

BLOCKCHAIN INTEGRATION IN SUSTAINABLE SUPPLY CHAINS: MEASURING CONTRIBUTION TO CIRCULAR ECONOMY GOALS

Mateusz ZACZYK

Silesian University of Technology, Faculty of Organization and Management; mateusz.zaczyk@polsl.pl,
ORCID: 0000-0002-3206-4784

Purpose: This paper addresses the lack of systematic frameworks for assessing blockchain technology's contribution to circular economy goals in supply chains. It develops a comprehensive conceptual model integrating blockchain capabilities with CE performance metrics to enable rigorous evaluation of blockchain implementations.

Design/methodology/approach: The study employs a conceptual-analytical research design based on systematic literature review across three domains: blockchain technology, circular economy metrics and supply chain visibility. The methodology includes systematic analysis, structured conceptual model development following established information systems frameworks, and secondary analysis of industry case studies to inform model design.

Findings: The framework comprises four integrated layers: Blockchain Technical Capabilities, CE Performance Metrics, Assessment Frameworks combining Visibility Evaluation with Blockchain Affordance Analysis and Multi-Tier Implementation. The model articulates seven critical relationships demonstrating how blockchain capabilities translate into actionable affordances and enable credible metric measurement.

Research limitations/implications: The primary limitation is absence of empirical validation; the model remains conceptual and untested in real-world implementations. Future research should focus on empirical testing through case studies, sector-specific adaptations, and integration with emerging technologies.

Practical implications: The framework provides decision-support for supply chain managers evaluating blockchain investments, design guidance for technology developers, a foundation for policymakers developing standardized assessment protocols, and due diligence tools for sustainable finance investors. The multi-tier structure enables realistic expectation-setting and phased implementation strategies.

Originality/value: This is one of the first comprehensive frameworks systematically integrating blockchain technical affordances with established CE measurement metrics through multi-layered assessment mechanisms. It moves beyond descriptive accounts to establish theoretical linkages between technology capabilities and measurable sustainability outcomes, providing both researchers and practitioners with actionable tools for evaluating blockchain-CE implementations.

Keywords: circular economy, blockchain technology, sustainable supply chain.

Category of the paper: research paper.

1. Introduction

In the face of growing challenges related to the depletion of natural resources, climate change and social pressure for sustainable development, the circular economy is gaining importance as a model for the transformation of production and consumption systems. A key element of effective CE implementation is ensuring full transparency, effective resource management and cooperation between supply chain participants. In this context, blockchain technology, thanks to its unique features such as data immutability, decentralization and the possibility of automating processes using smart contracts, is becoming a promising tool supporting the goals of the circular economy.

This article focuses on the development and presentation of a conceptual model for assessing the impact of blockchain integration in sustainable supply chains on the achievement of CE goals. This model combines the technical capabilities of blockchain with key circularity metrics and a framework for assessing the visibility and affordability of the technology, enabling multi-level analysis of the effects of implementations - from operational efficiency, through process automation, to systemic transformation. The goal is to provide a tool that will allow both researchers and business practitioners to measure and monitor the real contribution of blockchain to the transition towards a circular economy.

2. Materials and methods

This study adopts a conceptual-analytical research design aimed at developing a novel theoretical framework for assessing blockchain technology's contribution to circular economy goals in sustainable supply chains. The research recognizes that the integration of blockchain with circular economy principles is an emergent, socially constructed phenomenon requiring synthesis of multiple theoretical perspectives. The choice of a conceptual modeling approach, as opposed to purely empirical research, is justified by the nascent stage of blockchain-CE integration. Given the limited number of mature, large-scale implementations and the heterogeneity of existing pilots, a premature focus on empirical validation could result in context-specific findings with limited generalizability. Instead, this study prioritizes the development of a comprehensive theoretical foundation that can guide future empirical investigations across diverse contexts.

The literature review followed a systematic approach to ensure comprehensive coverage while maintaining flexibility appropriate for an emerging research domain. The review spanned three interconnected domains: blockchain technology capabilities and applications, circular

economy frameworks and performance metrics, supply chain visibility and traceability systems. Research strings used in the research were as follows:

- Blockchain domain: ("blockchain" OR "distributed ledger" OR "DLT" OR "smart contract*") AND ("supply chain" OR "logistics" OR "traceability").
- Circular economy domain: ("circular economy" OR "circularity" OR "closed-loop" OR "resource efficiency" OR "4R" OR "waste reduction") AND ("metric*" OR "indicator*" OR "measurement" OR "assessment").
- Integration domain: ("blockchain" AND "circular economy") OR ("blockchain" AND "sustainability" AND "supply chain").

