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Leveraging tokenization in blockchain-based circular economy: A paradigm shift towards sustainable resource management

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Abstract

Utilizing blockchain technology and circular supply chain management can bring about significant changes in achieving sustainability and enhancing resource utilization. This study highlights the significant role of tokenization in promoting sustainable resource management within blockchain-based circular supply chains. Tokenization provides a secure and efficient way to digitize assets, creating incentives, and facilitating efficient exchange within these supply chains. The paper explores in detail the benefits of tokenization, including faster transaction settlement, cost savings, democratization of access, transparency enhancement, and reduced infrastructure costs. It emphasizes that tokenization is a pivotal tool for promoting the transition towards a circular economy model. The study also acknowledges the challenges and limitations of tokenization, including regulatory issues, interoperability, and standardization challenges, among others, and provides recommendations for effective implementation. Overall, the paper highlights the potential of tokenization to revolutionize how we exchange ideas, information, and money through blockchain-based circular supply chains and emphasizes its significance in promoting sustainable resource management.

Keywords: Tokenization; Circular business models; Circular supply chain; Sustainability; Blockchain; NFT; Circular economy

1. Introduction

The Industrial Revolution brought about a paradigm shift in manufacturing methods that facilitated the production of consumer goods on a large scale. The resulting economic and industrial development, coupled with globalization, led to a decline in manufacturing costs and an increase in consumer purchasing power, which in turn created a linear model of supply and consumption (Roy et al., 2022). This model, however, resulted in a higher demand for natural resources, an increase in waste generation, and a rise in carbon emissions. The current environmental issues related to climate change and global resource scarcity can be traced back to the unregulated and unsustainable use of Earth's resources by governments and businesses in the past (Malik et al., 2023). The need for resources has increased significantly due to the growing population. To ensure we meet the demand, it is essential to measure resource consumption. Since resources are limited, it is important to adopt strategies for reusing them to cope with their depletion.

The Circular Economy (CE) offers a solution to the problems associated with linear supply chains by transitioning from a linear model of resource consumption to a regenerative and restorative system. Unlike linear supply chains, which are business-based, stand-alone, and focused on unlimited growth and maximum income, CE promotes a network-based, collaborative, and nexus-oriented approach. It values resources based on selected characteristics rather than just income and aims for a regenerative saving of resource generation patterns and a fair resource allocation. This shift is designed to convert linear production systems into closed-loop systems under the reduce, reuse, and recycle imperative, thereby addressing the inefficiencies and wastefulness inherent in linear supply chains. (Opferkuch et al., 2021)

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1.1. Blockchain and Circular Supply Chains:

Blockchain technology (BT) has the potential to revolutionize economic transactions by creating a cleaner process that balances the environment, economy, and society. As an open-source, peer-to-peer, distributed ledger system with automation capabilities, it can be used to create transparent, secure, and decentralized systems for circular supply chain management (Corsini et al., 2023).

Blockchain technology can effectively manage the complexities of circular supply chains and monitor reverse logistic processes for the reuse of products and their components. This technology enables the traceability of product-related information throughout their lifespan, thus allowing for their subsequent reuse. By providing a record of products and materials at each stage and their current condition, blockchain enables proactive planning for their reuse in locations where these components and materials are most needed. This contributes to the development of adequate reuse strategies that limit the waste of potentially useful resources, minimize the consumption of materials, and support the shift from a linear economy model to a more sustainable circular economy (CE). (Abderahman & Suhaiza, 2023)

1.2. Tokenization in Blockchain

Tokenization is the process of creating digital tokens on a blockchain to represent various assets, such as physical assets, financial assets, intellectual property, or data. This process has the potential to revolutionize how we exchange ideas, information, and money by utilizing technologies like blockchain, smart contracts, and digital assets. Tokenization has several benefits, including faster transaction settlement, cost savings, democratization of access, transparency enhancement, and reduced infrastructure costs.

Tokenization provides a secure and efficient way to digitize assets, ensuring that all information recorded on the blockchain is tamper-proof and cannot be altered, thus guaranteeing the authenticity of the digital assets.

