FINANCING CARBON REMOVAL THROUGH BLOCKCHAIN TECHNOLOGY: A CASE STUDY OF BLOCKCHAIN TOKENS

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Abstract

In the fight against climate change, innovative financing solutions are critical to accelerating the deployment of carbon removal technologies. This paper explores the novel application of a blockchain-based asset, smart contracts in the form of tokens, designed to fund carbon removal initiatives. By leveraging blockchain technology's inherent transparency and security, tokens offer a unique approach to mobilising resources and incentivising investments in environmentally critical projects. This study delves into the operational framework of tokens, examining their integration into carbon removal projects and evaluating their effectiveness as a financial instrument. This paper assesses the impact of tokens on project funding and carbon reduction outcomes, providing insights into the scalability and potential barriers to broader adoption. The findings suggest that blockchain technology not only enhances the efficiency of funding environmental projects but also ensures accountability and stakeholder engagement. The implications of this study are significant, offering a roadmap for policymakers and investors interested in harnessing the power of digital currencies to meet global sustainability goals.

1. INTRODUCTION

The escalating consequences of climate change, ranging from extreme weather events to biodiversity loss, underscore the urgent need for innovative strategies in carbon reduction and sustainability. According to the International Energy Agency's Sustainable Development Scenario (IEA-SDS), achieving the Paris Agreement's climate targets requires the construction of 70–100 carbon capture and storage (CCS) facilities annually, demanding capital investments between $655 billion and $1,280 billion (Rassool, 2021). Despite the recognised importance of CCS and carbon dioxide removal (CDR) technologies in achieving net-zero emissions, funding these initiatives remains a persistent challenge.

Traditional financing mechanisms are ill-equipped to meet the scale and urgency of the investment needed for CCS and CDR projects. Fragmentation across disciplinary knowledge bases limits the efficiency and adaptability of conventional funding models (Kher et al., 2020). Additionally, these models are constrained by their inherent limitations, such as inadequate risk assessment frameworks, a preference for short-term returns, and a lack of scalability (Aizawa & Yang, 2010). Consequently, alternative financing solutions that can address these shortcomings are imperative.

This paper examines the potential of blockchain technology to revolutionise the financing of carbon removal projects through tokenisation. Blockchain-based tokens, underpinned by smart contracts, offer a novel mechanism to mobilise resources, enhance transparency, and engage diverse stakeholders. By investigating the operational framework of these tokens and their integration into carbon removal initiatives, this study evaluates their effectiveness as financial instruments. It also assesses their impact on project funding, carbon reduction outcomes, and stakeholder involvement.

The findings of this study indicate that blockchain technology not only improves the efficiency and accountability of funding mechanisms but also addresses critical gaps in stakeholder engagement and project scalability. Real-world applications of blockchain-based carbon markets, such as the Toucan Protocol, which has facilitated the tokenisation of over 20 million retired carbon credits (Toucan, 2022), demonstrate the scalability and transparency of tokenised systems. Similarly, Moss.Earth has pioneered MCO2 tokens, raising millions to fund Amazon deforestation prevention projects (Castilho, 2022). This study contributes to the growing discourse on sustainable finance by presenting a data-driven evaluation of blockchain's role in accelerating global climate solutions.

2. PROBLEM STATEMENT

Climate change presents an existential challenge that demands immediate and transformative action (Cevik & Jalles, 2022). While advancements in renewable energy and energy efficiency have contributed to reducing greenhouse gas emissions, these measures alone are insufficient to achieve the net-zero emissions target by 2050. Carbon capture and storage (CCS) and carbon dioxide removal (CDR) technologies are critical for bridging this gap (Michaelowa et al., 2023). Yet, they face significant hurdles that limit their widespread adoption (Bui et al., 2018).

