ESGSB
Environmental, Social, Governance and Sustainable Business
ESGSB 2(1): 71–90
ISSN 3062-844X

Institute for Advanced Science, Social and Sustainable Future
MORALITY BEFORE KNOWLEDGE

CREDIT: Blockchain based trading optimization for circular credit systems accelerating green industry toward sustainable development goals 2030

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Received Date: January 9, 2025 Revised Date: February 9, 2025 Accepted Date: February 24, 2025

ABSTRACT

Background: A major challenge in modern industry is the high volume of waste ending in landfills and the limited implementation of circular economy principles, which hinder sustainable industrial development. This condition creates an urgent need for governance and incentive systems that improve waste management while providing long-term economic motivation for industrial actors. Previous studies highlight the role of circular economy models, carbon credit mechanisms, and blockchain technology in enhancing environmental performance and system transparency. **Methods:** This study adopts a qualitative, literature-based conceptual research approach to analyze circular economy practices, circular and carbon credit systems, and blockchain-based sustainability applications. The analysis focuses on synthesizing relevant theoretical insights to examine industrial waste challenges and evaluate the potential role of digital incentive systems. **Findings:** The results indicate that the proposed Circular Resource Exchange and Digital Incentive Trading (CREDIT) framework integrates blockchain-based activity recording, third-party verification, circular credit allocation, and inter-company credit trading within a unified system. These mechanisms are expected to enhance transparency and accountability while providing economic incentives for industries to adopt circular practices and support recycling-oriented ecosystems. **Conclusion**: Blockchain-enabled circular credit trading is a promising conceptual instrument for supporting the transition toward green industry and sustainable development. However, the framework remains exploratory and requires empirical validation through pilot implementation and further applied research. **Novelty/Originality of this article:** This study proposes an integrated conceptual framework that combines circular economy principles with blockchain-based digital incentive mechanisms, offering a new approach to circular credit governance, particularly in the context of developing economies.

KEYWORDS: blockchain technology; circular credit system; circular economy; green industry; sustainable development.

1. Introduction

Have you ever considered that waste could generate value rather than loss? Within a circular economy framework, waste is no longer perceived as a burden but as an economic opportunity. Blockchain-driven innovation increasingly enables this transformation. As stated by MacArthur, “A circular economy keeps products, components, and materials at their highest utility and value at all times,” emphasizing that resources can be optimized through redesign, innovation, and sustainable thinking.

Cite This Article:
Har, W. O. R. A. A. (2025). CREDIT: Blockchain based trading optimization for circular credit systems accelerating green industry toward sustainable development goals 2030. *Environmental, Social, Governance and Sustainable Business, 2*(1), 71-90. https://doi.org/10.61511/esgsb.v2i1.2025.2654

This concept is particularly relevant to Indonesia, where modern industries face rapidly increasing waste generation, most of which ends up in landfills. According to data from the National Waste Management Information System (SIPSN, 2025), Indonesia generates approximately 35.3 million tons of waste annually, yet only 38.63% is properly managed, while 61.37% remains inadequately treated. This condition reflects weak implementation of sustainable waste management practices, despite evidence that circular economy approaches can reduce waste generation by up to 50% while simultaneously creating new economic value through material reuse (Malihah et al., 2023). This growing pressure is further illustrated by the national trend of waste generation in Indonesia over recent years, as shown in (Fig. 1).

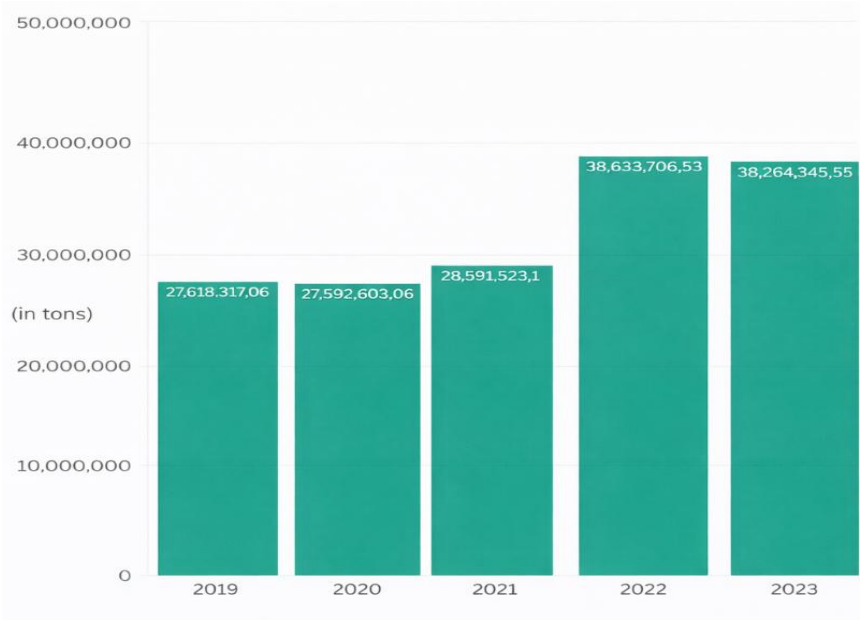

Fig. 1. Trend of waste generation in Indonesia (2019–2023)

High waste generation is closely linked to industrial sectors with significant pollution risks, including textiles and dyeing, palm oil processing, pulp and paper, nickel processing, as well as small and medium enterprises such as batik production and small-scale metal industries. These sectors are consistently monitored under the environmental performance rating program of the Ministry of Environment and Forestry due to their substantial waste outputs and strict management requirements (KLHK, 2022). This situation demonstrates that waste challenges originate not only from household consumption but also from industrial activities that have not fully adopted environmentally compliant waste management practices. Unmanaged waste accumulation at the upstream level ultimately increases pressure on municipal waste systems and strains national waste treatment infrastructure.

Low compliance levels further indicate suboptimal enforcement of key regulations, including Government Regulation No. 22 of 2021 on wastewater quality standards, Ministerial Regulation No. 6 of 2021 on hazardous waste management, and Extended Producer Responsibility obligations, which reportedly achieve only around 35% compliance (KLHK, 2023). These shortcomings highlight the urgent need for transparent, verifiable, and accountable reporting systems to ensure that incentives are allocated exclusively to industries that genuinely implement responsible waste management practices. In practice, limitations in data accessibility, fragmented reporting mechanisms, and uneven regional monitoring further weaken environmental governance. The current condition of waste management transparency in Indonesia is illustrated in (Fig. 2).