In blockchain ecosystems, incentive mechanisms are strategies designed to motivate participants to engage in behaviors contributing to the network's growth and development. These mechanisms leverage economic, psychological, and game theory principles to reward users for their contributions. Typical forms of incentives include token rewards, staking opportunities, and access to exclusive features. Staking, for instance, involves users locking up a certain amount of tokens as collateral to participate in network validation or governance, earning rewards in return. This encourages long-term commitment and helps secure the network's integrity, while also potentially reducing token circulation and increasing token scarcity and value (SAXE, 2023). In Northern Europe, a circular supply chain model is being used to encourage individuals to recycle plastic containers, cans, and bottles. The model offers financial rewards in the form of cryptographic tokens to those who participate. This system aims to promote a sustainable environment by incentivizing recycling and reducing waste (Saberli et al., 2018).

2. Circular Supply Chain Management

2.1. Principles of Circular Supply Chains

The principles of a circular supply chain are derived from the broader concept of the circular economy and circular design. These principles aim to eliminate waste and pollution upstream through design by selecting safe materials that are designed for repeated circulation, utilizing by-products, and engaging in material and product innovation. (Angelis et al., 2018)

Another crucial principle is to circulate materials and products by designing them to be used for as long as possible while maintaining their highest value. This can be achieved by designing products for repairability, upgradability, and emotional durability. It also involves creating reuse, repair, remanufacture, and recycling systems and business models (such as resale, rental, and sharing) that allow products and materials to be utilized more times, by more people, and for longer. (Ellen MacArthur Foundation, 2022)

The third principle emphasizes regenerating nature by designing to improve local biodiversity, air, and water quality. The goal is to design for regenerative outcomes, creating the conditions for nature to thrive and designing for successive cycles in which bio-based materials are used through different applications and are safely returned to the earth. This approach considers the environmental impact and seeks to minimize adverse effects while promoting the sustainable use of resources. (Ellen MacArthur Foundation, 2022)

The principles of circular economy are being promoted through the integration of open and closed material loops in supply chain management. This entails the development of supply chains that support both closed loops, in which

materials are recycled into the same product, and open loops, in which materials are repurposed for different products or industries (Angelis et al., 2018)

By embracing these principles and implementing corresponding practices, a more sustainable and efficient system can be established, benefiting both businesses and the environment.

2.2. Benefits of Circular Supply Chains

The adoption of circular supply chains has been recognized as an effective means to achieve environmental and economic sustainability. Such supply chains operate on the principles of constant material reuse and recycling, promoting the conservation of natural resources, reducing pollution caused by material extraction processes, and combating excessive natural resource exploitation. (Haupt & Hellweg, 2019) The benefits of circular supply chains include a significant reduction in greenhouse gas emissions, conservation of natural resources by extending material cycles, reduction in negative environmental impact, increase in recycling and reuse rates, and development of new businesses from waste (Rodriguez, 2022).

Circular supply chains have the potential to generate considerable savings, estimated at up to 70%, in materials (WEF, 2014). This translates to approximately one trillion dollars in annual savings. By improving material efficiency, circular supply chains not only fulfill the increasing material needs of the growing population but also mitigate the negative impacts of landfills and energy-intensive recycling processes (Geissdoerfer et al., 2018). Manufacturers who adopt circular supply chain practices can achieve more sustainable operations, with a central emphasis on reuse to significantly reduce the environmental harm usually associated with manufacturing activities (Angelis et al., 2018). Furthermore, circular supply chains promote the reuse of products and materials, creating an environment that encourages companies to invest in recycling initiatives. This leads to higher recycling rates and facilitates the repurposing of valuable resources that would otherwise end up in disposal sites. (Gebhardt et al., 2021)

Moreover, circular supply chains encourage the creation of new enterprises through innovation, service economy, and new business models, transforming waste into a resource for new products and services (Geissdoerfer et al., 2018). The adoption of circular supply chains also makes businesses more resilient to the fluctuating prices of raw materials, as they rely on the reuse and recycling of materials (Ghufran et al., 2022). This approach helps businesses maintain their operations even during unforeseen events. Finally, these supply chains provide benefits for the consumer by discouraging planned obsolescence, leading to longer-lasting products and potentially increasing disposable income (Rodriguez, 2022).

