsequent empirical chapters to interpret scaling conditions across cases.

1.2 Blockchain Technology in the Circular Economy

1.2.1 Origins and Mechanisms of Blockchain

Blockchain was initially developed as the enabling technology for cryptocurrencies including Bitcoin and subsequently deployed in many different application areas. It is a decentralized, distributed digital record of transactions for multiple nodes in a network and thus achieves levels of trust, transparency and tamper resistance (Nakamoto, 2008). Building on this, smart contracts or self-executing contracts, written as code on the blockchain, were developed to enable the execution of transactions in a trustless manner without the need for any intermediaries (Buterin 2014). More recently, non-fungible tokens (NFTs) were developed to represent non-fungible digital assets or tokens, where specific ownership, provenance and lifecycle data can be attached to them (Dounas et al., 2021).

1.2.2 Circular Economy: Principles and Challenges

The circular economy (CE) provides a promising alternative to the conventional linear "take-make-dispose" approach by closing loops, minimizing waste generation and maximizing the utilization of resources (Geissdoerfer et al., 2017). Repair, remanufacturing, and recycling are fundamental activities that enable the CE to obtain significant economic and environmental benefits.

Yet, the large-scale transition to the CE remains challenged by path dependencies and systemic barriers such as a lack of transparency, data fragmentation, and difficulties in coordination and cooperation among stakeholders along complex value chains (Kirchherr et al., 2018). This has led to a growing demand for tools that increase coordination, collaboration, traceability and trust across product systems.

1.2.3 Blockchain Solutions to Enable the CE

The alignment between blockchain properties and CE requirements has led to the proposal of integrating blockchain into the CE. Blockchain is known for its immutability, decentralisation, and transparency, among other characteristics (Kouhizadeh et al., 2021). Specifically, blockchain can enable digital product passports (Antikainen et al., 2018) that provide information about material content, origin, and life cycle that can be used for resource recovery and efficient waste-to-material recycling. Blockchain can also automate circular transactions through smart contracts, making execution across stakeholders tamper-proof and trustless (Saberi et al., 2019). This can help increase trust, reduce transaction costs and increase stakeholder accountability across circular supply chains (Creydt & Fischer, 2019).

1.2.4 Challenges in Blockchain Adoption for CE

Yet, the use of blockchain in CE applications remains limited. A survey identified several barriers to blockchain adoption in the CE, including technological complexity, lack of user-friendliness, high implementation costs, lack of organisational alignment, and difficulty in interoperating with existing legacy systems (Morkunas et al., 2019). Additional data privacy concerns, insufficiently interoperable standards, and a lack of common governance mechanisms were also noted (Saberi et al., 2019).

The presence of such barriers, along with organisational resistance and limited user awareness, suggests that a certain level of technological sophistication and complexity may even hinder adoption (Shojaei et al., 2021). Beyond these adoption barriers, the use of blockchain for CE traceability also raises a fundamental privacy–immutability tension. Traceability datasets may include personal data (e.g., identifiers in return/reuse transactions or service/repair logs) and commercially sensitive information. When such data are recorded on an immutable ledger, later rectification or erasure becomes difficult, challenging rights under the General Data Protection Regulation (GDPR), and creating ambiguity over who acts as the "data controller" in decentralised networks (Finck, 2018; EU Blockchain Observatory and Forum, 2018). Consequently, privacy-by-design guidance emphasises minimising on-chain personal data and relying on architectures where the blockchain stores only commitments/hashes or access-controlled pointers, while personal data remain off-chain and revocable (CNIL, 2018).

Consequently, blockchain does not remove the requirement for governance, it displaces it. Technical implementations must specify how the decentralised (and consortium) system will be governed in practice—how nodes join and leave, who has access to what information, how to manage protocol upgrades or forks, how disputes are settled, how contributors are incentivised, and who is liable for bad data or "garbage in, garbage out" errors. Academic research therefore separates out governance issues specific to public versus permissioned/consortium blockchains, as well as 'on-chain' versus 'off-chain' governance mechanisms—both of which present differing trade-offs between decentralisation/permissivity and compliance with regulatory expectations (Atzori, 2017; Beck et al., 2018; De Filippi & Loveluck, 2016). Given the need to coordinate across multiple stakeholders in CE applications, designing appropriate governance mechanisms will be necessary before most applications can scale past the pilot stage.

The immutability of tokens does not guarantee that NFTs will serve as durable and dependable lifecycle certificates, including product passports. NFTs tend to encode an on-chain identifier and ownership/transfer history, while extensive lifecycle data and metadata commonly reside off-chain due to costs and capacity limitations, raising potential long-term risks of broken data links, incomplete or inconsistent metadata, and diminished evidence quality over time (Cornelius, 2021; Wang et al., 2021; Wang et al., 2022). Furthermore, ownership of an NFT does not necessarily confer legal rights to the underlying asset it represents. Contractual agreements, custodianship and legal status of tokenised claims are the key determining factors. As such, credible NFT-based lifecycle certification would also rely on arrangements around long-term data stewardship (e.g. long-term persistent storage and data migration plans), metadata standardisation, and institutional/legal embedding.

A few empirical studies have emerged on blockchain-enabled CE use cases. These have largely focused on applications for traceability, transparency, and stakeholder cooperation, and have demonstrated specific advantages (Rejeb & Zailani, 2023; Kouhizadeh et al., 2021). Shojaei et al. (2021) showed that the construction supply chain could benefit from significantly enhanced traceability of materials and components to support reverse logistics and environmental compliance through blockchain. However, interoperability with other systems and a lack of common standards were still noted as barriers.

In consumer product tracking, Upadhyay et al. (2021) discovered that blockchain technology could create reliable digital identities for consumers, thus building trust and allowing secondary markets like resale and refurbishment, although consumer literacy remained a barrier to adoption. Philipp et al. (2019) reported similar improvements in transparency and real-time information exchange to guarantee circularity and sustainability compliance throughout the logistics process as key benefits. However, resistance within established organisations persisted. Alves et al. (2021) suggested blockchain could facilitate product-as-a-service and digital twin models in the textile industry, yet fragmented and uncertain regulation and governance remained key implementation barriers. Montecchi et al. (2019) noted that blockchain can strengthen the origin and authenticity of food products and their components, but user interface challenges have also limited consumer uptake.

Common themes emerging from these studies and reviews include: (1) blockchain clearly offers value in improving transparency, traceability, stakeholder accountability, and lifecycle data; (2) it can enable new types of service-oriented and collaborative circular business models; and (3) the scale-up of blockchain solutions remains constrained by technological immaturity, interoperability issues, uncertain regulation, lack of common standards, and insufficient user engagement. Reviews of the literature to date have noted a similar pattern, indicating that much of the research remains theoretical or at the pilot stage, with a paucity of large-scale applications and testing (Rejeb & Zailani, 2023).

2 Research Methodology and Settings

This chapter offers a detailed discussion of the research methodology and design. In particular, the methodological choices underpinning the dissertation are illustrated. The overall goal of this chapter is to demonstrate that the adopted research design is coherent with the theoretical framework outlined in Chapter 1. It also shows that this framework enables the exploration of blockchain-enabled CE transitions in combination with Service Design. As described in the previous chapter, blockchain-enabled CE solutions represent a still-immature and complex area, where technological, organisational, and user-centred elements are interrelated. Studying such complexity calls for methodologies that account for context, interpret meaning, and combine multiple sources of information.

Accordingly, the dissertation is based on a qualitative and interpretivist research design in which case study research serves as the central approach. Document analysis, semi-structured interviews, and observational data provide both depth and breadth to the analysis.

2.1 Research Philosophy

This dissertation's philosophical approach is grounded in the interpretivist paradigm, which recognises that knowledge is socially constructed, contingent on historical and contextual factors, and that multiple realities are understood through the meanings people assign to their experiences (Creswell, 2013; Walsham, 1995; Klein & Myers, 1999). This position aligns with the aim of the research, which seeks to understand how the application of blockchain technologies can facilitate CE transitions when coupled with Service Design. It does not assume that universal laws or deterministic relationships can be discovered and generalised but rather views knowledge as context-specific, processual, and practice-oriented (Orlikowski & Baroudi, 1991). This paradigm also aligns with the dissertation's focus on the interplay of technological, organisational, and user-related factors in shaping the adoption, implementation, and outcomes of blockchain in Service Design.

From the perspective of STS theory, the interpretivist approach is appropriate because it allows blockchain adoption to be examined as a process of socio-technical change that involves not only the introduction of new technologies but also the reconfiguration of infrastructures, business models, and user practices (Geels, 2002; Sarker et al., 2013). It also suggests that technology is not deterministic or autonomous; rather technologies are contextually situated in social, organisational, and cultural structures with processes of local adaptation, negotiation and design affecting their development and use (Pinch & Bijker, 1987).

In relation to BMI theory, the interpretivist framework is particularly relevant because it frames managerial and entrepreneurial choices as socially constructed, the product of experimentation, interpretation, and adaptation (Eisenhardt & Graebner, 2007). It also suggests that business models are not stable but emergent and dynamic, neither given nor predetermined, and their development is contextual and contingent on interactions among different stakeholders and logics (Zott et al., 2011).

Methodologically, this philosophical approach is a strong fit for qualitative case studies, a research design that is well suited for a comprehensive understanding of complex socio-technical phenomena (Yin, 2018; Eisenhardt, 1989). Case studies allow researchers to examine not only blockchain's technical affordances, but also its adoption/use/resistance/adaptation within organisational/sectoral contexts (Rejeb et al., 2023), and collect diverse data via interviews/document analysis/observation that can convey the meanings and experiences of study participants (Lincoln & Guba, 1985).

2.2 Research Approach and Rationale

A qualitative research design was selected for this dissertation since the study is exploratory in nature. A qualitative approach is appropriate for providing an in-depth understanding of phenomena in their natural settings, especially when the boundaries between technology, its users, and the institutional context become blurred (Yin, 2018). The study follows an iterative, theory-informed case analysis approach, moving between emerging case insights and relevant literature to refine concepts and mechanisms (Eisenhardt, 1989). Case study principles (e.g., structured within-case and cross-case comparison) are used to strengthen analytical rigor (Yin, 2018), while the interpretation of meanings, practices, and institutional conditions follows an interpretive qualitative logic. Moreover, qualitative methods allow for the collection of rich, context-specific data, providing insights into the use of blockchain and Service Design thinking in the context of circular economies by various stakeholders (Creswell & Creswell, 2022).

In line with the four research questions introduced in Chapter 1, the research design supports the investigation of how blockchain and smart contracts shape transparency, efficiency, and circularity in circular economy supply chains (RQ1); how blockchain supports business model innovation in blockchain-enabled circular economy solutions (RQ2); how institutional and regulatory conditions enable or constrain the adoption and scaling of blockchain-enabled circular economy solutions (RQ3); and how Service Design shapes the adoption and scalability of blockchain-enabled circular economy solutions (RQ4).

The dissertation is conducted as a multiple-case study. A multiple-case study is suitable because it is often the best choice for examining contemporary phenomena, such as blockchain-enabled CE business models, within real-life contexts (Yin, 2018).

This approach makes it possible to investigate the nuances and complexities surrounding the development, implementation, and scaling of technology-enabled business models across different industries, institutional arrangements, and stakeholder relationships.

Table 1. Overview of empirical material and analysis.

Case	Context	Main actors	Data sources	Main RQ contribution
Case 1: Blockchain-enabled circular electronics platform	Electronics lifecycle (digital product passport / traceability)	Manufacturers, repair/recycling actors, platform providers, users	Documents; expert interviews; platform/ technical materials; observations (if applicable)	RQ1 (traceability/efficiency/ circularity), RQ2 (service-based models)
Case 2: Smart supply chains + Service Design integration	Transnational logistics / documentation / coordination	Logistics actors, supply-chain partners, solution providers, users	Documents; expert interviews; observations (workshops/meetings); Service Design artefacts	RQ1 (transparency/coordination), RQ4 (Service Design → adoption)
Case 3: NFT-enriched smart contracts for decentralised CE models	Consumer-facing / decentralised ownership & incentives	Users, platforms, investors/partners, solution providers	Documents; expert interviews; observations (if applicable)	RQ2 (incentive-driven models), RQ3 (legal/regulatory barriers), RQ4 (adoption factors)

Source: Author's compilation based on the empirical material and Publications I–III.

Table 1 summarises the empirical material used in the three papers and indicates how each paper contributes to the research questions. Data were analysed through within-case interpretation and cross-case comparison.

The case selection process aimed to capture implementation diversity in blockchain-enabled CE solutions across different contexts and operational levels such as supply-chain coordination and governance/regulatory conditions. The main criteria for inclusion were: (1) demonstrated relevance to at least one of the research questions (RQ1–RQ4), (2) engagement of several stakeholder categories (firms/solution providers/users/public actors etc.) and (3) feasibility of access to empirical materials (interviews/supporting documentation). Empirical materials include semi-structured interviews with key stakeholders in each of the cases as well as documentary/secondary sources (project/company documents, regulatory/standards information, platform/technical documentation, publicly available reports etc.). The composition of these materials varies between the cases. Seven semi-structured interviews were conducted across the three cases along with multiple documentary and secondary materials used for each respective case. Because of the low number of interviews, the analysis placed strong emphasis on triangulation with documentary sources and pursued analytical, rather than statistical generalisation. Interview transcripts and documents were coded using thematic analysis, in iterative rounds, first within cases (drawing out mechanisms and context-dependent constraints) and subsequently across cases (identifying patterns/linking variation to cross-case regularities deriving from research questions and the GDP-framework).

2.3 Case Study Selection and Description

This work builds on the author's previously published work, drawing from it empirically grounded observations. The selected cases were chosen for their representativeness and the diversity of use cases and industry settings. Specifically, the three cases span the spectrum from infrastructure-level to decentralised consumer-facing blockchain solutions, capturing three analytically distinct levels of blockchain adoption—infrastructural, organisational/supply-chain, and end-user/market—while remaining consistent with the overarching goals of the study (Geels, 2002). This configuration allows the four research questions to be addressed in different combinations across the three cases. Cases 1 and 2 primarily inform RQ1; Cases 1 and 3 primarily inform RQ2; RQ3 is examined through cross-cutting governance and regulatory observations across the cases, with the clearest empirical emphasis in Case 3; and RQ4 is most prominent in Cases 2 and 3.

Case 1: Blockchain-Enabled Circular Electronics Platform

The first case examines the application of blockchain and smart contracts to CE in the electronics industry. Smart contracts were used to track products through all stages of their lifecycle, including manufacturing, distribution, repair, and recycling. The platform employed NFTs to mint and store digital product passports containing detailed device information and recording all changes and transactions in a tamper-proof and verifiable manner. The analysis assesses the opportunities and challenges for manufacturers, recyclers, and consumers. The study highlights blockchain's potential to enable more effective tracking, auditing, and incentivisation of circular flows, thereby improving supply chain transparency, efficiency, and circularity, but also notes challenges such as the need for standardisation, technical integration, and regulatory clarity.

Case 2: Smart Supply Chains and Service Design Integration
The second case focuses on blockchain applications in transnational smart supply chains. Here, blockchain is used to provide transparency and traceability, complemented by Service Design tools and approaches that enhance user engagement and cross-stakeholder collaboration. The focus is on how blockchain can support CE practices in logistics and distribution, particularly in ensuring compliance with sustainability regulations, reverse logistics, and green supply chain management, and how these developments translate into new or modified business models. Service Design tools such as blueprints were used to identify usability and user experience (UX) issues and to design more user-centred solutions for adoption, directly informing RQ4 on the role of Service Design in adoption and scalability.

Case 3: NFT-Enriched Smart Contracts for Decentralised Circular Business Models
The third case investigates NFTs and blockchain-enabled consumer-centric CE models. NFTs are used to represent and manage ownership, leasing, and incentivisation in decentralised business models, such as peer-to-peer exchange, second-life products, and gamified recycling. The emphasis is on user trust, experience, and the legal ambiguities surrounding NFT-based CE. This case illustrates blockchain's potential as an enabler of new value propositions and trust mechanisms that foster service-oriented, collaborative, and circular business models, while also demonstrating the socio-technical and behavioural challenges associated with scaling.

Collectively, the three cases provide a layered view of blockchain adoption in CE at infrastructure, organisational, and end-user levels. They are therefore well positioned to illustrate the mechanisms through which blockchain and Service Design can support circularity.

2.4 Data Collection Methods

In line with the qualitative and interpretivist nature of the research, the study utilises three primary methods of data collection: document analysis, semi-structured expert interviews, and observational data from case studies.

2.4.1 Document Analysis

Document analysis was used to elicit contextual information and insights relevant to the institutional and regulatory settings of each case. The analysed documents include regulatory reports, policy papers, sustainability standards, industry white papers, company reports, and technical documentation related to blockchain solutions. This method allows for understanding, in proper context, the institutional pressures, constraints, and incentives affecting blockchain adoption in a circular economy context.

2.4.2 Semi-structured Expert Interviews

Semi-structured expert interviews served as the primary empirical approach in this research. The interviews were conducted with a diverse group of stakeholders involved in blockchain-enabled CE models, including industry practitioners. The semi-structured nature of the interviews allowed for directed yet open-ended conversations, enabling deeper exploration of the attitudes, experiences, and challenges faced by stakeholders in each case.

Participants were selected purposively based on their expertise, practical experience, and involvement in blockchain or CE solutions, ensuring the richness and relevance of the data collected. The interviews were conducted during meetings and later transcribed for qualitative analysis.

In total, seven semi-structured interviews were conducted, complemented by document/secondary sources and observations as summarised in Table 1.

2.4.3 Observational Data

The selected case studies also provided observational data that complemented both the document analysis and interviews, adding further empirical depth to the research. These observations included participation in workshops, project meetings, presentations to stakeholders, and demonstrations of blockchain solutions. The observational data supported the triangulation of results, thereby increasing the credibility of the findings (Creswell & Creswell, 2022).

2.5 Data Analysis and Interpretation

The data gathered for this dissertation were analysed using thematic analysis (Braun & Clarke, 2021), which aligns with the chosen methodology and research questions. This method is recommended for its systematic approach, enabling careful coding, iterative theme development, and synthesis across datasets. Coding themes were developed inductively but were also informed by the overarching theoretical framework of the dissertation, STS and BMI theories.

Each case study emphasised particular aspects while allowing for comparison and the identification of cross-cutting themes. Case 1 (electronics) focused on lifecycle traceability, repair flows, and data provenance, while Case 2 (supply chains) examined stakeholder collaboration, usability challenges, and Service Design co-creation. Case 3 (NFT smart contracts) provided insights into user incentives, decentralised ownership, and trust as key factors for blockchain-enabled CE solutions. Through separate and collective analyses of the cases, the study generated both context-specific and cross-cutting findings, which are presented in Chapter 3. In this way, the dissertation offers not only actionable, case-specific evidence but also a broader, theoretically informed understanding of the interaction between blockchain and Service Design in the context of CE.

2.6 Ethical Considerations and Research Integrity

Research ethics were strictly observed throughout the research process. Careful attention was given to maintaining data anonymity and confidentiality. Additionally, all sources and intellectual contributions have been transparently acknowledged, in full adherence to academic integrity standards.

3 Results

This chapter summarises the empirical results of the dissertation and aligns them with the RQs that were formulated in Chapter 1. To answer the RQs and hence address the gaps stated in the previous chapter, this chapter builds upon the findings of the three interrelated case studies, which investigated how blockchain, smart contracts, NFTs, and Service Design can be embedded and applied within CE contexts. Blockchain tended to increase transparency and traceability overall and, in some cases, improved operational efficiency across the cases. Blockchain-enabled technologies can also enable new circular business models, such as product-as-a-service, fractional ownership, and tokenised incentives (e.g., through smart contracts and NFTs). Regulatory conditions strongly enable or constrain blockchain-enabled solutions. Regulatory uncertainty and the lack of standards were common barriers to adoption. Service Design played an important role in bridging the gap between complex technical back-end systems and user-centred front-end solutions that end users can understand, thereby supporting stakeholder acceptance and scalability.

3.1 Impacts of Blockchain on Transparency, Efficiency, and Circularity (RQ1)

This section presents findings that answer RQ1: How do blockchain and smart contracts shape transparency, efficiency, and circularity in circular economy supply chains? The discussion leverages all three cases to reflect on the extent to which blockchain solutions were able to advance traceability, accountability, and operational performance in CE-related use cases. In general, blockchain was found to be a central driver of transparency and product lifecycle traceability in all three empirical cases. In Case 1 (Circular Electronics Platform), blockchain-backed digital product passports (powered by NFTs) helped enable the creation of tamper-proof, auditable data "fingerprints" for electronic products. They provided information on the origin, repair history, and environmental impact data for the products, which could be referenced to support their reuse and recycling. The result was increased stakeholder confidence among all the actors involved in the take-back and reconditioning process, including manufacturers, recyclers, and consumers. The manufacturers also reported experiencing greater ease in meeting sustainability standards, and the recyclers found the data made available by NFT product passports to be particularly helpful for their own material recovery operations. Interviewees suggested that transparency features could strengthen consumer trust in sustainability claims.

In Case 2 (Smart Supply Chains), blockchain and smart contracts helped provide real-time tracking of physical flows in transnational logistics operations. This improved the accuracy of documentation for shipments, while also allowing some parts of the process (environmental compliance) to be automated. Customs officers and logistics service providers reported benefits in terms of increased speed, reliability, and transparency in cross-border procedures. These benefits, in turn, were found to also enhance operational efficiency and CE alignment of logistics flows (reverse logistics, waste reduction).

In Case 3 (NFT-Enriched Business Models), the NFTs were reported to help enable the assignment of identifiable, verifiable identities to products that were circulated in decentralised peer-to-peer and community-based systems. In this sense, the term "identity" is used in a technical sense: a unique token that ties a product to its digital record, enabling traceability. This does not inherently confer a legal identity to the underlying product, nor does it create ownership/rights to it; legal implications would flow from contractual arrangements, governing law and technical embedding in existing legal/registration frameworks. This gap partly explains why governance and legal certainty become key questions when scaling tokenised CE solutions. The use of blockchain as a supporting infrastructure allowed new forms of circular exchange (product returns, P2P leasing) to take place more easily. Transparency and the automation of tasks via smart contracts also improved transaction efficiency while eliminating intermediaries.

Nevertheless, all three cases reported various challenges. The high costs of blockchain setup, concerns over technological scalability, and the lack of standards for interoperability were seen to present roadblocks to broader adoption. Legal uncertainty about the properties of blockchain-enabled features (ownership recognition of NFTs) was also noted to dampen stakeholder confidence in using these solutions.

In other words, blockchain was found to have significantly supported the realisation of the core CE objectives, namely transparency and resource circularity. The efficiency improvements, however, are seen to require further support and standardisation in institutional, technological, and Service Design terms.

Blockchain improved traceability and accountability in electronics, logistics, and decentralised product systems. These findings point to how blockchain can meet the Greening of Digital Processes perspective: that digital infrastructures can be both operationally and environmentally purposive if built for transparency and circularity.

3.2 Blockchain-Enabled Business Model Innovations (RQ2)

This section addresses RQ2: How does blockchain support business model innovation in blockchain-enabled circular economy solutions? The three case studies together show that blockchain, more specifically by combining smart contracts and NFTs, creates opportunities for new decentralised and incentive-based circular business models.

Blockchain and NFT technologies in Case 3 illustrated the potential for new value creation models that could challenge traditional ownership-focused systems. Smart contracts functioned to automate the distribution of rewards to users who participated in the return of products for either reuse or recycling purposes, and NFTs were employed as a means of establishing verifiable digital identities associated with specific products. This approach pointed to the potential for product-as-a-service, pay-per-use, fractional ownership, and peer-to-peer leasing models. The new arrangements represented a shift away from linear product sales toward models focused on regenerative and participatory consumer practices.

Case 1 (Circular Electronics Platform) enabled business model innovation through the design and delivery of service-based business models for the electronics sector. NFT-powered digital passports enabled product tracking during multiple use cycles to support extended producer responsibility initiatives along with repair service and product resale solutions. This full transparency also enabled businesses to extract value from prolonging product life cycles while at the same time earning consumer trust and offering a differentiated sustainability guarantee.

In Case 2 (Smart Supply Chains), blockchain helped to operationalise the inclusion of compliance/sustainability targets in supply chain activities. This allowed for the development of compliance-as-a-service models through automation/blockchain and smart contracts to alleviate the administrative burden of regulatory reporting for logistics service providers operating across borders, and to incentivise circular logistics flows. Participants noted the opportunities to monetise compliance efficiencies and create new value through new forms of reverse logistics coordination.

However, several limitations to the predicted potentials were identified. Multiple stakeholders reported low consumer awareness of NFT-based systems as well as legal insecurity of such systems in the long term. The limited user base and subsequent demand restricted commercial use cases of decentralised CE platforms. Similarly, organisational and internal ability to change traditional business practices to tokenised and blockchain-enabled approaches were reported as a recurring challenge.

In short, blockchain technologies are likely not only to represent a layer of infrastructure for CE ecosystems, but also to promote innovation in rethinking value generation, capture, and distribution in these ecosystems. Through the use of NFTs and smart contracts as connection tools, blockchain technology has enabled production and consumption systems to shift toward distributed models that incorporate incentives and service-based approaches. To expand these innovative affordances, it will be necessary to focus more on user education along with institutional coordination and interface design according to the following discussion.

Blockchain supported distributed, service-oriented models in all cases. Extended producer responsibility, compliance-as-a-service, and NFT-enabled peer-to-peer models applied it as a driver of business model innovation. These findings align with BMI theory and demonstrate the value creation, delivery, and capture changes blockchain introduces in CE contexts.

3.3 Regulatory and Governance Conditions Affecting Blockchain Adoption (RQ3)

This section addresses RQ3: How do institutional and regulatory conditions enable or constrain the adoption and scaling of blockchain-enabled circular economy solutions? It synthesises cross-cutting governance and regulatory observations across the three cases, with the clearest illustrations coming from Cases 1 and 3 (Publication II and Publication III). The results show that adoption is influenced not only by technological and organisational factors, but also by clarity of legal and regulatory status and consistency with governance mechanisms. Unclear regulatory recognition of digital product passports and NFTs in the electronics sector limited the adoption of digital passports. Fragmented cross-border requirements in logistics impeded the adoption of blockchain-enabled documentation. The absence of rules for tokenised ownership structures and taxation in decentralised models has led to uncertainty and risk perception among users and investors.