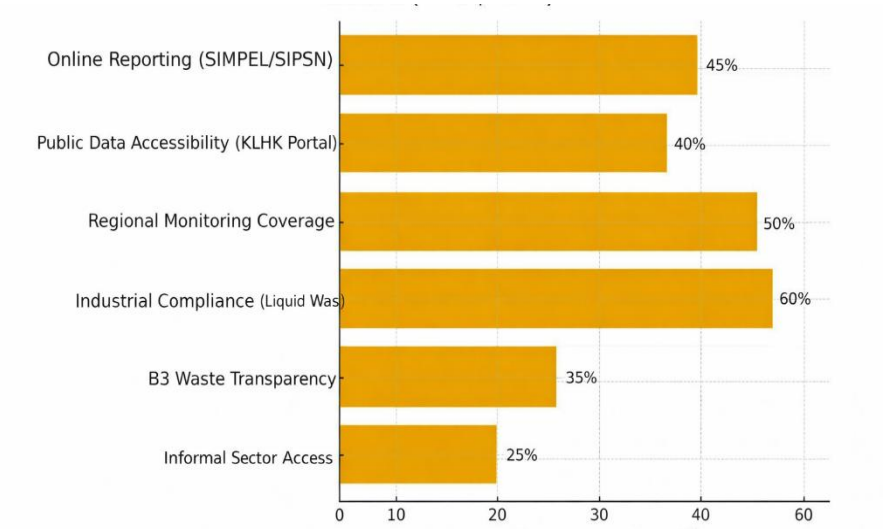

Fig. 2. Transparency levels of waste management in Indonesia based on official sources (KLHK, 2024)

The cumulative impacts of unmanaged industrial and domestic waste are evident in Indonesia's national waste crisis. Since 2022, the Bantar Gebang Integrated Waste Treatment Facility has experienced severe waste accumulation, receiving approximately 7,500–7,800 tons of waste per day, far exceeding its operational capacity of 2,000 tons per day and reaching nearly 80% of total capacity (Khansa et al., 2024). Moreover, in developing countries such as Indonesia, industrial wastewater pollution contributes to more than 14,000 deaths per day (DISLHK, 2019). Beyond environmental and public health risks, waste pollution generates substantial economic losses through increased healthcare costs, reduced fisheries and tourism revenues, and higher waste management expenditures, with global losses estimated to range from tens of billions to over one trillion United States dollars annually (McIlgorm et al., 2022).

These conditions necessitate a system that not only promotes effective waste management but also creates sustainable economic incentives. In parallel, incentive-based environmental governance literature suggests that economic rewards linked to verified environmental performance can influence organizational behavior more effectively than compliance-based regulation alone. The Circular Resource Exchange and Digital Incentive Trading (CREDIT) framework is proposed as a potential conceptual solution for Indonesia by integrating blockchain-based recordkeeping, third-party verification, digital incentive allocation, and inter-company credit trading. Blockchain technology has been widely recognized for its capacity to enhance transparency, traceability, and trust in environmental governance systems (Saberi et al., 2019; Kouhizadeh et al., 2021). Conceptually, this framework seeks to link verified waste recovery performance with incentive allocation rather than relying solely on aggregated reporting.

However, despite the growing body of literature on circular economy implementation, blockchain-based environmental governance, and incentive-driven sustainability mechanisms, existing studies remain fragmented (Geissdoerfer et al., 2017; Saberi et al., 2019; Kouhizadeh et al., 2021). Most prior research addresses these domains in isolation, without integrating verified waste recovery, digital incentive trading, and regulatory oversight within a single operational framework, particularly in developing country contexts (Kirchherr et al., 2018; Upadhyay et al., 2021). In Indonesia, systematic empirical or conceptual studies examining how blockchain-enabled digital incentives can simultaneously address transparency deficits, industrial compliance, and inclusive participation in circular economy systems remain limited (Sovacool et al., 2020).

This gap highlights the need for a unified conceptual framework that connects circular economy performance, verifiable digital incentives, and multi-stakeholder governance. Based on this background, this study aims to develop and conceptually analyze the Circular Resource Exchange and Digital Incentive Trading (CREDIT) framework as an integrated

model linking circular economy practices, blockchain-based transparency, and incentive-driven environmental governance. Rather than empirically testing system effectiveness, this study focuses on explaining the operational logic, governance structure, and potential contributions of the proposed framework to supporting Indonesia's transition toward a green and sustainable industrial economy.

2. Methods

2.1 Research approach and philosophical positioning

This study adopts a qualitative, literature-based conceptual research approach to address the low adoption of circular economy practices and limited transparency in industrial waste management. The approach is grounded in the ontological assumption that sustainability challenges are socially and institutionally constructed and in an epistemological stance that emphasizes theoretical synthesis rather than empirical measurement. Accordingly, this study does not seek to test hypotheses or measure causal effects, but rather to develop and clarify a conceptual framework that explains the interaction between circular economy principles, incentive-based governance, and blockchain technology. This methodological orientation is appropriate for exploratory and framework-development research, particularly in contexts where empirical data remain fragmented or inconsistent, such as industrial waste management in developing countries. The focus on conceptual analysis allows the integration of diverse theoretical perspectives into a coherent system model that can inform future empirical research and policy experimentation.

2.2 Data sources and literature selection

The primary data sources consist of peer-reviewed academic journal articles, government regulations, institutional reports, and international policy frameworks related to circular economy implementation, environmental incentive mechanisms, and blockchain-based sustainability systems. Literature selection was conducted through a structured review process, prioritizing sources published within the last ten years, while including seminal earlier works where conceptually relevant. Selection criteria emphasized thematic relevance, theoretical contribution, and applicability to developing country contexts, with particular attention to Indonesia. Sources that addressed only technical blockchain architecture without sustainability relevance, or sustainability studies without governance or incentive dimensions, were excluded to ensure analytical coherence.Data collection was conducted through a structured literature search and selection process. The search prioritized credible and up-to-date publications from recognized academic and institutional sources. Selection criteria emphasized thematic relevance to circular economy governance, digital incentive mechanisms, and transparency systems. This process ensured a comprehensive and systematic conceptual analysis.