The construction of the model proposed by the author in the second part of the article is the result of literature analysis, case studies observed in business reality and conceptual work.

3. Circular economy and blockchain technical capabilities

A sustainable supply chain is defined as a system that integrates environmental, social, and economic considerations into supply chain management, aiming to minimize negative impacts while maximizing benefits for all stakeholders (Negri et al., 2021). This approach is essential for achieving sustainable development goals and involves complex interactions among various actors, emphasizing the need for innovative practices and technologies to enhance efficiency and transparency. Key components of sustainable supply chains include environmental responsibility, social equity and economic viability (Gao et al., 2024; Fernando et al., 2022; Makprang, 2024).

Circular economy however is an economic model that aims to minimize waste and maximize resource reuse by closing material loops (Kara et al., 2022). In contrast to the traditional linear “take-make-throw” model, CE is based on the 4R principles: reduce, reuse, recycle, and recover (Sehrawat, 2025). The goal is to create a system in which products, materials, and resources remain in circulation for as long as possible, which contributes to reducing pressure on the natural environment and increasing economic efficiency (Ghisellini et al., 2016). The key objectives of the CE focus on sustainability, resource efficiency, and the integration of forward and reverse logistics (Mishra et al., 2023). CE aims to create a closed-loop system where products are designed for longevity, repairability, and recyclability, thereby minimizing waste and maximizing resource use (Kara et al., 2022). This transition necessitates a rethinking of logistics strategies to accommodate new material flows and business models (Aarikka-Stenroos et al., 2022). In practice, the circular economy requires a comprehensive approach to product design, supply chain management and cooperation between different stakeholders (Amir et al., 2023). Transparency of processes and the ability to monitor the flow

of materials are key here, which allows for the identification of areas for improvement and the effective implementation of circular strategies (Nascimento et al., 2019).

A number of metrics have been identified in the scientific literature and industry reports to assess the degree of circularity in organizations and supply chains (Corona et al., 2019). The most important include the materials circularity rate, supply chain visibility, waste reduction and carbon footprint (Calzolari et al., 2022). These metrics allow for a quantitative assessment of the effectiveness of circular activities and provide a basis for making informed strategic decisions. Table 1 shows a synthetic summary of the most commonly used circular economy metrics, which will be used later in the article to assess the impact of blockchain integration on the achievement of CE goals.

Table 1.
Circular Economy Metrics – a synthetic summary

Metric	Description	Source
Materials Circularity Rate	Share of recycled/reused materials in total input	Janik, Ryszko, 2017
Supply Chain Visibility	Traceability of materials/products through lifecycle	Kofos et al., 2022
Waste Reduction	Waste minimized/diverted from landfill or incineration	Domenech, Borrión, 2022
Carbon Footprint	Total greenhouse gas emissions	Gao, Liu, Wang, 2014
Resource Productivity	Economic output per unit of material input	Duflou et al., 2012
Percentage of Recycled Material Used	Proportion of recycled content in products/processes	Parchomenko et al., 2019
Product Recyclability	Share of product materials that can be recycled/reused	Okumura, 2022
Circular Water Consumption	Proportion of water reused in operations	Smol, Adam, Preisner, 2020
Product Longevity	Average lifespan of products	Bakker et al., 2021
Industrial Symbiosis Indicators	Use of waste/by-products as inputs for other processes	Domenech et al., 2019

Source: own elaboration based on sources indicated in the Table.

Integrating blockchain technology with the principles of the circular economy seems to be a natural and promising direction for the development of sustainable supply chains. The characteristic features of blockchain - such as decentralization, data immutability, consensus mechanisms, security, material tracking and programmability - perfectly meet the needs of transparency, credibility and process automation, which are key to the effective implementation of the circular economy model. In turn, circularity metrics allow not only to measure progress in closing material cycles, reducing waste or limiting emissions, but also provide specific reference points that can be linked to blockchain functionalities. Combining these two areas - technology and circularity indicators - allows for the creation of a comprehensive model that not only identifies the potential of blockchain, but above all allows for measuring and monitoring its actual impact on achieving the goals of the circular economy.