3. Tokenization in Circular Supply Chains

3.1. Asset Tokenization

Tangible assets, such as raw materials, components, and products, can be transformed into digital assets on blockchain platforms utilizing non-fungible tokens (NFTs) that serve as digital counterparts of the physical items. Each asset is assigned a unique identifier, often in the form of a QR code, which encapsulates all pertinent information for its identification and traceability throughout the distribution network. Through the creation of an NFT on the blockchain that corresponds to this unique identifier, a digital twin of the physical asset is established. This process guarantees the asset's distinctiveness and facilitates transparent tracking and tracing along the supply chain, capitalizing on the inherent advantages of blockchain technology, including security, immutability, and decentralization. (Chiacchio et al., 2022).

3.2. Incentive Mechanism

Tokenized incentive mechanisms, such as rewards and loyalty programs, have been identified as effective tools to encourage sustainable behaviors and facilitate resource recovery. These mechanisms leverage technology, including web applications and blockchain, to digitalize the recycling habit and reward system. By doing so, they recognize and reward individuals who correctly perform recycling tasks, thereby promoting transparency, efficiency, and effectiveness in recycling efforts. The integration of technology not only enhances the user experience through gamification but also ensures the accurate tracking and rewarding of sustainable behaviors without altering the existing recycling models (Gibovic & Bikfalvi, 2021). By providing tangible benefits for sustainable actions, these programs can increase individuals' motivation to engage in behaviors that contribute to resource recovery and environmental sustainability.

The efficacy of such incentive mechanisms can be comprehended through the perspective of behavioral psychology and environmental economics, which propose that incentives can modify behavior by rendering sustainable choices more alluring or advantageous. For instance, a rewards program that provides discounts, points, or other benefits for returning plastic bottles for recycling can incentivize individuals to partake in recycling efforts more consistently. Similarly, loyalty programs that offer incentives to customers for making sustainable purchases can motivate consumers to opt for eco-friendly products over less sustainable alternatives (Reese & Junge, 2017). The implementation of the GREEN\$ smart card in Hong Kong and similar initiatives have demonstrated the potential of monetary rewards to elicit behavioral shifts and enhance knowledge about recycling practices among participants (Gibovic & Bikfalvi, 2021).

3.3. Supply Chain Transparency and Traceability

Physical assets, such as raw materials, components, and products, can be represented in blockchain platforms by creating non-fungible tokens (NFTs). These tokens serve as digital twins of the physical assets and are given a unique identifier, usually a QR code. This virtual identity contains comprehensive details about the product, including its origin, journey through the supply chain, and any certifications or standards it meets. As a result, consumers and other stakeholders can easily verify the authenticity and sustainability attributes of the products they purchase, contributing to greater consumer trust and loyalty (Saberi et al., 2018). A digital twin of the physical asset is created by minting an NFT in the blockchain that corresponds to this unique identifier. This process ensures the asset is unique and enables transparent tracking and traceability across the supply chain. Blockchain technology provides inherent advantages such as security, immutability, and decentralization, which enhance the transparency and efficiency of the supply chain. (Chiacchio et al., 2022)

4. Case Studies

4.1. Tokenized Recycling Initiatives

Blockchain-based startups such as Plastic Bank are leading the way in using tokenization to create markets for plastic packaging waste. These initiatives offer credits through a blockchain-based app for the collection of plastic waste, providing incentives for mass participation. This not only changes the public's perception of waste as valuable but also addresses the economic, environmental, and social aspects of the plastic pollution problem. The credits earned can be exchanged for basic goods, providing an economic incentive for waste collection and recycling. (Peshkam, 2019)