2.3 Analytical techniques and theoretical framework

The analysis employs fishbone (cause-and-effect) analysis as a structured conceptual tool to identify key barriers, causal relationships, and systemic gaps in existing waste management and environmental incentive systems. This technique enables the decomposition of complex governance challenges into interrelated dimensions, including regulatory, technological, organizational, and economic factors. The theoretical foundation of the analysis is derived from three interrelated bodies of literature: circular economy theory, incentive-based environmental governance, and blockchain-enabled transparency and trust models. Rather than empirically validating these theories, the study synthesizes them to construct an integrated conceptual logic underpinning the proposed CREDIT framework.

2.4 Conceptual model development and presentation

Findings from the literature synthesis and fishbone analysis are systematically translated into a conceptual framework, referred to as the Circular Resource Exchange and Digital Incentive Trading (CREDIT) system. The framework illustrates stakeholder roles, information flows, verification processes, and incentive mechanisms within a blockchain-enabled circular economy ecosystem. Data are presented through descriptive narrative and conceptual system mapping to support logical interpretation of the proposed framework rather than empirical inference. This presentation approach enhances clarity by linking theoretical synthesis and analytical insights with visual representations of system processes. The methodological design enables conceptual reproducibility by clearly defining system components, stakeholder roles, and interactions within the framework. Rather than claiming universal applicability, the proposed framework is intended to be adaptable and context-sensitive, allowing future empirical studies to apply and test it across different industrial sectors and regulatory contexts, as illustrated in (Fig. 3).

Fig. 3. Fishbone CREDIT system

3. Results and Discussion

3.1 Core mechanisms of CREDIT

In response to the identified challenges in industrial waste management and limited incentive alignment, this study proposes the Circular Resource Exchange and Digital Incentive Trading (CREDIT) framework as a conceptual blockchain-based incentive system that integrates transparency and circular economy principles within industrial supply chains. The framework is designed to conceptually address the need for independent verification, circular credit allocation, and inter-company credit trading, thereby linking verified waste recovery activities with incentive-based governance mechanisms. Previous studies suggest that blockchain technology holds significant potential for enhancing transparency and enabling cross-sector value creation in sustainability-oriented systems (Chic et al., 2024). By integrating digital technology with circular economy principles, the CREDIT framework is expected to influence industrial behavior and support the transition toward green industrial practices, subject to regulatory readiness and empirical validation. Conceptually, the CREDIT framework operates through five interconnected mechanisms:

(1) recording of circular activities; (2) verification and auditing; (3) allocation of circular credits; (4) credit trading; and (5) integration with government regulation.

The recording of circular activities refers to the documentation of waste recovery and resource efficiency practices, such as recycling, material substitution, and by-product utilization. These activities are conceptually framed as mechanisms for reintegrating waste streams into industrial value chains rather than directing them to landfills. The framework also acknowledges the potential role of environmentally friendly inputs, such as recycled materials, in enhancing resource efficiency and reducing environmental pressure.

Verification and auditing constitute a critical governance component within the framework. Circular activities are intended to be examined by independent third parties, including certification bodies or accredited auditors, to ensure data authenticity and compliance with predefined technical and environmental standards. Once validated, verified activities are conceptually translated into digital records representing positive environmental performance.

The allocation of circular credits is designed as an incentive mechanism that rewards verified circular activities. Illustrative valuation scenarios are used to demonstrate how different recovery activities may receive differentiated credit values based on their complexity and contribution to resource efficiency. This differentiated approach is consistent with existing conceptual discussions on circular credit mechanisms (Ó BVRio, 2020) and studies highlighting the higher added value of industrial waste utilization (Volpin et al., 2024). Credit trading is conceptualized as a market-based mechanism that allows firms with surplus circular credits to exchange them with other firms facing higher compliance costs. While structurally comparable to carbon trading systems, the CREDIT framework focuses on material circularity rather than emission offsets, thereby linking economic value directly to verified waste recovery outcomes.

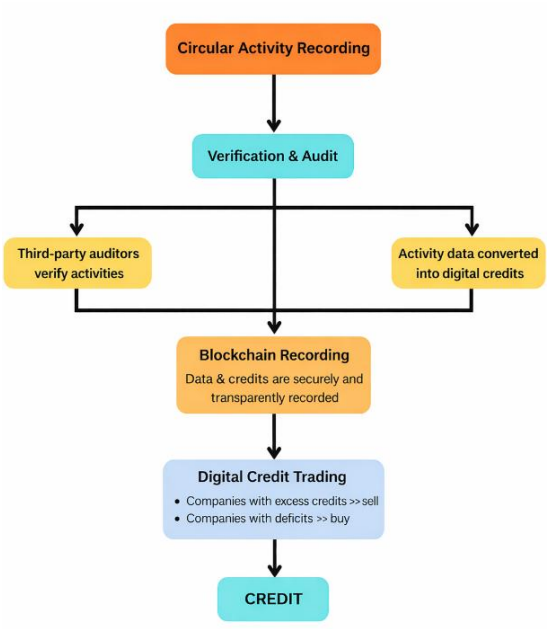

Fig. 4. Flowchart CREDIT

Integration with government regulation represents the institutional layer of the framework. Regulatory authorities are conceptually positioned as facilitators and supervisors, providing legal recognition for circular credits, aligning incentive structures with waste management regulations, and ensuring system accountability through blockchain-enabled monitoring. The interconnection of these mechanisms is illustrated in the system flow presented in (Fig. 4).

3.2 CREDIT features

To illustrate the operational logic of the proposed system, the CREDIT framework includes several conceptual features designed to demonstrate how circular economy principles may be translated into digital incentive mechanisms. These features aim to bridge the gap between sustainability objectives and practical implementation at the industrial level. They also provide a structured basis for integrating technological innovation with environmental governance strategies.

3.2.1 CREDIT dashboard

Through a web-based interface, users can easily observe the conversion of recycled waste into economic value, supported by graphs, calculators, and digital incentive simulations. The visualization is designed to provide a clear and practical illustration of how the system operates in real-world applications. It enables users to monitor key performance indicators, assess recycling efficiency, and track progress toward sustainability targets in real time. By presenting data in an accessible and interactive format, the dashboard supports informed decision-making related to circular resource management and incentive optimization. (Fig. 5).