Blockchain is a technology that has attracted a lot of interest from circular economy experts due to its ability to precisely track the flow of materials and increase the transparency of information exchange in the network (Rehman Khan et al., 2022). The foundation of blockchain

is decentralized architecture, which eliminates the need for a central controlling entity, which increases the system's resistance to manipulation and failures (Shrimali, Patel, 2022). Each transaction is recorded in a block, which, after being approved by network participants, becomes immutable, which guarantees the durability and authenticity of data (Thakre, Yadav, 2024). Consensus mechanisms are key to ensuring the consistency and trustworthiness of records in a distributed network (Lashkari, Musilek, 2021). They allow network participants to jointly approve transactions, eliminating the risk of forgery and double spending (Zhou et al., 2023). The security of the blockchain system is based on cryptography and the distribution of data, which protects it from unauthorized access and attacks (Idrees et al., 2021). Traceability, or the ability to track the origin and flow of materials in the supply chain, is one of the most important features of blockchain used in the circular economy (Centobelli et al., 2022). Thanks to the transparent and immutable record of information, it is possible to accurately monitor the life cycle of products, which supports the responsibility of producers and consumers and allows for the verification of environmental declarations (Luo et al., 2024). Blockchain programmability, implemented by smart contracts, among others, allows for the automation of processes such as the implementation of contracts for returns, recycling or financial incentive systems (Sen Gupta et al., 2021). This increases operational efficiency and supports the implementation of business models based on the principles of the circular economy (Upadhyay et al., 2021). The next section of the article will present a conceptual assessment model that integrates the technical capabilities of blockchain with key metrics of the circular economy, creating a tool to support both researchers and practitioners in the transformation of sustainable supply chains.

4. Measuring Blockchain's Contribution to Circular Economy Goals – the model proposal

The proposed model for assessing the impact of blockchain technology on achieving circular economy goals is conceptualized as an interdisciplinary framework integrating three main components: blockchain technical capabilities, circular economy performance indicators, and a framework for assessing supply chain visibility. The model is based on an extensive analysis of scientific literature and supported by the analysis of case studies from industrial practice that illustrate real blockchain applications in the context of circularity. Key blockchain features have been selected as technical foundations that enable the implementation of CE goals.

The construction of the proposed model

A) Identification of Model's Foundational Layers

The model construction began with the identification of two foundational layers: blockchain technical capabilities and circular economy performance indicators. These constructs were selected based on both their theoretical relevance and their practical observability in real-world pilots and industry use cases. The starting point for defining the first layer of the model was the analysis of the basic technological features of blockchain technology presented in the earlier part of the article. The proposed basic variant of the model took into account transparency and traceability, usability of smart contracts, decentralized verifiability and tokenization. Using the model in practice allows for the use of a wider range of blockchain technology features that have the potential to impact the goals of the circular economy.

In the practical use of the model, the first step is to identify those blockchain functionalities that are actually present or actively used in the analyzed project. Such identification should be carried out on the basis of a technical and functional analysis of the solution using the following approaches:

- analysis of technical documentation and system architecture,
- evaluation of implemented blockchain feature,
- interviews or use case analysis,
- checklist and analysis of the occurrence of features.

The model includes four key CE performance indicators: material circularity rate, supply chain visibility, waste reduction, and carbon footprint. These indicators were selected due to their widespread recognition in the literature and their direct verifiability and monitoring using blockchain data. Their selection allows for a comprehensive assessment of the blockchain's impact on various aspects of circularity – from material efficiency, through process transparency, to environmental impact. Similarly to the first element, using the model in practice allows for the use of a wider range of circularity indicators that are impacted by the usage of blockchain technology. In practice, this layer of the model should be refined by selecting indicators that relate to the circular economy objectives and can be measured or observed in the context of the project being analysed. This selection should be supported by:

- review of strategic documents, project objectives and scope of activity,
- reference to literature and industry standards,
- data availability analysis,
- industry and organizational context,
- validation of indicators with project stakeholders.

B) A Framework for Assessing Blockchain Affordability and Circular Economy Visibility

The model uses a visibility assessment layer, adapted from the existing CE visibility assessment frameworks, which examine the blockchain's ability to monitor and integrate data from multiple sources. In parallel, blockchain affordance analysis allows for linking specific technology features to circular economy goals, allowing for the identification of mechanisms through which blockchain improves circularity. In order to effectively assess the impact of blockchain technology on achieving circular economy goals, it is necessary to combine two perspectives: technical (blockchain features) and measurement (CE metrics). The technological capabilities themselves, constitute a potential that must be linked to specific, measurable effects in the field of circularity. For this purpose, the model introduces two complementary layers: a visibility assessment framework and a blockchain affordance analysis.