The primary barriers to scaling CCS and CDR technologies include high operational and capital costs, intensive energy requirements, and unresolved issues related to their commercial viability and scalability (Markusson et al., 2012). Many of these technologies are still in their

nascent stages, requiring substantial investments in research, development, and deployment (Davoudabadi et al., 2024). However, traditional financing mechanisms are often ill-suited for funding such ambitious projects (Chen et Volz, 2022; Ripple, 2024). These mechanisms tend to prioritise short-term returns over long-term, transformative outcomes (Aizawa et Yang 2010), leaving high impact yet high-risk projects underfunded. This funding gap stifles innovation and delays the deployment of critical technologies necessary for meeting global climate targets.

An additional challenge lies in the development of novel solutions, such as ocean-based CDR methods (Lockley, 2019; Marinix, 2024), which have the potential to address many limitations of existing technologies. These solutions require innovative financing models capable of attracting substantial investments while ensuring transparency, accountability, and stakeholder engagement (Juan et al., 2023). Without such mechanisms, the global ambition of achieving net-zero emissions by 2050 remains at risk (Zhuang, 2023; World Bank, 2024).

This study addresses these challenges by exploring the role of blockchain-based tokenisation as a financing mechanism for ocean CDR and other carbon removal technologies. By leveraging blockchain's inherent transparency, efficiency, and decentralised governance (Chen et al., 2020; Macrinici et al., 2018), this approach aims to overcome traditional funding limitations and catalyse the adoption of revolutionary solutions to combat climate change.

3. AIMS AND OBJECTIVES

This study aims to critically examine the application of blockchain technology, particularly tokenisation, as a transformative financing mechanism for carbon removal initiatives. By investigating the integration of blockchain tokens into carbon removal projects, the paper seeks to evaluate their potential to address funding challenges, enhance operational efficiency, and drive sustainable environmental outcomes. Such objectives include:

1. *Operational Framework*: To investigate the operational mechanisms of blockchain tokens, including their design, deployment, and governance, and how they integrate with carbon removal technologies.
2. *Financial Effectiveness*: To evaluate the effectiveness of blockchain tokens as financial instruments in mobilising resources, raising capital, and addressing funding gaps for carbon removal initiatives.
3. *Impact Assessment*: To assess the tangible and measurable impacts of token-based funding on project outcomes, specifically in terms of carbon sequestration achieved and the scalability of such initiatives.
4. *Scalability and Barriers*: To analyse the scalability of blockchain tokens in diverse environmental finance contexts and identify potential barriers to their

adoption, including technical, regulatory, and market challenges.
5. *Transparency and Stakeholder Engagement*: To explore the role of blockchain technology in enhancing transparency, ensuring accountability, and fostering robust stakeholder participation in environmental projects.

The study aims to demonstrate that blockchain technology offers a promising pathway for overcoming limitations in traditional environmental finance models. The findings are intended to provide actionable insights for policymakers, investors, and industry stakeholders, outlining how digital currencies and blockchain technology can be harnessed to achieve global sustainability goals. Furthermore, the study aspires to contribute to the broader discourse on sustainable finance by proposing a scalable and replicable model for integrating blockchain technology into environmental initiatives.

4. METHODOLOGY

This study employs an exploratory approach to evaluate the integration of blockchain tokens into carbon removal projects. The methodology focuses on assessing a token-based ecosystem, with a particular emphasis on environmental impact, technological viability, sustainability, and regulatory compliance.

The first step is to outline the criteria for the integration of blockchain tokens into carbon removal initiatives. The integration ensures that viable and sustainable projects are selected by focusing on measurable environmental impact, technological feasibility, and compliance with international standards. Blockchain tokens in the form of smart contracts deployed as innovative financial instruments provide solid designs to fund carbon removal projects. The integration process includes selection criteria, prioritising:

- *Environmental impact* - measured by potential carbon sequestration capacity based on established scientific models (Davoudabadi et al., 2024).
- *Technological viability* - evaluated through readiness levels and compatibility with blockchain systems (Chen et Volz, 2022).
- *Sustainability* - ensured by aligning project goals with long-term ecological and economic benefits (Ripple, 2024).
- *Regulatory compliance* - adhering to international standards such as MiCAR and AML/KYC regulations.