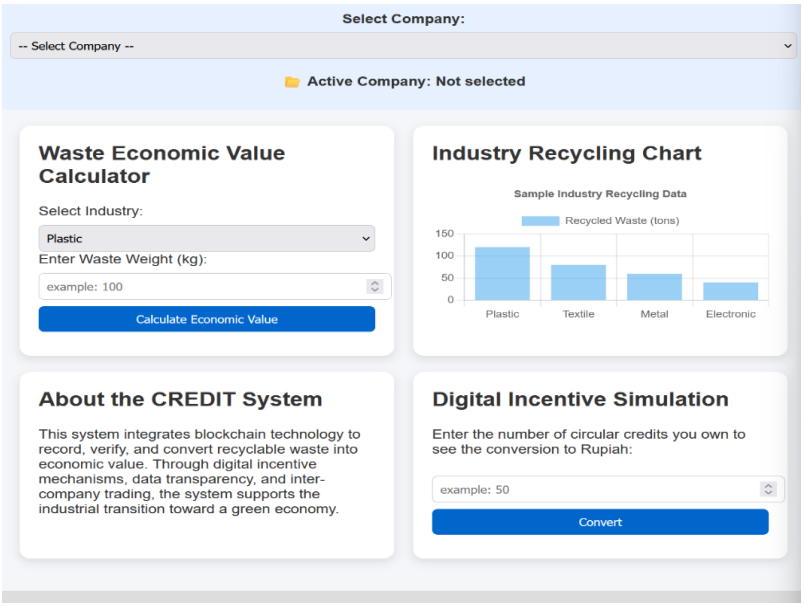

Fig. 5. CREDIT dashboard

3.2.2 Waste economic value calculator

This feature enables companies to calculate potential financial gains from recycling activities. By entering waste weight in kilograms or tons, the system automatically converts the input into estimated monetary value based on prevailing market prices for recycled materials. The calculation process is transparent and standardized, allowing users to easily interpret the results and compare performance over time. As a result, companies gain a clearer and more quantitative understanding of the economic value generated through their circular activities (Fig. 6).

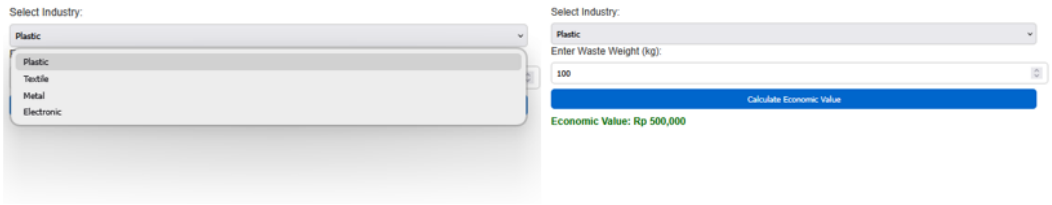

Fig. 6. Waste economic value calculator

3.2.3 Recycling performance graphs

This feature presents visual data related to waste generation, the volume of waste successfully recycled, and the economic value generated by each company. The graphs function as intuitive monitoring tools that allow both industrial actors and regulators to track performance developments and emerging trends in real time. By displaying data in a comparative and time-based format, the system facilitates performance evaluation across different reporting periods. This visualization supports transparency, accountability, and evidence-based decision-making in circular economy governance (Fig. 7).

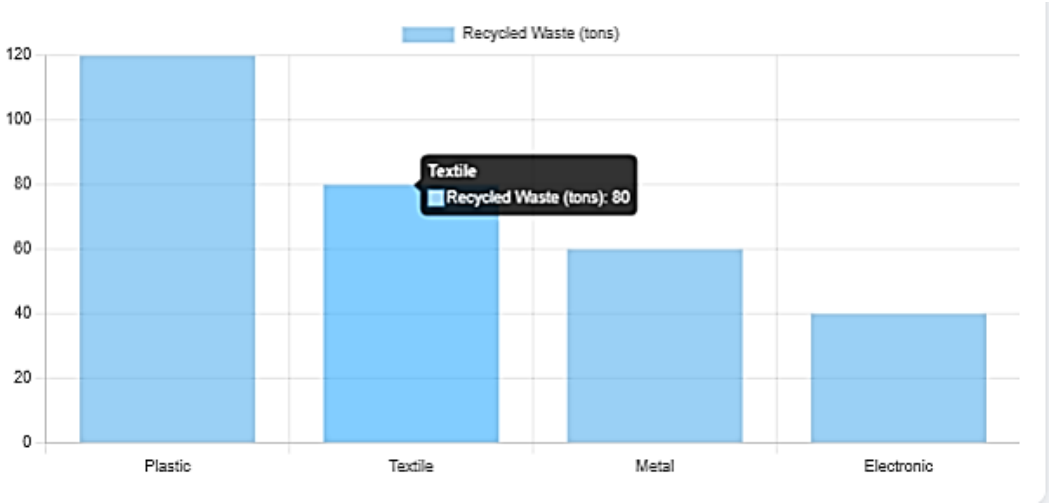

Fig. 7. Recycling performance graphs

3.2.4 Digital incentive simulation

The CREDIT system introduces an innovative digital incentive feature that links verified recycling performance with economic rewards. Through blockchain technology, all corporate recycling activities are securely audited and converted into digital credits. These credits can be traded among companies, creating a market-based mechanism that reflects environmental responsibility and circular performance. In addition to direct financial gains from recycling activities, companies may also benefit from digital credit trading, whose value may increase over time depending on market demand and regulatory support (Fig. 8).

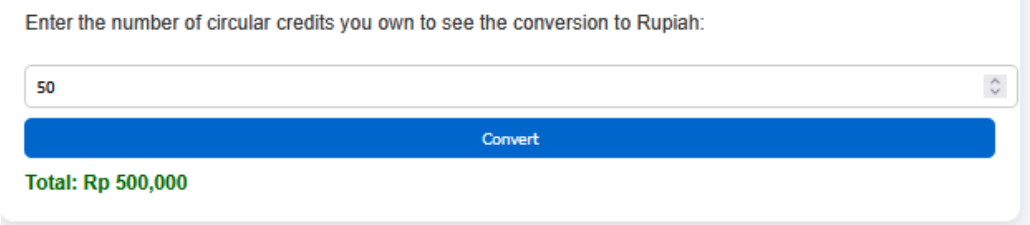

Fig. 8. Digital incentive simulation

3.3 Conceptual impact and relevance

The CREDIT framework is particularly relevant to the Indonesian context because it conceptually introduces an incentive-based mechanism that is expected to motivate industries to adopt circular economy practices not solely due to regulatory pressure, but also through potential economic signals derived from verified waste recovery activities. Prior studies indicate that incentive-driven governance models can improve institutional performance and compliance when financial rewards are directly linked to verified outcomes rather than procedural obligations (Gunawan et al., 2021). By applying similar incentive logic to waste management, the CREDIT framework conceptually illustrates how industrial behavior may shift toward more proactive and performance-oriented sustainability practices, subject to regulatory readiness and institutional capacity.