Visibility Assessment Framework

Supply chain visibility is a fundamental element enabling monitoring and verification of the flow of materials, their condition and interactions between participants in the system. Blockchain, thanks to its decentralized and immutable nature, increases the level of this visibility by integrating data from various sources. An important point of reference for this layer is the Circular Economy Visibility Evaluation Framework, which indicates that without high-quality, integrated and reliable data, it is not possible to reliably monitor and assess circularity (Kofos et al., 2022). The authors of this approach emphasize that blockchain platforms, by integrating data from many stakeholders and sources, can significantly increase the visibility of material flows throughout the supply chain, which is a necessary condition for effective management and reporting of CE indicators. This enables reliable tracking of materials throughout the product life cycle, allowing for accurate measurement of indicators such as Material Circularity Rate or Waste Reduction. This visibility is essential for eliminating problems such as greenwashing and for ensuring transparency and reliability of data used in reporting and decision-making.

Blockchain Affordability Analysis

The affordance of technology refers to what actions and capabilities technology makes available to users and systems. Analyzing blockchain affordance allows to understand how specific features of the technology translate into the realization of circular economy goals. For example:

- Transparency and traceability enable verification of recycled content, which translates into a reliable Material Circularity Rate (Kouhizadeh, Zhu, Sarkis, 2023).
- Smart contracts automate incentive and material recovery processes, which increases operational efficiency and supports Waste Reduction (Pattanayak et al., 2025).

- Decentralized verification eliminates the need to trust individual entities, which strengthens data credibility and reduces the risk of greenwashing (Cerchione, 2025).
- Tokenization introduces incentive mechanisms, e.g. rewards for pro-environmental activities, which facilitates the involvement of various stakeholders in circular practices (Pattanayak et al., 2025).

Such a link between blockchain functions and specific CE effects enables not only the identification of potential benefits of the technology, but also their measurement and monitoring over time. Combining the visibility assessment framework with affordance analysis creates a coherent mechanism that allows us to move from abstract technology features and metrics to a practical tool for assessing the impact of blockchain on supply chain circularity. Visibility provides data and information, while affordance indicates how this data can be used to achieve CE goals through specific mechanisms and processes.

C) Multi-level impact and implementation assessment

The model considers different levels of blockchain impact – from short-term operational efficiency improvements (e.g., material tracking, waste reduction), through medium-term process automation (e.g., smart contracts), to long-term systemic transformation (e.g., decentralized secondary markets, full product lifecycle responsibility). This approach allows for the assessment of both direct and indirect effects of blockchain implementations in the context of CE. This approach is also based on the assumption that the transformation towards a circular economy is a multi-stage and multi-dimensional process, requiring actions at different organizational and systemic levels.

Short-term improvement in operational efficiency

At the lowest level, blockchain primarily supports operational improvements, such as tracking materials and components in the supply chain and reducing waste. Thanks to the transparency and immutability of data, blockchain enables accurate recording of material flows, which allows for better resource management and reduction of losses. Examples include systems for monitoring electronics recycling or secondary raw materials, which gain credibility and efficiency thanks to blockchain. Such activities fit into the 4R, which is the basis of many CE strategies.

Medium-term process automation

In the medium term, blockchain enables the automation of processes through smart contracts that can independently implement the terms of contracts for material returns, recycling, or financial incentives. This automation increases operational efficiency and reduces transaction costs, while strengthening incentive mechanisms for supply chain participants.

Examples include buy-back programs that are automatically triggered after scanning QR codes or tokenization of incentives for system participants.

Long-term systemic transformation

At the systemic level, blockchain has the potential to fundamentally change the structure and functioning of supply chains and secondary markets. For example, decentralized platforms for the exchange of materials and products (peer-to-peer marketplaces) can reduce dependence on traditional intermediaries and increase resource efficiency. In addition, blockchain supports the concept of "chain of responsibility", or full responsibility for the life cycle of products, which promotes the design of products for ease of recycling and reuse.

This approach is consistent with systems theory, which emphasizes the interconnectedness and feedback between elements of the economic and environmental systems. The transformation of the circular economy therefore requires actions at multiple levels, from operational to strategic, which the model reflects through a multi-level assessment of the impact of blockchain.