Blockchain's decentralised ledger ensures secure and immutable recording of all transactions, reinforcing the integrity and transparency of carbon offset projects (Kher et al., 2020). The second step includes a multi-tiered approach to selecting projects and allocating tokens, ensuring democratic involvement, accountability, and milestone-based fund release for transparency and

effectiveness. The selection of carbon removal projects is guided by a multi-tiered evaluation process (Toucan, 2022; Marinix Ocean Tech, 2024):

1. *Expert committee review* - comprising environmental scientists, blockchain technologists, and financial analysts, the committee evaluates project proposals based on predefined criteria.
2. *Token holder participation* - blockchain-enabled voting mechanisms empower token holders to participate in project selection, fostering community involvement and democratising fund allocation.
3. *Smart contracts for accountability* - funds are released in phases via smart contracts, contingent upon achieving predefined milestones. This automated system ensures efficient resource utilisation and minimises the risk of fund mismanagement (Chen & Volz, 2022).

The third step highlights the strategic allocation of funds raised through tokens, ensuring additional progress across phases from R&D to scaling. It also includes incentivising contributors for sustained stakeholder involvement. The deployment of tokens as a funding mechanism addresses key barriers identified in the report, such as the need for innovative financial instruments like green bonds and sustainability-linked loans to attract private sector investment (Rassool, 2021). Funds raised through token sales are allocated strategically across project phases to maximise impact (Marinix Ocean Tech, 2024):

1. *Initial phases*:
   o Research and Development (R&D) - supporting innovation and feasibility studies.
   o Pilot testing - validating technological and operational effectiveness.
   o Initial deployment - establishing foundational infrastructure and processes.
2. *Scaling and operations*:
   o Expansion of successful pilots into broader applications.
   o Maintenance of ongoing operations to ensure sustained carbon sequestration.
3. *Incentivisation*: A portion of the tokens is reserved to reward key contributors, such as researchers and operational staff, based on milestone achievements (Globacap, 2022).

The operational framework proposed, draws on the empirical success of blockchain initiatives like JustCarbon, which commoditises carbon dioxide removal credits and integrates them into global carbon markets (Neville, 2022). The phased funding model ensures additional progress while minimising financial risks and maximising transparency. This way, the participatory framework has been provided by blockchain for all stakeholders, ensuring transparency, inclusivity, and trust while aligning with regulatory standards. Stakeholder engagement is integral to the success of the token ecosystem:

1. *Transparency and reporting* (Macrinici et al., 2018) - blockchain platforms provide real-time access to detailed project reports, financial transactions, and environmental impact metrics, ensuring accountability to all stakeholders.
2. *Inclusive participation* (Chen et al., 2020) - token holders, ranging from individual investors to institutional participants, are actively involved in decision-making processes through blockchain-based voting systems.
3. *Trust building* - the immutable nature of blockchain transactions fosters trust among stakeholders, encouraging long-term commitment and investment. The ecosystem aligns with MiCAR standards, promoting market integrity and compliance (European Supervisory Authorities, 2024; Juan et al., 2023).

5. BLOCKCHAIN PLATFORM

Blockchain technology is increasingly being utilised to enhance transparency, efficiency, and trust in environmental initiatives, particularly in Carbon Capture and Storage (CCS) and Carbon Dioxide Removal (CDR) projects. By tokenising carbon credits, blockchain facilitates the creation, tracking, and trading of these credits, thereby supporting global carbon offset efforts. This section highlights key blockchain-based carbon credit initiatives, showcasing their unique contributions to environmental sustainability:

- *Toucan Protocol*: Toucan serves as a bridging protocol that transforms real-world carbon credits into blockchain tokens known as Tokenized CO2 (TCO2). These tokens represent retired but unclaimed carbon offsets, enabling seamless trading and integration into decentralised finance (DeFi) applications (Toucan, 2022). Toucan aims to enhance liquidity and accessibility in the carbon credit market.
- *Moss.Earth*: A Brazilian startup Moss.Earth introduced MCO2 tokens, which are ERC-20 utility tokens on the Ethereum blockchain. These tokens support efforts to prevent deforestation in the Amazon by allowing individuals and organisations to purchase and retire them, directly funding conservation projects (Castilho, 2022).
- *JustCarbon*: Launched in 2022, JustCarbon is a blockchain-based platform that commoditises carbon dioxide removal credits derived from high-quality, nature-based projects. Verified to international standards, these credits ensure integrity and effectiveness in offsetting emissions (Neville, 2022).
- *Net Zero company*: This Swedish startup developed the Carbon Removal Token (CRT), leveraging blockchain technology to provide accessibility, transparency, and traceability in the market for verified carbon credits. Each CRT represents one tonne of sequestered CO2 from certified projects, offering a clear link between

investment and environmental impact (Lawrence, 2024).

- *IBM and Mitsubishi collaboration*: IBM and Mitsubishi partnered to utilise blockchain technology for tracking the capture and reuse of CO2. This initiative enhances transparency and efficiency in carbon trading markets by providing immutable records of CO2 capture and usage (Ledger Insights, 2021).
- *The Marinix token*: The Marinix project employs the Polygon blockchain to address Ethereum's limitations regarding transaction speed, cost, and energy consumption. Each Marinix token represents a futures contract for one metric ton of carbon captured and stored using the CRS method. This approach integrates innovative blockchain features to ensure cost efficiency and environmental sustainability (Buterin, 2014; Baliga, 2017; Marinix Ocean Tech, 2024).

Smart contracts play a central role in the operation of these blockchain-based tokens, automating project management and fund allocation. These contracts execute transactions and specific actions automatically when predefined conditions are met, ensuring that project milestones related to carbon removal are verifiably completed before funds are released. Compliance with guidelines (e.g. MiCAR) ensures standardisation and minimises fraud risks, as contract terms remain visible and immutable once deployed (European Supervisory Authorities, 2024; Chen & Volz, 2022; Zhao et al., 2023).

Accurate and timely data management is essential for blockchain-based projects. By maintaining an immutable ledger of all transactions and updates, blockchain ensures robust monitoring (Macrinici et al., 2018) and verification of carbon credits (Toucan, 2022). Integration with IoT devices (Shu et al., 2022) further enhances data collection and reporting, allowing real-time tracking of environmental parameters (Zhuang, 2023) and carbon removal progress. This integration improves transparency and provides reliable information for token holders and regulators (Shu et al., 2022).

The number and scope of blockchain-based carbon credit projects continue to evolve dynamically. These initiatives range from startups focusing on niche applications to large-scale collaborations involving multinational corporations. Together, they represent a growing ecosystem that integrates blockchain technology into environmental sustainability efforts, pushing the boundaries of what is achievable in the fight against climate change.

6. ECONOMIC MODEL AND INCENTIVIZATION

The economic model of blockchain-based carbon removal tokens combines financial viability with environmental impact, positioning these tokens as dual-purpose assets. This duality appeals to diverse investors, including those driven by financial returns and others prioritising ecological benefits. Tokens represent a tangible stake in carbon removal projects, offering:

1. Quantifiable environmental impact - each token is tied to specific carbon removal metrics like one metric ton of carbon removed (Toucan, 2022; Castilho, 2022; Neville, 2022; Marinix, 2024), ensuring that investments contribute directly to measurable environmental outcomes.
2. Potential financial returns - tokens appreciate in value based on market demand for carbon credits and the success of associated projects, attracting institutional investors and individuals alike (Chen & Volz, 2022).