The results indicate that scalability and reliability remain important conditions for the broader adoption of blockchain in CE contexts. Moreover, blockchain adoption is not only a question of technical feasibility but it is also linked to regulatory consistency and legal certainty. However, this is not considered here as a separate “theory” but rather as part of the socio-technical environment in which a blockchain-enabled business model has to operate.

3.4 Role of Service Design in Blockchain Adoption and Scalability (RQ4)

This section addresses RQ4: How does Service Design shape the adoption and scalability of blockchain-enabled circular economy solutions? Results from the case studies provide some evidence that Service Design performs an important enabling function to provide an interface for complex blockchain systems in a user-centric manner to promote wider stakeholder involvement and diffusion of the system.

In Case 2 (Smart Supply Chains), the stakeholder engagement and blueprinting exercises revealed user and adoption challenges with a broad range of users. Co-design and iterative prototyping were not part of a regular approach here, but interviewees cited their relevance for future adoption. According to the results, end-users would need to be involved from early stages and interfaces aligned with actual workflows to overcome the discrepancy between technical possibilities and real-life functionality. Otherwise, blockchain might overcomplicate instead of facilitating CE processes (co-design, prototyping).

Although Case 1 (Circular Electronics Platform) and Case 3 (NFT-Based Models) did not implement formal Service Design methodologies to the same extent, both revealed the consequences of this absence. In Case 3, for instance, many end users reported confusion around the purpose and value of NFTs, and low digital literacy was cited as a key barrier to participation in tokenised circular marketplaces. Likewise, in Case 1, stakeholders noted that system interfaces often lacked intuitiveness, making it difficult for non-technical actors to engage fully with blockchain features like product passports.

These observations underline the importance of Service Design in shaping how blockchain-enabled circular economy solutions are understood and used in practice. Across the cases, Service Design-related factors were associated with usability, stakeholder alignment, and trust, all of which influenced adoption prospects. Rather than functioning as a secondary implementation layer, Service Design appears to have mediated the relationship between technical capability and practical uptake.

A clearer Service Design approach was applied in Case 2, which supported stakeholder trust and adoption. Cases with no clear Service Design (Cases 1 and 3) encountered usability challenges and confusion of users, making scaling more difficult. This aligns with previous findings that Service Design acts as an organisational lever of socio-technical transitions. Service Design is one of the mechanisms connecting infrastructures and practices.

Sections 3.1–3.4 summarise the case evidence and answer RQ1–RQ4. The next section integrates these results into a cross-case synthesis model (Figure 2) and develops the resulting propositions and implications.

4 Discussion

The aim of this chapter is to formulate the central contribution of the dissertation. In answering the four research questions and advancing the dissertation's central aim, this chapter argues that the Greening of Digital Processes (GDP) provides the most suitable integrative lens for analysing blockchain adoption in circular economy transitions. It integrates three interdependent dimensions of the GDP: (1) blockchain as enabling digital infrastructure; (2) the mediating role of Service Design in translating complexity into meaningful interfaces and use practices; and (3) governance as the systemic condition required for sustainability and scale. Drawing on the conclusions of the case study chapters, this chapter examines the interplay of these three dimensions in shaping the role of blockchain in the development of circular economy business models. It provides a critical interpretation of the empirical findings presented in Chapter 3 and situates them within the theoretical frame outlined above. It also brings together insights from all three cases and further explores the connections between blockchain, smart contracts, NFTs, Service Design, and CE business models. Each of the four research questions is discussed in relation to the findings, and their theoretical and practical or policy implications are identified.

To structure the discussion, the synthesis model (Figure 2) is used. It reflects the interdependencies between blockchain infrastructure, Service Design, and service governance under the GDP lens. This conceptual frame helps to examine digital transformation as a shift towards green goals, not only in terms of efficiency. The findings suggest that blockchain is an important infrastructure for enabling CE transparency and traceability, but that its transformative potential for business models remained limited unless it was accompanied by user-centred Service Design and regulatory alignment with broader environmental goals.

In this sense, the findings can also be interpreted as extending STS Theory and BMI Theory by showing that blockchain implementation and adoption are systemic rather than purely technological processes. This is also in line with the GDP perspective and its emphasis on the interconnection between CE innovation, digital infrastructure, design practices, and governance conditions.

4.1 Cross-Case Synthesis and Integrated Framework

This section synthesises the findings across the three papers to explain how governance and regulation, together with Service Design, enable or constrain blockchain-enabled infrastructures, and how these infrastructures, in turn, enable or constrain circular supply-chain practices and circular business-model innovation. The results from the three cases can be integrated and discussed through the lens of the Greening of Digital Processes (GDP). In contrast to Industry 4.0 approaches, which have often emphasised automation, digitalisation, and efficiency gains, the GDP perspective suggests that digital technologies can also be purposefully oriented toward environmental goals such as net zero, carbon neutrality, and regenerative sustainability (Liao et al., 2023; Falcke et al., 2024; Rejeb et al., 2025; Khan et al., 2026). The findings indicate that blockchain technology, coupled with Service Design, can act as an important facilitator of digitalisation aligned with environmental outcomes when supported by appropriate governance and regulatory arrangements. This leads to four main contributions, outlined below. Taken together, the three studies indicate that blockchain does not automatically deliver circularity (Sardar et al., 2026). Rather, it shifts the primary scaling constraints towards governance design, business-model viability, and user-centred service configuration.

Cross-case insight 1: Blockchain as enabling infrastructure
Results from all three cases highlight blockchain as a technology that offers unique attributes in the form of immutable, decentralised records. These are important factors in improving life-cycle transparency and circularity (Saberi et al., 2019; Shojaei et al., 2021; Upadhyay et al., 2021). This suggests that blockchain's relevance in circular economy transitions lies primarily in its infrastructural role, but that this role becomes meaningful only when embedded in broader socio-technical arrangements.

Cross-case insight 2: Service Design as socio-technical integrator
Service Design methods offer a user-centred means of unlocking the technical potential of blockchain and other advanced technologies for practical adoption. This is achieved by reducing cognitive barriers and incorporating essential elements of inclusiveness (McAloone & Pigosso, 2018). This extends the analysis beyond technical implementation by showing that Service Design mediates the relationship between technological capability and practical adoption.

Cross-case insight 3: New circular business models
NFT-integrated smart contracts as business models can support ownership decentralisation, product-as-a-service models, recycling incentives, and other circular arrangements (De Giovanni, 2022; Dos Santos et al., 2021). In this sense, business-model innovation is treated not as a direct output of technology but as a conditional process shaped by organisational incentives, stakeholder acceptance, and implementation feasibility.

Cross-case insight 4: Governance and regulatory alignment
Blockchain-enabled CE solutions need to be scaled through convergent standards and aligned governance models, while the current lack of regulatory clarity remains a significant obstacle (Korhonen et al., 2018; Kouhizadeh et al., 2021). This highlights governance and regulation as explanatory conditions of scaling rather than as external background factors.

Table 2 summarises the key cross-case findings and highlights common patterns and differences across the cases.

Table 2. Cross-case summary of key findings.

Dimension	Case 1	Case 2	Case 3	Cross-case insight
Role of blockchain	Supports transparency and lifecycle traceability	Supports secure data exchange and coordination	Enables decentralised ownership and transactions	Blockchain acts as an enabling infrastructure, but its value depends on embedding in broader socio-technical systems
Role of Service Design	Improves usability and user interaction	Supports stakeholder engagement	Facilitates adoption by reducing complexity	Service Design acts as a socio-technical integrator, bridging technological capability and practical adoption
Business model innovation	Limited transformation of existing models	Experimentation with new value propositions	NFT-enabled ownership and incentive mechanisms	Business model innovation is a conditional and context-dependent process shaped by organisational incentives, stakeholder acceptance, and implementation feasibility
Governance & regulation	Characterised by regulatory uncertainty	Characterised by fragmented standards	Characterised by emerging but inconsistent frameworks	Governance and regulatory alignment are critical conditions for scaling blockchain-enabled circular economy solutions

Source: Author's synthesis.

Blockchain-enabled CE solutions therefore need to address technical, social, economic, and governance factors in a co-creative manner, echoing the BMI perspective. They also require a systems-level focus that goes beyond individual technologies or business models, which is consistent with the STS perspective.

Table 3 offers a cross-case analysis of the empirical data. It shows how blockchain as infrastructure, Service Design as an integrator, new business models, and governance conditions represent the greening of digital processes in the CE context.

Table 3. Synthesising Results: Blockchain and the Greening of Digital Processes (RQ1–RQ4).

Cross-case insight	**Cross-case evidence**	**Theoretical link**
1. Blockchain as enabling infrastructure	Digital product passports, real-time logistics tracking, NFT identities	Supports **STS** (system-level reconfiguration)
2. Service Design as socio-technical integrator	Co-design in supply chains improved adoption; absence hindered scaling	Aligns with **STS + BMI**
3. New circular business models	Compliance-as-a-service, product-as-a-service, fractional ownership	Confirms **BMI** as driver of CE innovation
4. Governance and regulatory alignment	Lack of legal clarity across all cases limited adoption	Interpreted as socio-technical precondition under **STS**

Source: Author's synthesis.

In combination, these cross-cases insights show that blockchain-enabled CE transitions cannot be adequately described as technology upgrades. Instead, they should be conceptualised as multi-level socio-technical transformations that combine:

Infrastructure (blockchain as digital infrastructure),

Design (Service Design for user experience and adoption),

Business Logic (novel circular business models), and

Governance (facilitating regulation and standards).

The Greening of Digital Processes lens better captures this systemic alignment than efficiency-oriented Industry X.0 narratives. Although Industry X.0 can still serve as a useful complementary lens for understanding how CE is embedded in digital industrial value streams, the findings of this thesis suggest that it requires a stronger focus on ecological objectives, user-centred design, and governance alignment in order to explain the scaling of blockchain-enabled circular models.

The findings of this dissertation therefore contribute to the broader discourse on digital sustainability by illustrating how blockchain and Service Design, in combination, operationalise the GDP paradigm by translating ecological and social objectives into digital infrastructures and platforms.

Figure 2 presents the conceptual framework applied throughout this dissertation. It conceptualises blockchain-enabled infrastructures as an enabling layer that is itself enabled and constrained by governance and regulation, as well as by Service Design, and which in turn shapes supply-chain processes, business-model innovation, and sustainability impacts. Whereas governance and regulation shape standards, regulatory requirements, and legal certainty, user-centred Service Design shapes usability, stakeholder participation, and technology adoption. Together, these dimensions shape the implementation and use of blockchain-enabled infrastructures built from technological components such as blockchain, smart contracts, and NFTs, which enable properties such as transparency, traceability, and automation. Together, these dimensions can enable innovation across business-model dimensions, including product-as-a-service, compliance-as-a-service, and NFT-enabled ownership structures. This may in turn lead to sustainability impacts such as increased transparency, resource circularity, inclusivity, and participation.

The model visually captures the main argument developed across the dissertation: blockchain-enabled CE adoption, and the related greening of digital processes, is a socio-technical phenomenon in which technology is only one of three interacting elements and must be combined with human-centred design and enabling governance structures.

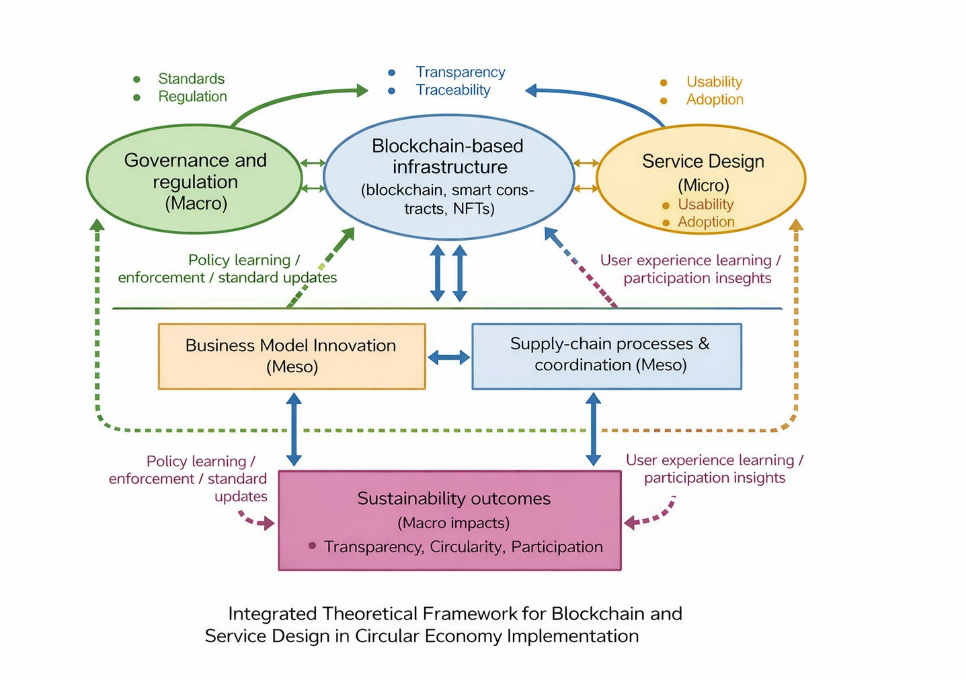

Figure 2. Integrated theoretical framework for blockchain and Service Design in circular economy implementation (Greening of Digital Processes lens). The framework positions governance and regulation (macro) and Service Design (micro) as shaping conditions for blockchain-enabled infrastructure (meso enabling layer), which enables business model innovation and supply-chain processes and coordination (meso) that contribute to sustainability outcomes (macro impacts). Arrows indicate key enabling relationships and feedback loops (policy learning and service improvement) across levels.
Source: Author's own elaboration.

4.2 Enhancing Transparency and Traceability through Blockchain

The empirical results from the three case studies show substantial potential for blockchain to overcome issues of transparency and traceability in CE systems. In the case of the Circular Electronics Platform, the blockchain-enabled digital product passports and NFTs enabled stakeholders to have access to irrefutable product histories, repairs, and claims about their sustainability. The traceability offered by these technologies to verify circular activities made it possible to overcome information asymmetries among producers, recyclers, and consumers in the processes of reuse and recycling.

The results of the research on these three blockchain-enabled CE solutions largely converge with prior research that recognised blockchain technology to promote traceability and auditability in product lifecycles (Kouhizadeh et al., 2021; Shojaei et al., 2021). It confirms that blockchain-enabled records allow greater trust and accountability in transactions involving the passing of products through their lifecycles, leading to higher stakeholder engagement in CE practices. At the same time, as reported by Saberi et al. (2019), several limitations, including a lack of interoperability and the still relatively high costs of the technology and associated organisation hinder more widespread diffusion.

From the lens of the Greening of Digital Processes (GDP) framework, blockchain should be regarded not only as an efficiency tool, but also as an ecological enabler of product lifecycle transparency, blending digital infrastructures and sustainability goals.

4.3 Business Model Innovation through Blockchain and NFTs

Aligning with BMI theory (Bocken et al., 2022), the results indicate that blockchain enables new value creation and capture patterns in CE ecosystems. In each case study, several business model innovations emerged:

1. NFT-based digital identities enabled product-as-a-service, peer-to-peer leasing, and reward-based recycling models.
2. Compliance-as-a-service was applied in smart supply chains to automate environmental reporting and lower administrative costs.
3. Blockchain passports underpinned aftermarket services for electronics, allowing for extended producer responsibility and consumer trust.

These results echo earlier claims about blockchain's transformative potential in CE (Pournader et al., 2019; De Giovanni, 2022; Dos Santos et al., 2021). However, consumer adoption was limited by unfamiliarity with tokenised platforms and unclear regulatory status of NFTs.

The results confirm that blockchain-enabled business models do not emerge merely from technology's affordances. They are co-constructed: blockchain offers the infrastructure, Service Design turns affordances into services, and governance conditions shape what is considered legitimate. In GDP terms, these innovations represent the intentional coupling of digital tools with ecological goals, driving value creation beyond extraction.

4.4 Institutional and Regulatory Challenges in Blockchain Adoption

Regulatory and governance factors were another critical precondition impacting all three cases. In the electronics industry, an unclear legal framework around digital passports of products and NFT ownership and property rights restricted institutional adoption.

In the logistics industry, the lack of harmonisation of international standards made it difficult to validate blockchain-enabled digital documents in foreign countries. In the decentralised consumer industry, lack of clarity on taxation and IP rights of digital assets, as well as enforceability of smart contracts, limited consumer and investor trust. From a practical viewpoint, blockchain-enabled solutions for the circular economy require legal and governance considerations to realise full scalability beyond pilot stages. Key questions relate to matters of property and ownership (e.g., what exactly is transferred when a token changes ownership and what rights does it practically have attached to it), liability (e.g., when information linked to a token is incorrect or incomplete, who is liable and how responsibility is distributed over involved parties) and enforceability (smart-contract-execution per se does not solve disputes nor can it replace law. Legally enforceable outcomes are dependent on agreed contractual terms, applicable law and dispute-resolution clauses. The technical benefits of blockchain infrastructures stand unaffected by these considerations while legal certainty and stakeholder trust alongside cross-border scalability possibilities face significant impacts. Regulatory approaches also differ across jurisdictions (more principles-based vs more prescriptive guidance), which affects how transferable and enforceable tokenised solutions are in cross-border settings.

This also aligns with previous research that found governance a key enabler of blockchain innovation (Casino et al., 2019; Steenmans & Taylor, 2021). While not explicitly linked to Institutional Theory in this study, the lack of legal framework and harmonisation of governance aspects can be seen as a practical precondition: without these, broad application of blockchain is not possible, and innovation remains at the pilot level.

From a GDP perspective, the digital sustainability aspects of both industries need to co-evolve with technology and regulation. Regulatory frameworks are needed to support the ecological intention in digital infrastructures so that it is not limited by institutional path dependency or lack of legal clarity.

From a policy perspective, clearly defined standards and interoperability requirements can mitigate implementation uncertainty and enable scaling of blockchain-enabled circular economy solutions. Especially new traceability and reporting infrastructures that are emerging (e.g. Digital Product Passports (DPPs) and sustainability reporting requirements such as the Corporate Sustainability Reporting Directive (CSRD) and the European Sustainability Reporting Standards (ESRS)**,** can further strengthen auditability and comparability across value chains (Petrik et al., 2026). These governance efforts can be complemented by established standards such as ISO 14001 (environmental management systems) and ISO 20400 (sustainable procurement guidance)**,** which help organisations translate sustainability requirements into operational processes and supplier expectations.

4.5 The Role of Service Design in Enhancing Blockchain Adoption

The data collected point to a strong correlation between Service Design factors and the scalability of blockchain-enabled CE systems. In the Smart Supply Chains case, the main barriers to adoption were related to system usability and a lack of understanding of regulations. While a formal co-design workshop and systematic prototyping process were not part of the study design, the stakeholders interviewed repeatedly highlighted the value of these methods in mitigating resistance and easing implementation. In particular, involving participants at an early stage created a sense of ownership and confidence in the blockchain system.

In the two cases with no Service Design methods applied (electronics platform and NFT marketplaces), stakeholders' challenges were more significant, including lower digital literacy, lack of understanding of system purpose, and weak adoption.

Overall, the present dissertation contributes to previous research in this area (Montecchi et al., 2019; Bai et al., 2022) by providing empirical evidence that usability and adoption are indeed issues and that SD may help address them. Rather than being just an enabler for information management and collaboration, SD is shown here as a strategic vehicle for scaling blockchain infrastructures, helping to match technological complexity with stakeholders' needs, lower cognitive barriers, and nurture trust.

Within the GDP framework, Service Design plays a systemic role in aligning the capabilities of digital infrastructures with technical viability, ecological, and social outcomes, making blockchain both technically feasible and socially inclusive.

4.6 Contributions to the Integrated Theoretical Framework

Study findings contribute to a tentative integrated framework connecting Socio-Technical Systems (STS) Theory and Business Model Innovation (BMI) Theory, reframed as a special case under the central paradigm of the Greening of Digital Processes.

From an STS perspective, findings support that blockchain adoption occurs in socio-technical ensembles: technology infrastructures, organisational practices, user design, and governance conditions co-evolve. Blockchain only took hold when synchronised with stakeholder capacity and regulatory legitimacy (Trist & Bamforth, 1951; Geels, 2002).

From a BMI perspective, findings confirm and extend previous research showing that blockchain facilitates entirely new value logics (e.g., product-as-a-service, peer-to-peer recycling), but only when expressed through design and governance into implementable models (Bocken et al., 2022).

Reframing institutional dynamics as governance conditions rather than relying on Institutional Theory alone provides a more operational explanation of adoption, particularly where regulatory clarity, organisational support, trust structures, digital readiness, and ecosystem engagement shape implementation pathways (Bennich, 2024; Ansah et al., 2023; Polcumpally et al., 2024; Mahula et al., 2025).

Taken together, these pieces reinforce the claim that blockchain in CE is best interpreted as a special case of the Greening of Digital Processes, a socio-technical (re)configuration integrating digital infrastructures, human-centred design, and governance conditions toward ecological ends.

4.7 Practical and Policy Implications

The insights gained from this research are of interest beyond academia. This section describes how stakeholders, particularly developers and policymakers, can apply these insights in practice.

Developers of blockchain solutions must understand that simply deploying technology does not constitute a complete solution. Blockchain solutions should follow Service Design principles centred around accessibility and stakeholder participation. More specifically, this could look like accessible design, participatory design, and standardisation around interoperability.

Policymakers can provide clearer guidelines for the governance and implementation of smart contracts, NFTs, and other blockchain-powered reporting systems. By standardising regulatory regimes, blockchain programmes can be scaled past the pilot stage. Moreover, governance systems should encourage collaborative creation between regulators, companies, and civil society.

Specifically, the European Union (EU) Digital Product Passport (DPP) can standardise lifecycle data parameters and improve interoperability standards along value chains. Implementation of CSRD/ESRS reporting requirements leads to increased demand for sustainability data which can be both traceable and auditable.

4.8 Addressing Research Gaps and Scope Conditions

This thesis responds to calls (Rejeb & Zailani, 2023) for more evidence of blockchain technologies in practical CE-related contexts. First, scholarly discourse has been speculative regarding blockchain's promise to facilitate CE transitions. This dissertation contributes new qualitative empirical evidence to this under-researched theme. Second, while some studies have described conceptual frameworks explaining potential blockchain transformation in CE (Hamzeh et al., 2021; Huang et al., 2021; Zheng et al., 2020), this thesis provides a more fine-grained qualitative analysis of blockchain, Service Design, and governance in empirical cases.

Results are most applicable to contexts where numerous stakeholders require interoperable traceability/accountability throughout the value chain (repair/return loops, compliance-reporting initiatives, cross-border commerce). Applicability is reduced where regulation is uncertain, technological interoperability is poor, or stakeholders have few incentives to participate. Tokenisation for consumer-facing use cases requires clear utility and legal certainty for end-users. Back-end applications (automating traceability/compliance) could see increased adoption if there are standardised requirements for on-chain data/reporting.

Key barriers (prioritised):

1. Institutional (highest impact): legal uncertainty; lack of harmonised standards/interoperability; unclear accountability
2. Organisational: weak data governance; missing partner alignment; low internal capabilities
3. Economic: high setup/integration cost; unclear return on investment (ROI); limited resources among small and medium-sized enterprises (SMEs)
4. Technological: integration with legacy systems; data quality; privacy/security constraints

Limitations and future research directions are presented in the Conclusion section "Limitations and Future Research Directions"

Overall, the findings represent an initial step in research on blockchain and the circular economy. The dissertation indicates that blockchain can support CE transformations, while highlighting the critical roles of Service Design and governance conditions. Further research should address the identified limitations and test the GDP framework in other contexts to advance theoretical and practical understanding of blockchain in sustainable circular transitions.

Taken together, these findings clarify the scope conditions under which blockchain can support circular economy transitions. The conclusion now summarises the dissertation's overall contributions, limitations, and implications.

5 Conclusion

The aim of this dissertation was to develop a theoretically grounded and empirically informed framework explaining how digitalisation—specifically blockchain-enabled infrastructures—can enable or constrain circular economy implementation when viewed through the lens of the Greening of Digital Processes (GDP). The findings show that, while blockchain functions as a form of enabling infrastructure, this alone is not sufficient to generate or scale circular economy outcomes. Two additional pillars are needed: user-centred Service Design and enabling governance. Together, these elements form a socio-technical model that not only integrates the findings of this dissertation but also clarifies the conditions under which digitally enabled circular transitions can be scaled more broadly.

Empirically, the dissertation examined how blockchain, smart contracts, NFTs, and Service Design methods support and accelerate circular economy business model transitions through an embedded qualitative multiple-case study. It focused on technological and business model innovation, use, and governance dynamics. It further investigated how blockchain-enabled solutions could help overcome transparency, traceability, usability, and regulatory challenges that currently limit CE scalability.

5.1 Summary of Research Findings

The empirical findings, derived from the three case studies, enrich the current body of knowledge on blockchain's role in CE: the blockchain-enabled circular electronics platform, smart supply chains powered by Service Design, and NFT-enhanced smart contracts for decentralised CE models.

The findings indicate that blockchain effectively enhanced transparency, traceability, and trust in complex supply chains across all three cases. Particularly, NFT-based digital product passports and smart contracts enabled more effective product lifecycle management, material recovery processes, and accountability mechanisms between producers, recyclers, and consumers.

The cases also highlighted the potential of blockchain for business model innovation, particularly in decentralised, service-oriented, and incentive-based models. These included tokenised asset sharing, product-as-a-service, and NFT-based recycling incentives, although adoption was limited by institutional and user-related barriers.

All three cases encountered high setup costs, limited interoperability, legal uncertainties, and uneven regulatory support. Regarding Service Design, Case 2 demonstrated the importance of participatory approaches and usability considerations for adoption. The lack of structured SD methods in the other two cases was associated with lower user engagement and more pronounced adoption challenges.

5.2 Theoretical Contributions

The following sections discuss the dissertation's contributions to the two primary theoretical traditions on which it draws: Socio-Technical Systems (STS) theory and Business Model Innovation (BMI) theory. The dissertation's holistic contribution to theory and practice, in terms of developing a new and systemic framework for understanding and enacting sustainability transitions, is summarised in the final section. In contrast to prior studies that tend to foreground either technological affordances or circular business models in isolation, this dissertation shows that blockchain-enabled circularity is best explained as a conditional socio-technical process shaped jointly by infrastructure, governance, Service Design, and value-creation logic.