D) Model validation and adaptation

The model is designed with verification and scalability in mind, with the purpose of using case studies from real-world implementations and audit mechanisms based on immutable blockchain ledgers in the future. Additionally, integration with AI and IoT technologies is planned, which will allow for the development of predictive tools for managing materials and product life cycles. The model also takes into account challenges such as data standardization, technology scalability, and regulatory compliance. Implementing the model in practice requires taking into account several important challenges:

- Data standardization and interoperability - for blockchain to effectively integrate data from different sources and platforms, common data standards and communication protocols must be developed. The lack of standardization makes it difficult to scale solutions and implement them widely.
- Technology scalability - blockchain, especially in public versions, struggles with limitations in transaction throughput and energy consumption. Hybrid solutions, private or consortium blockchains, and the development of technologies such as proof-of-stake can mitigate these limitations.
- Regulatory compliance - data protection, privacy, and environmental certification regulations must evolve to take into account the specifics and capabilities of blockchain. Cooperation with regulators is key to building trust and acceptance of the technology.

It is planned that validation and adaptation of the model will be based on the synergy of practical implementations, audits based on immutable blockchain data, and integration with modern AI and IoT technologies. At the same time, successful implementation requires

overcoming challenges related to standardization, scalability, and regulations. This approach ensures that the model is not only theoretically consistent, but also practically useful and scalable in different circular economy contexts. The proposed model, the design assumptions of which are presented in the above fragment of the article, takes the graphical form shown in Figure 1.

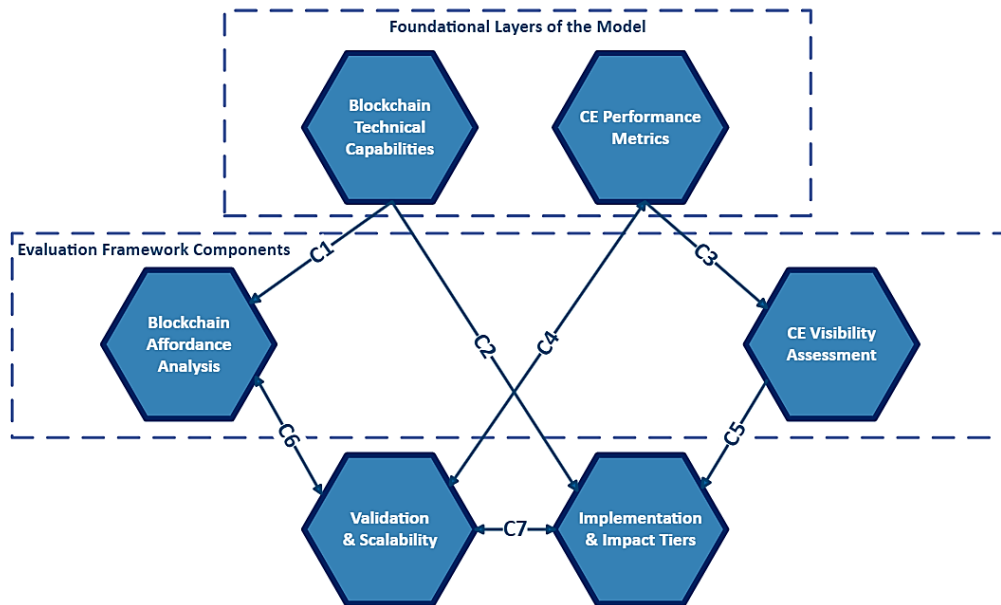


Figure 1. The Model Measuring Blockchain's Contribution to Circular Economy Goals.

Source: own elaboration.

Figure 1 presents the basic structural elements of the model and indicates 7 connections between them. The characteristics of the individual connections are presented below.

C1 – Blockchain Technical Capabilities -> Blockchain Affordance Analysis

Demonstrates how technical features of blockchain enable specific CE outcomes. This link highlights the functional translation of blockchain tools into CE affordances. For example, transparency enables verification of recycled content, while tokenization supports user engagement in take-back schemes.

C2 – Blockchain Technical Capabilities -> Implementation & Impact Tiers

Shows how practical CE implementations rely on the technical foundation provided by blockchain. As impact tiers evolve, blockchain capabilities such as decentralized verification or smart contracts become critical enablers. This link reinforces the cyclical nature of innovation and capability development.

C3 – CE Performance Metrics -> CE Visibility Assessment

Illustrates how performance indicators are dependent on robust visibility mechanisms to ensure accurate measurement and monitoring. Without visibility, performance metrics such as the material circularity rate or carbon reduction cannot be credibly validated. Visibility ensures traceability across the value chain, enabling real-time tracking and reporting.