The integration of blockchain technology within the CREDIT framework is expected to strengthen transparency, accountability, and data integrity within industrial waste governance systems. Blockchain-based reporting theoretically enables government agencies and other stakeholders to monitor sustainability performance through immutable records, thereby reducing information asymmetry and enhancing trust among participating actors. Previous studies on blockchain and Internet of Things (IoT) integration in Indonesia suggest that such digital systems can enhance operational efficiency, traceability, and transparency across complex value chains (Chakim et al., 2024). When conceptually applied to waste management and circular economy systems, these technologies offer a mechanism for producing more reliable records of recycling activities and reducing the risk of data manipulation, which is frequently associated with greenwashing practices.

In addition, the incorporation of IoT-based verification mechanisms within the CREDIT framework is proposed as a means to generate waste processing data automatically and objectively from physical activities. This technological integration theoretically enhances system credibility by linking digital credits to observable environmental performance rather than self-reported data. As demonstrated by (Chakim et al., 2024), the combination of IoT sensors and blockchain platforms allows continuous data capture and secure validation, which is particularly relevant for developing country contexts where manual reporting systems often face limitations in accuracy, consistency, and enforcement capacity.

From an economic and social perspective, the CREDIT framework conceptually offers opportunities for small and medium enterprises to participate in circular economy initiatives by lowering entry barriers through standardized and transparent incentive mechanisms. The introduction of a minimum reference price for circular credits **is** presented as a potential stabilizing instrument to reduce market volatility and protect smaller actors. Existing literature on incentive-based governance suggests that participation and long-term commitment are more likely when rewards are perceived as fair, performance-based, and transparent (Gunawan et al., 2021). Nevertheless, the actual distributional effects and economic viability of such mechanisms require empirical validation through pilot implementation and stakeholder engagement.

Beyond addressing national waste management challenges, the CREDIT framework proposes an alternative sustainability approach that conceptually differentiates it from existing instruments such as carbon trading schemes and Extended Producer Responsibility obligations. While conventional mechanisms primarily focus on emission reduction targets or administrative compliance thresholds, CREDIT emphasizes value generation based on verified material recovery performance through tradable digital incentives. This performance-oriented incentive logic has the potential to reinforce circular economy principles in a more measurable and outcome-focused manner. However, the realization of these impacts remains contingent upon consistent policy support, digital infrastructure readiness, and institutional coordination. Within these conditions, the CREDIT framework may contribute to strengthening Indonesia's competitiveness while supporting a transparent and incentive-driven green industrial transition.

3.4 Comparison of CREDIT with existing environmental incentive mechanisms

A variety of environmental management and incentive mechanisms have been implemented globally and in Indonesia to promote producer responsibility and sustainable practices. Despite their contributions, many of these instruments continue to face structural and operational limitations, particularly in translating regulatory compliance into verifiable and measurable improvements in waste reduction and material recovery. Among the most widely adopted mechanisms are Extended Producer Responsibility (EPR) frameworks, eco-label certification schemes, carbon pricing instruments, and community-based waste bank systems.

Extended Producer Responsibility (EPR) policies require producers to assume responsibility for post-consumer waste management throughout the product life cycle. However, their effectiveness has been increasingly challenged by the growing complexity of modern supply chains, especially the rapid expansion of cross-border trade and digital commerce. Hilton et al. (2019) highlight that online sales and fragmented distribution channels complicate waste tracking, enforcement, and accountability, resulting in gaps between formal producer obligations and actual waste recovery outcomes. In practice, EPR implementation often remains administrative and compliance-oriented, with limited mechanisms for verifying real recycling performance or incentivizing continuous improvement beyond minimum regulatory thresholds.

Eco-label certification schemes represent another commonly used instrument aimed at encouraging environmentally responsible production and consumption. While eco-labels can enhance corporate reputation and consumer awareness, empirical evidence from Indonesia indicates that their effectiveness as long-term behavioral drivers is constrained. Isharyadi et al. (2022) report that limited producer awareness, relatively high certification costs, and the absence of direct financial incentives reduce the attractiveness of eco-labels, particularly for small and medium enterprises. Consequently, eco-labels frequently function as reputational signals rather than as mechanisms that actively incentivize sustained improvements in circular practices and material recovery performance.

Carbon pricing mechanisms, including carbon taxes and emissions trading systems, are widely recognized for their role in internalizing the environmental costs of greenhouse gas emissions. While effective in supporting climate change mitigation, these instruments do not directly target waste reduction or material circularity. Savin et al. (2024) note that carbon pricing frameworks primarily focus on emissions control, leaving significant policy and knowledge gaps related to resource efficiency, recycling performance, and waste recovery. As a result, firms may achieve compliance through emission offsets or credit purchases without substantially improving their material management practices.

At the community level, waste bank systems have demonstrated notable success in increasing public participation in waste segregation and recycling activities. Budiyarto et al. (2025) show that waste bank initiatives across Indonesian regions contribute to enhanced economic value generation from household waste and improved community engagement. Despite these positive outcomes, waste bank systems typically operate at relatively small scales, remain fragmented, and are weakly integrated into industrial supply chains and national environmental governance structures. Their limited connection to industrial actors constrains their capacity to influence upstream production practices and large-scale material flows.

In comparison, the CREDIT framework proposes an alternative conceptual approach that seeks to integrate third-party verification, blockchain-based transparency, and incentive allocation within a single system architecture. Rather than replacing existing mechanisms, CREDIT is positioned as a complementary framework that emphasizes performance-based incentives linked to verified material recovery outcomes. By conceptually monetizing recycling performance through tradable digital credits, the framework addresses some of the limitations associated with compliance-oriented or reputational instruments, particularly the risk of greenwashing and weak accountability.

However, it is important to emphasize that the comparative advantages of the CREDIT framework remain theoretical and context-dependent. Its effectiveness in accelerating industrial adoption of circular economy practices depends on regulatory alignment, institutional capacity, technological readiness, and stakeholder acceptance. As such, CREDIT should be understood as a conceptual contribution that offers an integrated design logic for future policy experimentation and empirical evaluation, particularly within developing economy contexts such as Indonesia.

