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Analysis of Blockchain Integration in Carbon Trade Management: A Perspective on Forest Cover and REDD+ Schemes in Indonesia

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ABSTRACT

The integration of blockchain technology in carbon trade management offers transformative potential for improving transparency, monitoring, and efficiency in Indonesia's REDD+ schemes. This study employs a qualitative approach, analyzing data from three informants—a blockchain expert, an environmental policymaker, and a conservationist—using NVivo software for thematic analysis. Findings reveal that blockchain enhances transparency and trust, streamlines Monitoring, Reporting, and Verification (MRV) processes, and addresses challenges in carbon trade systems. However, barriers such as infrastructure gaps, high implementation costs, and regulatory ambiguities remain. The study underscores the need for targeted capacity building, pilot programs, and robust policy frameworks to enable effective blockchain adoption in Indonesia's carbon markets.

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1. INTRODUCTION

The implementation of carbon trading and REDD+ initiatives in Indonesia is crucial for mitigating climate change and promoting sustainable forest management. These mechanisms aim to reduce deforestation and land degradation, which are significant contributors to greenhouse gas emissions. Carbon trading systems are designed to reduce emissions by allowing firms to buy and sell emission permits, creating a market-based approach that incentivizes companies to lower their carbon footprint [1]. In Indonesia, carbon markets have the potential to enhance environmental resilience by improving carbon and energy performance, although technical and stakeholder engagement challenges remain [1], [2]. Similarly, REDD+ focuses on reducing emissions from deforestation and forest degradation while promoting conservation and sustainable forest management [3]. Despite its potential, REDD+ also faces challenges such as the need for stronger international cooperation and the development of additional tools to support forest carbon emission mitigation [3]. Monitoring and transparency issues are significant barriers to the effective implementation of both carbon trading and REDD+ in Indonesia, as they can lead to fraudulent activities that undermine the credibility and success of these initiatives [2].

Addressing these issues requires cooperation among various stakeholders, including government, the private sector, and local communities, to ensure the integrity and effectiveness of carbon trading systems [2].

Blockchain technology offers a promising solution to improve the integrity and efficiency of carbon trade mechanisms in Indonesia through a decentralized, secure, and transparent digital ledger. It addresses key issues like traceability, accountability, and stakeholder trust, which are vital for effective carbon trading. The immutable nature of blockchain ensures reliable tracking of carbon credits, compliance with REDD+ guidelines, and accurate forest cover records. However, its integration in Indonesia's carbon trade systems remains limited, with few empirical studies exploring its feasibility and impact. Blockchain-based visualization tools can enhance transparency and detect fraud in carbon markets, offering real-time support for monitoring carbon offsets [4]. It also supports compliance with international standards, creating a more secure carbon credit market [4]. When combined with IoT, blockchain enables decentralized, real-time emission data collection, while smart contracts streamline trading in a transparent, corruption-resistant environment [5]. Additionally, blockchain strengthens transparency in renewable energy supply chains by securely verifying Renewable Energy Certificates (RECs) [6] and supports emission traceability and offsetting in the aviation sector through collaborative, transparent platforms [7].

This study aims to fill this gap by analyzing the role of blockchain technology in improving carbon trade management in Indonesia, with a specific focus on forest cover preservation and REDD+ schemes. Employing a qualitative approach, this research investigates the perspectives of key informants—blockchain experts, environmental policymakers, and conservationists—on the integration of blockchain in carbon trade systems.

Indonesia plays a vital role in global climate change mitigation due to its extensive tropical forests that act as major carbon sinks. However, deforestation and land degradation threaten these ecosystems and climate goals. To address this, Indonesia has adopted REDD+ and carbon trading mechanisms as key strategies to reduce emissions while supporting sustainable development. REDD+ relies on collaboration among government, indigenous communities, and the private sector to align policies with local practices [8], and has shown promise through economic incentives and capacity building, despite ongoing challenges like plantation expansion and illegal logging [9]. However, not all stakeholders benefit equally, especially smallholders and indigenous groups, underscoring the need for stronger international cooperation and NGO accountability [10]. Carbon trading, supported by international entities such as the EU, is becoming a core part of Indonesia's mitigation efforts [1], although technical and stakeholder issues remain [1]. Forest Land Redistribution (FLR) programs also contribute by aiming to align economic and environmental goals through regional sustainability and biodiversity conservation [11].