This dual functionality intends to make tokens attractive to both environmentally conscious individuals and institutional investors seeking sustainable and socially responsible investment opportunities. The token ecosystem incorporates structured incentives to align financial and environmental objectives:

1. *Financial returns*: Investors benefit from token value appreciation and carbon credit sales revenue. These returns appeal to corporate investors fulfilling corporate social responsibility (CSR) goals and to individuals driven by personal values of sustainability (Juan et al., 2023).
2. *Early adopter rewards* (Juan et al., 2023; Chen et al., 2020): Early participants are rewarded with additional tokens or privileges, incentivising initial engagement and commitment to the ecosystem.
3. *Performance-based rewards*: Contributors to the success of carbon removal projects, including researchers and operational staff, are compensated with tokens tied to project milestones, fostering a sense of ownership and alignment with project goals (Udeh et al., 2024; Marinix Ocean Tech, 2024).

The structured incentives for stakeholders not only foster engagement and alignment with both financial and environmental objectives but also directly influence the broader dynamics of the carbon token market. As early adopters and performance-based contributors drive token circulation and project success, their participation creates a feedback loop that enhances market confidence, incentivises further investments, and stabilises demand for tokenised carbon credits. Several key factors shape the demand for tokens:

1. *Global carbon market trends*: The increasing emphasis on reducing carbon footprints and the rising value of carbon credits fuel demand for tokenised carbon assets (World Bank, 2024).
2. *Regulatory evolution* (European Supervisory Authorities, 2024; Ripple, 2024; KPMG, 2024): Supportive frameworks for carbon trading and environmental finance bolster token adoption, while changes in digital asset laws and carbon reporting standards influence token utility and investor confidence.

3. *Technological advancements* (Bui et al., 2018; Shu et al., 2022; Davoudabadi et al., 2024): Progress in carbon removal technologies enhances the scalability and impact of projects funded by tokens, further driving market interest.

By continuously monitoring these dynamics, project teams and management can adapt strategies to maintain competitiveness, ensure regulatory compliance, and enhance token attractiveness (Shu et al., 2022). Beyond financial and environmental impacts, blockchain-based tokens contribute to broader socio-economic goals. According to Blaufelder et al. (2021), goals of sustainable revenue streams and job creation can be achieved. The sale of carbon credits generates ongoing income, which reinvested fosters a cycle of innovation and growth and creates employment opportunities in research, development, and operational roles, supporting local economies. Also, token-funded initiatives often include community engagement efforts, contributing to local sustainability projects and raising awareness about climate change (Globacap, 2022).

Integrating blockchain technology in carbon removal projects addresses pressing environmental challenges and establishes a viable economic framework that balances financial returns with ecological benefits. By leveraging market dynamics, incentivisation strategies, and socio-economic contributions, blockchain-based tokens create a sustainable model for scaling carbon removal initiatives. This approach aligns with global sustainability goals and paves the way for innovative and impactful investment opportunities.

7. TOKEN DISTRIBUTION AND MANAGEMENT

The distribution and management of blockchain-based tokens are critical components of a successful carbon removal funding model. This section outlines the structured approach to Initial Coin Offerings (ICOs), token governance, compliance frameworks, and strategies for mitigating associated financial risks.

The funding process begins with a structured ICO designed to ensure compliance with local and international financial regulations. These include the European Union's MiCAR (Markets in Crypto-Assets Regulation), Anti-Money Laundering (AML), and Know Your Customer (KYC) requirements. Key steps in the ICO process include the legal review and investor communication. In the first step, legal advisors review documentation and processes to ensure alignment with regulatory standards, providing the transparency and security necessary to build investor trust (Polygon Technology, 2023; Chen & Volz, 2022). Afterwards, comprehensive white papers and detailed project roadmaps are shared with potential investors, equipping them with the information required to make informed decisions. Transparency at this stage aligns with best practices for regulatory compliance in ICOs (Udeh et al., 2024).