3.5 Stakeholder roles and governance structure

The effective functioning of the CREDIT framework is highly dependent on a clearly defined governance structure and coordinated engagement among multiple stakeholder groups. Existing literature emphasizes that governance in blockchain-based systems extends beyond technological architecture and requires institutional coordination, role clarity, and decision-making mechanisms to ensure accountability, legitimacy, and long-term system viability (Beck et al., 2018). In the context of circular economy implementation, governance frameworks must balance regulatory oversight, independent verification, and inclusive participation in order to maintain credibility and public trust.

Within the proposed CREDIT framework, government institutions are conceptually positioned as regulators, facilitators, and system supervisors. Their roles include establishing legal frameworks that recognize digital circular credits, aligning the CREDIT system with existing waste management and environmental regulations, and defining national standards for waste valuation and reporting. In addition, governments may play a role in setting reference pricing mechanisms for circular credits to reduce market volatility and enhance system stability. Such involvement is particularly important in developing country contexts, where the integration of circular economy principles into waste management systems requires coordination across sectors, administrative levels, and regulatory domains (Wikurendra et al., 2024). Through access to blockchain-based monitoring platforms, regulators are expected to gain improved visibility over recycling performance and compliance trends, thereby reducing information asymmetry and strengthening governance capacity.

Industrial actors, including large manufacturing firms and small and medium enterprises, represent the primary participants within the CREDIT ecosystem. These stakeholders are responsible for implementing circular practices, documenting waste recovery activities, and engaging in circular credit transactions. By conceptually linking verified recycling performance with economic incentives, the CREDIT framework illustrates how industries may be encouraged to integrate circular economy principles into their operational strategies rather than treating sustainability solely as a compliance obligation. Prior studies indicate that multi-stakeholder engagement enhances accountability and collective responsibility in environmental governance initiatives, underscoring the importance of active industrial participation in system design and implementation (Siangulube, 2024).

Third-party verification bodies, including independent auditors, certification agencies, and academic or research institutions, function as neutral guarantors of data integrity within the framework. Their role is to validate reported waste recovery activities, assess compliance with technical and environmental standards, and ensure that issued digital credits reflect genuine environmental performance. Blockchain-based transparency mechanisms are theoretically expected to enhance auditability and trust by ensuring traceability of verification records and reducing opportunities for data manipulation (Wang et al., 2020). Independent verification is therefore a critical component in minimizing greenwashing risks and maintaining stakeholder confidence in the system.

Technology providers and platform operators are responsible for developing, maintaining, and securing the blockchain infrastructure that underpins the CREDIT framework. Their responsibilities include ensuring cybersecurity, data immutability, system scalability, and interoperability with complementary technologies such as Internet

of Things (IoT)–based monitoring tools. As highlighted by (Beck et al., 2018), the long-term sustainability of blockchain platforms is closely linked to governance arrangements that balance technological innovation with institutional oversight and stakeholder coordination. Within the CREDIT framework, technology providers are therefore viewed not only as service providers but also as key actors in system governance.

In addition, waste processors and community-based actors, including informal sector participants, play a crucial role in material recovery and recycling processes. Their inclusion within the CREDIT framework is essential to promote social inclusivity and recognize the contributions of grassroots actors to circular economy objectives. However, effective governance must address challenges related to digital access, technological literacy, and equitable participation to prevent exclusion and ensure fair benefit distribution (Siangulube, 2024). Capacity-building initiatives and simplified digital interfaces may therefore be necessary to support meaningful participation by these actors.

To facilitate coordination, transparency, and accountability, the interactions and responsibilities among stakeholders are conceptually integrated within a centralized blockchain-based platform. Each stakeholder contributes regulatory oversight, operational data, verification, or technical support to ensure the integrity of circular credit allocation and trading processes. The governance structure and stakeholder interactions within the CREDIT system are illustrated in (Fig. 9).

Fig. 9. Stakeholder roles

3.6 SWOT analysis

To ensure that the CREDIT framework is not only conceptually innovative but also strategically relevant and contextually feasible within Indonesia's industrial ecosystem, a structured assessment is required. Accordingly, this study extends the analytical discussion through a SWOT analysis to systematically examine the internal strengths and weaknesses of the proposed system, as well as the external opportunities and threats that may influence its long-term viability as a circular economy instrument. This analysis provides an exploratory evaluation rather than an empirical prediction of implementation outcomes. The results of the SWOT analysis are summarized in (Table. 1).

To examine the practical feasibility and strategic positioning of the CREDIT system within Indonesia's industrial and regulatory landscape, a SWOT analysis was conducted to identify key internal strengths and weaknesses, as well as external opportunities and threats that may influence its long-term implementation. This analytical approach provides

a concise yet structured assessment of the system's readiness to support circular economy adoption under existing institutional and market conditions.

Table. 1 SWOT analysis

Aspect	Comprehensive description
Strengths	Ensure transparency, security, and accountability of circular transaction data; Encourage active industrial participation in recycling activities; Automatically calculate and display the economic value of waste; Strengthen commitment to the Sustainable Development Goals, particularly Goals 9 and 12; Support the implementation of national green policies through an integrated digital reporting system.
Weaknesses	Dependence on digital infrastructure, including reliable internet networks, servers, and robust cybersecurity systems; Limited technological literacy among industries and communities, which may hinder early adoption; Tokenization systems and digital trading mechanisms require clear legal and financial regulatory frameworks; Measurement of the economic value of waste requires national standardization to ensure consistency across industries.
Opportunities	Open pathways toward the green transition and the circular economy; Offer opportunities for collaboration with government agencies, technology startups, universities, and industrial sectors in research and implementation; Enable development into a national circular credit platform integrating multiple industrial sectors; Enhance export competitiveness, as companies implementing green systems are more trusted in global markets; Provide a foundation for the development of a digital circular credit market in Indonesia.
Threats	Risk of digital token value fluctuations that may affect incentive stability and user confidence; Potential resistance from conservative industries that are not yet prepared to adopt new digital systems; Competition from similar foreign platforms with more advanced technological maturity.