Despite various initiatives, there remains an urgent need to address systemic inefficiencies in carbon trade management in Indonesia. These include a lack of transparency in transactions, inadequate forest cover monitoring, and risks of fraud in carbon credit verification. As carbon trading becomes an increasingly important financial mechanism for conservation, ensuring the credibility and effectiveness of these systems is essential. Failure to resolve these issues could lead to missed opportunities for both environmental protection and economic gains, further worsening the climate crisis. In practice, Indonesia's carbon trade mechanisms under the REDD+ framework still face persistent challenges, including unreliable and opaque tracking systems that erode stakeholder trust and hinder market participation. Additionally, current forest monitoring methods are often inefficient and inaccurate, complicating compliance with REDD+ goals. The absence of a secure,

decentralized system for managing carbon transactions further increases the risk of data manipulation and fraud, threatening the integrity of carbon trading initiatives.

Blockchain technology has emerged as a potential solution to these challenges by offering features such as immutability, transparency, and decentralization. These capabilities could significantly improve carbon credit tracking, monitoring accuracy, and transaction security. However, the adoption of blockchain in Indonesia's carbon trade management remains limited, largely due to gaps in awareness, technological infrastructure, and policy support. This highlights a critical need for research that investigates the feasibility, benefits, and limitations of integrating blockchain technology into carbon trading systems. Addressing this gap, the present study aims to explore how blockchain can enhance the effectiveness of REDD+ schemes and contribute to more sustainable forest management in Indonesia.

2. LITERATURE REVIEW

2.1 Carbon Trade Management and REDD+ Schemes

Carbon trading, as a market-based approach, plays a key role in reducing greenhouse gas emissions by enabling entities to trade carbon credits. This mechanism is especially relevant in developing countries like Indonesia, where REDD+ is implemented to curb deforestation and promote sustainable land use. Effective REDD+ implementation requires strong monitoring, reporting, and verification (MRV) systems, yet issues like weak governance and limited data accuracy remain challenges. Regulatory barriers such as overlapping jurisdictions and enforcement problems hinder MRV development [12], [13], while data transparency issues reduce the credibility of carbon trading [13]. Despite these obstacles, carbon trading offers opportunities for technology transfer and access to international finance, supporting sustainable development [12], [13]. Strengthening public-private partnerships and institutional capacity is essential to improve carbon trading and REDD+ outcomes [12], [13]. Voluntary Carbon Markets (VCMs) further support these efforts by providing incentives beyond legal requirements [14], while carbon trading mechanisms can also boost financial sustainability through increased liquidity, price discovery, and risk management [15]. These issues underscore the need for innovative solutions to enhance the efficiency and integrity of REDD+ initiatives in Indonesia.

2.2 Challenges in Carbon Trade Management

Carbon trade systems face significant challenges, particularly in developing countries like Indonesia, where governance weaknesses and limited technological infrastructure hinder effective implementation. Key issues include transparency deficits, verification challenges, and a high risk of fraud. Blockchain technology offers promising solutions by enhancing transparency through decentralized, immutable records and reducing fraud risks. It enables all transactions to be recorded in a verifiable ledger accessible to stakeholders [16], while visualization techniques integrated with blockchain

simplify records and support decision-making and fraud detection (Tsai, 2025). Verification issues, especially the lack of standardized MRV (Monitoring, Reporting, and Verification) methods, can be addressed by adopting common standards for carbon accounting as proposed by the Integrity Council for the Voluntary Carbon Market (IC-VCM) [17]. Blockchain can further automate verification through smart contracts, ensuring the authenticity of carbon credits [16]. Additionally, its immutable nature prevents fraudulent actions like double-counting or false reporting [4], and advanced visualization tools help detect arbitrage activities and streamline operations, reducing the overall fraud risk in carbon markets [4].