After the ICO, tokens are distributed to investors' digital wallets via automated and secure smart contracts, minimising errors and delays. Governance structures for token management can be centralised or decentralised (Chen et al., 2020):

- *Centralised governance* - involves a core team overseeing decisions, ensuring swift and cohesive management.
- *Decentralised governance* - facilitated through blockchain-based voting systems, allowing token holders to propose and vote on project-related matters. This approach fosters inclusivity, stakeholder engagement, and enhanced transparency (Zhuang, 2023; Juan et al., 2023).

In environmental projects, community involvement is vital. For instance, token holders can vote on subsequent projects after the ICO, which builds a strong, informed community and raises awareness about the importance of carbon sequestration (Marinix Ocean Tech, 2024; Shu et al., 2022).

Adherence to robust compliance frameworks safeguards against legal risks and enhances the credibility of governance structures, fostering trust among stakeholders. Compliance ensures decentralised governance mechanisms operate within established regulatory boundaries, balancing innovation with accountability. Key components include:

1. *AML and KYC regulations* - Critical for preventing illicit activities and maintaining financial integrity.
2. *MiCAR guidelines* - Ensures compliance with European Union standards, promoting market transparency and investor protection (European Supervisory Authorities, 2024; Kalaiarasi & Kirubahari, 2023).
3. *Smart contract audits* - Regular audits ensure that smart contracts meet current regulatory standards and adapt to legislative changes (Shu et al., 2022; Zhao et al., 2023).

By involving token holders in decision-making, decentralised governance mechanisms help identify and mitigate potential risks early. Diverse stakeholder input can reveal vulnerabilities in project execution, enabling proactive solutions. Furthermore, robust governance structures, such as blockchain-based voting systems, ensure transparent accountability, reducing the likelihood of mismanagement or fraud that could destabilise token circulation and undermine market confidence. The innovative nature of blockchain technology and the volatility of carbon credit markets introduce significant financial risks. Key risks include:

- *Fraudulent certificates*: For example, sales of carbon credits linked to illegally appropriated Amazon land, which compromise the integrity of carbon mechanisms (FT, 2024).

- *Regulatory disparities*: The lack of uniform regulations across jurisdictions complicates tokenised carbon credit trading (CoinMetro, 2024).
- *Double counting*: Instances where the same carbon credits are sold multiple times, reducing their reliability (Graham, 2023).

Robust risk management strategies, including regular audits, regulatory monitoring, and stakeholder education (Zhao et al., 2023), are essential to maintaining investor confidence and ensuring the project's financial sustainability.

8. RESULTS AND DISCUSSION

Blockchain-based tokens offer an innovative and transparent funding mechanism for advancing carbon removal technologies. Initial Coin Offerings (ICOs) have demonstrated substantial market interest, with fundraising potential ranging from a few million to over €70 million (CarbonCredits.com, 2022). This showcases strong investor confidence in the scalability and impact of such initiatives (Chen & Volz, 2022). The integration of blockchain facilitates an efficient fundraising process by providing a clear, immutable link between investments and their corresponding environmental impacts, appealing to a broad spectrum of investors.

However, challenges persist, particularly concerning market dynamics and token value fluctuations (ECB, 2022), which can destabilise ongoing funding streams. Ensuring token value aligns with the price of carbon in voluntary markets is critical for maintaining financial sustainability. Analysing transaction data from blockchain ledgers provides actionable insights into investor behaviour and token circulation patterns. This data highlights initial uptake patterns, emphasises the importance of strategic management of market perceptions, and underscores the necessity of balancing token supply with demand in accordance with (MiCAR) standards (European Supervisory Authorities, 2024). The scalability and replicability of tokens in environmental financing depend on several interrelated factors:

1. *Technological scalability*: Innovative approach to enhancing natural carbon sequestration (e.g. Marinix) demonstrates scalability potential (Shu et al., 2022). The integration of blockchain technology and carbon removal processes can be adapted to various environments globally (Bui et al., 2018), allowing for broad application and impact.
2. *Economic replicability*: The token model offers a replicable framework (Chen et Volz, 2022) for funding diverse environmental projects where traditional financing methods often fail. Its ability to attract investments by combining financial and environmental value (Juan et al., 2023) highlights its viability as a long-term funding solution.
3. *Sustainability challenges*:
   - Maintaining investor interest and ensuring market stability for carbon credits are vital for the token's long-term success.
     - Regulatory changes (European Supervisory Authorities, 2024), technological advancements, and market saturation (Deloitte, 2022) represent potential barriers that must be addressed strategically.
     - Environmental risks associated with scaling up carbon sequestration initiatives, such as potential ecological disruptions, need to be thoroughly assessed to ensure net-positive outcomes (Zhuang, 2023).

Integrating blockchain technology into environmental finance significantly enhances transparency, accountability, and operational efficiency, which drives market demand for tokenised carbon credits (Zhuang, 2023). The effectiveness of tokenised carbon credits can be evaluated using a comprehensive framework, such as the one proposed by Markusson et al. (2012), which addresses key uncertainties in CCS projects. This framework can be broadly applied to assess the performance and scalability of blockchain-based tokens across various carbon removal initiatives:

- *Technical feasibility*: Assessing the operational and technological capabilities of carbon removal processes (Hoiss et al., 2021) supported by tokenised funding mechanisms, including their scalability and adaptability (Tian et al., 2022) to different environmental contexts.
- *Economic viability*: Evaluating the cost-effectiveness of token-based funding compared to traditional financing models (Cao, 2023), including the ability to attract diverse investor bases and sustain market stability (Tönnissen et al., 2020).
- *Financial risks*: Identifying and mitigating risks such as market volatility, potential fraud, double counting of carbon credits (USCFTC, 2023), and regulatory uncertainties (KPMG, 2024) could undermine tokenised carbon markets' credibility and effectiveness.
- *Public acceptance*: Gauging stakeholder confidence and engagement through decentralised governance mechanisms (Chen et al., 2020) that ensure transparency and inclusivity, building trust among investors, project developers, and regulatory bodies (World Economic Forum, 2023).

By addressing these indicators, tokenised carbon credit initiatives can enhance their credibility and accountability, ensuring long-term sustainability and scalability. This framework provides a structured approach for analysing the performance of blockchain-based tokens in driving carbon removal projects, offering actionable insights for improving both their environmental and financial impact.

In addition, findings from Kaal (2023) on decentralised governance models highlight the importance of flexibility and responsiveness in managing blockchain-based projects. Decentralised governance allows token holders to participate in decision-making processes, promoting adaptability in response to emerging challenges. This participatory model ensures that the project remains

aligned with both environmental and economic objectives, fostering resilience and sustained impact.

9. FUTURE RESEARCH DIRECTIONS

Integrating blockchain technology and token economics into environmental sustainability initiatives has revolutionised how carbon removal and related projects are financed. However, the long-term efficacy and scalability of these systems require deeper exploration. These studies are crucial for advancing token economics as a transformative tool in achieving environmental and socio-economic objectives.

The intersection of token economics and environmental sustainability offers a promising avenue for innovative research. Future studies could investigate the following areas of:

- *Diversification of applications* – via exploration of the viability of token-based funding models across various environmental domains, such as renewable energy, wildlife conservation, pollution control, and sustainable agriculture (Chen & Volz, 2022; Udeh et al., 2024). Assessing the flexibility of token systems in these diverse contexts could reveal valuable insights into their universal applicability.
- *Efficacy of token incentives* – by examining how token incentives enhance community participation, stakeholder engagement, and long-term commitment in environmental initiatives. Psychological and behavioural studies on participant motivation could deepen understanding of how tokens drive engagement (Juan et al., 2023; Zhao et al., 2023).
- *Comparative Analyses* – by conducting comparative studies evaluating the efficiency of token economics versus traditional funding mechanisms. Key metrics should include investment attraction, accountability, and achievement of sustainability goals.
- *Integration with emerging technologies* – by investigating how emerging technologies such as IoT, AI, and machine learning could synergise with token-based models to improve data accuracy, project monitoring, and decision-making processes.