The analysis indicates that CREDIT demonstrates strong strategic value through its ability to integrate transparency, accountability, and performance-based incentives into waste management governance. Its capacity to convert verified material recovery into economic value aligns closely with Indonesia's green economy agenda and relevant Sustainable Development Goals, positioning CREDIT as a policy-relevant digital innovation. These strengths create a foundation for encouraging measurable circular practices beyond formal regulatory compliance. Nevertheless, the SWOT findings also reveal critical limitations that may constrain early adoption, particularly the system's reliance on digital infrastructure, standardized valuation mechanisms, and sufficient technological capacity among industrial actors and waste-processing small and medium enterprises. Without targeted regulatory frameworks, capacity-building initiatives, and national standardization, these constraints could reduce system inclusivity and limit scalability.

At the same time, opportunities for cross-sector collaboration, institutional integration, and the development of a national circular credit platform strengthen the long-term prospects of CREDIT. Conversely, external risks such as digital credit price volatility, resistance from technologically conservative industries, and competition from more mature international platforms emphasize the importance of governance arrangements that ensure market stability, legal certainty, and stakeholder trust. Overall, the SWOT analysis suggests that the effectiveness of CREDIT depends not only on its technological architecture, but also on coordinated policy support, stakeholder readiness, and governance mechanisms that embed ethical, social, and equity considerations. These factors are essential to ensuring that

CREDIT evolves into a resilient and inclusive instrument for accelerating Indonesia's circular economy transition.

3.7 Ethical, social, and equity considerations

The implementation of blockchain-based circular incentive systems such as CREDIT must be assessed not only from a technological and economic perspective but also through ethical, social, and equity lenses. This broader assessment is essential to ensure that digital innovation in waste governance does not unintentionally reproduce existing structural inequalities. In the context of waste management in Indonesia, these dimensions are particularly important due to the significant involvement of informal actors, community-based initiatives, and social enterprises in material recovery and recycling activities. These interrelated considerations are conceptually illustrated in (Fig. 10), which presents the CREDIT system as a framework that aligns technological transparency with social inclusion and equitable incentive distribution.

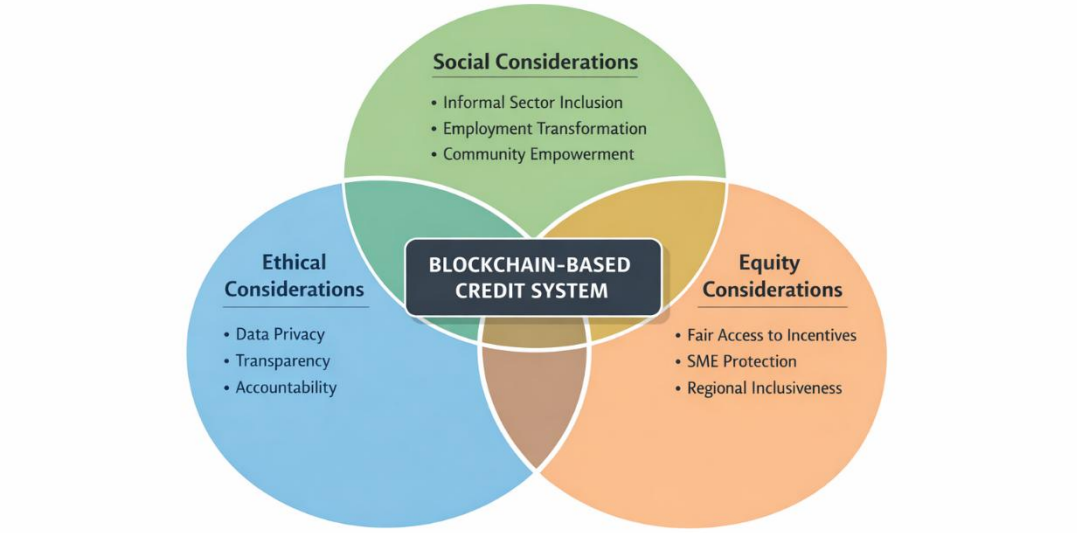

Fig. 10. Conceptual framework of ethical, social, and equity considerations in the CREDIT system

From a social inclusion perspective, previous studies emphasize the critical role of the informal sector in achieving sustainable and inclusive waste management systems. Sembiring & Nitivattananon (2010) demonstrate that the integration of informal waste workers into formal waste management frameworks improves collection efficiency, enhances social recognition, and contributes to income stability for marginalized groups. In Indonesia, informal waste actors remain central to material recovery processes, yet they are often excluded from formal incentive mechanisms. Excluding these actors from digital incentive systems may reinforce existing inequalities; therefore, the CREDIT system must be designed to formally recognize and reward informal and community-based recycling contributions through accessible digital mechanisms.

At the community level, alternative waste management models further illustrate the importance of socially grounded approaches. Yandri et al. (2023) document the practice of "waste sadaqah" in Java, where waste collection is embedded within religious and social solidarity frameworks. This model demonstrates that community trust, shared values, and collective participation significantly enhance waste segregation and recycling performance. These findings suggest that incentive systems that align with local norms and social values are more likely to achieve long-term behavioral change. Incorporating community-based mechanisms into the CREDIT system can enhance ethical legitimacy by aligning technological innovation with local cultural values and social norms.

Institutional integration between community initiatives and municipal governance also plays a decisive role in ensuring long-term equity. Kubota et al. (2020) show that waste bank

programs in Makassar become more effective when aligned with local government policies, regulatory support, and logistical infrastructure. This evidence underscores the need for CREDIT to operate within a multi-level governance framework that connects national digital platforms with local waste management institutions**.** This finding underscores the importance of multi-level governance in preventing fragmentation and ensuring that community-based actors are not excluded from formal incentive systems due to administrative or technical barriers.

Despite its potential benefits, the adoption of blockchain technology also introduces ethical risks related to unequal access and digital exclusion. Small-scale enterprises and informal actors may face limitations in digital infrastructure, internet connectivity, and technological literacy. Without deliberate inclusion strategies, blockchain-based incentive systems may disproportionately benefit technologically advanced firms. Without appropriate safeguards, blockchain-based systems may unintentionally privilege technologically advanced actors. Therefore, ethical system design within CREDIT should prioritize capacity-building programs, technical assistance, simplified digital interfaces, and platform access subsidies to reduce entry barriers and promote inclusive participation.