C4 – CE Performance Metrics -> Validation & Scalability

Ensures that performance metrics are backed by credible, auditable, and standardized data sources. Validated and scalable systems allow metrics to be recognized across industries and regulatory systems.

C5 – CE Visibility Assessment -> Implementation & Impact Tiers

Represents how visibility supports implementation stages and helps scale CE initiatives by identifying process bottlenecks and material flows. Visibility tools provide the necessary infrastructure to gradually implement CE solutions, from short-term traceability to long-term product lifecycle accountability.

C6 – Blockchain Affordance Analysis <-> Validation & Scalability

Emphasizes the importance of validating how blockchain-enabled CE capabilities perform in real-world contexts and can be scaled sustainably. Each affordance needs to be tested for impact, audited for credibility, and proven scalable across industries. This includes considering energy use, transaction costs, and data standardization.

C7 – Validation & Scalability <-> Implementation & Impact Tiers

Highlights the need to evaluate and validate CE implementations before scaling them across industries or regions. Each implementation must be assessed for actual impact and replicability. Case studies, verified indicators, and interoperability tests are critical to moving from pilot to scaled solutions.

The model described in this article could be a useful tool which can be used in various ways, such as:

- evaluation of specific blockchain-based pilot projects in logistics, industry, or waste management,
- comparison of alternative solutions — to decide which blockchain implementation better supports CE goals,
- verification of technological maturity of a given blockchain-based solution,
- decision-making support for public and private stakeholders looking to invest in technologies that promote circularity.

The practical application of the model described conceptually in this article will be the subject of further work by the author. Subsequent articles will focus on model validation, presentation of practical research results using it, and the development potential of the proposed tool.

5. Conclusion

This study addresses a critical gap at the intersection of blockchain technology and circular economy research by developing a comprehensive conceptual framework for measuring blockchain's contribution to circular economy goals in sustainable supply chains. The proposed model integrates blockchain technical capabilities, circular economy performance metrics, assessment frameworks, and multi-tiered implementation impacts into a coherent system that enables systematic evaluation and optimization of blockchain deployments for circularity outcomes. The research makes three primary theoretical contributions. First, the model provides a structured integration of affordance theory with circular economy measurement frameworks, explicitly connecting blockchain's technical features to their action possibilities for achieving circular economy objectives. Second, the framework introduces a multi-layered visibility and credibility mechanism addressing one of the circular economy's most persistent challenges: reliable measurement and verification of circularity performance. By demonstrating how blockchain-enabled visibility supports the credibility of CE metrics, the model articulates a pathway to overcome greenwashing concerns and establish trust among supply chain stakeholders. Third, the model's temporal dimension—distinguishing between short-term operational improvements, medium-term process automation, and long-term systemic transformation—provides a framework for understanding blockchain adoption as an evolutionary process rather than a binary implementation. This perspective aligns with systems theory and organizational change literature.

The framework offers substantial value for multiple stakeholder groups. Supply chain managers and sustainability officers gain a structured decision-support tool for evaluating blockchain investments, enabling assessment of whether proposed solutions align with circularity objectives before committing resources. Technology vendors and blockchain developers receive guidance on critical design priorities, with the affordance perspective highlighting that systems must enable and encourage specific circularity-enhancing actions. Policymakers and standard-setting bodies obtain a foundation for developing standardized assessment protocols for blockchain-CE implementations. Investors and financial institutions focused on sustainable finance gain a framework for due diligence on blockchain-enabled circular economy ventures, helping direct capital toward genuinely impactful innovations.

Despite its contributions, this study has several important limitations. The most significant limitation is the absence of primary empirical validation; the model has not been tested through real-world implementations. While grounded in extensive literature review and informed by secondary case study analysis, its practical utility, completeness, and accuracy remain to be verified in diverse organizational contexts. The selection of four primary CE metrics, while justified by their widespread recognition and measurability, may not capture the full spectrum of circularity objectives, particularly social dimensions of circular economy. The model is

designed to be extensible to additional metrics, but the current formulation has inherent scope boundaries. Technological dynamism presents another challenge. Blockchain technology is evolving rapidly, with ongoing developments in scalability solutions, consensus mechanisms, and interoperability standards. The model may require periodic updating to reflect technological advances and integration with other emerging technologies. Data availability and quality assumptions may limit applicability. The model assumes reliable, granular data about material flows and environmental impacts, which may be scarce in many supply chains, particularly in developing regions or informal sectors. Finally, the framework focuses primarily on technological and measurement dimensions, giving less attention to organizational and governance challenges such as power dynamics, resistance to transparency, and competing economic interests among supply chain actors, which could be an interesting future research area.