Socio-Technical Systems (STS) theory: The dissertation contributes to STS perspectives on blockchain by empirically showing how its adoption, use, and scaling are always deeply entangled with social, organisational, and governance contexts. The cases demonstrated that the technical affordances of blockchain are neither necessary nor sufficient for implementation success. Enabling and governing conditions for adoption included alignment with stakeholder capacities and willingness, user-centred design where applied, and regulatory legitimacy.

Business Model Innovation (BMI) theory: The dissertation provides an empirical contribution to BMI theory by showing how the design and governance of blockchain infrastructures can enable new value creation and capture mechanisms. Specifically, it showcases sustainable business models (product-as-a-service, peer-to-peer leasing, incentivised take-back for recycling) that are enabled by blockchain infrastructures and co-constructs of technology, stakeholder needs, and governing conditions, rather than being adopted solely because of technical affordances.

Greening of Digital Processes (GDP): The dissertation applied and extended the GDP framework, an emerging conceptual lens for unpacking interactions between digitalisation and sustainability. It shows how blockchain can serve as a core infrastructure within this framework, while Service Design translates between the infrastructure and adopters, and governance mechanisms establish legitimacy and enable scaling. The cases demonstrated the presence or absence of formal Service Design activity, supporting the idea that design is a critical determinant of adoption.

These contributions provide building blocks toward a holistic framework for understanding blockchain's potential to enable sustainable circular transitions and for scaling them in the context of socio-technical transitions more broadly.

Theoretically, the concept of Greening of Digital Processes can be situated in the wider literature on digital sustainability and green digital transformation (Degli Esposti et al., 2021). Scholars have highlighted the desirability of deliberately designed, sustainable digital infrastructures that minimise environmental impact and support system-level sustainability transitions (Melville, 2010; Falcke et al., 2024). Recent literature shows that digital technologies, from blockchain to AI, are increasingly deployed for ecological purposes—a trend often referred to as green digital transformation. By conceptualising blockchain adoption in terms of GDP, this dissertation anchors its analysis in this nascent but relevant field at the intersection of digitalisation and sustainability.

5.3 Practical Implications

The results have implications for practitioners and policymakers:

Practitioners and businesses: The cases confirmed that blockchain provides opportunities to underpin circular supply chains through increased transparency and accountability. However, usability issues were most pronounced in cases with less structured Service Design, suggesting that a user-centred and participatory approach should be adopted to ensure usability and adoption. Smart Supply Chains showed that stakeholder involvement increased ownership and trust, whereas the electronic platforms and NFT models suffered from confusion and lower adoption. Early participatory approaches can increase successful adoption and long-term viability of blockchain in CE.

Developers and technology providers: Interoperability, scalability, and user-friendly interfaces were recurring issues across cases. Developers and tech providers should integrate these criteria early in design and implementation. Collaboration with industry actors and governance bodies can help create systems more aligned with real-world needs, reducing duplication and fragmentation of standards.

Policymakers and regulators: Regulatory uncertainty regarding blockchain adoption, NFTs, smart contracts, and digital product passports limited institutional trust. Well-defined legal frameworks and internationally harmonised standards are needed. Policymakers could clarify ownership rules, liability, and reporting obligations to build trust and unlock investment.

General implication: Blockchain adoption for CE should be considered a socio-technical process. The three elements, digital infrastructure (blockchain), design (user-centred Service Design), and governance (legal and institutional support) are interdependent for success.

5.4 Limitations and Future Research Directions

Methodological limitations: As qualitative case study research, this dissertation focused on emerging, complex socio-technical patterns. This limits generalisability beyond the cases studied. Comparative analysis allowed for cross-case abstractions, but further testing at higher industry and context levels is needed. Future research could use quantitative or mixed methods to examine blockchain-enabled CE adoption patterns at larger scales.

Geographical focus: Most cases were European. Institutional, cultural, and regulatory differences elsewhere may influence adoption patterns. Cross-national comparative research could enhance understanding of blockchain-enabled CE in different settings.

Temporal aspect: Due to rapid technological development, this dissertation represents a snapshot of blockchain adoption. Some challenges, such as scalability, interoperability, or regulatory uncertainty, may have been addressed since. Longitudinal research is needed to track blockchain-enabled CE solutions over time.

Behavioural, privacy/data-governance dimensions: Although this thesis concentrated on behavioural user acceptance elements and governance prerequisites, it did not investigate in depth (i) privacy-preserving traceability frameworks/data governance principles for GDPR compliance on immutable databases, (ii) collaborative governance approaches for consortium/permissioned blockchain networks in CE (allocation of decision rights, conflict management, responsibility, incentive mechanisms), and (iii) ongoing maintenance and longevity of NFT-based passports (e.g. permanence of metadata, standardisation, portability between networks, smart legal contracts). These dimensions are essential for institutional trust and upscaling. Upcoming research could thus pair behavioural end-user adoption research with legal–technical assessments on privacy, governance, and certification longevity. Despite these limitations, the thesis provides empirically and theoretically nuanced insights into the socio-technical conditions of blockchain-enabled CE. Broader, comparative, and longitudinal research would advance both theory and practice in this emerging field.

5.5 Final Reflections and Closing Remarks

The study indicates that blockchain can be an important enabler of CE solutions when combined with Service Design and appropriate governance. Findings reveal that blockchain's potential derives not only from technological capabilities but also from alignment with human-centred design and regulatory frameworks. The infrastructure-design-governance triad offers pathways for CE solutions to address usability challenges, build trust, and scale initiatives.

Digitalisation of CE should be conceptualised as a socio-technical transition rather than mere technology replacement. From a GDP perspective, digital infrastructures need to be purpose-driven toward ecological ends. Blockchain, NFTs, and smart contracts can increase transparency, traceability, and enable new business models, but sustainability impact is realised when embedded in co-design processes and aligned with governance.

Scaling blockchain-enabled CE models depends on collective efforts across technology development, industry practices, policy, and academia. Interdisciplinary collaboration ensures digital innovations are technically feasible, socially inclusive, and ecologically effective.

By providing empirically grounded insights and a unifying framework, the dissertation contributes to the emerging discourse on digital sustainability. Blockchain-enabled CE solutions can potentially move beyond pilot projects to become integral to a sustainable economy. This research offers conceptual foundations and practical guidance for scalable, inclusive, and regenerative blockchain-enabled circular transitions.

In conclusion, blockchain's potential for the circular economy is realised only when positioned within the Greening of Digital Processes: a socio-technical transition in which digital infrastructures are designed according to user-centred principles and enabled through adaptive governance. This dissertation clarifies this confluence and provides an integrative framework and practical guidance for upscaling blockchain-facilitated circular solutions that are both socially equitable and technically resilient.

List of Figures

References

Accenture. (2017). *Industry X.0: Realizing digital value in industrial sectors.* Accenture Report.

Aivazidou, E., Tsolakis, N., & Mollona, E. (2025). *Circular Economy 5.0 on Its Way: A Digital Sustainability Transition*. Academy of Management Perspectives. DOI: 10.5465/amp.2023.0161

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

Ansah, B. O., Voss, W., Asiama, K. O., & Wuni, I. Y. (2023). *A systematic review of the institutional success factors for blockchain-based land administration. Land Use Policy, 125*, 106473. https://doi.org/10.1016/j.landusepol.2022.106473

Antikainen, M., Uusitalo, T., & Kivikytö-Reponen, P. (2018). Digitalisation as an enabler of circular economy. *Procedia CIRP, 73*, 45–49. https://doi.org/10.1016/j.procir.2018.04.027

Atzori, M. (2017). *Blockchain technology and decentralised governance: Is the state still necessary?* Journal of Governance and Regulation, 6(1), 45–62. https://doi.org/10.22495/jgr_v6_i1_p5

Bai, C., Dallasega, P., Orzes, G., & Sarkis, J. (2022). Industry 4.0 technologies assessment: A sustainability perspective. *International Journal of Production Economics, 246*, 108490. DOI: 10.1016/j.ijpe.2020.107776

Bellavista, P., Esposito, C., Foschini, L., Giannelli, C., Mazzocca, N., & Montanari, R. (2021). Interoperable blockchains for highly-integrated supply chains in collaborative manufacturing. Sensors, 21(15), 4955. https://doi.org/10.3390/s21154955

Bennich, A. (2024). *The digital imperative: Institutional pressures to digitalise. Technology in Society, 76*, 102436. DOI: 10.1016/j.techsoc.2023.102436

Blomkvist, J., Holmlid, S., & Segelström, F. (2010). Service Design Research: Which direction do we want it to take? In S. Holmlid, J.-V. Nisula, & S. Clatworthy (Eds.), ServDes 2010: Exchanging Knowledge, 1–3 December, Linköping, Sweden. https://doi.org/10.21606/servdes2010.13

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

Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production, 65*, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039

Bocken, N. M. P., Strupeit, L., Whalen, K., & Nußholz, J. L. K. (2019). A review and evaluation of circular business model innovation tools. Sustainability, 14(1), 444. https://doi.org/10.3390/su11082210

Bocken, N., & Konietzko, J. (2022). Circular business model innovation in consumer-facing corporations. *Technological Forecasting and Social Change, 185*, 122076. https://doi.org/10.1016/j.techfore.2022.122076

Böhmecke-Schwafert, M., Wehinger, M., & Teigland, R. (2022). Blockchain for the circular economy: Theorizing blockchain’s role in the transition to a circular economy through an empirical investigation. Business Strategy and the Environment, 31(8), 3786–3801. https://doi.org/10.1002/bse.3032

Braun, V., & Clarke, V. (2021). *Thematic Analysis: A Practical Guide*. London: SAGE Publications.
Bücker, C., Pantel, J., & Geissdoerfer, M. (2025). Digital technologies as enablers of the circular economy: An empirical perspective on the role of companies in driving customer behaviour change. R&D Management, 55(5), 1595–1633.
Buterin, V. (2014). A next-generation smart contract and decentralised application platform. *Ethereum White Paper*. https://ethereum.org/en/whitepaper/
Camacho-Otero, J., Boks, C., & Pettersen, I. N. (2018). Consumption in the circular economy: A literature review. Sustainability, 10(8), 2758.
Carayannis, E. G., Dezi, L., Gregori, G. L., & Calo, E. (2022). Smart environments and circular economy: Innovation dynamics, entrepreneurial ecosystems, and policy implications. Journal of the Knowledge Economy, 13(1), 28–52.
Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). *A systematic literature review of blockchain-based applications: Current status, classification and open issues*. Telematics and Informatics, 36, 55–81. https://doi.org/10.1016/j.tele.2018.11.006
Chauhan, C., Parida, V., & Dhir, A. (2022). Linking circular economy and digitalisation technologies: A systematic literature review. Technological Forecasting and Social Change, 177, 121508.
CNIL. (2018). *Blockchain and the GDPR: Solutions for a responsible use of the blockchain in the context of personal data*. Commission Nationale de l'Informatique et des Libertés.
Cornelius, K. (2021). Betraying blockchain: Accountability, transparency and document standards for non-fungible tokens (NFTs). *Information, 12*(9), 358. https://doi.org/10.3390/info12090358
Creswell, J. W. (2013). Qualitative inquiry and research design: Choosing among five approaches (3rd ed.). Sage Publications.
Creswell, J. W., & Creswell, J. D. (2022). *Research Design: Qualitative, Quantitative, and Mixed Methods Approaches* (6th ed.). SAGE Publications.
Creydt, M., & Fischer, M. (2019). Blockchain and more—Digital technologies for traceability and transparency in sustainable food supply chains. *Journal of Food Science*, 84(6), 1384–1397. https://doi.org/10.1111/1750-3841.14607
De Filippi, P., & Loveluck, B. (2016). The invisible politics of Bitcoin: Governance crisis of a decentralised infrastructure. Internet Policy Review, 5(3). https://doi.org/10.14763/2016.3.427
De Giovanni, P. (2022). *Leveraging the circular economy with a closed-loop supply chain and a reverse omnichannel using blockchain technology and incentives*. International Journal of Operations & Production Management, 42(7), 959–994
de Pádua Pieroni, M., Pigosso, D. C. A., & McAloone, T. C. (2018). Sustainable qualifying criteria for designing circular business models. Procedia CIRP, 69, 799–804. https://doi.org/10.1016/j.procir.2017.11.014
Dos Santos, R. B., Torrisi, N. M., & Pantoni, R. P. (2021). Third party certification of agri-food supply chain using smart contracts and blockchain tokens. Sensors, 21(16), 5307. https://doi.org/10.3390/s21165307
Dounas, T., Jabi, W., & Lombardi, D. (2021). Non-fungible building components: Using smart contracts for a circular economy in the built environment. Blucher Design Proceedings.
Eisenhardt, K. M. (1989). Building theories from case study research. Academy of Management Review, 14(4), 532–550.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. Academy of Management Journal, 50(1), 25–32.

Ellen MacArthur Foundation. (2019). *Completing the picture: How the circular economy tackles climate change.* Ellen MacArthur Foundation. https://ellenmacarthurfoundation.org

European Commission. (2021). *2030 Digital Compass: The European way for the digital decade.* Publications Office of the European Union. https://ec.europa.eu

Falcke, L. A., Zobel, A. K., Yoo, Y., & Tucci, C. L. (2024). Digital sustainability strategies: Digitally-enabled and digital-first innovation for net zero. Academy of Management Perspectives. https://doi.org/10.5465/amp.2023.0169

Falcke, L. A., Zobel, A.-K., Yoo, Y., & Tucci, C. L. (2024). *Digital Sustainability Strategies: Digitally Enabled and Digital-First Innovation for Net Zero. Academy of Management Perspectives.* DOI: 10.5465/amp.2023.0169

Finck, M. (2019). *Blockchain and the General Data Protection Regulation*. European Parliamentary Research Service.

Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. Research Policy, 31(8–9), 1257–1274. https://doi.org/10.1016/S0048-7333(02)00062-8

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

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

Greene, M., Hobson, K., & Jaeger-Erben, M. (2024). Bringing the circular economy home – Insights from socio-technical perspectives on everyday consumption. Cleaner and Responsible Consumption, 12, 100157.

Hariyani, D., Hariyani, P., Mishra, S., & Sharma, M. K. (2024). *Leveraging digital technologies for advancing circular economy practices and enhancing life cycle analysis: A systematic literature review. Waste Management Bulletin, 2*(3), 69–83. https://doi.org/10.1016/j.wmb.2024.06.007

Kalmykova, Y., Sadagopan, M., & Rosado, L. (2018). Circular economy: From review of theories and practices to development of implementation tools. *Resources, Conservation and Recycling, 135,* 190–201. https://doi.org/10.1016/j.resconrec.2017.10.034

Khan, M. I., Yasmeen, T., Hadi, N. U., Asif, M., Farooq, M., Kurniawan, T. A., Khan, M., & Al-Ghamdi, S. G. (2026). Digital sustainability as an emerging paradigm: Insights from the Saudi Arabian experience and global implications. Journal of Open Innovation: Technology, Market, and Complexity, 12(1), 100731. https://doi.org/10.1016/j.joitmc.2026.100731

Kirchherr, J., Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production, 175,* 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111

Kirchherr, J., Piscicelli, L., Bour, R., Kostense-Smit, E., Muller, J., Huibrechtse-Truijens, A., & Hekkert, M. (2018). Barriers to the circular economy: Evidence from the European Union (EU). Ecological Economics, 150, 264–272. https://doi.org/10.1016/j.ecolecon.2018.04.028

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

Kirchherr, J., Reike, D., & Hekkert, M. (2018). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation and Recycling, 127*, 221–232. http://dx.doi.org/10.2139/ssrn.3037579

Klein, H. K., & Myers, M. D. (1999). A set of principles for conducting and evaluating interpretive field studies in information systems. MIS Quarterly, 23(1), 67–94.

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics, 143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Koskela-Huotari, K., Edvardsson, B., Jonas, J. M., & Vargo, S. L. (2016). Innovation in service ecosystems—Breaking, making, and maintaining institutionalised rules of resource integration. *Journal of Business Research, 69*(8), 2964–2971. https://doi.org/10.1016/j.jbusres.2016.02.029

Kouhizadeh, M., Saberi, S., & Sarkis, J. (2021). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. *International Journal of Production Economics, 231*, 107831. https://doi.org/10.1016/j.ijpe.2020.107831

Kristoffersen, E., Blomsma, F., Mikalef, P., & Li, J. (2020). The smart circular economy: A digital-enabled circular strategies framework for manufacturing companies. *Journal of Business Research, 120*, 241–261. http://dx.doi.org/10.1016/j.jbusres.2020.07.044

Kristoffersen, E., Blomsma, F., Mikalef, P., & Li, J. (2021). *The effects of business analytics capability on circular economy implementation, resource orchestration capability, and firm performance: A resource-based view*. Technological Forecasting and Social Change, 171, 120972. https://doi.org/10.1016/j.techfore.2021.120972

Kristoffersen, E., Mikalef, P., Blomsma, F., & Li, J. (2021). The effects of business analytics capability on circular economy implementation, resource orchestration capability, and firm performance. International Journal of Production Economics, 239, 108205. https://doi.org/10.1016/j.ijpe.2021.108205

Lakatos, E. S., Rhazzali, A. L., Pernice, U., Panait, O. B., Arion, F. H., & Cioca, L.-I. (2026). Integrating emerging digital technologies into circular economy practices. *Processes, 14*(3), 556. https://doi.org/10.3390/pr14030556

Liao, H.-T., Pan, C.-L., & Zhang, Y. (2023). Smart digital platforms for carbon neutral management and services: Business models based on ITU standards for green digital transformation.Frontiers in Ecology and Evolution, 11, 1134381. https://doi.org/10.3389/fevo.2023.1134381

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Sage Publications.

Mahula, S., Tan, E., & Crompvoets, J. (2025). *The impact of institutions on blockchain adoption in the European public sector: a qualitative comparative analysis. Data & Policy, 7*, e84. https://doi.org/10.1017/dap.2025.10037

Markard, J., Raven, R., & Truffer, B. (2012). Sustainability transitions: An emerging field of research and its prospects. *Research Policy, 41*(6), 955–967. https://doi.org/10.1016/j.respol.2012.02.013

McAloone, T. C., & Pigosso, D. C. A. (2018). Designing Product Service Systems for a Circular Economy. In M. Charter (Ed.), *Designing for the Circular Economy* (pp. 102–112). Routledge.

Melville, N. P. (2010). Information systems innovation for environmental sustainability. *MIS Quarterly, 34*(1), 1–21.
Millar, N., McLaughlin, E., & Börger, T. (2019). The circular economy: Swings and roundabouts? *Ecological Economics, 158,* 11–19. https://doi.org/10.1016/j.ecolecon.2018.12.012
Montecchi, M., Plangger, K., & Etter, M. (2019). It's real, trust me! Establishing supply chain provenance using blockchain. *Business Horizons, 64*(3), 373–384. https://doi.org/10.1016/j.bushor.2019.01.008
Morkunas, V. J., Paschen, J., & Boon, E. (2019). How blockchain technologies impact your business model. Business Horizons, 62(3), 295–306. https://doi.org/10.1016/j.bushor.2019.01.009
Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. https://bitcoin.org/bitcoin.pdf
Orlikowski, W. J., & Baroudi, J. J. (1991). Studying information technology in organisations: Research approaches and assumptions. Information Systems Research, 2(1), 1–28.
Perotti, F. A., Zollo, L., Cautela, C., & Caputo, A. (2024). Investigating digital technologies' implementation in circular businesses: Evidence from the going circular path. Journal of Management & Organization, 30(3), 421–451.
Petrik, D., Strobel, G., Schoormann, T., Möller, F., Hoppe-Ludwig, C., & Springer, V. (2026). Digital product passports. *Electronic Markets, 36*(1), 25. https://doi.org/10.1007/s12525-026-00877-0
Philipp, R., Gerlitz, L., & Prause, G. (2019). Smart contracts for entrepreneurial collaboration in logistics networks. In Proceedings of the 11th International Scientific Conference "New Challenges of Economic and Business Development – 2019: Incentives for Sustainable Economic Growth" (pp. 652–663). University of Latvia.
Pieroni, M. P., McAloone, T. C., & Pigosso, D. C. A. (2019). Business model innovation for circular economy and sustainability: A review of approaches. *Journal of Cleaner Production, 215*, 198–216. https://doi.org/10.1016/j.jclepro.2019.01.036
Pinch, T. J., & Bijker, W. E. (1987). The social construction of facts and artifacts. In Bijker, W. E., Hughes, T. P., & Pinch, T. J. (Eds.), The social construction of technological systems (pp. 17–50). MIT Press.
Polcumpally, A. T., Pandey, K. K., Kumar, A., & Samadhiya, A. (2024). *Blockchain governance and trust: A multi-sector thematic systematic review and exploration of future research directions. Heliyon, 10*(12), e32975. https://doi.org/10.1016/j.heliyon.2024.e32975
Pournader, M., Shi, Y., Seuring, S., & Koh, S. C. L. (2019). Blockchain applications in supply chains, transport and logistics: A systematic review of the literature. *International Journal of Production Research, 58*(7), 2063–2081. https://doi.org/10.1080/00207543.2019.1650976
Ranta, V., Aarikka-Stenroos, L., & Väisänen, J.-M. (2021). Digital technologies catalyzing business model innovation for circular economy—Multiple case study. Resources, Conservation & Recycling, 164, 105155.
Rejeb, A., & Zailani, S. (2023). Blockchain and circular economy: A systematic literature review. *Sustainable Production and Consumption, 35*, 177–195. https://doi.org/10.13044/j.sdewes.d10.0436

Rejeb, A., Rejeb, K., Keogh, J. G., & Süle, E. (2025). *When Industry 5.0 Meets the Circular Economy: A Systematic Literature Review. Circular Economy and Sustainability, 5*(4), 2621–2652. https://doi.org/10.1007/s43615-025-00570-y

Rip, A., & Kemp, R. (1998). Technological change. In S. Rayner & E. L. Malone (Eds.), *Human choice and climate change* (Vol. 2, pp. 327–399). Columbus, OH: Battelle Press.

Rosa, P., Sassanelli, C., & Terzi, S. (2020). Towards circular business models: A systematic literature review on classification frameworks and archetypes. Journal of Cleaner Production, 236, 117696.

Rosati, P., Lynn, T., Kreps, D., & Conboy, K. (2024). *Digital Sustainability: Key Definitions and Concepts.* In *Digital Sustainability: Leveraging Digital Technology to Combat Climate Change* (pp. 1–24). Springer. https://doi.org/10.1007/978-3-031-61749-2_1

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). *Blockchain technology and its relationships to sustainable supply chain management*. International Journal of Production Research, 57(7), 2117–2135. https://doi.org/10.1080/00207543.2018.1533261

Sangiorgi, D. (2011). Transformative services and transformation design. *International Journal of Design, 5*(2), 29–40.

Sarker, S., Xiao, X., & Beaulieu, T. (2013). Qualitative studies in information systems: A critical review and some guiding principles. MIS Quarterly, 37(4), iii–xviii.

Schöggl, J.-P., Rusch, M., Stumpf, L., & Baumgartner, R. J. (2023). Implementation of digital technologies for a circular economy and sustainability management in the manufacturing sector. Sustainable Production and Consumption, 35, 401–410.

Shojaei, A., Ketabi, R., Razkenari, M., Hakim, H., & Wang, J. (2021). Enabling a circular economy in the built environment sector through blockchain technology. Journal of Cleaner Production, 294, 126352.

Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. Research Policy, 34(10), 1491–1510. https://doi.org/10.1016/j.respol.2005.07.005

Steenmans, K., & Taylor, M. (2021). *Regulatory opportunities and challenges for blockchain adoption for circular economies*. Journal of Industrial Ecology, 25(6), 1530–1541. https://doi.org/10.1111/jiec.13131

Stickdorn, M., Hormess, M. E., Lawrence, A., & Schneider, J. (2018). *This is Service Design doing: Applying Service Design thinking in the real world*. O'Reilly Media.

Sunny, J., Undralla, N., & Pillai, V. M. (2020). Supply chain transparency through blockchain-based traceability: An overview with demonstration. *Computers & Industrial Engineering, 150*, 106895. https://doi.org/10.1016/j.cie.2020.106895

Teece, D. J. (2010). Business models, business strategy and innovation. *Long Range Planning, 43*(2–3), 172–194.

Trist, E. L., & Bamforth, K. W. (1951). Some social and psychological consequences of the longwall method of coal-getting. *Human Relations, 4*(1), 3–38. https://doi.org/10.1177/001872675100400101

Upadhyay, A. (2021). Blockchain technology and the circular economy: Implications for sustainability and social responsibility. *Journal of Cleaner Production, 263,* 121241. https://doi.org/10.1016/j.jclepro.2020.121241

Walsham, G. (1995). Interpretive case studies in IS research: Nature and method. European Journal of Information Systems, 4(2), 74–81.

Wang, Q., Li, R., Wang, Q., & Chen, S. (2021). *Non-fungible token (NFT): Overview, evaluation, opportunities and challenges*. arXiv:2105.07447. https://doi.org/10.48550/arXiv.2105.07447.

Wang, Y., Han, J., & Beynon-Davies, P. (2018). Understanding blockchain technology for future supply chains: A systematic literature review and research agenda. *Supply Chain Management, 26*(2), 208–224.

Wang, Z., Gao, J., & Wei, X. (2023). Do NFTs' owners really possess their assets? A first look at the NFT-to-Asset connection fragility. In Proceedings of the ACM Web Conference 2023 (pp. 2099–2109). Association for Computing Machinery. https://doi.org/10.1145/3543507.3583205

Yin, R. K. (2018). *Case Study Research and Applications: Design and Methods* (6th ed.). SAGE Publications.

Zott, C., Amit, R., & Massa, L. (2011). The business model: Recent developments and future research. *Journal of Management, 37*(4), 1019–1042.

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Abstract

Digitalisation for the Circular Economy: Blockchain, Service Design, and the Greening of Digital Processes

In the context of the global transition towards a circular economy (CE), systemic and transformative solutions are needed to scale up regenerative business models in contrast to the predominant linear "take–make–waste" production–consumption system. Blockchain-enabled solutions are decentralised, transparent, and programmable digital infrastructures that have been proposed as promising enablers of CE. However, their application has so far been limited by technological immaturity, regulatory uncertainty, and low user uptake.

