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

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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

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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).

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