The RecycleToCoin system is an innovative solution that incentivizes the public to actively participate in recycling efforts. It specifically targets the disposal of single-use plastic bottles and aluminum cans, utilizing a unique combination of a blockchain-based mobile application, physical machines, and designated collection points. This cutting-edge system enables individuals to exchange their recyclable waste for BCDC tokens, which can then be redeemed for various rewards. These include eGift Cards via the platform's partner, GiftPay, or can be exchanged for other popular cryptocurrencies. Furthermore, RecycleToCoin has established a strategic partnership with Plastic Bank. Through this collaboration, individuals have the option to donate their tokens to support Plastic Bank's important mission. RecycleToCoin also repurchases these donated tokens every month, significantly contributing to Plastic Bank's vital work. (Recycling Magazine, 2017)

Another startup named "Empower" incentivizes individuals to participate in recycling efforts by issuing rewards in the form of digital tokens, known as EMPs (EmpowerCoins), for collecting and delivering plastic waste for recycling. The Empower App based on blockchain technology plays a crucial role in facilitating direct and fair payments in EMP tokens by providing users with their simple sovereign ID and a wallet for EMP tokens. This setup ensures that anyone can participate in the collection of plastic waste and receive an immediate reward for their efforts, without the need for intermediaries such as banks or central entities that could potentially reduce the value of the payment through fees or make micropayments impractical. Additionally, the app's design addresses common barriers such as the lack of IDs and affordable access to bank accounts, making it accessible to a wider audience, including the extremely poor. This approach not only incentivizes the collection and recycling of plastic waste but also contributes to fighting inequality and extreme poverty by creating meaningful job opportunities with fair compensation.

4.2. Tokenized Material Passport Systems

A material passport is a digital document or dataset that provides a detailed inventory of all the materials and components used in a building, infrastructure project, or even in the manufacturing process. It includes information about the quality, origin, location, and characteristics of these materials, as well as their environmental impacts, such as carbon footprint and potential for reuse or recycling. The concept is rooted in the principles of the circular economy,

aiming to enhance the sustainability and efficiency of the construction and real estate sectors by enabling the recovery and reuse of materials at the end of a building's life cycle (Hoosain et al., 2020).

The token-based material passport system facilitates the exchange of materials with supply chain participants by leveraging blockchain technology to create a decentralized and transparent record of material information. In this system, each material or component is associated with a digital token that represents its material passport. This passport contains detailed information about the material's characteristics, history, and potential for reuse or recycling.

When a supply chain participant wishes to exchange materials, they can use these tokens to securely and efficiently share the material passport data. The token-based access control mechanism ensures that only authorized participants can access this data, thereby maintaining privacy and security. This process is facilitated by smart contracts on the blockchain, which automate the exchange process, ensuring that it is executed according to predefined rules without the need for intermediaries (Hunhevicz et al., 2023).

This system not only streamlines the exchange of materials among participants but also promotes the circular economy by making it easier to identify, track, and reuse materials. By providing a scalable and flexible mechanism for data access, the token-based material passport system addresses the challenges of the fragmented Architecture, Engineering, and Construction (AEC) industry, where stakeholders frequently change over the lifecycle of a building.

5. Challenges and Future Directions

5.1. Regulatory and Compliance Challenges

Implementing tokenization in circular supply chain management involves navigating a complex regulatory landscape, primarily due to the novelty of the technology and its application in this context. Regulatory considerations and compliance requirements can vary significantly across jurisdictions, but some common themes emerge:

- **Token Classification:** One of the primary regulatory considerations is the classification of tokens. Depending on their characteristics, tokens can be classified as utility tokens, security tokens, or commodity tokens, each subject to different regulatory frameworks. The classification impacts the regulatory obligations of the entities involved in issuing, trading, and managing these tokens. (Sunyaev et al., 2021)
- **Environmental Regulations:** In circular supply chain management, tokenization can be used to verify compliance with environmental standards and regulations. This requires that the tokenization system accurately reflects the environmental attributes of materials and products, such as carbon footprint or recycling certifications, in compliance with relevant environmental regulations (Sunyaev et al., 2021).
- **Data Privacy and Protection:** Implementing tokenization in supply chain management must comply with data protection regulations such as the General Data Protection Regulation (GDPR) in the European Union. This involves ensuring that any personal data encoded into tokens or managed through DLT systems is processed in a manner that respects privacy rights and complies with legal requirements for data protection (Sunyaev et al., 2021).
- **Global Regulatory Framework:** Given the international nature of circular supply chains, firms should also consider the global regulatory framework for crypto assets and stablecoins. The Financial Stability Board (FSB) has proposed a framework for the international regulation of crypto assets, which highlights the challenges around the national application of crypto asset regulation and supervision (PwC, 2022)
- **International Collaboration and Regulatory Arbitrage:** As tokenization enables cross-border transactions of tokenized assets, international collaboration among central banks and regulatory bodies is crucial. This collaboration aims to limit regulatory arbitrage and ensure a cohesive approach to the regulatory challenges posed by tokenization. Creating interoperability with existing systems is key to enabling the widespread adoption of tokenization in supply chains (Stefanoski et al., 2023)