This dissertation examines how blockchain technology, smart contracts, non-fungible tokens (NFTs), and Service Design can support the development and scaling of circular business models, with particular attention to user-centred design. The research is informed by the Greening of Digital Processes (GDP) perspective, which serves as the overarching analytical framework for the dissertation, its three constituent papers, and a related synthesis publication. GDP conceptualises CE innovation through three interrelated dimensions: (a) blockchain as enabling infrastructure, (b) Service Design as an accelerator of adoption and scaling, and (c) governance as an essential condition for scaling.

The dissertation uses a qualitative multiple-case study design in which expert interviews, document analysis, and observations provide the main sources of empirical data. The three cases were: (a) a blockchain-enabled CE electronics platform with digital product passports; (b) a smart cross-border supply chain incorporating Service Design; and (c) an NFT-based smart-contract application enabling decentralised circular business models.

The findings indicate that blockchain technology can contribute to greater transparency, lifecycle traceability, and accountability, as well as to business model innovations oriented towards services and incentives. Service Design, in turn, can improve usability and user acceptance in circular use cases by linking technical features to real-world workflows. At the same time, regulatory uncertainty and the lack of standards remain the most prominent challenges to scaling blockchain-enabled CE solutions.

The dissertation and its three constituent papers make three theoretical contributions. First, the GDP perspective is advanced as a systemic framework for CE research that explains digitally enabled circular transitions in a way that complements existing socio-technical systems and business model innovation research. Second, Service Design is shown to mediate between technological possibilities and user uptake in blockchain-enabled CE applications. Third, by combining empirical findings across three cases, the dissertation identifies the key governance requirements for scaling blockchain-enabled solutions in CE.

In practical terms, the dissertation provides recommendations for technology developers, regulators, and CE practitioners regarding the design, regulation, and implementation of blockchain-enabled CE solutions. Finally, it identifies avenues for future research, including consumer engagement with tokenised incentive schemes, the application of specific blockchain use cases in other sectors, and longitudinal studies of how digital infrastructures for CE evolve over time.

Lühikokkuvõte

Digitaliseerimine ringmajanduse toetamiseks: plokiahel, teenusedisain ja digitaalsete protsesside keskkonnahoidlikumaks muutmine

Üleilmse ringmajandusele ülemineku kontekstis on vaja süsteemseid ja ümberkujundavaid lahendusi, mis võimaldaksid laiendada väärtust taastavaid ärimudeleid ning vähendada domineeriva lineaarse „võta–tooda–viska ära" tootmis- ja tarbimissüsteemi ulatust. Plokiahelapõhiseid lahendusi on käsitletud ringmajanduse võimaldajatena, kuna olemuselt on tegemist detsentraliseeritud, läbipaistva ja programmeeritava digitaalse taristuga. Seni on rakenduste kasutuselevõttu siiski piiranud tehnoloogia ebaküpsus, regulatiivne ebakindlus ja vähene kasutajate huvi.

Doktoritöös uuritakse, kuidas plokiaheltehnoloogia, nutilepingud, mittevahetatavad tokenid (NFT-d) ja teenusedisain saavad toetada ringmajanduslike ärimudelite arendamist ja skaleerimist, pöörates erilist tähelepanu kasutajakesksele disainile. Uurimus lähtub digitaalsete protsesside keskkonnahoidlikumaks muutmise vaatenurgast (Greening of Digital Processes, GDP), mis toimib väitekirja, selle kolme aluseks oleva publikatsiooni ning ühe seotud sünteesiva publikatsiooni üldise analüütilise raamistikuna. GDP käsitleb ringmajanduslikku innovatsiooni kolme läbipõimunud mõõtme kaudu: (a) plokiahel kui võimaldav taristu, (b) teenusedisain kui kasutuselevõttu ja skaleerimist toetav tegur ning (c) valitsemine kui skaleerimise oluline eeltingimus.

Väitekirjas kasutatakse kvalitatiivset mitmikjuhtumi uuringu disaini, mille peamised empiirilised andmeallikad on ekspertintervjuud, dokumendianalüüs ja vaatlused. Uuritud kolm juhtumit olid järgmised: (a) plokiahelapõhine ringmajanduslik elektroonikaplatvorm digitaalsete tootepassidega, (b) teenusedisaini integreeriv nutikas piiriülene tarneahel ning (c) NFT-põhine nutilepingu rakendus, mis võimaldab detsentraliseeritud ringmajanduslikke ärimudeleid.

Tulemused näitavad, et plokiaheltehnoloogia võib suurendada läbipaistvust, elutsükli jälgitavust ja vastutust ning toetada teenuste- ja stiimulipõhiseid uuendusi ärimudelites. Teenusedisain võib omakorda parandada kasutatavust ja kasutajate omaksvõttu ringmajanduslikes rakendustes, sidudes tehnilised lahendused tegelike töövoogudega. Samal ajal jäävad regulatiivne ebakindlus ja standardite puudumine plokiahelapõhiste ringmajanduslahenduste skaleerimise peamisteks takistusteks.

Väitekiri ja kolm selle aluseks olevat publikatsiooni annavad kolm peamist teoreetilist panust. Esiteks arendatakse edasi GDP vaatenurka kui süsteemset raamistikku ringmajanduse uurimiseks, mis aitab selgitada digitaalselt võimaldatud ringmajanduslikke üleminekuid viisil, mis täiendab senist sotsiotehniliste süsteemide ja ärimudeliinnovatsiooni käsitlevat uurimistööd. Teiseks näidatakse, et teenusedisain vahendab tehnoloogiliste võimaluste ja kasutajatepoolse omaksvõtu vahelist seost plokiahelapõhistes ringmajanduse rakendustes. Kolmandaks tuuakse kolme juhtumi empiiriliste tulemuste ühendamise kaudu esile peamised valitsemisalased eeldused, mis on vajalikud plokiahelapõhiste lahenduste skaleerimiseks ringmajanduses.

Praktilisest vaatenurgast pakub käesolev väitekiri soovitusi tehnoloogiate arendajatele, regulaatoritele ja ringmajanduse praktikutele plokiahelapõhiste ringmajanduslahenduste disaini, regulatsiooni ja rakendamise kohta. Samuti osutab töö võimalikele edasistele

uurimissuundadele, sealhulgas tarbijate kaasamisele tokeniseeritud stiimulisüsteemidesse, konkreetsete plokiahela kasutusjuhtude rakendamisele teistes sektorites ning pikisuunalistele uuringutele, mis käsitlevad ringmajanduse digitaristute arengut ajas.

Appendix 1

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Advancing Circular Economy Models: The Synergistic Role of Service Design and Blockchain Technology in Enhancing Sustainability and Consumer Engagement

Vera Gerasimova

Tallinn University of Technology, Department of Business Administration, School of Business, Estonia

Abstract

This paper examines the transformative potential of integrating Service Design and Blockchain technology within Circular Economy models, aimed at enhancing sustainability and consumer engagement. Through the lens of two in-depth case studies—the Circular Electronics Platform and the Sustainable Food Supply Chain—we illustrate how these innovations can significantly improve transparency, efficiency, and participation in sustainable practices. The first case study investigates into the electronics industry, demonstrating a platform that uses Blockchain to manage the lifecycle of devices, thus promoting recycling and reuse. The second case study explores a Blockchain-based platform that enhances transparency in the food supply chain, empowering consumers with information to make sustainable choices. Our analysis reveals that the synergy between Blockchain technology and Service Design not only addresses environmental challenges but also fosters a deeper connection between consumers and sustainable practices. We discuss the broader implications of these findings, including the potential for scalability, the importance of consumer trust, and the need for interdisciplinary collaboration to further embed sustainability into the fabric of our economies. The paper concludes with recommendations for future research, emphasizing the exploration of standardized frameworks, the role of policy, and the integration of emerging technologies to advance Circular Economy goals. This study contributes to the growing body of literature on sustainable practices by highlighting innovative approaches to integrating technology and design in the pursuit of environmental sustainability.

Keywords

Blockchain Technology, Circular Economy, Service Design, Sustainable Practices, Transparent Supply Chain

JEL Classification

Q57, O33, L86

Introduction

The concept of a Circular Economy (CE) represents a significant shift away from the traditional linear economic models that have dominated global industries for decades. Unlike linear models, which follow a 'take, make, dispose' approach, CE models aim to minimize waste and make the most of resources. As emphasized by Geissdoerfer et al. (2017), this approach not only enhances sustainability but also presents opportunities for industrial growth by redefining product life cycles and reducing environmental impact (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). By focusing on closed-loop systems, CE models offer businesses a way to minimize resource dependency while creating value through sustainable practices. This shift from a traditional linear model to a circular one not only conserves resources but also strengthens economic resilience by creating durable products that maintain value over time. As Geissdoerfer et al. (2017) argue, rethinking product life cycles encourages companies to invest in product design and material efficiency, leading to innovations that can reduce environmental impact and foster economic growth.

Service Design (SD) further strengthens CE principles by focusing on the user experience and system efficiency, providing a framework to foster sustainability through user-centered practices (McAloone & Pigosso, 2018). SD emphasizes creating products and services that are intuitive for consumers to engage with, encouraging sustainable practices such as product sharing, repair, and recycling. This user-centered approach not only optimizes the efficiency of resource use but also makes sustainable practices more accessible and attractive to consumers. McAloone and Pigosso (2018) highlight that SD's integration of user-focused design can lead to greater

Corresponding author:
Vera Gerasimova, TalTech, Department of Business Administration, Tallinn
Email: vera.gerasimova@taltech.ee

consumer satisfaction and engagement, which is critical for achieving widespread adoption of circular practices.

When combined with Blockchain, these innovations enable new levels of trust and engagement within CE models (Saberi et al., 2019). Blockchain's decentralized and immutable record-keeping system allows all stakeholders in a product's lifecycle—manufacturers, consumers, and recyclers—to access and verify information on product origins and lifecycle. This transparency strengthens consumer trust and accountability across the supply chain, making it easier to verify sustainable sourcing and responsible production. Saberi et al. (2019) suggest that these qualities of Blockchain support CE models by enabling seamless tracking of materials and products, facilitating closed-loop systems, and reducing inefficiencies within supply chains. Together, SD and Blockchain provide a robust framework that aligns business operations with CE principles, encouraging sustainable practices while simultaneously fostering deeper consumer engagement and operational resilience.By focusing on the user experience and the efficient use of resources, SD can significantly increase consumer engagement and operational sustainability. Furthermore, the advent of Blockchain technology offers unprecedented opportunities to bolster these efforts. With its ability to ensure transparency, traceability, and security, Blockchain technology can support the foundational principles of the CE, enhancing trust and participation among consumers and stakeholders alike. Blockchain technology also offers unprecedented opportunities to strengthen these efforts. Due to its ability to ensure transparency, traceability, and security, Blockchain technology can support the foundational principles of the CE, enhancing trust and participation among consumers and stakeholders alike. Evidence from European integration efforts shows that blockchain not only supports transparency but also drives economic growth and resilience, making it a valuable tool for circular economy practices (Zhylinska, Bazhenova, & Zatonatska, 2020).

This article explores the synergy between SD and Blockchain technology as a catalyst for transforming CE models. Through a detailed examination of their roles, potential applications, and successful case studies, it aims to demonstrate how these innovative approaches can not only enhance consumer engagement but also promote sustainability at a broader scale. Addressing both the academic community and the wider public, this discussion underscores the importance of integrating cutting-edge technology and design thinking into CE strategies to meet the environmental and economic challenges of our times. While prior research has explored the role of Blockchain in supply chain transparency (Saberi et al., 2019) and SD as a user-centered approach (Meroni & Sangiorgi, 2011), limited work has integrated both approaches within SE models. This gap leaves an opportunity to examine how combining Blockchain's transparency and SD's user focus can better address CE goals like consumer engagement and lifecycle management. This paper aims to investigate the transformative potential of integrating Blockchain and SD within CE models, focusing on enhancing sustainability and fostering deeper consumer engagement. By exploring case studies in the electronics and food sectors, this study seeks to illustrate how these technologies together can enhance transparency, resource efficiency, and consumer trust within CE systems. This study contributes to existing literature by (1) analyzing the synergy between blockchain and SD in CE applications, (2) providing case studies showcasing Blockchain-enabled transparency in sustainable supply chains, and (3) proposing practical and theoretical directions for future research on scalable and user-centered CE models.

In recent years, the dynamic interplay between technological innovation and supply chain management has become a critical focal point for enhancing CE models. This intersection is notably marked by the advent of smart technologies, such as Blockchain, which promise to revolutionize traditional supply chain mechanisms by introducing unparalleled levels of transparency, efficiency, and trust. SD emerges as a complementary force, offering a holistic framework to innovate supply chains into smarter, more sustainable systems. Together, these technologies not only pave the way for a more sustainable future but also ensure that supply chains contribute positively to the CE ethos (Gerasimova, Philipp, & Prause, 2021). Recent advancements in blockchain technology, notably NFT-enriched smart contracts, present novel opportunities for enhancing CE models. These innovations promise to redefine consumer engagement and sustainability practices by ensuring more secure and transparent transactions (Gerasimova, Prause, & Hoffmann, 2023). The integration of innovative technologies is critical for the success of CE models. Kona, Guťan, and Horváth (2020) highlight how the Slovak Republic's focus on smart city KPIs demonstrates the value of technology for achieving sustainability goals, which can similarly be applied within CE models to enhance transparency and resource management.

The remainder of this paper is structured as follows: Section 2 reviews relevant literature on CE, Blockchain, and SD. Section 3 presents the methodology and case studies, focusing on applications in electronics and food supply chains. Section 4 discusses the findings, and Section 5 concludes with insights for future research on integrating Blockchain and SD to support sustainable practices in CE models

Literature Review

Understanding the Circular Economy

The CE is not just an alternative economic model; it is a response to the urgent need for a sustainable future. It challenges the status quo of the linear economy, which has historically been predicated on the availability of abundant resources, and seeks to redefine what growth means in the 21st century. The CE model, which emphasizes waste reduction and resource optimization, has gained support not only as an economic framework but also as an environmental imperative (Geissdoerfer et al., 2017), aligning with recent policy shifts toward sustainability goals (European Commission, 2020). This model also brings attention to the importance of designing waste out of systems and focuses on regenerating natural systems, thus aligning economic activity with the protection of natural resources (Geissdoerfer, Savaget, Bocken, & Hultink, 2017). The CE advocates for a systemic shift to long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling. This approach not only reduces environmental impact but also offers economic benefits by creating new opportunities for growth and innovation in sectors such as renewable energy, material recovery, and product lifecycle extension (Stahel, 2016). Moreover, the CE is intrinsically linked to technological innovation and development. Emerging technologies play a crucial role in enabling the transition from linear to circular models by facilitating the creation of more efficient and effective systems for resource management, product tracking, and consumer engagement (Korhonen, Honkasalo, & Seppälä, 2018). However, the integration of these technologies into existing economic and social structures presents a significant challenge, necessitating a reevaluation of current practices and policies. The adoption of CE principles also requires a shift in consumer behavior and business strategies. It challenges individuals and companies to rethink how resources are used and to value the longevity and recyclability of materials and products. This shift is not straightforward, as it involves overcoming deeply ingrained habits and preferences that favor new and disposable goods over durable and repairable ones (Lewandowski, 2016). Despite the theoretical benefits of CE models, industries face significant barriers, such as insufficient regulatory support and limited consumer engagement, which continue to hinder large-scale adoption of circular practices (Ahmadov et al., 2023). Despite these challenges, the potential rewards of a CE are substantial. By fostering innovation and sustainability, it offers a pathway to a more resilient and flexible economic system. The transition to such a model requires collaborative efforts among policymakers, businesses, consumers, and researchers. It is through these collective efforts that the CE can move from a theoretical concept to a practical reality, contributing to a more sustainable and prosperous future for all (Velenturf & Purnell, 2021).

In exploring the transition towards CEmodels, it becomes evident that SMEs encounter distinct challenges, ranging from limited resources to a lack of expertise in implementing sustainable practices. Ahmadov, Durst, Gerstlberger, and Kraut (2023) offer a comprehensive review on the multi-level perspectives affecting SMEs' transition to circular economies, underscoring the necessity of a holistic approach that accounts for micro (firm-level), meso (industry and community level), and macro (policy and societal level) influences. This backdrop highlights the critical need for innovative solutions that can address these layered challenges. It is within this context that blockchain technology and SD emerge as promising avenues for facilitating SMEs' transition to CE models, promising to mitigate barriers through enhanced transparency, efficiency, and user-centered approaches. A comprehensive study conducted in Estonia evidenced the distinct challenges and opportunities for SMEs in transitioning to a CE poses. The research by Küttim et al. (2023) identified critical barriers such as the lack of best practices expertise, insufficient state funding, and low levels of industry cooperation, alongside the vital enablers that support this transition. These insights underline the importance of addressing both internal and external factors to facilitate the macro transformation towards a CE, highlighting the need for innovative solutions like blockchain and SD to integrate business pragmatism with systemic regulatory action and stakeholder engagement. With the foundational understanding of the CE established, let's delve into how SD plays a pivotal role in enhancing CE models, focusing on efficiency and consumer experience in the next section.

The Role of Service Design in Circular Economy

SD, with its user-centered, co-creative, sequenced, and evidencing characteristics, offers a powerful framework for enhancing CE models. It bridges the gap between the innovative potential of CEprinciples and their practical application, focusing on creating systems that are not only environmentally sustainable but also economically viable and user-friendly (McAloone & Pigosso, 2018). By centering on the needs and behaviors of end-users, SD encourages sustainable practices by making them more accessible and appealing. Additionally, its co-creative approach involves stakeholders throughout the design process, fostering collaboration across industries and creating shared ownership of circular initiatives. This collaborative design process is essential for developing solutions that not only meet environmental goals but also align with business objectives, promoting long-term success and wider adoption of circular practices.

At the heart of SD is the principle of user-centered design, which ensures that CE solutions are developed with a deep understanding of the needs and behaviors of consumers. This approach is crucial for encouraging consumer participation in circular practices, such as recycling, sharing, and repairing, by making these practices more accessible and appealing (Meroni & Sangiorgi, 2011). SD promotes co-creation and collaboration among stakeholders, including businesses, consumers, and governments. This collaborative approach is essential for developing CE initiatives that are practical and effective, as it leverages the diverse perspectives and expertise of all participants (Stickdorn, Hormess, Lawrence, & Schneider, 2018). By engaging stakeholders, SD ensures that solutions address real challenges and are more likely to be integrated. This approach not only fosters a sense of shared responsibility but also helps uncover unique insights and innovative ideas that may not emerge from a single stakeholder perspective. In the context of the Circular Economy, this collaborative model is crucial for aligning environmental goals with economic and social priorities, creating systems that are resilient, adaptable, and deeply connected to community needs.

By mapping out the sequence of interactions between consumers and services, SD helps in creating seamless experiences that encourage sustainable behaviors. This detailed planning ensures that every touchpoint is an opportunity to reinforce CE values and practices (Zomerdijk & Voss, 2010). Through careful design of each stage in the customer journey, SD makes sustainable choices intuitive and accessible, encouraging consumers to engage in behaviors like recycling, reusing, and choosing eco-friendly options. Each interaction is crafted to align consumer actions with sustainability goals, promoting positive habits and fostering a deeper connection to CE principles. This structured approach not only enhances the user experience but also builds a consistent, values-driven system that guides consumers toward environmentally responsible decisions.

SD relies on evidence and research to inform the development of services. This empirical basis is particularly important in the CE, where new and innovative models of consumption and production are being explored. By grounding these models in solid research, SD increases the likelihood of their success and scalability (Blomkvist, Holmlid, & Segelström, 2010).

In integrating SD into CE models, companies and organizations can create systems that are not only sustainable but also directly address the needs and expectations of their users. The rise of digital platforms has enabled SD to offer innovative business models, such as product-as-a-service and subscription-based models, which align consumer needs with circular practices, reducing waste and promoting product longevity (Meroni & Sangiorgi, 2021).This alignment is crucial for the widespread adoption and success of CE initiatives. For instance, designing a product-as-a-service model that offers consumers access to products rather than ownership can reduce waste and extend the lifecycle of products, all while maintaining a high level of customer satisfaction (Tukker, 2015).

SD holds a pivotal role in the evolution of supply chains towards smart, integrated systems. By focusing on user experiences and backend processes, SD ensures that technological innovations such as Blockchain are seamlessly integrated, thus fostering efficient and sustainable supply chain operations. (Gerasimova, Philipp, & Prause, 2021).

With SD's important role in enhancing CE models established, we will explore the integration and benefits of Blockchain technology in supporting these models in the next section.

Blockchain Technology as an Enabler

Groundbreaking enablement of the CE can be found in blockchain technology, the decentralized ledger ensuring transparency, security, and traceability. Its basic characteristics are aligned perfectly with the need for transparency in the product life cycle and authentication of recycled materials, which is facilitated through secure transactions in a sharing economy (Kewell, Adams, & Parry, 2017). Blockchain operates as a decentralized, tamper-proof digital ledger where each transaction is encrypted, time-stamped, and linked to previous entries, forming a chain of blocks. This structure ensures transparency and security in data, making it particularly valuable for CE models that depend on trust and accountability across supply chains (Upadhyay et al., 2021).Transparency and Traceability: Blockchain technology can transparently create tamper-proof records of transactions, ensuring that products and materials are traceable across the entire value chain. This allows consumers and businesses to verify the sustainability credentials of products, tracking the history and origin of items from production through to recycling or disposal (Saberi, Kouhizadeh, Sarkis, & Shen, 2019). By recording each transaction on a transparent, immutable ledger, blockchain allows all participants, including consumers, to view the product lifecycle, from raw material sourcing to recycling. This visibility fosters trust, as stakeholders can verify the sustainability credentials of products and trace each stage in the value chain, reducing fraud and supporting ethical sourcing (Pakseresht et al., 2022). Recent advancements in blockchain technology address scalability and environmental concerns through innovations like Proof of Stake and sharding, which reduce energy consumption, making blockchain applications more viable for CE models (Sedlmeir et al., 2020). Unlike the traditional Proof of Work system, PoS validates transactions with much lower energy demands. Sharding, which breaks down the blockchain into smaller parts, speeds up processing and reduces congestion. Together, these improvements make blockchain systems more efficient and environmentally friendly, allowing them to better support transparent, high-volume supply chains within CE models.

Security and Trust: Due to its decentralized nature, Blockchain secures transactions against fraud and tampering. Blockchain’s encryption and data immutability prevent unauthorized tampering, which is crucial for maintaining accountability in CE models. This level of security helps establish an ecosystem of trust among manufacturers, consumers, and recyclers, reinforcing sustainable practices and building consumer confidence (Upadhyay et al., 2021). This builds trust among all stakeholders in the CE—from consumers to manufacturers and recyclers—facilitating broader collaboration and participation in sustainable practices (Nowiński & Kozma, 2017).

Facilitating Sharing Economy Models: Blockchain technology enables sharing without friction, as it ensures seamless and secure transactions between parties. These transactions are way cheaper, while they easily share goods and services among users at a firm or individually (Chang, Chang, & Chen, 2022). The circular economy frameworks of smart contracts have changed transactional security and efficiency. This would be further advanced by integrating NFTs with smart contracts, which embed unique digital signatures to physical products for a level of traceability and authenticity verification unparalleled in its benefits (Gerasimova, Prause, & Hoffmann, 2023). Besides, within the processes of the CE, smart contracts would automate numerous processes since they are, in fact, self-executing contracts, with terms of agreement directly written into code. This includes, for example, automatic execution of payments with the return of rented or leased items, further reducing the barriers to efficient circular practices (Christidis and Devetsikiotis, 2016). Transnational smart supply chains are developed with blockchain technology and its coupling through smart contracts. This integration will be based on the CE's core principles of enhanced traceability, reduced inefficiency, and increased consumer trust in sustainability practices. Blockchain’s capability for creating secure, seamless transactions allows it to support the sharing economy model central to CE initiatives. With features like smart contracts and NFTs, blockchain can streamline transactions, ensuring product authenticity and traceability. For example, in the context of a sharing economy, smart contracts can automate payments upon product return, further lowering operational barriers and fostering efficient circular practices (Gerasimova et al., 2023)

Potential Applications and Challenges

While the potential for the Blockchain in improving models of CE is high, its application comes fraught with a number of challenges as well. It includes factors such as energy consumption of Blockchain networks, requirement of technical expertise, and standards with respect to establishing interoperability among different Blockchain systems that need to be tackled in a holistic manner to fully leverage the capability of this technology toward sustainability (Morkunas, Paschen, & Boon, 2019). Blockchain’s applications in CE models are extensive but come with challenges, including energy-intensive operations. The exploration of energy-efficient alternatives, such as proof-of-stake and sharding, offers promising paths forward. Additionally, addressing interoperability among diverse blockchain systems is essential for establishing standardized digital passports and streamlined collaboration across industries (Bellavista et al., 2021). Sedlmeir et al. (2020) highlight that PoW-based blockchains are particularly energy-hungry compared to traditional databases. Alternatives such as Proof-of-Stake (PoS) and consortium blockchains are proposed to mitigate these issues, offering more sustainable paths for blockchain adoption within CEmodels.

Prause and Boevsky (2019) explore the application of blockchain technology and smart contracts in smart rural supply chains, highlighting the unique challenges rural areas face, such as limited business sophistication and investment attraction. Their research underscores the potential of blockchain to facilitate collaboration among rural SMEs, optimize supply chains, and enhance transparency and efficiency. This expansion into rural applications of blockchain and smart contracts signifies a broader applicability and reinforces the technology's role in advancing sustainable practices across diverse economic landscapes.

In addition to revolutionizing CE models, blockchain technology and smart contracts present significant opportunities for enhancing logistics networks. Philipp, Gerlitz, and Prause (2019) discuss how smart contracts can streamline entrepreneurial collaboration in logistics networks, enabling SMEs to overcome traditional barriers to entry and compete more effectively with larger players. By automating contractual processes and ensuring transparency and trust, smart contracts facilitate cross-organizational business processes, allowing SMEs to partake in trans-national networks and venture into new business sectors previously dominated by major corporations. This application of blockchain technology exemplifies its capacity to democratize access to markets and promote sustainable entrepreneurial activities within and beyond logistics networks.