These measures are closely aligned with the concept of a just transition, which emphasizes that sustainability transformations must be socially inclusive, protect vulnerable groups, and ensure the fair distribution of economic benefits. By embedding ethical safeguards and equity-oriented governance mechanisms into system architecture, CREDIT can contribute to a transition that balances environmental effectiveness with social justice. Ultimately, addressing ethical, social, and equity considerations is essential to ensure that CREDIT contributes not only to waste reduction and resource efficiency but also to social empowerment and equitable economic development in Indonesia.

3.8 Technological integration and digital governance of the CREDIT system

The effectiveness and long-term scalability of the CREDIT system depend not only on its core blockchain infrastructure but also on its capacity to leverage complementary digital technologies that improve data accuracy, process automation, and governance effectiveness. In the context of waste management and circular economy implementation in Indonesia, the convergence of blockchain, Internet of Things (IoT), smart contracts, and digital governance frameworks provides an integrated technological backbone for transparent, verifiable, and accountable incentive systems.

The integration of Internet of Things (IoT) technology plays a critical role in strengthening the reliability of data recorded within the CREDIT platform. Dorri et al. (2017) explain that IoT-enabled systems allow real-time data collection through sensors that monitor physical activities, such as material flows, weight measurements, and processing stages. By generating data directly from physical processes, IoT reduces dependence on self-reported information, which is often vulnerable to errors and manipulation. When combined with optimized blockchain architectures, IoT data can be securely transmitted and stored in a decentralized ledger, reducing the risk of data manipulation and improving system scalability. Within the CREDIT framework, IoT sensors installed at industrial facilities, recycling centers, and waste processing sites can automatically capture information on waste generation and recovery, thereby enhancing data objectivity and strengthening the credibility of circular activity records.

Beyond data collection, smart contracts function as a key mechanism for automating transactions and regulatory enforcement within blockchain-based systems. Sari et al. (2024) highlight that smart contracts enable self-executing agreements based on predefined rules, reducing administrative burdens and increasing legal certainty in digital transactions. This automation is particularly relevant in regulatory-intensive sectors such as waste management, where manual verification processes are often inefficient. In the Indonesian context, their analysis emphasizes the importance of aligning smart contract implementation with national financial regulations, taxation policies, and consumer protection frameworks. Applied to the CREDIT system, smart contracts can automatically

issue circular credits once recycling activities are verified, execute credit trading transactions between companies, and enforce compliance requirements in a consistent and non-discretionary manner. This automation not only improves operational efficiency but also supports regulatory transparency by ensuring that incentive allocation follows standardized and auditable rules.

The broader success of technology-driven systems such as CREDIT also depends on the maturity of digital governance frameworks. Murdhani (2025) identifies that digital governance in Indonesia faces challenges related to institutional coordination, regulatory harmonization, and uneven digital infrastructure readiness across regions. These constraints may limit the uniform adoption of blockchain-based systems if not addressed through coordinated policy design. However, the study also highlights significant opportunities arising from increased government commitment to e-governance, data integration, and public-sector digital transformation. Within this governance context, the CREDIT system can serve as a complementary digital governance instrument by providing regulators with real-time access to verified waste management data, supporting evidence-based policymaking, and facilitating inter-agency coordination across environmental, industrial, and fiscal authorities. Integrating CREDIT with national digital governance initiatives can enhance oversight capacity while ensuring that technological innovation aligns with public accountability and legal frameworks.

Taken together, the integration of IoT, smart contracts, and digital governance mechanisms reinforces both the technical robustness and institutional legitimacy of the CREDIT system. IoT technologies enhance data accuracy at the operational level, smart contracts automate incentive distribution and compliance enforcement, and digital governance frameworks ensure regulatory alignment and public accountability. This layered technological architecture positions CREDIT not merely as a digital platform, but as an enabling infrastructure for policy-driven circular economy transformation, capable of supporting Indonesia's transition toward a transparent, efficient, and inclusive circular economy.

4. Conclusions

This study presents the Circular Resource Exchange and Digital Incentive Trading (CREDIT) system as a conceptual framework for addressing industrial waste management challenges and strengthening circular economy implementation in Indonesia. By integrating blockchain-based transparency, third-party verification, and digital incentive mechanisms, CREDIT conceptually reframes waste from an environmental burden into a verifiable economic signal that supports circular practices. The analysis suggests that incentive-based mechanisms supported by transparent digital infrastructure have the potential to encourage industrial adoption of circular economy principles beyond formal regulatory compliance. In contrast to conventional instruments such as carbon trading and Extended Producer Responsibility schemes, CREDIT links economic incentives directly to verified material recovery performance, thereby conceptually enhancing accountability and reducing greenwashing risks.

From a governance perspective, the framework demonstrates relevance to Indonesia's policy context by outlining how digital monitoring, stakeholder participation, and regulatory alignment could be strengthened through emerging technologies such as blockchain, Internet of Things, and smart contracts. The inclusion of ethical, social, and equity considerations further highlights the importance of ensuring that small and medium enterprises, informal actors, and social enterprises are not excluded from digital incentive systems. However, this study is primarily conceptual and does not provide empirical evidence of system effectiveness. Future research should therefore focus on pilot implementations, empirical performance evaluation, and behavioral analysis across industrial sectors. With appropriate policy support and empirical validation, the CREDIT framework may offer a promising direction for advancing transparent and inclusive circular economy governance in Indonesia.

Acknowledgement

The author wish to express their sincere gratitude to their friends and colleagues for their support and constructive discussions, which fostered valuable insights and significantly contributed to the development of this manuscript. They also thank the organizers of the INESCO 2025 Vol. 2 competition, hosted by the Accounting Student Association (HMPS) at Universitas Muhammadiyah Purwokerto, for providing journal publication facilities.

Author Contribution

All aspects of this work, including conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing (original draft and review & editing), visualization, supervision, project administration, and funding acquisition, were carried out by W. O. R. A. A. H.

Funding

The publication of this article was funded by the organizers of the INESCO 2025 Vol. 2 competition, hosted by the Accounting Student Association (HMPS) at Universitas Muhammadiyah Purwokerto.

Ethical Review Board Statement

Not available.

Informed Consent Statement

Not available.

Data Availability Statement

Not available.

Conflicts of Interest

The author declares no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Declaration of Generative AI Use

During the preparation of this work, the author used Grammarly to assist in improving grammar, clarity, and academic tone of the manuscript. In addition, the author paraphrased certain words or phrases to enhance readability and expression. After using these tools and techniques, the author reviewed and edited the content as needed and took full responsibility for the content of the publication.

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