2.3 Blockchain Technology: Features and Potential

Blockchain technology, with its decentralized, immutable, and transparent nature, offers significant potential to revolutionize carbon trading systems by addressing inefficiencies, enhancing traceability, and streamlining monitoring, reporting, and verification (MRV) processes. Its secure, tamper-proof ledger ensures that once data is recorded, it cannot be altered, preserving the integrity of transactions and building trust among stakeholders [18], [19]. The use of cryptographic security further minimizes risks of fraud and unauthorized access, which is vital for maintaining confidence in carbon markets [20]. Blockchain also enhances transparency by granting all stakeholders access to transaction records, thereby fostering accountability [21], while enabling real-time tracking of carbon credits to prevent double-counting and verify credit origins [18], [20]. Its decentralized nature eliminates the need for a central authority, reducing the potential for corruption and manipulation [18], [19], and smart contracts can automate transactions, removing intermediaries and increasing the overall efficiency of carbon credit exchanges [21].

2.4 Blockchain Integration in Carbon Trade Management

The integration of blockchain technology into carbon trade systems offers significant potential to enhance transparency, efficiency, and trust, as demonstrated in various global initiatives. Blockchain's decentralized ledger can address persistent issues in carbon credit markets, such as lack of transparency, high transaction costs, and fraud. In Indonesia, although the use of blockchain in carbon trading is still in its early stages, it shows promise in supporting frameworks like REDD+ through accurate monitoring and transparent carbon credit allocation. By tokenizing carbon credits and employing smart contracts, blockchain can streamline trading processes, reduce reliance on intermediaries, and lower transaction costs [16]. Visualization techniques integrated with blockchain also support real-time monitoring and fraud detection, improving decision-making and reducing operational risks [4]. Its immutable ledger ensures

compliance with international standards by preventing fraud and enabling real-time tracking of carbon offset activities [4], while smart contracts automate transactions and reduce opportunities for discrepancies and corruption [5]. Beyond carbon trading, blockchain contributes to transparency and traceability in renewable energy supply chains, fostering decentralized models and enhancing grid resilience [6]. However, challenges such as regulatory barriers, technological constraints, and scalability must be addressed to support broader adoption in sustainable finance and carbon markets [22]. Moreover, blockchain can facilitate stakeholder collaboration by creating a shared platform for data exchange and decision-making. Despite these advantages, barriers such as high implementation costs, technological complexity, and lack of regulatory frameworks remain significant obstacles.

2.5 Research Gap

While the potential of blockchain technology in carbon trade management has been recognized, empirical studies focusing on its application in the context of Indonesia's REDD+ initiatives are scarce. Existing literature predominantly addresses blockchain's technical aspects, with limited exploration of its practical implications for forest conservation and carbon market development. This study aims to bridge this gap by providing a qualitative analysis of blockchain integration in carbon trade management, focusing on its role in addressing the unique challenges faced by Indonesia's REDD+ schemes.

3. METHODS

3.1 Research Design

This study employs a qualitative research approach to explore the integration of blockchain technology in managing carbon trade systems within the context of Indonesia's REDD+ schemes. The qualitative method was chosen to gain in-depth insights into the perceptions, challenges, and opportunities associated with blockchain adoption from the perspectives of key stakeholders. By focusing on a specific context—Indonesia's forest conservation and carbon trade mechanisms—this study provides a comprehensive understanding of how blockchain can address existing inefficiencies and enhance REDD+ implementation.