Further underlining the versatility of blockchain technology, recent studies reveal its pivotal role in fostering entrepreneurial collaboration within maritime supply chains. Philipp, Prause, and Gerlitz (2019) discuss how blockchain and smart contracts not only streamline transaction processes but also significantly reduce the traditional barriers for SMEs' participation in global trade. By automating contractual obligations and ensuring transparent, efficient operations, these technologies offer a promising avenue for integrating smaller enterprises into the complex logistics networks spanning across international waters. This is particularly relevant in sectors such as maritime logistics, where the entry barriers for SMEs have traditionally been high due to the sector's complexity and the significant resources required for global operations. The environmental and technical limitations of Blockchain, such as energy consumption and interoperability with other systems, are notable concerns that need to be addressed.

Overall, Blockchain's role in enabling and enhancing CE practices through its transparency, security, and support for sharing economy models illustrates a promising avenue for achieving sustainability. Building on blockchain’s role in ensuring transparency and traceability, the next section explores how these features can be leveraged through service design to deepen consumer engagement and foster trust in sustainable practices.

Building Consumer Engagement through Service Design and Blockchain

In the quest for a more sustainable future, engaging consumers in CE practices is not just beneficial - t's essential. The integration of SD and Blockchain technology offers a multi-faceted approach to engage consumers more deeply by enhancing their experience and trust in CE systems.

Enhancing Trust Through Enhanced Transparency: The Blockchain's inherent transparency goes beyond simply tracking product origins. It can also record and verify the environmental impact of consumer choices, such as carbon footprint reductions achieved through recycling or buying sustainably produced products. This level of detail, accessible to consumers in an easy-to-understand format, can significantly deepen their trust in brands and the CE model as a whole, encouraging more sustainable behaviors (Upadhyay, Mukhuty, Kumar, & Kazançoğlu, 2021).

SD as a Bridge to Consumer Adoption: Effective SD bridges the gap between the theoretical benefits of the CE and practical consumer adoption. By employing SD principles, organizations can tailor CE initiatives to fit seamlessly into consumers' lives, making sustainable choices more convenient and desirable. For example, subscription-based models for household items, facilitated by Blockchain for secure, transparent transactions, can transform the way consumers access and use products, moving towards a less wasteful consumption pattern (Piscicelli, Ludden, & Cooper, 2018).

Leveraging Blockchain for Community-Driven Initiatives: Beyond individual consumer engagement, Blockchain technology enables the creation of decentralized platforms for community-driven sustainability initiatives. These platforms can empower communities to take collective action, such as local recycling programs or shared renewable energy projects, creating a sense of shared purpose and community engagement in sustainability efforts (Chang, Chang, & Chen, 2022).

The Role of Gamification in SD: Incorporating gamification elements into SD can further enhance consumer engagement with CE practices. By rewarding sustainable choices with points, badges, or other incentives, and recording these achievements in a Blockchain for transparency and permanence, organizations can make participation in the CE more rewarding and fun for consumers. This approach not only encourages repeated sustainable behaviors but also fosters a community of like-minded individuals who are motivated to make a positive environmental impact (Deterding, Sicart, Nacke, O'Hara, & Dixon, 2011). Blockchain technology can also empower consumers by giving them ownership and control over their data. This shift can enhance consumer trust and willingness to share data about their consumption habits, preferences, and sustainability impacts, which, in turn, can help businesses and organizations to tailor their CE initiatives more effectively to meet consumer needs (Zyskind, Nathan, & Pentland, 2015).

Despite the theoretical benefits of CE models, industries face significant barriers, such as insufficient regulatory support and limited consumer engagement, which continue to hinder large-scale adoption of circular practices (Ahmadov et al., 2023). Behavioral economics suggests that consumers' willingness to engage in sustainable practices is strongly influenced by perceived convenience and alignment with personal values (Piscicelli, Ludden, & Cooper, 2018). Addressing these behavioral factors can enhance consumer engagement by making sustainable choices more intuitive and aligned with existing habits. Together, these recent developments—scalable blockchain solutions, NFT-enabled traceability, and behaviorally-informed SD underscore the increasing feasibility and impact of integrating technology with CE principles. By exploring these synergies, this study contributes to a deeper understanding of how recent innovations can drive sustainable practices.

Methods

This study employed a qualitative case study methodology to explore how SD and Blockchain technology can be integrated to enhance CE models. The research procedure was conducted in following main phases:

Case Study selection: relevant case studies were chosen based on their relation to the integration of SD and Blockchain for sustainability. The selection criteria included (a) relevance to the research objective, (b) evidence of impacts on sustainability or consumer engagement, and (c) representation of diverse industry sectors. Based on these criteria, two case studies were selected: the Circular Electronics Platform and the Sustainable Food Supply Chain. The first case provides insights into lifecycle tracking in the electronics industry, while the second focuses on transparency in food sourcing.

Data collection: data was collected through a limited number of discussions with key stakeholders involved in each case study. These discussions provided preliminary insights into each case and impact on CE practices. To supplement these discussions, relevant documents, reports, and existing literature were also analyzed to corroborate and expand upon the information provided by stakeholders.

Data analysis: thematic analysis was conducted to identify common themes and insights across the case studies. Data was analysed to uncover key themes related to sustainability, consumer engagement, and operational efficiency. This approach enabled a detailed examination of the role of SD and Blockchain in advancing CE objectives, even with a rather limited primary data set.

To provide a clear overview of the methodology, Table 1 summarizes the procedure, sample, and details about the case studies.

Case Study 1: Sustainable Food Supply ChainThe Sustainable Food Supply Chain case study explores a blockchain-based platform that enhances transparency from farm to table. This platform records key data at each stage of the food supply chain, providing consumers with insights into the origin, production methods, and environmental impact of their food. By offering detailed traceability, the platform empowers consumers to make informed choices about sustainably sourced products. This case highlights the role of technology in fostering consumer engagement and improving accountability in food supply chains, reflecting the broader trend of integrating digital tools to support CE practices.

Case Study 2: Circular Electronics Platform utilizes blockchain technology to track the lifecycle of electronic devices, from production through use, repair, and recycling. Each device is assigned a digital identity that stores its entire lifecycle data, promoting responsible usage and facilitating end-of-life management. This platform enhances transparency and encourages sustainable behaviors by making information about each product's journey accessible to consumers, manufacturers, and recyclers. The case demonstrates how innovative digital solutions can effectively support CE goals by reducing e-waste and extending product lifecycles.

Table 1. Summary of methodology, procedure, sample, and case studies details.

Aspect	Description
Methodology	Qualitative case study analysis
Procedure	- Step 1: Selection of case studies based on relevance, impact, and sector - Step 2: Data collection through discussions with stakeholders and document analysis - Step 3: Thematic analysis for identifying patterns and insights2
Sample	- Case 1: Circular Electronics Platform (Electronics Industry) - Case 2: Sustainable Food Supply Chain (Food Industry)
Data Collection	Informal discussions with stakeholders; analysis of documents, publications, and relevant literature
Data Analysis	Thematic analysis to identify themes related to sustainability, engagement, and operational efficiency
Cast study selection criteria	- Integration of SD and Blockchain - Measurable sustainability impacts - Representation of diverse industries
Case studies details	Case 1: Circular Electronics Platform - Focus on lifecycle tracking and recycling in electronics Case 2: Sustainable Food Supply Chain - Focus on transparency and traceability in food sourcing

Source: compiled by the author.

Results

Case Study 1: Sustainable Food Supply Chain on Blockchain

The Sustainable Food Supply Chain case study demonstrates blockchain's transformative potential in achieving transparency and traceability in the food industry, aligning it with CE principles. Blockchain technology enables every step in the food production process—from farming, processing, and distribution to retail and consumption—to be tracked in real time. By recording critical information at each stage, blockchain creates an immutable ledger that provides transparency for consumers and regulatory bodies alike. This system enhances consumer trust by allowing them to access data on food origins, farming practices, and environmental impact directly, ensuring that claims of sustainability are not only visible but also verifiable (Pakseresht et al., 2022).

Blockchain in food supply chains addresses common issues like information asymmetry and lack of accountability, which have traditionally been barriers to sustainable practices. With the integration of blockchain, companies can assure consumers of ethical practices, as blockchain prevents any tampering with recorded information. Research indicates that supply chains which implement blockchain technology observe a notable increase in consumer engagement with sustainable products, as consumers gain confidence in the authenticity of the products they purchase (Sharma et al., 2021).

Moreover, this blockchain-enabled visibility into supply chain operations also facilitates better coordination among suppliers, distributors, and retailers, enabling improved inventory management. Real-time tracking helps businesses manage food inventory based on demand, significantly reducing waste due to spoilage or overstocking. A reduction in food waste has direct environmental benefits, as it reduces the carbon footprint associated with waste management and resource use. Blockchain also streamlines compliance with food safety regulations, as each product's journey can be easily reviewed, verified, and traced back to the source if any issues arise. Such transparency has been shown to reduce food recalls and improve response times in case of contamination incidents (Upadhyay et al., 2021).

An additional layer of consumer engagement can be achieved through integrating user-friendly platforms where consumers can scan a product's QR code and view its sustainability profile. This not only strengthens consumer trust but also drives brand loyalty, as consumers are increasingly choosing brands that align with their ethical values. The blockchain-based transparency in this case study serves as a replicable model for other perishable goods industries, highlighting how end-to-end traceability can effectively support the shift toward sustainable consumption. As more industries adopt similar models, blockchain could serve as a backbone technology for achieving large-scale sustainability in the CE.

Case Study 2: Circular Electronics Platform with Blockchain

The Circular Electronics Platform case study highlights the integration of blockchain into the electronics industry and addresses the growing environmental concerns around e-waste and resource scarcity. In this platform, blockchain assigns each electronic device a unique digital identity, or 'passport,' which tracks its lifecycle from production through use, maintenance, and disposal or recycling. This traceability is a crucial element in a CE, as it provides transparency in product lifecycle management, encourages consumers to make responsible choices, and supports extended producer responsibility initiatives. Studies have shown that such blockchain-enabled digital identities can significantly enhance material traceability, aiding in the optimization of recycling and reuse initiatives (Shojaei et al., 2021).

The integration of smart contracts into the Circular Electronics Platform is another innovative feature, allowing for automated actions based on predefined conditions. For example, smart contracts can automatically enforce warranties, trigger recycling reminders, and reward consumers for returning end-of-life products. This automation reduces operational costs and streamlines the logistics of lifecycle management, as each contract can be programmed to execute specific actions without requiring manual intervention. As a result, manufacturers are motivated to participate actively in circular practices, as they benefit from streamlined operations and improved brand reputation (De Giovanni, 2022).

The Circular Electronics Platform offers multiple environmental benefits. By promoting repair, refurbishment, and recycling, this model reduces e-waste—a significant environmental concern, as electronics often contain hazardous substances that can contaminate soil and water if not properly disposed of. The platform also helps in managing resources more efficiently, as it allows for the recovery of valuable metals and components. These practices not only mitigate resource extraction but also lower the carbon footprint associated with new material production. The data generated from blockchain tracking enables companies to analyze consumer behavior and preferences, informing the design of future products that are both sustainable and aligned with market demands.

This case also emphasizes the platform's role in building consumer trust. Blockchain's transparency and stability appeal to consumers who are conscious of the environmental impact of their purchases. By offering easy access to a product's lifecycle data, the platform empowers consumers to make choices that support sustainability and circularity. The Circular Electronics Platform provides a blueprint for other industries seeking to implement circular principles, demonstrating that blockchain can enhance product lifecycle transparency and operational efficiency in sectors where end-to-end traceability is important. As regulatory pressures on electronic waste increase globally, platforms like these are likely to play a central role in shaping sustainable business practices (Upadhyay et al., 2021). In conclusion, this case study illustrates how blockchain technology can address industry-specific challenges while advancing CE goals.

Challenges and Future Directions

Scalability and Adoption: While the Circular Electronics Platform offers significant potential to promote sustainability in electronics, achieving industrial-scale scalability and widespread adoption presents considerable challenges. Key issues include the computational resources required for large-scale blockchain networks, particularly when handling vast datasets across multiple stakeholders. One solution being explored is the adoption of energy-efficient consensus mechanisms, such as proof-of-stake, which can maintain network security with reduced energy consumption compared to traditional proof-of-work systems. This shift could make blockchain-based CE models more viable for large-scale deployment (Nguyen et al., 2019). Scaling blockchain within global supply chains is hindered by high energy demands and interoperability issues across different blockchain platforms. Potential solutions, such as layer-2 scaling solutions and sharding, offer promising paths to achieve scalability by enhancing transaction processing efficiency (Gangwal et al., 2022).

Interoperability between different blockchain platforms and standardization of digital passports across various manufacturers are also essential for ensuring seamless data exchange and compatibility. Advances in layer-2 solutions—such as side chains that operate in tandem with the main blockchain—may help improve transaction speeds and reduce costs, making scalability more attainable. Additionally, achieving mass consumer engagement will require targeted educational efforts to increase awareness and participation, thereby realizing the full potential of blockchain in driving circular practices (Kouhizadeh et al., 2022).

Innovation and Collaboration Opportunities: The future of the platform involves leveraging cutting-edge recycling technologies and exploring advancements in materials recovery to further minimize the environmental impact of e-waste. For example, blockchain can be integrated with Internet of Things (IoT) devices to provide real-time monitoring and automated lifecycle tracking, optimizing recycling processes. Collaborative efforts between governments, environmental organizations, and the technology sector can enhance these systems and drive the electronics industry towards a sustainable, circular model. This alignment can also support regulatory compliance, enabling companies to meet increasingly rigorous environmental standards on a global scale (Khan & Ahmad, 2022).

Case studies like the Circular Electronics Platform and the Sustainable Food Supply Chain illustrate the transformative potential of blockchain when combined with SD principles. These platforms showcase how traceability, transparency, and user-centric design can facilitate sustainable practices across industries, thus supporting a future where circular business models are commonplace rather than exceptional. By continuously innovating and collaborating, stakeholders can capitalize on these models to foster substantial environmental and economic benefits.

Blockchain’s Role in Lifecycle Management: The Circular Electronics Platform has not only shown an increase in the recycling and refurbishment rates of electronic devices but also underscored blockchain's ability to streamline lifecycle management. By creating digital product passports, blockchain allows stakeholders to access and update product histories, significantly extending product lifespans and reducing waste. This practical application supports Atzori’s (2017) theoretical framework on blockchain's environmental impact, showing tangible results in waste reduction and sustainable lifecycle management. Integrating SD into the user experience enhances consumer engagement and facilitates ease of interaction with the platform, resonating with Blomkvist, Holmlid, and Segelström’s (2010) principles on the importance of user-centric approaches in achieving satisfaction and engagement.

The Broader Impact of Blockchain in Sustainable Food Supply Chains: The Sustainable Food Supply Chain platform goes beyond consumer empowerment to support sustainable agricultural practices. Blockchain-enabled traceability aligns with Kamilaris, Fonts, and Prenafeta-Boldú's (2019) findings on blockchain's potential in agriculture, enhancing credibility and accountability in the food supply chain. Through SD, complex supply chain data is presented in an accessible way, connecting consumers with their consumption choices and fostering informed decisions about sustainability. This approach echoes Sangiorgi’s (2011) emphasis on SD as a tool for transforming service experiences and creating stronger consumer connections with sustainable practices.

Future Research Directions: Future work should focus on exploring sharding techniques—which divide the blockchain into smaller, manageable sections (or shards) that process transactions in parallel—to enhance the scalability and performance of blockchain systems. Additionally, advancements in quantum computing could offer new pathways for addressing blockchain’s scalability challenges, as quantum algorithms promise faster transaction speeds and enhanced processing capabilities. Although still in developmental stages, these technologies hold great promise for overcoming the current limitations of blockchain-based CE platforms. With sustained research and investment, these innovations could make blockchain a highly scalable and efficient enabler of circular models, driving the broader adoption of sustainable practices across various sectors (Upadhyay et al., 2021).

Discussion

This discussion builds on findings from the two case studies—the Circular Electronics Platform and the Sustainable Food Supply Chain—exploring how each uniquely applies SD and Blockchain to promote CE principles. The Circular Electronics Platform focuses on lifecycle tracking and e-waste management within the electronics industry, while the Sustainable Food Supply Chain prioritizes transparency in food sourcing to enhance consumer trust in sustainability. Together, these cases offer insights into diverse approaches within CE models and provide a basis for comparing key indicators of success.

To compare the effectiveness of these case studies, we focus on four key indicators: transparency, user engagement, resource efficiency, and sustainability impact. These indicators allow us to evaluate the unique contributions and limitations of each case, offering a structured approach to assess the role of SD and Blockchain in CE applications.

Transparency is central to both case studies, particularly in the Sustainable Food Supply Chain, which uses Blockchain to provide consumers with direct access to sourcing and production data. This approach aligns with literature emphasizing Blockchain’s role in enhancing traceability and building consumer trust in supply chains (Saberi et al., 2019). In comparison, the Circular Electronics Platform also improves transparency but focuses on lifecycle tracking within the electronics sector, making information about the recycling and reuse potential of electronic products accessible to both consumers and recyclers.

User engagement, facilitated by SD, varied between cases. The Circular Electronics Platform leveraged user-centered design to promote responsible disposal behaviors, supporting studies that highlight the role of SD in encouraging sustainable actions (Meroni & Sangiorgi, 2021). In contrast, the Sustainable Food Supply Chain focused on transparency but offered fewer touchpoints for direct consumer interaction, reflecting a more passive form of engagement compared to the electronics case.

Resource efficiency was prominent in the Circular Electronics Platform, which promotes recycling and reduces e-waste, aligning with CE goals to minimize waste (Stahel, 2016). By tracking each product’s lifecycle, this platform encourages consumers to recycle and reuse electronics, directly contributing to resource conservation. The

Sustainable Food Supply Chain case, on the other hand, indirectly supports resource efficiency by providing consumers with sustainable sourcing information, encouraging them to make environmentally conscious choices, though it does not engage directly in resource recovery.

Sustainability impact, a critical measure for CE initiatives, was evident in both cases. The Circular Electronics Platform's lifecycle tracking directly addresses e-waste reduction, which has significant environmental benefits. Similarly, the Sustainable Food Supply Chain enhances sustainability by promoting ethically sourced food, aligning with the literature on blockchain's ability to support sustainable supply chains (Pakseresht et al., 2022).

The findings from these case studies generally align with existing literature on Blockchain and SD applications in CE models. For example, the emphasis on transparency in both cases supports research by Saberi et al. (2019) on Blockchain's role in enhancing trust and accountability. However, unlike earlier studies that often focus on technical implementation challenges, the Circular Electronics Platform demonstrated that SD can make sustainability data more accessible and meaningful to end-users, an aspect less frequently covered in CE literature (Zomerdijk & Voss, 2010).

An unexpected insight from the Circular Electronics Platform was the observed increase in consumer responsibility through lifecycle tracking, suggesting that Blockchain's impact may extend beyond transparency to influence behavioral change. This aligns with emerging perspectives in SD literature that emphasize the potential for design frameworks to engage users actively in sustainability (McAloone & Pigosso, 2018).

Overall, both case studies demonstrate that integrating Blockchain and SD can enhance different dimentions of CE models, with each approach being adaptable to sector-specific needs. For instance, the electronics sector benefits from lifecycle tracking, while the food sector leverages traceability to foster consumer trust. These findings suggest that future CE initiatives could achieve greater success by customizing their approaches based on industry-specific challenges and consumer expectations. Despite these promising results, scalability remains a notable challenge. Both case studies operate within specific sectors and may face limitations when applied to larger, more complex systems. Future research should explore how scalable blockchain solutions, like Proof of Stake, could help adapt these models for broader applications without compromising sustainability (Sedlmeir et al., 2020). Additionally, the reliance on user-centered design in engaging consumers raises questions about the generalizability of these findings across varied cultural or demographic groups.

In summary, the comparison between the Circular Electronics Platform and Sustainable Food Supply Chain highlights the versatility of Blockchain and SD in advancing CE objectives. Both cases contribute valuable insights, with each approach emphasizing different aspects of transparency, engagement, and sustainability. This study confirms and expands upon existing literature, underscoring the potential for interdisciplinary approaches that combine technological innovation with user-centered design to create impactful and adaptable CE solutions.

While both case studies demonstrate Blockchain's potential for sustainability, current technological limitations, such as energy consumption, highlight the need for more efficient solutions. Advances like Proof of Stake and layer-2 solutions could address these issues and make Blockchain more adaptable to CE goals (Shi et al., 2021). This aligns with advancements in parallel sectors, such as clean shipping within the Baltic Sea Region, where environmentally responsible practices have been successfully integrated to reduce impact (Olaniyi et al., 2022). These insights reflect the potential scalability of Blockchain and SD integration in high-impact industries, demonstrating how interdisciplinary approaches can contribute to CE goals across varied sectors. In summary, the integration of Blockchain and SD within CE models offers significant potential to enhance transparency, engagement, and sustainability across industries. Both the Circular Electronics Platform and Sustainable Food Supply Chain showcase how these technologies can be tailored to address sector-specific challenges while supporting the shared goals of resource efficiency and environmental responsibility. These findings, supported by evidence from broader industry applications, underscore the need for scalable, interdisciplinary strategies to achieve a sustainable future

Conclusion

This study demonstrates the transformative potential of integrating SD and Blockchain technology within CE models. Through the Circular Electronics Platform and Sustainable Food Supply Chain case studies, we illustrate how Blockchain's transparency, paired with SD's user-centered approach, can drive sustainability by enhancing lifecycle tracking, resource efficiency, and consumer trust. The results highlight how these technologies can address key CE challenges, providing adaptable frameworks that can be applied across various industries. This is consistent with the principles outlined by Velenturf and Purnell (2021), who emphasize the need for robust, user-friendly systems to drive sustainable production and consumption.

This research underscores the potential for Blockchain and SD to reshape sustainable practices by promoting transparency and consumer engagement. By enabling traceable and accessible information flows, these models foster deeper connections between consumers and sustainable practices, setting a strong foundation for broader industry adoption. Studies by Upadhyay et al. (2021) further support this, highlighting Blockchain's role in enhancing accountability in supply chains, a critical aspect for fostering trust and responsible consumer behavior

Despite these promising benefits, integrating Blockchain and SD on a larger scale presents challenges, including scalability, interoperability, and regulatory compliance. Future research should explore scalable solutions such as Proof of Stake and energy-efficient blockchain protocols, which may offer paths forward for sustainable large-scale applications (Nguyen et al., 2019). Additionally, frameworks that consider interoperability and standards across blockchain networks are necessary, as highlighted by Bellavista et al. (2021), to support cross-sector implementation and broader adoption.

In terms of practical applications, Tukker (2015) emphasizes the value of product-service models in creating resource-efficient, circular systems, underscoring the role of SD in bridging consumer needs with sustainable product life cycles. Policy incentives, such as regulatory support for low-energy blockchain protocols, could further aid in scaling these models, encouraging broader adoption and enhancing consumer confidence in sustainable practices.

The integration of Blockchain and SD in CE models opens several avenues for further research. Developing standardized frameworks to implement Blockchain across diverse sectors would enable interoperability and ease of adoption. Understanding behavioral factors that influence sustainable consumer behavior is also essential, as these factors can inform user-centered designs to encourage deeper engagement. Moreover, exploring complementary emerging technologies, such as AI and IoT, may reveal additional synergies that could enhance the efficiency and effectiveness of CE models (Zyskind, Nathan, & Pentland, 2015).

This study confirms that interdisciplinary approaches—combining Blockchain, SD, and policy support—can offer impactful solutions for CE goals. Such frameworks align with the increasing demand for sustainable business practices, as seen in sectors adopting Blockchain to promote transparency and lifecycle management, suggesting promising directions for continued innovation (Atzori, 2017).

References

Ahmadov, T., Gerstlberger, W., & Rahman, K. (2024). Exploring pathways to circular economy practices in Estonian manufacturing SMEs: A fuzzy-set QCA approach on stakeholder pressure and collaboration. *Scientific Papers of the University of Pardubice. Series D, Faculty of Economics and Administration*, 32(1), 2007. https://doi.org/10.46585/sp32012007

Ahmadov, T., Durst, S., Gerstlberger, W., & Kraut, E. (2023). SMEs on the way to a circular economy: Insights from a multi-perspective review. *Management Review Quarterly*. https://doi.org/10.1007/s11301-022-00312-5

Atzori, M. (2017). Blockchain technology and decentralized governance: Is the state still necessary? *Journal of Governance and Regulation*, 6(1), 45-62. https://doi.org/10.22495/jgr_v6_i1_p5

Bellavista, P., Esposito, C., Foschini, L., Giannelli, C., Mazzocca, N., & Montanari, R. (2021). Interoperable blockchains for highly-integrated supply chains in collaborative manufacturing. *Sensors* (Basel, Switzerland), 21(15), Article 4955. https://doi.org/10.3390/s21154955

Blomkvist, J., Holmlid, S., & Segelström, F. (2010). Service design research: Yesterday, today, and tomorrow. *In Proceedings of the 2010 ServDes Conference*.