The transition to a circular economy represents one of the most critical challenges of the 21st century, requiring fundamental transformation of production and consumption systems. Blockchain technology holds significant promise as an enabler of this transformation, yet realizing this promise requires moving beyond technological optimism to develop rigorous frameworks for designing, implementing, and evaluating blockchain solutions in service of measurable circularity outcomes. This study contributes to that endeavor by providing a theoretically grounded, practically oriented conceptual framework that bridges blockchain capabilities with circular economy performance measurement. The framework is not an endpoint but a foundation—a structured starting point for empirical research, practical implementation, and ongoing refinement. As blockchain technology matures and circular economy principles become increasingly embedded in business strategy and public policy, tools like the proposed model will be essential for ensuring that technological innovation genuinely advances sustainability goals.

References

1. Aarikka-Stenroos, L., Chiaroni, D., Kaipainen, J., Urbinati, A. (2022). Companies' circular business models enabled by supply chain collaborations: An empirical-based framework, synthesis, and research agenda. *Industrial Marketing Management*, 105, pp. 322-339.
2. Amir, S., Salehi, N., Roci, M., Sweet, S., Rashid, A. (2023). Towards circular economy: A guiding framework for circular supply chain implementation. *Business Strategy and the Environment*, 32(6), pp. 2684-2701.
3. Bakker, C.A., Mugge, R., Boks, C., Oguchi, M. (2021). Understanding and managing product lifetimes in support of a circular economy. *Journal of cleaner production*, 279, 123764.

4. Calzolari, T., Genovese, A., Brint, A. (2022). Circular Economy indicators for supply chains: A systematic literature review. *Environmental and Sustainability Indicators*, 13, 100160.
5. Centobelli, P., Cerchione, R., Del Vecchio, P., Oropallo, E., Secundo, G. (2022). Blockchain technology for bridging trust, traceability and transparency in circular supply chain. *Information & Management*, 59(7), 103508.
6. Cerchione, R. (2025). Design and evaluation of a blockchain- based system for increasing customer engagement in circular economy. *Corporate Social Responsibility and Environmental Management*, 32(1), 160-175.
7. Corona, B., Shen, L., Reike, D., Carreón, J.R., Worrell, E. (2019). Towards sustainable development through the circular economy—A review and critical assessment on current circularity metrics. *Resources, Conservation and Recycling*, 151, 104498.
8. Domenech, T., Borrion, A. (2022). Embedding circular economy principles into urban regeneration and waste management: Framework and metrics. *Sustainability*, 14(3), 1293.
9. Domenech, T., Bleischwitz, R., Doranova, A., Panayotopoulos, D., Roman, L. (2019). Mapping Industrial Symbiosis Development in Europe_ typologies of networks, characteristics, performance and contribution to the Circular Economy. *Resources, conservation and recycling*, 141, pp. 76-98.
10. Duflo, J.R., Sutherland, J.W., Dornfeld, D., Herrmann, C., Jeswiet, J., Kara, S., Kellens, K. (2012). Towards energy and resource efficient manufacturing: A processes and systems approach. *CIRP annals*, 61(2), pp. 587-609.
11. Fernando, Y., Halili, M., Tseng, M.L., Tseng, J.W., Lim, M.K. (2022). Sustainable social supply chain practices and firm social performance: Framework and empirical evidence. *Sustainable Production and Consumption*, 32, pp. 160-172.
12. Gao, J.Q., Li, D., Qiao, G.H., Jia, Q.R., Li, S.R., Gao, H.L. (2024). Circular economy strategies in supply chains, enhancing resource efficiency and sustainable development goals. *Environmental Science and Pollution Research*, 31(6), pp. 8751-8767.
13. Gao, T., Liu, Q., Wang, J. (2014). A comparative study of carbon footprint and assessment standards. *International Journal of Low-Carbon Technologies*, 9(3), pp. 237-243.
14. 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, pp. 11-32.
15. Idrees, S.M., Nowostawski, M., Jameel, R., Mourya, A.K. (2021). Security aspects of blockchain technology intended for industrial applications. *Electronics*, 10(8), 951.
16. Janik, A., Ryszko, A. (2017). *Towards measuring circularity at product level—Methodology and application of material circularity indicator*. 7th Carpathian Logistics Congress-CLC.
17. Kara, S., Hauschild, M., Sutherland, J., McAloone, T. (2022). Closed-loop systems to circular economy: A pathway to environmental sustainability? *CIRP Annals*, 71(2), pp. 505-528.