To validate the scalability and adaptability of token-based systems, pilot projects should be implemented in diverse ecological and economic contexts. Experimental designs should include control groups using traditional funding mechanisms to compare outcomes with token-based approaches, evaluating metrics such as token adoption rates, economic efficiency, carbon sequestration achieved, and local biodiversity impact (Shu et al., 2022). Incorporating stakeholder feedback and leveraging blockchain analytics will further refine token designs, as engaging local stakeholders is crucial for improving operational models and enhancing community acceptance (Chen et al., 2020). Additionally, aligning token-funded projects with local and international environmental policies ensures regulatory compliance

and scalability across jurisdictions, strengthening their viability as a funding mechanism for large-scale environmental initiatives.

Long-term research on projects like Moss.Earth and Toucan Protocol can provide valuable insights into the persistence of environmental benefits and market dynamics, informing the scalability of tokenised funding systems. Such research is crucial for understanding the enduring impacts of token economics on environmental projects. Key research areas include monitoring the longevity of environmental benefits, such as carbon sequestration, biodiversity improvements, and ecosystem health, across multiple projects over extended periods (Zhuang, 2023; Davoudabadi et al., 2024). Additionally, studying market dynamics, including investor behaviour, market liquidity, and price trends, can help identify factors that sustain interest and trust in token markets. Socio-economic analyses are also essential to evaluate how token-funded projects affect local economies, employment, and community well-being, as well as their integration within broader environmental policies and frameworks to uncover systemic implications (Kaal, 2023). Lastly, research should focus on assessing how tokenised funding models can be standardised and aligned with international frameworks, such as the Paris Agreement and Sustainable Development Goals (SDGs), to ensure global applicability and impact.

10. CONCLUSION

Integrating tokens into the carbon market represents a transformative step in addressing the pressing global need for innovative environmental finance solutions. This paper has demonstrated how blockchain technology, through its capacity for decentralisation, transparency, and security, can revolutionise how carbon removal and sequestration efforts are financed. By aligning the economic incentives of diverse stakeholders, tokens enable a dynamic funding ecosystem that fosters participation from individuals, corporations, and governments alike.

This study has outlined a comprehensive framework for implementing tokenised systems, including project selection criteria, scalable token allocation mechanisms, and the application of advanced monitoring technologies. These elements not only enhance the operational efficiency and accountability of carbon removal initiatives but also create an adaptable model capable of addressing the diverse challenges of traditional finance, such as inefficiency, risk aversion, and lack of scalability. The token model presents a path to a more equitable and impactful funding system that bridges the gap between environmental imperatives and economic realities.

The potential of blockchain and token economics extends far beyond financing. Decentralised governance models offer a participatory approach that democratises decision-making and fosters community engagement, while smart contracts ensure that funds are allocated based on verified outcomes. This technology integration and

transparency address longstanding issues of trust and accountability in the carbon market, making it a credible and robust mechanism for global climate action.

Looking ahead, future research must focus on comparative analyses of token-based funding versus traditional mechanisms to validate their efficacy across different environmental contexts. Pilot projects in geographically and ecologically diverse settings will test the adaptability and scalability of tokenised systems, while longitudinal studies will shed light on their long-term sustainability and socio-economic impacts. Such research will provide the scientific and operational foundation needed to refine these systems and expand their applicability to broader sustainability goals.

In conclusion, blockchain-enabled tokens have the potential to redefine the landscape of environmental finance by combining technological innovation with ecological responsibility. As these systems evolve, they will play an increasingly critical role in accelerating global climate change mitigation efforts and advancing sustainable development goals. By creating an ecosystem that is transparent, efficient, and inclusive, blockchain technology holds the promise of building a carbon-neutral future—one where financial systems and environmental stewardship coexist harmoniously, driving humanity toward a more resilient and sustainable world.

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