Chang, S., Chang, E. C., & Chen, Y.–J. (2022). Blockchain meets sharing economy: A case of smart contract-enabled ridesharing service. *Sustainability*, 14(8), Article 4884. https://doi.org/10.3390/su14084884

Christidis, K., & Devetsikiotis, M. (2016). Blockchains and smart contracts for the internet of things. *IEEE Access*, 4, 2292-2303. https://doi.org/10.1109/ACCESS.2016.2566339

De Giovanni, P. (2022). Leveraging the circular economy with a closed-loop supply chain and a reverse omnichannel using blockchain technology and incentives. *International Journal of Operations & Production Management*, 42(7), 959-994. https://doi.org/10.1108/IJOPM-07-2021-0445

Deterding, S., Sicart, M., Nacke, L., O'Hara, K., & Dixon, D. (2011). Gamification. Using game-design elements in non-gaming contexts. *In Proceedings of the 2011 Annual Conference Extended Abstracts on Human Factors in Computing Systems - CHI EA '11*. https://doi.org/10.1145/1979742.1979575

European Commission. (2020). *A new Circular Economy Action Plan: For a cleaner and more competitive Europe*. European Union

Gangwal, A., Gangavalli, H. R., & Thirupathi, A. (2022). A survey of layer-two blockchain protocols. *Journal of Network and Computer Applications*, 209, 103539. https://doi.org/10.48550/arXiv.2204.08032

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

Gerasimova, V., Prause, G., & Hoffmann, T. (2023). NFT-enriched smart contracts for smart circular economy models. *Entrepreneurship and Sustainability Issues*, 11(2), 93-110. https://doi.org/10.9770/jesi.2023.11.2(8)

Kamilaris, A., Fonts, A., & Prenafeta-Boldú, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. *Trends in Food Science & Technology*, 91, 640-652. https://doi.org/10.1016/j.tifs.2019.07.034

Kewell, B., Adams, R., & Parry, G. (2017). Blockchain for good? *Strategic Change*, 26(5), 429-437. https://doi.org/10.1002/jsc.2143

Khan, A. R., & Ahmad, R. (2022). A blockchain-based IoT-enabled e-waste tracking and tracing system for smart cities. *IEEE Access*, 10, 86256-86269. https://doi.org/10.1109/ACCESS.2022.3198973

Kona, A., Guťan, D., & Horváth, P. (2020). Slovak Republic on the way to build smart cities based on KPIs with first Slovak smart city index. *Scientific Papers of the University of Pardubice, Series D, Faculty of Economics and Administration,*

28(4), Article 1061. https://doi.org/10.46585/sp28041061
Kouhizadeh, M., Saberi, S., & Sarkis, J. (2021). Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers. *International Journal of Production Economics*.
Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics*, 143, 37-46. https://doi.org/10.1016/j.ecolecon.2017.06.041
Küttim, M., Gerstlberger, W., Hurt, U., Kotov, A., Kull, M., Niine, T., & Ahmadov, T. (2023). Enablers and barriers in circular economy: The case of Estonia. Presented at the XXXIV ISPIM Innovation Conference, Ljubljana, Slovenia.
Lewandowski, M. (2016). Designing the business models for circular economy—Towards the conceptual framework. *Sustainability*, 8(1), Article 43. https://doi.org/10.3390/su8010043
McAloone, T., & Pigosso, D. (2018). Designing product service systems for a circular economy. *In Designing for the circular economy*. Routledge.
Meroni, A., & Sangiorgi, D. (2011). Design for Services. Gower Publishing. https://doi.org/10.4324/9781315576657
Morkunas, V. J., Paschen, J., & Boon, E. (2019). How blockchain technologies impact your business model. *Business Horizons*, 62(3), 295-306. https://doi.org/10.1016/j.bushor.2019.01.009
Nguyen, C. T., Hoang, D., Nguyen, D. N., Niyato, D., Nguyen, H., & Dutkiewicz, E. (2019). Proof-of-stake consensus mechanisms for future blockchain networks: Fundamentals, applications and opportunities. *IEEE Access*, 7, 85727-85745. https://doi.org/10.1109/ACCESS.2019.2925010
Nowiński, W., & Kozma, M. (2017). How can blockchain technology disrupt existing business models? *Entrepreneurial Business and Economics Review*, 5(3), 173-188. https://doi.org/10.15678/EBER.2017.050308
Olaniyi, E. O., Prause, G., Gerasimova, V., & Inkinen, T. (2022). Clean cruise shipping: Experience from the BSR. *Sustainability*, 14(5002). https://doi.org/10.3390/su14095002
Pakseresht, A., Yavari, A., Kaliji, S. A., & Hakelius, K. (2022). The intersection of blockchain technology and circular economy in the agri-food sector. *Sustainable Production and Consumption*, 35, 260-274. https://doi.org/10.1016/j.spc.2022.11.002
Philipp, R., Gerlitz, L., & Prause, G. (2019). Smart contracts for entrepreneurial collaboration in logistics networks. *In Proceedings of the 11th international scientific conference "New Challenges of Economic and Business Development – 2019: Incentives for Sustainable Economic Growth* (pp. 652-663). Faculty of Business, Management and Economics, University of Latvia.
Philipp, R., Prause, G., & Gerlitz, L. (2019). Blockchain and smart contracts for entrepreneurial collaboration in maritime supply chains. *Transport and Telecommunication Journal*, 20(4), 365-378. https://doi.org/10.2478/ttj-2019-0032
Piscicelli, L., Ludden, G. D. S., & Cooper, T. (2018). What makes a sustainable business model successful? An empirical comparison of two peer-to-peer goods-sharing platforms. *Journal of Cleaner Production*, 172, 4580-4591. https://doi.org/10.1016/j.jclepro.2017.08.170
Prause, G., & Boevsky, I. (2019). Smart contracts for smart rural supply chains. *Bulgarian Journal of Agricultural Science*, 25(3), 454-463.
Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, 57(7), 2117-2135. https://doi.org/10.1080/00207543.2018.1533261
Sangiorgi, D. (2011). Transformative services and transformation design. *International Journal of Design*, 5(2), 29-40.
Sedlmeir, J., Buhl, H. U., Fridgen, G., & Keller, R. (2020). The energy consumption of blockchain technology: Beyond myth. *Business & Information Systems Engineering*, 62(6), 599-608. https://doi.org/10.1007/s12599-020-00656-x
Shi, X., Xiao, H., Liu, W., Lackner, K. S., Buterin, V., & Stocker, T. F. (2021). Confronting the carbon-footprint challenge of blockchain. *Environmental Science & Technology*. https://doi.org/10.1021/acs.est.2c05165
Shojaei, A., Ketabi, R., Razkenari, M., Hakim, H., & Wang, J. (2021). Enabling a circular economy in the built environment sector through blockchain technology. *Journal of Cleaner Production*, 294, 126352. https://doi.org/10.1016/J.JCLEPRO.2021.126352.
Stahel, W. R. (2016). The circular economy. *Nature*, 531(7595), 435-438. https://doi.org/10.1038/531435a
Stickdorn, M., Hormess, M. E., Lawrence, A., & Schneider, J. (2018). *This is service design doing: Applying service design thinking in the real world*. O'Reilly Media.
Tian, F. (2017). An agri-food supply chain traceability system for China based on RFID & blockchain technology. *13th International Conference on Service Systems and Service Management (ICSSSM*), 1-6. https://doi.org/10.1109/ICSSSM.2017.7996119
Tukker, A. (2015). Product services for a resource-efficient and circular economy – A review. *Journal of Cleaner Production*, 97, 76-91. https://doi.org/10.1016/j.jclepro.2013.11.049
Upadhyay, A., Mukhuty, S., Kumar, V., & Kazançoğlu, Y. (2021). Blockchain technology and the circular economy: Implications for sustainability and social responsibility. *Journal of Cleaner Production*. https://doi.org/10.1016/j.jclepro.2021.126344
Velenturf, A., & Purnell, P. (2021). Principles for a sustainable circular economy. *Sustainable Production and Consumption*, 27, 286-299. https://doi.org/10.1016/j.spc.2021.01.018
Yin, R. K. (2018). Case study research and applications: *Design and methods*. Sage Publications.
Zhylinska, O., Bazhenova, O., & Zatonatska, T. (2020). Innovation processes and economic growth in the context of European integration. *Scientific Papers of the University of Pardubice, Series D, Faculty of Economics and Administration, 28*(3), Article 1209. https://doi.org/10.46585/sp28031209
Zomerdijk, L. G., & Voss, C. A. (2010). Service design for experience-centric services. *Journal of Service Research*, 13(1), 67-82. https://doi.org/10.1177/1094670509351960
Zyskind, G., Nathan, O., & Pentland, A. S. (2015). Decentralizing privacy: Using blockchain to protect personal data. 2015 IEEE *Security and Privacy Workshops*. https://doi.org/10.1109/SPW.2015

Appendix 2

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SERVICE DESIGN FOR TRANS-NATIONAL SMART SUPPLY CHAINS

Vera Gerasimova[1], Robert Philipp[1,2], Gunnar Prause[1,2]

[1]Department of Business Administration, Tallinn University of Technology
Tallinn, Estonia, Ehitajate tee 5
Email: vera.gerasimova@taltech.ee, gunnar.prause@taltech.ee

[2]Wismar Business School, Wismar University of Applied Sciences
Wismar, Germany, Philipp-Müller-Str. 14
Email: robert.philipp@hs-wismar.de
…………………….

Keywords: Service Design, Smart Supply Chains, Smart Contracts, Blockchain, Business Processes

Supply chain management passes through fundamental changes driven by new smart technologies. Smart contracting and blockchain technology represent innovative form of automation bearing the potential to establish new forms of cross-organisational collaboration and their underlying business processes. First cases in trans-national supply chains highlight that these technologies are able to support the integration of entrepreneurs and SMEs by reducing high entry barriers and weakening the dominating position of big players. However, the success of these approaches and new systems depend on the acceptance of the users of such systems as well as with the ability to cope with the requirements in the trans-cultural environment.

A promising and proven approach to facilitate the business success of innovative products and services emerge more often as result of cross-sectoral combination of technologies, design and business models comprising concepts like Open Innovation and Design Management. Unfortunately, the logistics sector is lagging behind in the application and implementation of design management concepts, which is surprising since smart supply chain management requires service solutions integrating networked technical systems and self-organised decentral structures on application level.

Recent research revealed that especially the logistics processes based on technical innovations like blockchain technology and smart contracting can benefit and be improved by service design solutions due to its international and often multi-modal nature. All stakeholders in trans-national logistics and supply chain processes follow their own business models as well as their cultural and organisational background so that the underlying technical solutions have to be covered on application level by smart service design interfaces in order to avoid frictions, inefficiencies and mistakes due to different mind-sets.

The paper investigates and discusses the research question of what service design can contribute to the integration, modelling and reconfiguration of trans-national supply chains and logistics processes. The origin is the Open Systems Interconnection (OSI) model for IT systems that link the technical level with the application layer and that will be exerted to an application in maritime supply chain management. The underlying technical solution is blockchain and smart contract based whereas the international stakeholders are interacting via the user interface for which service design blueprint is developed and empirically validated. The empiric results lean on expert interviews and a case study approach that was part of the EU projects “Connect2SmallPorts” as well as “Creative Ports”.

References

1. Olaniyi, E.O.; Atari, S.; Prause, G. (2018). Maritime energy contracting for clean shipping. *Transport and Telecommunication*, 19 (1), 31−44.10.2478/ttj-2018-0004.
2. Philipp, R.; Prause, G.; Gerlitz, L. (2019). Blockchain and Smart Contracts for Entrepreneurial Collaboration in Maritime Supply Chains. *Transport and Telecommunication Journal*, 20 (4), 365−378. doi:10.2478/ttj-2019-0030
3. Prause, G. (2014). A Green Corridor Balanced Scorecard. *Transport and Telecommunication*, 15 (4), 299−307.10.2478/ttj-2014-0026.
4. Prendeville, S., & Bocken, N. (2017). Sustainable Business Models through Service Design. *Procedia Manufacturing*, 8, 292–299. doi:10.1016/j.promfg.2017.02.037
5. Shostack, G. L. (1984). Designing services that deliver. *Harvard Business Review*, 62(1), 133-139.

Appendix 3

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NFT-ENRICHED SMART CONTRACTS FOR SMART CIRCULAR ECONOMY MODELS

Vera Gerasimova [1], Gunnar Prause [2], Thomas Hoffmann [3]

[1,2,3] Tallinn University of Technology, Ehitajate tee 5, 19086, Tallinn, Estonia

[2] University of Applied Sciences Wismar: Technology, Business and Design, Philipp-Müller-Str. 14, 23966 Wismar, Germany

E-mails:[1] vera.gerasimova@taltech.ee; [2]gunnar.prause@hs-wismar.de; [3] thomas.hoffmann@taltech.ee

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Abstract. A smart contract is an electronic transaction protocol intended to digitally facilitate, verify, or enforce the execution of the terms of underlying legal agreements. Thus, by following the traditional perception, smart contracts target reducing transaction costs, including arbitration and enforcement costs, by realizing trackable and irreversible transactions using blockchain technology for distributed databases. However, the potential of smart contracts goes far beyond cost reductions by facilitating the entrepreneurial collaboration of cross-organizational business processes. Industry 4.0 aims to create smart supply chains. Smart contracts and Non-Fungible Token (NFT) solutions can realize new smart business models in the circular economy. The recent case study from the automobile industry demonstrates how using NFT technology in the form of a digital certificate can become an integral part of smart product lifecycle management in the frame of a circular economy integrating innovative business models with smart service design concepts. By doing so, the use of NFT paves the way for dynamic and adaptable supply chains, evolving needs of stakeholders towards a sustainable and circular economy. The authors participated in research projects related to smart supply chains and circular economy. Thus, the paper discusses the question of how and to what extent smart contracting, blockchain technology, NFT solutions, and Service Design can facilitate the implementation of smart business models in the context of the circular economy. The research is based on expert interviews, surveys, and case studies from EU projects focusing on the Baltic Sea Region.

Keywords: smart contracts; Non-Fungible Token (NFT); smart supply chains; service design; business models; circular economy

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Additional disciplines: law; information and communication; ecology and environment; transport engineering; environmental engineering; informatics

1. Introduction

The classical pathway of mass production has been known as a linear model where products that reach the final stage of their lifecycle are trashed so that the remaining resources are wasted, creating an imbalance between resource supply and goods demand (Murray et al., 2017). With the current trend in production and consumption rate, sustaining development and providing future generations with resources will not be possible. Overcoming the contradiction between the need for economic growth and the necessity for accomplishing environmental sustainability is thus one of the most compelling issues of our time (Hobson & Lynch, 2016; Marques et al., 2018; Zecca et al., 2023).

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Catering the need for an alternative model of sustainable development with closed material loops, the Circular Economy (CE) emerged within the debates. The concept gained increasing attention on national - e.g. in the Netherlands (Dutch Ministry of Environment, 2016) as well as regional (European Commission, 2018) policy targets and is covered increasingly in business sector reports (e.g. Ellen Macarthur Foundation, 2013a, 2013b). The number of academic studies on the CE is increasing, and different authors have reviewed its various definitions and approaches.

While there is no comprehensive definition of the CE concept yet, the main objective of CE is to maintain the value of materials by keeping them in circulation and, consequently, reduce our reliance on material extraction (Kirchherr et al., 2017). According to Hislop & Hill, "the circular economy represents a development strategy that maximizes resource efficiency and minimizes waste production, within the context of sustainable economic and social development" (Hislop & Hill, 2011, p. 2).

However, after decades of discussion and research around CE, the linear model is still deeply entrenched. There are political, economic, technological, and legal obstacles to the transition to a circular economy (Hart et al., 2019). There is a strong need for political support to promote the circular economy concept (Araujo Galvão et al., 2018). The absence of incentives to adopt CE still exists, and new incentives are required to increase the speed of transition to CE.

Approaches to overcome these deficits have their sources in political incentive systems and new production paradigms labelled smart supply chain management in the context of Industry 4.0 (Prause, 2014, 2015; Ahmadov et al., 2022). The main aims of those approaches are laid on the fusion of the virtual and the physical world based on smart internet technologies and networked production processes coming along with energy and resource efficiency, increased productivity, shortening of innovation and time-to-market cycles together with a horizontal and vertical integration through value networks and an end-to-end digital integration of engineering across the entire value chain. Thus, the internet–linked production facilities and networked manufacturing systems open up a machine-to-machine-communication and interaction, called M2M, which allows to name, identify and trace single products during their whole creation process and later on during their lifetime, which generates new perspectives for the entire supply chain including product design and development, operations management and logistics.

Of particular interest for the circular economy is the possibility to identify and trace products during their lifecycle (Eshghie et al., 2022), which opens the opportunity to attach special conditions, services and rights to events during different phases of their lifetime. Recent research stresses the potential of blockchain technologies together with smart contracts to facilitate event-triggered and automatized transactions within supply chains (Philipp et al., 2019). Such blockchain and smart contract platforms allow supply chain parties to encode business rules based on negotiated legal agreements, i.e., a smart contract can be considered as an electronic transaction protocol to enforce digitally the negotiation and execution of the terms of an underlying legal contract designed to fulfil conditions like payments, legal obligations, and enforcement without third parties.

In the circular economy context, such a smart contract realizes the digital execution of legal agreements and linked transactions related to special events on the product lifecycle. Non-Fungible Token (NFT) represent digital assets that can be integrated into blockchains and can be used to realize links to specific data sets and to identify and attribute special features to a product. Besides this, NFT can be used to parametrize smart contracts to realize special services related to the product or to implement and specify smart business models.

The paper highlights the potential of using blockchain technologies together with smart contracts to facilitate event-triggered and automated transactions within supply chains, allowing supply chain parties to encode business rules based on negotiated legal agreements. In the circular economy context, smart contracts can realize the digital execution of legal agreements and linked transactions linked to special events in the product lifecycle. NFTs represent digital assets that can be integrated into blockchains and used to connect specific data sets and identify and attribute special features to a product. NFTs can also be used to parametrize smart contracts to realize special services related to the product or to implement and specify smart business models.

The research presented in this paper is based on literature expert interviews, surveys conducted within the context of European Union (EU) projects focusing on the Baltic Sea Region, and a case study. The author aimed to explore how and to what extent smart contracting, in cooperation with blockchain technology and NFT solutions, can facilitate the implementation of smart business models in the circular economy context.

2. Circular Economy

The Circular Economy (CE) concept addresses resource depletion and environmental degradation caused by the linear economic model. The concept of the CE can be traced back to the early 1970s when the Club of Rome, a global think tank, published a report titled "The Limits to Growth" (Meadows et al., 1972). The report highlighted the issue of resource depletion and predicted that the world's resources would be exhausted within the next century if the linear economic model continued to be used. The report called for a new economic model focusing on sustainability and resource efficiency. In the 1980s and 1990s; the idea of CE gained momentum, with several researchers and organizations advocating for a new economic model that focused on waste reduction and resource efficiency. In 1994, Walter R. Stahel, a Swiss architect and economist, coined the term "cradle to cradle" to describe the idea of a closed-loop system that allows for the continuous reuse of resources and materials (Stahel, 2010).

In the 2000s, the CE concept gained traction in business, with several companies adopting CE principles in their operations. In 2012, the Ellen MacArthur Foundation, a UK-based charity, was founded to promote the CE concept globally (Ellen MacArthur Foundation, 2012). The foundation's report, "Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition," provided a comprehensive overview of the concept and its potential benefits.

In 2015, the CE concept gained global recognition when it was included in the United Nations' Sustainable Development Goals (SDGs). Goal 12 of the SDGs calls for sustainable consumption and production patterns, with a specific target to "implement the 10-year framework of programs on sustainable consumption and production, all countries taking action, with developed countries taking the lead" (United Nations, 2015).

Today, the CE concept is widely recognized as a critical strategy for achieving sustainability and reducing resource depletion and waste. The concept has gained widespread adoption in business, with several companies adopting circular economy principles. The CE concept has also obtained significant support from governments and international organizations, with several countries and organizations developing circular economy strategies and policies.

The CE concept has evolved from a relatively new idea in the 1970s to a mainstream concept in the 21st century. The concept has been supported by businesses, governments, and international organizations and is now recognized as a critical strategy for achieving sustainability and reducing resource depletion and waste. CE has become an increasingly popular topic of discussion in recent years due to its potential to address some of the most pressing sustainability challenges facing society. CE aims to reduce waste and promote sustainable consumption and production by maximizing the value of resources through a closed-loop system. CE is also an economic model that aims to reduce waste and promote sustainable consumption and production. It is based on the concept of closed-loop systems, where resources are kept in use for as long as possible through reuse, repair, and recycling (Ellen MacArthur Foundation, 2013a, 2013b). CE is seen as a way to decouple economic growth from resource consumption and environmental degradation by promoting more efficient use of resources and reducing waste.

The principles of CE are based on the idea of designing waste and pollution, keeping products and materials in use, and regenerating natural systems (Ellen MacArthur Foundation, 2019). These principles are reflected in various practices, such as product design for circularity, closed-loop supply chains, and collaborative consumption models. One of the key principles of CE is product design for circularity, which involves designing products to minimize waste and maximize their lifespan. This can include designing products that are easy to repair, upgrade, or recycle (Bocken et al., 2016). Another essential principle is closed-loop supply chains, which

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involve creating a closed system where materials and products are kept in use for as long as possible (Tukker et al., 2015). This can involve practices such as remanufacturing, refurbishing, and recycling.

There are many examples of CE in practice across various industries and sectors. One example is the textile industry, where circular models are being developed to reduce waste and increase resource efficiency (Ghisellini et al., 2016). This can involve using recycled fibres, designing products for disassembly, and implementing closed-loop supply chains. Another example of CE in practice is the sharing economy, which involves collaborative consumption models promoting the sharing of resources and products (Bardhi & Eckhardt, 2012). This can include practices such as ride-sharing, co-working spaces, and tool libraries.

CE offers a promising approach to promoting sustainable consumption and production by maximizing the value of resources through a closed-loop system. Its principles are reflected in various practices, such as product design for circularity, closed-loop supply chains, and collaborative consumption models. There are many examples of CE in practice across multiple industries and sectors, and policymakers, businesses, and consumers increasingly recognize its potential for promoting sustainable development.

CE is closely related to sustainability, as it provides a framework for economic growth that aligns with sustainable development principles. Sustainability is defined as meeting the needs of the present without compromising the ability of future generations to meet their own needs (United Nations, 1987). The circular economy is seen as a critical approach for achieving sustainability as it seeks to reduce the depletion of natural resources, minimize waste, and lower greenhouse gas emissions (Ellen MacArthur Foundation, 2015).

The circular economy model emphasizes the importance of designing products and services with the end in mind. It involves a shift away from the traditional linear take-make-dispose model to one where resources are kept in use for as long as possible through strategies such as recycling, reuse, and remanufacturing (Kirchherr et al., 2017). By keeping materials in circulation, the circular economy reduces the need for virgin resource extraction, which can have negative environmental and social impacts. The circular economy offers numerous benefits for achieving sustainability. One key benefit is the reduction in resource depletion. By keeping resources in circulation, the circular economy minimizes the need for virgin resource extraction, which can lead to habitat destruction, air and water pollution, and other negative environmental impacts (Kirchherr et al., 2017). Another benefit of the CE is the waste reduction. The circular economy minimizes waste generation by designing products and services for longevity and end-of-life considerations. It encourages the use of resources more efficiently and effectively. This can also reduce the need for landfill space and associated costs (Stahel, 2016). The CE can also create new economic opportunities. For example, the recycling and remanufacturing industries can provide new jobs and revenue streams while reducing the reliance on the traditional linear economic model (Ellen MacArthur Foundation, 2015).

CE promotes the efficient use of resources, reduces the environmental impact of economic activities, and helps to preserve natural ecosystems. These benefits make CE an essential concept for achieving sustainable development and addressing modern challenges while promoting innovation and economic growth.

3. Smart Contracts for Smart Supply Chains

Supply chain management (SCM) coordinates and optimizes cross-company business processes based on downstream flows of goods and services and upstream flows of information and finance (Jacobs & Chase, 2020). Coordinating supply chain flows represents a challenging task, and recent research results advocate a significant potential in blockchain technologies for facilitating supply chain management (Gligor et al., 2021).

This enthusiasm towards blockchains stems from the underlying technological concept that uses time-stamped ledgers of transactions without a central authority. In other words, transactions are not recorded centrally, and each party maintains a local copy of the ledger consisting of a linked list of encrypted blocks comprising a set of transactions that are hashed and grouped in blocks and thus broadcasted and recorded by each participant in the blockchain network (Sternberg et al., 2021). When a new block is proposed, the participants in the network agree upon a single valid copy of this block according to a consensus mechanism. Once a block is collectively accepted, it is practically impossible to change it or remove it i.e. a blockchain can be considered a replicated append-only transactional data store, which can replace a centralized register of transactions maintained by a trusted authority (Philipp et al., 2019). With blockchain technology, the necessary visibility and transparency can be generated in SCM – which is especially beneficial for SCRM.

A closer look at the term blockchain indicates that often two meanings are mixed, namely a distributed database and a data structure consisting of a linked list of blocks of transactions, where each block is cryptographically chained to the previous one by including their hash value and a cryptographic signature, in such a way that it is impossible to alter an earlier block without re-creating the entire chain since that block. Blockchain platforms additionally offer the possibility of executing scripts on top of a blockchain, called smart contracts, allowing parties to encode business rules like negotiated legal agreements. Thus, a smart contract can be considered an electronic transaction protocol to digitally enforce the negotiation and execution of the terms of an underlying legal contract designed to fulfil conditions like payments, legal obligations, and enforcement without third parties. Such a smart contract realizes the digital execution of legal agreements and linked transactions between distributed units within a network or supply chain with reduced transaction costs, being trackable and irreversible (Prause, 2019).

One of the newest developments in the context of smart contracts is non-fungible token (NFT) representing digital data stored in a blockchain. Such an NFT can be distributed to a specific and exclusive individual owner, i.e. it represents a proof of ownership of a blockchain record and can transferred, i.e. traded. The essential characteristics of NFTs are that they contain links to digital files, are uniquely identifiable, and are easy to create. In particular business sectors, especially in the cultural and creative industry (CCI), NFTs enjoy high economic importance because the linked digital files represent the market value of an NFT. It must be pointed out that NFTs represent a public certificate of authenticity or proof of ownership defined by the blockchain. Still, they do not grant a copyright in the represented object itself – which also means that the author (or licensed user) may create a generally unlimited number of further NFTs representing the same object. Neither do NFTs grant any other legal rights over their associated digital file (Wang et al., 2021) - they are, in other words, a mere "digital label" (e.g., with the function of a price tag) to any object selected to be represented by it.

In a CE context, NFTs can be used as uniquely identifiable tokens that refer to a digital file that stores rights and conditions for certain tripper points in the product lifecycle. Underlying smart contracts can use these NFTs for executing scripts with parameters stored in the digital files, i.e., in such a way, smart contracts can be parametrized through NFTs with actual parameters along the lifecycle of a product.

Overall, there are many benefits associated with blockchain implementation in supply chain management. The study of Ayan et al. (2022) confirms that blockchain technology can enhance supply chain transparency, traceability, and accountability, leading to increased efficiency, reduced waste, and improved environmental and social sustainability. The authors also provide case studies from the food, fashion, and energy industries to illustrate the potential of blockchain in promoting sustainability. Dounas et al. (2021) also state that using NFTs in construction and architecture allows the expansion of Digital Twins applications using blockchain technologies, where components are connected with particular aspects of the building performance and their maintenance is potentially automated through smart contracts. (Dounas et al., 2021).