18. Kofos, A., Ubacht, J., Rukanova, B., Korevaar, G., Kouwenhoven, N., Tan, Y.H. (2022). Circular economy visibility evaluation framework. *Journal of Responsible Technology*, 10, 100026.
19. Kouhizadeh, M., Zhu, Q., Sarkis, J. (2023). Circular economy performance measurements and blockchain technology: an examination of relationships. *The International Journal of Logistics Management*, 34(3), pp. 720-743.
20. Lashkari, B., Musilek, P. (2021). A comprehensive review of blockchain consensus mechanisms. *IEEE access*, 9, pp. 43620-43652.
21. Luo, Y., Shen, J., Liang, H., Sun, L., Dong, L. (2024). Supporting building life cycle carbon monitoring, reporting and verification: A traceable and immutable blockchain-empowered information management system and application in Hong Kong. *Resources, Conservation and Recycling*, 208, 107736.
22. Makprang, K. (2024). Sustainability in supply chains: strategies and practices for a greener future. *RMUTT Global Business Accounting and Finance Review*, 8(1), pp. 85-108.
23. Mishra, A., Dutta, P., Jayasankar, S., Jain, P., Mathiyazhagan, K. (2023). A review of reverse logistics and closed-loop supply chains in the perspective of circular economy. *Benchmarking: an International Journal*, 30(3), pp. 975-1020.
24. Nascimento, D.L.M., Alencastro, V., Quelhas, O.L.G., Caiado, R.G.G., Garza-Reyes, J.A., Rocha-Lona, L., Tortorella, G. (2019). Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal. *Journal of manufacturing technology management*, 30(3), pp. 607-627.
25. Negri, M., Cagno, E., Colicchia, C., Sarkis, J. (2021). Integrating sustainability and resilience in the supply chain: A systematic literature review and a research agenda. *Business Strategy and the Environment*, 30(7), pp. 2858-2886.
26. Okumura, S. (2022). Reuse-efficiency model for evaluating circularity of end-of-life products. *Computers & Industrial Engineering*, 171, 108232.
27. Parchomenko, A., Nelen, D., Gillabel, J., Rechberger, H. (2019). Measuring the circular economy-A Multiple Correspondence Analysis of 63 metrics. *Journal of Cleaner Production*, 210, pp. 200-216.
28. Sehrawat, M., Nandwani, A., Rohila, M., Jain, A. (2025). Redefining Consumer Behaviour in a Circular Economy: Strategies for Sustainable Living. In: *Social System Reforms to Achieve Global Sustainability* (pp. 391-420). IGI Global Scientific Publishing.
29. Rehman Khan, S.A., Yu, Z., Sarwat, S., Godil, D.I., Amin, S., Shujaat, S. (2022). The role of block chain technology in circular economy practices to improve organisational performance. *International Journal of Logistics Research and Applications*, 25(4-5), pp. 605-622.
30. Sen Gupta, Y., Mukherjee, S., Dutta, R., Bhattacharya, S. (2022). A blockchain-based approach using smart contracts to develop a smart waste management system. *International Journal of Environmental Science and Technology*, 19(8), pp. 7833-7856.

31. Shrimali, B., Patel, H.B. (2022). Blockchain state-of-the-art: architecture, use cases, consensus, challenges and opportunities. *Journal of King Saud University-Computer and Information Sciences*, 34(9), pp. 6793-6807.
32. Smol, M., Adam, C., Preisner, M. (2020). Circular economy model framework in the European water and wastewater sector. *Journal of Material Cycles and Waste Management*, 22, pp. 682-697.
33. Thakre, B., Yadav, U. (2024). Evaluation of Data Management in Blockchainbased Systems. In: *Data Management and Security in Blockchain Systems* (pp. 1-37). Bentham Science Publishers.
34. Upadhyay, A., Mukhuty, S., Kumar, V., Kazancoglu, Y. (2021). Blockchain technology and the circular economy: Implications for sustainability and social responsibility. *Journal of cleaner production*, 293, 126130.
35. Zhou, S., Li, K., Xiao, L., Cai, J., Liang, W., Castiglione, A. (2023). A systematic review of consensus mechanisms in blockchain. *Mathematics*, 11(10), 2248.