5.2. Interoperability and Integration

Interoperability is crucial for the success of blockchain-based tokenization solutions. Categories of interoperability requirements include business, platform, governance, compliance, and data standards. Business interoperability ensures data exchange across different ecosystems. Platform interoperability mitigates inherent risks. Governance, compliance, and data standards are crucial for building scalable solutions. Addressing these categories ensures seamless integration and operation of blockchain solutions (WEF, 2023)

The interoperability model for blockchain consists of three layers: the Business Model Layer, the Platform Layer, and the Infrastructure Layer. The Business Model Layer focuses on governance models, legal frameworks, and commercial arrangements. The Platform Layer concerns the technical compatibility of blockchain platforms, including consensus mechanisms and data synchronization. The Infrastructure Layer involves the underlying technical infrastructure that supports blockchain platforms. These layers collectively address the considerations necessary for achieving interoperability between blockchain solutions.

To overcome challenges related to interoperability, various strategies can be employed, such as cross-authentication, oracles, and API gateways. Cross-authentication is a technical solution that facilitates interoperability without relying on a central trusted entity. In comparison, oracles act as a link between different blockchain platforms or between a blockchain and external data sources. API gateways are also useful in connecting disparate blockchain platforms that have fundamental differences. By implementing these approaches, organizations can effectively achieve blockchain interoperability and enhance the efficiency of their operations.

5.3. Scalability and Adoption

To address the scalability challenges associated with tokenization, particularly in the context of blockchain-based circular supply chains, several solutions can be considered:

- Layer 2 scaling solutions like state channels, optimistic rollups, and sidechains to increase transaction throughput and reduce fees while maintaining security. (Esmaeilian et al., 2020)
- Sharding and off-chain protocols like Plasma and Rollups to improve transaction throughput and lower fees without compromising decentralization and security (Esmaeilian et al., 2020).
- Consensus mechanism optimization beyond Proof of Work (PoW) and Proof of Stake (PoS) to find a balance between scalability, decentralization, and security. (Sharomi, 2023)
- Interoperability solutions like cross-chain bridges and protocols to enhance token portability and broaden the utility and adoption of token ecosystems. (Anthony, 2024)
- Scalable governance models that refine decision-making processes and accommodate growth while ensuring broad and inclusive participation to maintain the integrity and effectiveness of the ecosystem (Sharomi, 2023).

6. Conclusion

In conclusion, the adoption of circular economy principles, the integration of blockchain technology, and the use of tokenization can help promote sustainable resource management. Tokenization, as a process of creating digital tokens on a blockchain, plays a pivotal role in digitizing assets, incentivizing participation, and facilitating efficient exchanges within blockchain-based circular supply chains. The use of tokenization can provide faster transaction settlement, cost savings, democratization of access, transparency enhancement, and reduced infrastructure costs. However, challenges such as technological barriers and the need for regulatory frameworks must be addressed for the successful implementation of tokenization. With its potential for enhancing resource utilization, reducing waste, and creating a closed-loop system, tokenization in a blockchain-based circular economy presents a paradigm shift toward sustainable resource management.

6.1. Future Outlook

The future of tokenization in advancing circular supply chain management and fostering sustainable resource management is highly promising. By incentivizing sustainable behaviors, enhancing transparency, improving efficiency, and supporting accurate sustainability reporting, tokenization has the potential to significantly contribute to the global transition towards a more sustainable and circular economy.

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