4. Previous research on NFT-enriched Smart Contracts for Circular Economy models

In recent years, a growing share of literature has addressed the applications of blockchain technologies and smart contracts in various sectors. These studies have highlighted the potential of these technologies for improving operational efficiency, transparency, and trust among supply chain participants (Kshetri, 2018; Tapscott & Tapscott, 2016). There is also an emerging body of literature exploring the potential of NFTs, which represent unique digital assets that can be integrated into blockchain platforms (Non-Fungible Tokens, 2021). These studies have suggested that NFTs can provide new ways of managing and verifying ownership, tracking product life cycles, and creating digital twins of physical assets (Adhami et al., 2018; Khaqqi et al., 2018). Consequently, NFT-enriched smart contracts have also gained significant attention in recent years for their potential use in circular economy models to safeguard a maximal use of products to save resources or to enhance the possibilities of reuse and recycling.

Navarro et al. (2022) investigated the design, implementation, evaluation, and operation of a verifiable registry for digital product passports of ICT products using blockchain technology. Their experimental results confirm that digital product passports can serve as viable instruments for promoting transparency and environmental accountability in the ICT sector and as an example for other product sectors to meet the world's climate change goals, which are too important to overlook.

Another research by Alves et al. (2022) examined current approaches to traceability in the textile and clothing value chain and explored the technologies necessary for promoting a circular economy in this industry. The specific focus was put on blockchain technology for registering activities on traceable items throughout the value chain and the Internet of Things (IoT) technology for identifying the digital twins of these traceable items. The authors concluded that more efficient and sustainable management of the textile and clothing value chain can be achieved by leveraging these technologies.

A study by Dos Santos et al. (2021) proposes a method for efficient and unrestricted publicity of third-party certification of plant agricultural products using smart contracts and blockchain tokens, providing economic incentives to actors in the supply chain. The study finds that this method can improve food safety and reduce counterfeiting and greenwashing. Implementing tokenization can enhance transparency, promote sustainable consumer behavior, and lead to a more trustworthy supply chain.

Research by Wu et al. (2023) aimed to find a better way to keep track of construction waste material when it's traded across borders. The researchers proposed a blockchain-based solution to create a digital passport for each piece of waste material. The framework involves digitizing into NFT-enabled passports, preventing duplicate issuances, enhancing transparency, improving trading efficiency, and securing transaction records. A prototype of the framework was developed and found to be feasible with satisfactory performance, serving as a reference for future blockchain NFT-enabled passport applications in the circular economy.

5. Service Design for Circular Economy

Service Design (SD) is a process that involves creating user-centered services that meet the needs and expectations of users while also considering the broader context in which the service operates. This approach places the user at the center of the design process and emphasizes the importance of understanding user needs, behaviors, and preferences. SD has been used in various fields, including healthcare, education, and retail, to create services that meet users' needs while also achieving business goals. The concept of SD emerged in the early 1990s as a response to the increasing complexity of service provision in the post-industrial economy. Since then, the field has rapidly developed, with practitioners and academics exploring and refining the principles and methods of SD.

SD can be employed to create sustainable business models by addressing the social and environmental aspects of the business. The social aspect of sustainability involves creating services that meet the needs of all stakeholders, including customers, employees, and the wider community. The environmental aspect of sustainability involves reducing the environmental impact of the business by adopting sustainable practices. According to Bitner et al. (2008), SD can help to create sustainable business models by focusing on three key areas: service delivery, service environment, and service communication. Service delivery involves designing services that meet the needs and expectations of customers while also being efficient and effective. Service environment involves creating a physical and virtual environment that supports the service and enhances the customer experience. Service communication involves creating clear and effective communication channels that enable customers to access the service and provide feedback.

A sustainable business model is a business model that generates economic, social, and environmental value. According to Stubbs and Cocklin (2008), sustainable business models involve four key components: economic viability, social responsibility, environmental responsibility, and innovation. Economic viability involves creating a profitable business model that generates value for stakeholders. Social responsibility involves creating a business model that considers the social impact of the business on all stakeholders. Environmental responsibility involves creating a business model that minimizes the environmental impact of the business. Innovation involves creating a business model adaptable and responsive to changing market conditions. SD can facilitate the development of sustainable business models by incorporating the four components of sustainable business models into the design process. According to Sangiorgi (2011), SD can facilitate the creation of sustainable business models by adopting a systemic approach that considers the interdependencies between economic, social, and environmental factors. SD can also facilitate the adoption of sustainable practices by involving stakeholders in the design process and creating services that meet the needs and expectations of all stakeholders.

SD can also be beneficial for the creation of smart services discussed in this paper and have the potential to revolutionize the way supply chains operate. Designing and implementing such systems is complex and requires a user-centered approach. Designing services that use Smart contracts technology also requires a deep understanding of the technology and the specific industry in which the service will be applied.

SD employs a range of tools to create and improve the product or service. Two common tools used in SD, such as co-creation, are journey mapping and service blueprint, which can be largely applied to contribute to CE. Journey mapping is a visual tool that maps out a customer's steps when interacting with a service, from initial awareness to post-service follow-up. This tool helps designers and stakeholders identify pain points and opportunities for improvement throughout the customer journey (Stickdorn et al., 2018). Service blueprinting is another tool that visually maps out the service process but from the internal perspective of the service provider. This tool helps identify the different people, processes, and technologies involved in delivering the service and areas for improvement (Bitner et al., 2008). Both journey mapping and service blueprinting are effective co-creation tools for SD, as they involve collaboration between designers, stakeholders, and customers to ensure that services are designed with the customer experience in mind. By using these tools, service designers can create more effective and efficient services that meet the needs of all parties' needs.

SD can create services that utilize Smart Contracts in several ways. One way is by identifying the key stakeholders and their needs and designing the service to meet them using smart contracts. This can include designing the user interface for interacting with the smart contract, as well as the process for creating and executing the contract. Another way SD can be used is by identifying potential pain points or inefficiencies in existing processes and using smart contracts to streamline and automate those processes. This can include using smart contracts to automate payment and settlement processes and enforce compliance with regulatory requirements. SD can also be used to design the governance and decision-making processes for smart contract-based services. This includes designing the process for amending or updating the smart contract and determining the appropriate level of decentralization for the service. As such, organizations need to consider the integration of SD in the development of smart contract-based services. In conclusion, SD can be a valuable tool in creating smart services and dealing with emerging challenges related to CE.

6. Methodology

This paper employs a mixed-methods research design that includes expert interviews, desktop research, a literature review, and a case study approach. Using multiple methods allows for a comprehensive and multi-dimensional analysis of the research topic, providing a more robust understanding of the phenomenon under investigation. The expert interviews provide insights from professionals with extensive experience and knowledge in the field. At the same time, the desktop research and literature review offer a broad and systematic review of existing literature and data sources. The case study approach enables in-depth analysis of a particular phenomenon or context, providing a detailed and contextualized understanding of the research topic. Together, these methods provide a rigorous and comprehensive approach to research and analysis.

This paper aims to investigate how smart contracting, in cooperation with blockchain technology and NFT solutions, can facilitate the implementation of smart business models in the circular economy context.

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The research is based on expert interviews, surveys, and a case study conducted in the context of EU projects focusing on the Baltic Sea Region.

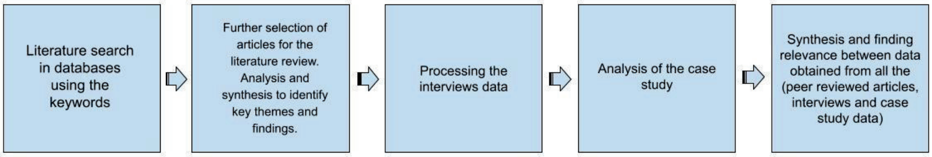

Figure 1. Methodological procedure of the study

Source: authors' own elaboration

This literature review was conducted using desktop research, which involved a comprehensive search of relevant academic articles and literature from reputable sources. The search used Scopus, Google Scholar, and Web of Science databases. Keywords used in the search included "NFTs," "smart contracts," "circular economy," "blockchain," "supply chain," and "sustainability." The inclusion criteria for articles in this literature review were relevance to the topic, recency, and peer-reviewed status. Articles published between 1999 and 2022 were included to ensure that the most recent and up-to-date research was included. The search initially yielded many results, which were then screened based on their abstract and title to identify relevant articles. After screening the initial results, 20 academic articles were selected for the literature review, representing the most relevant scientific papers related to our study. These articles were then analyzed and synthesized to identify key themes and findings related to the benefits of using NFT-enriched smart contracts in circular economy models.

Overall, desktop research provides a comprehensive and efficient method for conducting literature reviews. It allows researchers to access a vast array of relevant literature from different sources and enables the efficient screening and selection of articles that meet the inclusion criteria. Furthermore, using various databases ensures the inclusion of diverse perspectives and insights, enhancing the validity and reliability of the review's findings. In addition, expert interviews were conducted to understand the potential of smart contracts and NFT solutions in implementing circular economy practices. The interviews were conducted with professionals from various fields, including blockchain technology experts, supply chain managers, and circular economy practitioners. The interviews were conducted using a semi-structured approach, and the questions focused on exploring the role of smart contracts and NFT solutions in circular economy practices.

Surveys were conducted to gather quantitative data on using smart contracts and NFT solutions in circular economy practices. The survey questions were designed to understand the level of awareness, adoption, and perceived benefits of using smart contracts and NFT solutions in circular economy practices. The surveys were distributed among professionals from various fields, including blockchain technology experts, supply chain managers, and circular economy practitioners.

The expert interviews, surveys, and case study data were analyzed using a qualitative and quantitative approach. We review a case study focusing on Alfa Romeo's Tonale hybrid SUV to explore the potential of smart contracts and NFTs in facilitating smart circular economy business models. The qualitative analysis was conducted to identify themes and patterns in the data, while the quantitative analysis was conducted to obtain numerical data on the use of smart contracts and NFT solutions in circular economy practices. The findings from the analysis were used to answer the research question and provide insights into the potential of smart contracting in the context of the circular economy.

The authors aimed to explore how and to what extent smart contracting, in cooperation with blockchain technology and NFT solutions, can facilitate the implementation of smart business models in the context of circular economy. Expert interviews allowed the author to gather insights and opinions from individuals who possess in-depth knowledge and experience in the fields of circular economy, smart contracting, and blockchain

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2023 Volume 11 Number 2 (December)
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technology. These experts were selected based on their expertise and experience in the industry, and their opinions were used to shape the research questions and the study. The research comprises 12 interviews that were conducted between September 2022 and March 2023 in Estonia and Germany in a structured format in the frame of national and EU projects on circular economy, allowing the author to gather specific information about the challenges and opportunities associated with implementing smart business models in the context of circular economy.

The survey component of the research aimed to gather data from a larger sample of individuals with varying levels of expertise and experience in the field. The survey was designed to collect information on the use of smart contracts and NFT solutions in the context of a circular economy and identify any barriers to implementation and potential areas for improvement. Finally, a case study was conducted to provide real-world example of implementing smart business models in the circular economy context. This case study was selected based on its relevance to the research questions. It provides insights into the industry's practical applications of smart contracting and NFT solutions.

Overall, the combination of expert interviews, surveys, and the case study provided a comprehensive picture of the challenges and opportunities associated with implementing smart business models in the circular economy context. The gained empirical measures represent a classical multi-method approach combining quantitative and qualitative data from different sources that were analyzed and interpreted using a methodological triangulation approach in the sense of Altrichter et al. (2008) to acquire a more detailed and better-balanced picture of the research situation. Finally, the empirical results of the research are discussed in the context of the current literature.

7. Two Case Studies: The Alfa Romeo's Tonale and the EV-Purchasing Model

Alfa Romeo's Tonale hybrid SUV represents a groundbreaking application of blockchain technology and NFTs in the automotive industry. This case study provides insight into how smart contracts and NFTs can revolutionize the automotive industry, transforming customer experiences and influencing business models in the circular economy context.

The Alfa Romeo's Tonale, set to launch in 2023, stands out in the automotive market by incorporating blockchain technology. Each Tonale comes with a complimentary NFT a digital certificate linked to the vehicle (Alfa Romeo, 2023). This digital certificate will continuously update with essential vehicle data, ensuring a consistent and reliable record of the vehicle's history. Hence, the NFT records and updates information about maintenance and milestones, such as reaching 100,000 miles. It provides a well-documented vehicle history, offering added value to the owner if the vehicle is ever sold. This utilization of NFTs offers an innovative solution to a longstanding issue in the used car market – information asymmetry and difficulty verifying a vehicle's history.

Moreover, smart contracts' realized integration with NFTs could automate various vehicle-related transactions. For instance, smart contracts could be set to trigger maintenance services when the vehicle reaches certain milestones. This innovative approach illustrates how blockchain technology, when integrated with smart contracts and NFTs, can significantly enhance automotive companies' customer experience and service efficiency. Thus, integrating smart contracts, NFTs, and service design in Tonale's model can potentially revolutionize the automotive industry's business model. For instance, a "product-as-a-service" model could be explored, wherein customers pay for access to the vehicle rather than its ownership. Such a model could encourage manufacturers to design more durable, repairable, and recyclable vehicles since they would be responsible for their end-of-life management.

The Tonale case demonstrates that a well-implemented service design can ensure a consistent supply of used materials to recycling plants. The digital certificate, in this case, adds value to owners who keep their vehicles well-maintained and reach certain usage milestones, motivating them to contribute to circular economy aims, i.e. this system also facilitates the resale process, as the digital certificate provides potential buyers with an entire, reliable history of the vehicle. The service design process requires collaboration among various

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2023 Volume 11 Number 2 (December)
http://doi.org/10.9770/jesi.2023.11.2(7)

stakeholders, including manufacturers, dealers, service providers, and customers. This can ensure a seamless transition of the product through its lifecycle and enhance the transparency of the product lifecycle, particularly for complex products such as cars. In conclusion, the Alfa Romeo Tonale case demonstrates how the innovative combination of blockchain technology, smart contracts, NFTs, and service design can substantially enable the automotive industry to contribute to the circular economy. This case study provides valuable insights that could guide future research and policy-making initiatives to promote adopting these technologies in various industries.

A second case highlights the role NFT's can play in business model development. In recent times, new business models have emerged that leverage the use of electric vehicles (EVs) to enhance sustainability. The discussed case represents an anonymized company, well-known to the authors and based in Estonia. It purchases brand-new electric cars directly from manufacturers at discounted prices, rents them to individuals, and replaces them when they reach 10,000 km. It presents an interesting case for examination. While this model may seem unsustainable at first glance due to the rapid turnover of vehicles, some aspects could be considered eco-friendly. The cars are electric, reducing carbon emissions during usage (Hawkins et al., 2013). Moreover, the low mileage at which the cars are sold in the regular market suggests that the vehicles will still have a long life ahead of them, potentially replacing older, less efficient vehicles.

A closer view to the benefits of the EV Turnover Model reveals the implicit sustainability aspects to this model:

1. Lowered Carbon Footprint: By maintaining a fleet of new electric vehicles and ensuring their rapid turnover, these companies ensure that the cars on the road are equipped with the latest energy-efficient technologies. Such practices can lead to reduced greenhouse gas emissions over the vehicle's operational life (Sprei & Ginnebaugh, 2018).
2. Second-Life Utility: Selling a car after just 10,000 km ensures that it remains in near-pristine condition, which could substitute and effectively retire an older, potentially more polluting vehicle on the road. This means these vehicles will likely serve two owners throughout their lifespan, optimizing their utility (International Energy Agency, 2019).
3. Economic Incentives for Sustainability: The model also offers a unique economic proposition by allowing consumers to regularly experience new vehicles without long-term commitment, thereby potentially increasing the adoption rate of EVs (Sierzchula et al., 2014).
4. Promotion of Electric Vehicles: By making the latest electric vehicles accessible and affordable to the general public through leasing, this model indirectly promotes the transition from conventional fuel-based vehicles to electric ones. This transition is crucial for reducing the overall carbon footprint of the transportation sector (International Energy Agency, 2019).

By comparing the EV model with the Alfa Romeo Tonale hybrid SUV, it becomes evident that the latter offers more comprehensive sustainability features. For example, Tonale's NFT system keeps a digital record of the vehicle's history, promoting responsible ownership and potentially extending the vehicle's lifespan (Alfa Romeo, 2023). This contrasts with the business model described above, which focuses on quick turnover rather than long-term utilization and accumulating a well-documented history (McKinsey & Company, 2017).

8. Results and Discussion

Both models aim to capitalize on the transition to cleaner and more sustainable forms of transportation; Tonale's approach offers broader implications for a circular economy. By incorporating blockchain technology and NFTs, Alfa Romeo supports sustainability and enhances customer experience and operational efficiency (Geissdoerfer et al., 2017). In juxtaposition, the Alfa Romeo Tonale hybrid SUV offers a different layer of sustainability and innovation. Beyond its hybrid functionality, its integration of NFTs to provide a digital log of the vehicle's history promotes extended vehicle life cycles and responsible ownership, leading to new features in the classical business models in the car sector (Alfa Romeo, 2023):

1. Digital Accountability: The NFT system, by offering an indisputable, continuous record of the car's milestones and maintenance, fosters an environment of accountability. This might discourage rapid turnover and encourage longer ownership, which has sustainability implications (Ajanovic & Haas, 2016).

2. Market Valuation: Such well-documented histories can elevate the vehicle's second-hand market value. Prospective buyers would be more inclined to purchase a vehicle with a transparent record, ensuring these vehicles remain in circulation for longer (Delucchi & Lipman, 2001).
3. Circular Economy Aspects: Tonale's approach, encompassing the fusion of technology like blockchain and NFTs, underscores the broader goals of a circular economy. Through lifecycle traceability and fostering responsible ownership, the potential waste and rapid turnover could be curtailed (Geissdoerfer et al., 2017).

Conclusively, while both models advocate for eco-friendliness and sustainability, they do so from different angles. The EV turnover model emphasizes rapid renewal, whereas the Tonale hybrid SUV leans towards comprehensive lifecycle management.

Navigating the sustainable landscape presented by Alfa Romeo's Tonale hybrid SUV and contrasting it with alternative EV business models, one can appreciate the multifaceted approaches toward achieving sustainability in the automotive domain (Geissdoerfer et al., 2017). Both models signify the industry's shift towards greener practices; however, their differences illuminate the vast spectrum of sustainable opportunities and challenges. As smart contracts and NFTs steadily permeate this industry and business models evolve to prioritize sustainability, the journey towards a cleaner, more efficient automotive future gains momentum (Tapscott & Tapscott, 2016; Kshetri, 2017). This discourse serves as a testament to the industry's commitment to sustainability and the innovations that arise from it.

Summing up the review of the two distinct cases - the Alfa Romeo's Tonale Hybrid SUV's integration of NFT technology and the sustainable business model of purchasing, renting, and reselling electric cars - several recommendations emerge for stakeholders in the automotive industry:

1. Digital Integration and Traceability: The integration of NFTs by Alfa Romeo showcases the potential of digital traceability in enhancing the car ownership experience. Manufacturers should explore the possibility of integrating similar technologies, not just as a value proposition for consumers but also as a measure to ensure proper maintenance longevity and even to reduce fraudulent practices in used-car markets (Tapscott & Tapscott, 2016).
2. Sustainable Business Models: Purchasing electric vehicles, renting them out until a set mileage, and then selling them is an innovative approach that speaks to a broader strategy. It reduces the environmental impact by promoting electric vehicle usage and ensures cars have a longer life cycle with multiple users. Other companies can adopt similar models, emphasizing economic benefits and environmental sustainability (Eisenhardt & Graebner, 2007).
3. Incentives for Electric Vehicles (EVs): Given the environmental advantages of EVs, governments and policymakers should provide further incentives to consumers and businesses that promote their usage. This could include tax breaks, grants for R&D in sustainable transport, or even subsidies for consumers.
4. Collaborative Initiatives: As seen in the two cases, innovation often results from a synergy of different sectors - tech and automotive, in the case of Alfa Romeo, and the rental and resale market in the electric car business model. Collaborative efforts between industries can lead to groundbreaking business models and sustainable solutions (Chesbrough, 2003).
5. Consumer Education: The success of both models largely depends on consumer acceptance. It's essential to invest in consumer education initiatives about the benefits of such models, both in terms of personal benefits (like the NFT's ability to record car data) and broader societal advantages (such as the environmental benefits of EVs).
6. Adaptable Supply Chains: In an era of rapid technological advancements, automotive companies should ensure adaptable supply chains. This adaptability allows for the quick integration of innovations, whether they are in the realm of digital tech like NFTs or in sustainable business practices.
7. Research and Development: Continued investment in R&D is essential. Both cases underscore the significance of innovation in driving the industry forward. Auto companies should allocate resources to refine existing models and pioneer new, disruptive solutions that cater to an evolving market and a planet needing sustainable solutions.

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2023 Volume 11 Number 2 (December)
http://doi.org/10.9770/jesi.2023.11.2(7)

Consequently, while the two cases present unique strategies and outcomes, they collectively highlight the automotive industry's vast potential for innovation, sustainability, and consumer-centric solutions. Adopting these recommendations can benefit individual stakeholders and pave the way for a more sustainable and efficient automotive ecosystem. Hence, the potential of using smart contracts together with NFTs to facilitate the implementation of smart circular economy business models, using the case of Alfa Romeo's Tonale hybrid SUV as a reference. The research is based on expert interviews, surveys, and a case study conducted in the context of EU projects focusing on the Baltic Sea Region.

The authors emphasize the need for an alternative model of sustainable development with closed material loops in terms of the CE, which maintains the value of materials and reduces reliance on material extraction. The linear model is still deeply entrenched due to political, economic, technological, and legal obstacles, and the transition to a circular economy requires political support and incentives. Hence, smart supply chain management and Industry 4.0 approaches aim to fuse the virtual and physical worlds based on smart internet technologies and networked production processes. These approaches open up machine-to-machine communication and interaction, allowing for the identification and tracking of products during their lifecycle, which generates new perspectives for the entire supply chain, including product design and development, operations management, and logistics.

The results of this study suggest that smart contracting, blockchain technology, and NFT solutions can facilitate the implementation of smart business models in the context of the circular economy. The study found that smart contracts enable automated, secure, and transparent execution of agreements and transactions, which can reduce the transaction costs associated with traditional contracts. Smart contracts can also ensure that the terms of agreements are executed as intended, without the need for intermediaries.

The study also found that NFTs can be used to create digital representations of physical assets, which can be used to verify their authenticity and ownership. NFTs can also be used to encode special features and conditions related to the product, such as its environmental impact, recycling potential, and end-of-life options. This allows for the creating of smart business models that incentivize sustainable practices and promote circular economy principles. Furthermore, the study found that the combination of smart contracts and NFTs can enable the creation of new business models, such as "product-as-a-service", where customers pay for access to the product rather than ownership. This can encourage manufacturers to design more durable, repairable, and recyclable products, as they would be responsible for the end-of-life management of the product.

The study also highlights that SD can be crucial in ensuring a consistent supply of used materials to recycling plants. By using SD principles, a system can be created that encourages suppliers to provide a steady flow of used products that meet the quality and quantity requirements of the recycling plants. One approach to achieving this is designing a supply chain that considers the needs and motivations of all stakeholders involved. Prause (2015) states that a sustainable business model should motivate the product owner to contribute to circular economy aims, which can be achieved through different incentive types, including refund systems and tax incentives.

The case of the Tonale hybrid SUV by Alfa Romeo comes with a complimentary NFT, essentially a digital certificate, which continuously updates with information about the vehicle, tracking maintenance and milestones (Alfa Romeo, 2023). This innovative approach embodies the seamless blend of physical and digital realities, creating a robust ecosystem of information around the product and thereby enriching its value and lifecycle management.

This case study demonstrates the potential for smart supply chain management and Industry 4.0 approaches, allowing for identifying and tracking products during their lifecycle, thereby opening up new perspectives for the entire supply chain, including product design and development, operations management, and logistics. Thus, smart contracts, coupled with blockchain technologies, allow for event-triggered and automated transactions within supply chains. This revolutionary method enables supply chain parties to encode business rules based on

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2023 Volume 11 Number 2 (December)
http://doi.org/10.9770/jesi.2023.11.2(7)

negotiated legal agreements. In the context of a circular economy, smart contracts realize the digital execution of legal agreements and linked transactions corresponding to special events in the product lifecycle.

Tonale's NFTs represent digital assets integrated into blockchains, used to link specific data sets and identify and attribute special features to the product. NFTs can be used to parameterize smart contracts to realize special services related to the product or to implement and specify smart business models. Hence, the Alfa Romeo Tonale case study shows that the combination of smart contracts and NFTs can enable the creation of new business models, such as product-as-a-service, where customers pay for access to the product rather than ownership. This encourages manufacturers to design more durable, repairable, and recyclable products, as they would be responsible for the end-of-life management of the product.

The Tonale case also shows how service design can be crucial in enhancing the overall user experience. By tracking and documenting the vehicle's history, users can have a clear picture of the vehicle's status, facilitating maintenance and improving resale value. A system can be created that encourages owners to maintain their vehicles well and reach usage milestones, motivating more sustainable behavior.

To design an effective incentive system, service design techniques such as journey mapping and co-creation can be utilized. By considering the needs and motivations of all stakeholders involved, a sustainable business model can be established that motivates vehicle owners to contribute to circular economy aims. In conclusion, the Tonale case provides an effective model for incorporating blockchain technologies, smart contracts, and NFTs into the automotive industry, presenting new business models and approaches to contribute towards a circular economy. It demonstrates how NFTs can bridge the physical and digital worlds, facilitating new ways of managing and interacting with products.

Finally, the study identifies challenges associated with adopting smart contracts and NFTs in the circular economy context, such as the need for standardization of smart contract templates, the development of interoperable NFT standards, and the legal recognition of smart contracts and digital assets. Furthermore, it suggests the need for education and awareness-raising among stakeholders regarding these technologies' potential benefits and challenges.

9. Conclusions

Smart contracts, blockchain technologies, and NFTs are reshaping the contours of supply chain management and the broader scope of the circular economy. These technologies offer potential far beyond cost reduction, facilitating cross-organizational business processes, promoting transparency and traceability, and paving the way for innovative business models. This paper explores the utility of these digital tools in the context of circular economy, using the case of Alfa Romeo's Tonale hybrid SUV as a case study. The Tonale case demonstrates how an NFT, essentially a digital certificate, can become an integral part of the product lifecycle, constantly updating with information about the vehicle, including maintenance and milestones. This offers valuable insights for the vehicle owners and potential future buyers, thus contributing to a more efficient and transparent used car market. Hence, it showcases how innovative technological applications can promote product durability, repairability, and recyclability, all cornerstones of the circular economy. It also exhibits how these digital tools can catalyze new business models like product-as-a-service, shifting the focus from product ownership to product utility.

In summary, implementing smart contracts and NFTs facilitates the creation of robust, well-documented product lifecycles, empowering consumers, producers, and suppliers alike. They pave the way for dynamic and adaptable supply chains that cater to the evolving needs of stakeholders, thereby contributing towards a sustainable and circular economy.

Nonetheless, the study also acknowledges the challenges in integrating smart contracts and NFTs into the broader economic landscape, including issues surrounding legal recognition, the need for standardization, and the development of interoperable standards. There is also an evident need for increased education and awareness among stakeholders regarding these emerging technologies, their potential benefits, and associated challenges.

Ultimately, this research advocates for the continued exploration and integration of such digital tools in various industries, contributing towards the transition to smart supply chains and circular economies. The findings and discussions from this paper can be utilized to develop future policies and initiatives aimed at promoting smart contracting and NFT solutions across industries.

References

Adhami, S., Giudici, G., & Martinazzi, S. (2018). Why do businesses go crypto? An empirical analysis of initial coin offerings. *Journal of Economics and Business*, 100, 64-75. https://doi.org/10.1016/j.jeconbus.2018.04.001

Ahmadov, T., Gerstlberger, W., & Prause, G. (2022). Fiscal incentives for circular economy: Insights from the Baltic States. In press.

Ajanovic, A., & Haas, R. (2016). Dissemination of electric vehicles in urban areas: Major factors for success. *Energy*, 115, 1451-1458. https://doi.org/10.1016/j.energy.2016.05.040

Alfa Romeo. (2023). Tonale hybrid SUV and its digital integration. Alfa Romeo Official Communications.

Altrichter, H., Feldman, A., Posch, P., & Somekh, B. (2005). Teachers investigate their work. https://doi.org/10.4324/9780203978979

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

Ayan, B., Güner, E., & Son-Turan, S. (2022). Blockchain technology and sustainability in supply chains and a closer look at different industries: A mixed method approach. *Logistics*, 6(4), 85. https://doi.org/10.3390/logistics6040085

Baldé, C. P., Forti, V., Gray, V., Kuehr, R., & Stegmann, P. (2017). *The Global E-waste Monitor – 2017*. United Nations University, International Telecommunication Union & International Solid Waste Association.

Bardhi, F., & Eckhardt, G. M. (2012). Access-based consumption: the case of car sharing: table 1.. *Journal of Consumer Research*, 39(4), 881-898. https://doi.org/10.1086/666376

Bitner, M. J., Ostrom, A. L., & Morgan, F. N. (2008). Service blueprinting: a practical technique for service innovation. *California Management Review*, 50(3), 66-94. https://doi.org/10.2307/41166446

Bocken, N., de Pauw, I., Bakker, C., & van der Grinten, B. (2016). Product design and business model strategies for a circular economy. *Journal of Industrial and Production Engineering*, 33(5), 308-320. https://doi.org/10.1080/21681015.2016.1172124

Chesbrough, H. (2003). *Open innovation: The new imperative for creating and profiting from technology*. Harvard Business School Press.

Delucchi, M. A., & Lipman, T. (2001). An analysis of the retail and lifecycle cost of battery-powered electric vehicles. *Transportation Research Part D: Transport and Environment*, 6(6), 371-404. https://doi.org/10.1016/s1361-9209(00)00031-6

Dos Santos, R. B., Torrisi, N. M., & Pantoni, R. P. (2021). Third party certification of agri-food supply chain using smart contracts and blockchain tokens. *Sensors*, 21(16), 5307. https://doi.org/10.3390/s21165307

Dounas, T., Jabi, W., & Lombardi, D. (2021). Non-fungible building components: Using smart contracts for a circular economy in the built environment. *Blucher Design Proceedings*. https://doi.org/10.5151/sigradi2021-20

Dutch Ministry of Environment. (2016). *Circular economy in the Netherlands by 2050*. https://www.oecd.org/environment/ministerial/whatsnew/2016-ENV-Ministerial-Netherlands-Circular-economy-in-the-Netherlands-by-2050.pdf

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, 50(1), 25-32. https://doi.org/10.5465/amj.2007.24160888

ISSN 2345-0282 (online) http://jssidoi.org/jesi/
2023 Volume 11 Number 2 (December)
http://doi.org/10.9770/jesi.2023.11.2(7)

Ellen MacArthur Foundation. (2012). *Towards the circular economy (Vol. 1): An economic and business rationale for an accelerated transition*. https://www.aquafil.com/assets/uploads/ellen-macarthur-foundation.pdf

Ellen MacArthur Foundation. (2013a). *Towards the circular economy: Economic and business rationale for an accelerated transition.* https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Ellen-MacArthur-Foundation-Towards-the-Circular-Economy-vol.1.pdf

Ellen MacArthur Foundation. (2013b). *Towards the circular economy: Economic and business rationale for an accelerated transition.* https://www.aquafil.com/assets/uploads/ellen-macarthur-foundation.pdf

Ellen MacArthur Foundation. (2015). *Towards a circular economy: Business rationale for an accelerated transition*. Ellen MacArthur Foundation. https://kidv.nl/media/rapportages/towards_a_circular_economy.pdf?1.2.1

Ellen MacArthur Foundation. (2019). *Completing the picture: How the circular economy tackles climate change*. https://www.ellenmacarthurfoundation.org/publications

Eshghie, M., Li, Q., Kasche, G. A., Jacobson, F., Bassi, C., & Artho, C. (2022). CircleChain: Tokenizing products with a role-based scheme for a circular economy. arXiv preprint arXiv:2205.11212. https://doi.org/10.48550/arxiv.2205.11212

European Commission. Environment. Circular Economy. (2018, September 17). Implementation of the Circular Economy Action Plan. http://ec.europa.eu/environment/circular-economy/index_en.htm

Galvão, G. D. A., de Nadae, J., Clemente, D. H., Chinen, G., & de Carvalho, M. M. (2018). Circular economy: Overview of barriers. *Procedia CIRP*, 73, 79-85. https://doi.org/10.1016/j.procir.2018.04.011

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

Geng, Y., & Doberstein, B. (2008). Developing the circular economy in China: Challenges and opportunities for achieving 'leapfrog development'. *International Journal of Sustainable Development & World Ecology*, 15(3), 231-239. https://doi.org/10.3843/susdev.15.3:6

Ghisellini, P., Cialani, C., & Ulgiati, S. (2016). A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems. *Journal of Cleaner Production*, 114, 11-32. https://doi.org/10.1016/j.jclepro.2015.09.007

Gligor, D., Davis-Sramek, B., Tan, A., Alex, V., Russo, I., Golgeci, I., & Wan, X. (2021). Utilizing blockchain technology for supply chain transparency: A resource orchestration perspective. *Journal of Business Logistics*, 43. https://doi.org/10.1111/jbl.12287

Goovaerts, L., & Verbeek, A. (2018). Sustainable Banking: Finance in the Circular Economy. In F. Flachenecker & J. Rentschler (Eds.), *Investing in Resource Efficiency*. Springer, Cham. https://doi.org/10.1007/978-3-319-78867-8_9

Hart, J., Adams, K. T., Giesekam, J., Tingley, D. D., & Pomponi, F. (2019). Barriers and drivers in a circular economy: The case of the built environment. *Procedia CIRP*, 80, 619-624. https://doi.org/10.1016/j.procir.2018.12.015

Hawkins, T. R., Singh, B., Majeau-Bettez, G., & Strømman, A. H. (2012). Comparative environmental life cycle assessment of conventional and electric vehicles. *Journal of Industrial Ecology*, 17(1), 53-64. https://doi.org/10.1111/j.1530-9290.2012.00532.x

Heck, P. (2006). Circular economy related international practices and policy trends: Current situation and practices on sustainable production and consumption and international circular economy development policy summary and analysis. Institut für angewandtes Stoffstrommanagement (IfaS).

Hislop, H., & Hill, J. (2011). *Reinventing the wheel: A circular economy for resource security*. Green Alliance.

Hobson, K., & Lynch, N. (2016). Diversifying and de-growing the circular economy: Radical social transformation in a resource-scarce world. *Futures*, 82, 15-25. https://doi.org/10.1016/J.FUTURES.2016.05.012

International Energy Agency. (2019). Global EV Outlook 2019: Scaling-up the transition to electric mobility. OECD Publishing. https://doi.org/10.1787/35fb60bd-en

Jacobs, F. R., & Chase, R. B. (2020). *Operations and supply chain management* (16th ed.). McGraw-Hill. ISBN-13: 9781264091676

Khaqqi, K. N., Sikorski, J. J., Hadinoto, K., & Kraft, M. (2018). Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application. *Applied Energy*, 209, 8-19. https://doi.org/10.1016/j.apenergy.2017.10.070

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

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics*, 143, 37-46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Korhonen, J., Nuur, C., Feldmann, A., & Birkie, S. E. (2018). Circular economy as an essentially contested concept. *Journal of Cleaner Production*, 175, 544–552. https://doi.org/10.1016/j.jclepro.2017.12.111

Kotzab, H. (1999). Improving supply chain performance by efficient consumer response? A critical comparison of existing ECR approaches. *Journal of Business & Industrial Marketing*, 14(5/6), 364-377. https://doi.org/10.1108/08858629910290111

Kshetri, N. (2017). Can blockchain strengthen the internet of things? *IT Professional*, 19(4), 68-72. https://doi.org/10.1109/mitp.2017.3051335

Marques, R. C., Simões, P., Silva Pinto, F. (2018). Tariff regulation in the waste sector: An unavoidable future. *Waste Management*, 78, 292-300. https://doi.org/10.1016/j.wasman.2018.05.028

McKinsey & Company. (2017). Electrifying insights: How automakers can drive electrified vehicle sales and profitability. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/electrifying-insights-how-automakers-can-drive-electrified-vehicle-sales-and-profitability

Meadows, D. H., Randers, J., & Behrens, W. W. (1972). The limits to growth: A report for the Club of Rome's project on the predicament of mankind. https://doi.org/10.1349/ddlp.1

Mougayar, W. (2016). The business blockchain: promise, practice, and application of the next Internet technology. John Wiley & Sons.

Murray, A., Skene, K., & Haynes, K. (2017). The circular economy: An interdisciplinary exploration of the concept and application in a global context. *Journal of Business Ethics*, 140(3), 369-380. https://doi.org/10.1007/s10551-015-2693-2

Nadini, M., Alessandretti, L., Di Giacinto, F., Martino, M., Aiello, L. M., & Baronchelli, A. (2021). Mapping the NFT revolution: Market trends, trade networks, and visual features. *Scientific Reports*, 11(20902). https://doi.org/10.1038/s41598-021-00053-8

Navarro, L., Esteban, J. C., Miralles, M. F., & Griso, D. F. (2022). Digital transformation of the circular economy: Digital product passports for transparency, verifiability, accountability. Manuscript submitted for publication to *ACM DLT Journal*.

Philipp, R., Prause, G., & Gerlitz, L. (2019). Blockchain and smart contracts for entrepreneurial collaboration in maritime supply chains. *Transport and Telecommunication Journal*, 20(4), 365-378. https://doi.org/10.2478/ttj-2019-0030

Prause, G. (2014). A Green Corridor Balanced Scorecard. Transport and Telecommunication Journal, 15 (4), 299−307. https://doi.org/10.2478/ttj-2014-0026

Prause, G. (2015). Sustainable business models and structures for industry 4.0. *Journal of Security and Sustainability Issues*, 5(2), 159-169. https://doi.org/10.9770/jssi.2015.5.2(3)

Prause, G. (2016). E-residency: A business platform for industry 4.0? *Entrepreneurship and Sustainability Issues*, 3(3), 216-227. https://doi.org/10.9770/jesi.2016.3.3(1)

Prause, G. (2019). Smart contracts for smart supply chains. *IFAC-PapersOnLine*, 52(13), 2501-2506. https://doi.org/10.1016/j.ifacol.2019.11.582

Prause, G., & Hoffmann, T. (2020). Innovative management of common-pool resources by smart contracts. *Marketing and Management of Innovations*, 1, 265-275. https://doi.org/10.21272/mmi.2020.1-22

Reyes, P., & Bhutta, M. (2005). Efficient consumer response: Literature review. *International Journal of Integrated Supply Management*, 1, 346-386. https://doi.org/10.1504/IJISM.2005.006301

Sanders, E. B.-N., & Stappers, P. J. (2014). Probes, toolkits, and prototypes: Three approaches to making in codesigning. *CoDesign*, 10(1), 5-14. https://doi.org/10.1080/15710882.2014.888183

Sangiorgi, D. (2011). Transformative services and transformation design. *International Journal of Design*, 5(2), 29-40.

Sierzchula, W., Bakker, S., Maat, K., & Van Wee, B. (2014). The influence of financial incentives and other socio-economic factors on electric vehicle adoption. *Energy Policy*, 68, 183-194. https://doi.org/10.1016/j.enpol.2014.01.043

Sprei, F., & Ginnebaugh, D. L. (2018). Unbundling cars to daily use and infrequent use vehicles—the potential role of car sharing. *Energy Efficiency*, 11(6), 1433-1447. https://doi.org/10.1007/s12053-018-9636-6

Stahel, W. R. (2010). The performance economy. Springer. https://doi.org/10.1057/9780230274907

Stahel, W. R. (2016). The circular economy. *Nature*, 531(7595), 435-438. https://doi.org/10.1038/531435a

Sternberg, H. S., Hofmann, E., & Roeck, D. (2021). The struggle is real: Insights from a supply chain blockchain case. *Journal of Business Logistics*, 42(1), 71-87. https://doi.org/10.1111/jbl.12240

Stickdorn, M., Hormess, M. E., Lawrence, A., & Schneider, J. (2018). This is service design doing: Applying service design thinking in the real world. O'Reilly Media, Inc.

Stubbs, W., & Cocklin, C. (2008). Conceptualizing a "sustainability business model." *Organization & Environment*, 21(2), 103-127. https://doi.org/10.1177/1086026608318042

Tapscott, D., & Tapscott, A. (2016). Blockchain revolution: How the technology behind Bitcoin is changing money, business, and the world. New York, NY: Penguin.

Tukker, A. (2015). Product services for a resource-efficient and circular economy – a review. *Journal of Cleaner Production*, 97, 76-91. https://doi.org/10.1016/j.jclepro.2013.11.049

United Nations. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development.* https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

United Nations. (1987). *Our common future: Report of the World Commission on Environment and Development* (United Nations-WCED-World Commission on Environment and Development). Retrieved from www.un-documents.net/our-common-future.pdf

Wang, Q., Li, R., Wang, Q., & Chen, S. (2021). Non-Fungible Token (NFT): Overview, Evaluation, Opportunities and Challenges https://www.researchgate.net/publication/351656444_NonFungible_Token_NFT_Overview_Evaluation_Opportunities_and_Challenges

World Commission on Environment and Development. (1987). *Our common future*. Oxford University Press.

Wu, L., Lu, W., Peng, Z., & Webster, C. (2023). A blockchain non-fungible token-enabled 'passport' for construction waste material cross-jurisdictional trading. *Automation in Constructio*n, 149, 104783. https://doi.org/10.1016/j.autcon.2023.104783

Zecca, E., Pronti, A., & Chioatto, E. (2023). Environmental policies, waste and circular convergence in the European context. *Insights into Regional Development,* 5(3), 95-121. https://doi.org/10.9770/IRD.2023.5.3(6)

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Vera GERASIMOVA is a PhD student in Business at School of Business and Governance, Tallinn University of Technology. Her research interests include Service Design, Digitalization, Sustainable Business Models.
ORCID ID: 0000-0002-7333-2271

Prof. Dr. Gunnar PRAUSE is the Professor at Wismar Business School, Wismar University and School of Business and Governance, Tallinn University of Technology. His research interests include Logistics, Industry 4.0, Digitalization, Operations Management, Sustainable Supply Management, SCM.
ORCHID ID: 0000-0002-3293-1331

Thomas HOFFMANN is Tenured Associate Professor of Private Law at TalTech Law School, Tallinn University of Technology. His research interests include Comparative Law, Legal Cases, Legal Analysis, Legal Research, International Law, Business Law, Jurisprudence, Contract Law, Private International Law, Law and Legal Studies.
ORCHID ID: 0000-0003-4761-0722

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Appendix 4

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NFT-SOLUTIONS FOR SUSTAINABLE ENTREPRENEURSHIP

Vera Gerasimova[1], Wolfgang Gerstlberger[1], Gunnar Prause[1,2]

[1]*Tallinn University of Technology, Ehitajate tee 5, 19086, Tallinn, Estonia*

[2]*Wismar University of Applied Sciences, Philipp-Müller-Str. 14, 23966 Wismar, Germany*
(e-mail: vera.gerasimova@taltech.ee)

Abstract: The classical pathway of mass production followed a linear model with trashed products and wasted remaining resources at the final stage of their lifecycle. Smart approaches of manufacturing and product lifecycle management aim for circular economy models to implement sustainable business models in order to overcome imbalances between resource supply and demand of goods. Non-Fungible Token (NFT) solutions together with smart contracts seem to have the potential to realize new sustainable business models in the context of circular economy. The study demonstrates how NFT technology can become an integral part of smart product lifecycle management for sustainable supply chain management and circular business models.The paper explores the potential of NFTs and blockchain technology to revolutionize traditional production models into sustainable, circular frameworks. NFTs, with their unique digital identifiers, provide a new method for tracking products throughout their lifecycle, ensuring traceability and transparency in the supply chain. By integrating NFTs with smart contracts, businesses can facilitate automated, secure, and transparent transactions, essential for effective circular economy practices. The study investigates the role of NFTs in improving product lifecycle management (PLM) by keeping detailed records of product history, including maintenance, usage and ownership changes. By linking digital identifiers to physical assets, NFTs enable the creation of digital twins, offering a reliable digital representation of products for various lifecycle management tasks.

The paper includes two case studies demonstrating the practical application of NFTs in different industries. The first case study focuses on the automotive sector, specifically the integration of NFTs in Alfa Romeo's Tonale hybrid SUV. NFTs enhance transparency and accountability in vehicle maintenance records and support a shift towards a "product-as-a-service" model, emphasizing product utility over ownership. This aligns with circular economy principles by promoting longer product lifecycles and reducing waste. The second case study explores Pyrum AG's innovative recycling technology, which utilizes NFTs to manage the supply chain of used tires. NFTs encourage timely delivery and proper recycling of tires, ensuring a continuous supply of raw materials for recycling. This supports the circular economy's objectives of reducing the reliance on newly sourced materials and minimizing environmental impact.

Through expert interviews and a comprehensive literature review, the study identifies challenges and opportunities of implementing NFT-based solutions in circular economy models. The findings indicate that while these technologies offer significant benefits, such as improved operational efficiency and enhanced sustainability, challenges like the need for regulatory frameworks and industry standards remain.

The paper concludes that integrating NFTs with blockchain technology and smart contracts presents a promising solution for sustainable product lifecycle management. NFTs provide a strong digital infrastructure for tracking and managing products, playing a crucial role in the shift towards a more sustainable and circular economy. This study adds to the growing body of literature on digital technologies in sustainability practices and offers valuable insights for future research and policy development in this field.

Keywords: Non-Fungible Token (NFT); smart contracts; entrepreneurship. product lifecycle management; circular economy.

REFERENCES

Alfa Romeo. (2023). Tonale hybrid SUV and its digital integration. *Alfa Romeo Official Communications*.

Altrichter, H., Feldman, A., Posch, P., and Somekh, B. (2005). Teachers investigate their work. DOI: 10.4324/9780203978979

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

Ayan, B., Güner, E., and Son-Turan, S. (2022). Blockchain technology and sustainability in supply chains and a closer look at different industries: A mixed method approach. *Logistics*, 6(4), 85. DOI: 10.3390/logistics6040085

Dos Santos, R. B., Torrisi, N. M., and Pantoni, R. P. (2021). Third party certification of agri-food supply chain using smart contracts and blockchain tokens. *Sensors*, 21(16), 5307. DOI: 10.3390/s21165307

Ellen MacArthur Foundation. (2019). *Completing the picture: How the circular economy tackles climate change*. https://www.ellenmacarthurfoundation.org/publications

Eshghie, M., Li, Q., Kasche, G. A., Jacobson, F., Bassi, C., and Artho, C. (2022). CircleChain: *Tokenizing products with a role-based scheme for a circular economy*. DOI: 10.48550/arxiv.2205.11212.

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

Gerasimov, V.; Prause, G.; and Hoffmann, T (2023). NFT-enriched smart contracts for smart circular economy models. *Journal of Entrepreneurship and Sustainability Issues*, 11 (2), 93−110. DOI: 10.9770/jesi.2023.11.2(7).

Gligor, D., Davis-Sramek, B., Tan, A., Alex, V., Russo, I., Golgeci, I., and Wan, X. (2021). Utilizing blockchain technology for supply chain transparency: A resource orchestration perspective. *Journal of Business Logistics*, 43. DOI: 10.1111/jbl.12287

Hart, J., Adams, K. T., Giesekam, J., Tingley, D. D., & Pomponi, F. (2019). Barriers and drivers in a circular economy: The case of the built environment. *Procedia CIRP*, 80, 619-624. DOI: 10.1016/j.procir.2018.12.015

Hislop, H. and Hill, J. (2011). *Reinventing the wheel: A circular economy for resource security*. Green Alliance.

Hobson, K. and Lynch, N. (2016). Diversifying and de-growing the circular economy: Radical social transformation in a resource-scarce world. *Futures*, 82, 15-25. DOI: 10.1016/J.FUTURES.2016.05.012

Jacobs, F. R. and Chase, R. B. (2020). *Operations and supply chain management* (16th ed.). McGraw-Hill. ISBN-13: 9781264091676

Khaqqi, K. N., Sikorski, J. J., Hadinoto, K., & Kraft, M. (2018). Incorporating seller/buyer reputation-based system in blockchain-enabled emission trading application. *Applied Energy*, 209, 8-19. DOI: 10.1016/j.apenergy.2017.10.070

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

Kotzab, H. (1999). Improving supply chain performance by efficient consumer response? A critical comparison of existing ECR approaches. *Journal of Business & Industrial Marketing*, 14(5/6), 364-377. DOI: 10.1108/08858629910290111

Murray, A., Skene, K., & Haynes, K. (2017). The circular economy: An interdisciplinary exploration of the concept and application in a global context. *Journal of Business Ethics*, 140(3), 369-380. DOI: 10.1007/s10551-015-2693-2

Philipp, R.; Prause, G., and Gerlitz, L. (2019). Blockchain and smart contracts for entrepreneurial collaboration in maritime supply chains. *Transport and Telecommunication Journal*, 20(4), 365-378. DOI: 10.2478/ttj-2019-0030

Prause, G. (2015). Sustainable business models and structures for industry 4.0. *Journal of Security and Sustainability Issues*, 5(2), 159-169. DOI: 10.9770/jssi.2015.5.2(3)

Prause, G. (2016). E-residency: A business platform for industry 4.0? *Entrepreneurship and Sustainability Issues*, 3(3), 216-227. DOI: 10.9770/jesi.2016.3.3(1)

Prause, G. (2019). Smart contracts for smart supply chains. *IFAC-PapersOnLine*, 52(13), 2501-2506. DOI: 10.1016/j.ifacol.2019.11.582

Pyrum (2023). Pyrum Innovations AG: Company presentation.

Reyes, P. and Bhutta, M. (2005). Efficient consumer response: Literature review. *International Journal of Integrated Supply Management*, 1, 346-386. DOI: 10.1504/IJISM.2005.006301

Saaksvuori, Antti (2008). *Product Lifecycle Management*. Springer. ISBN 9783540781738

Tapscott, D. and Tapscott, A. (2016). *Blockchain revolution: How the technology behind Bitcoin is changing money, business, and the world*. New York, NY: Penguin.

Vandermerwe, S. and Rada, J. (1988) "Servitization of business: Adding value by adding services", *European Management Journal*, vol. 6, no. 4, 1988

Wang, Q., Li, R., Wang, Q., and Chen, S. (2021). *Non-Fungible Token (NFT): Overview, Evaluation, Opportunities and Challenges*, DOI: 10.48550/arXiv.2105.0744.

Wu, L., Lu, W., Peng, Z., and Webster, C. (2023). A blockchain non-fungible token-enabled 'passport' for construction waste material cross-jurisdictional trading. *Automation in Construction*, 149, 104783. DOI: 10.1016/j.autcon.2023.104783

Curriculum vitae

Personal data

Name:	Vera Gerasimova
Date of birth:	26.02.1992
Place of birth:	Russia
Citizenship:	Russian

Contact data

E-mail:	vera.a.gerasimova@gmail.com

Education

2019–2024	Tallinn University of Technology, PhD
2013–2015	Peter the Great St. Petersburg Polytechnic University (SPbPU), MSC
2009–2013	Peter the Great St. Petersburg Polytechnic University (SPbPU), BSC
1999–2009	Secondary School No. 86 of Petrogradsky District, Saint Petersburg

Language competence

English	Fluent
Estonian	Basic
Russian	Native

Professional employment

2019–…	Tallinn University of Technology, School of Business and Governance, Department of Business Administration, junior researcher

Elulookirjeldus

Isikuandmed

Nimi:	Vera Gerasimova
Sünniaeg:	26.02.1992
Sünnikoht:	Venemaa
Kodakondsus:	Venemaa

Kontaktandmed

E-post:	vera.a.gerasimova@gmail.com

Hariduskäik

2019–2024	Tallinna Tehnikaülikool, PhD
2013–2015	Peter the Great St. Petersburg Polytechnic University (SPbPU), MSC
2009–2013	Peter the Great St. Petersburg Polytechnic University (SPbPU), BSC
1999–2009	Peterburi Petrogradi rajooni 86. keskkool

Keelteoskus

Eesti keel	Algtase
Inglise keel	Kõrgtase
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