3.2 Informants

The research involves three key informants selected through purposive sampling to ensure their relevance and expertise in the study's focus areas: a Blockchain Expert with extensive knowledge and experience in blockchain technology, particularly its applications in environmental and sustainability projects; an Environmental Policy Maker, a government official or policy expert involved in the design and implementation of REDD+ initiatives and carbon trade regulations in Indonesia; and a Conservationist with practical experience in forest management, REDD+ implementation, and carbon credit verification processes. These informants were chosen to provide diverse perspectives on the technical, policy, and practical implications of blockchain integration in carbon trade management.

3.3 Data Collection

Data were collected through semi-structured interviews with the three informants, using an interview protocol designed to elicit detailed responses on current challenges in Indonesia's carbon trade systems, perceived benefits and limitations of

blockchain technology for carbon trade management, and practical considerations and barriers to implementing blockchain in the context of REDD+ schemes. The interviews were conducted in a conversational format, allowing informants to elaborate on their experiences and provide contextual insights. With the informants' consent, all interviews were recorded, transcribed, and translated into English for analysis.

3.4 Data Analysis

The transcribed interviews were analyzed using NVivo software to identify key themes, patterns, and relationships in the data. Thematic analysis was employed to categorize the data into three core themes: Transparency and Trust, focusing on how blockchain can enhance transparency and build trust among stakeholders; Monitoring and Verification, examining the role of blockchain in improving MRV processes for forest cover and carbon credits; and Implementation Barriers, highlighting challenges such as infrastructure limitations, high costs, and lack of policy alignment. NVivo facilitated efficient coding and visualization of the data, allowing the researcher to draw meaningful conclusions based on the informants' perspectives.

4. RESULTS AND DISCUSSION

4.1 Transparency and Trust

The blockchain expert emphasized blockchain's ability to ensure transaction transparency:

"Blockchain provides an immutable record of all transactions, which can eliminate issues like double-counting carbon credits and build trust among stakeholders." The policymaker added: "In Indonesia, trust has always been an issue in carbon trade systems. By making data accessible and tamper-proof, blockchain can create accountability, especially in international partnerships." These insights highlight the perceived potential of blockchain to enhance transparency and foster trust among actors involved in carbon trading, particularly in contexts where governance and data integrity are often questioned.

However, the conservationist highlighted a critical challenge: "While transparency is great, we have to ensure that local communities understand how the technology works. Otherwise, there's a risk of alienating key stakeholders." This underscores the importance of inclusive implementation, where technological solutions must be accompanied by capacity building and local engagement to avoid excluding the very communities essential to the success of REDD+ initiatives.

4.2 Monitoring and Verification (MRV)

All informants agreed that blockchain could revolutionize MRV (Monitoring, Reporting, and Verification) processes by integrating with technologies such as satellite imagery and IoT. The blockchain expert explained: "Combining blockchain with IoT devices for real-time data collection can make monitoring more accurate and less labor-intensive." This highlights the potential for blockchain to automate and improve the accuracy of environmental monitoring, reducing human error and increasing efficiency. The policymaker supported this view, stating: "Blockchain offers a standardized system for recording emissions reductions. It could resolve inconsistencies in how data is reported across different regions." These statements suggest that blockchain could play a crucial role in harmonizing data collection and reporting practices across Indonesia's diverse landscapes.

However, the conservationist pointed out a critical limitation related to data quality: "The accuracy of blockchain depends on the quality of data we feed into it. Inconsistent or manipulated inputs will undermine the entire system." This remark emphasizes that while blockchain can secure and store data effectively, the reliability of the system still hinges on accurate, credible data inputs. Without addressing the foundational issues of data collection and verification at the source,

even the most advanced blockchain systems may fail to deliver on their promise.

4.3 Implementation Barriers

Despite its promise, blockchain adoption faces several significant barriers in Indonesia. The policymaker identified infrastructure gaps as a major challenge: "Many remote areas in Indonesia lack the internet connectivity required for blockchain systems, which makes implementation challenging." This highlights the digital divide that could hinder the deployment of advanced technologies in rural and forested regions where REDD+ initiatives are often implemented. The conservationist further emphasized the issue of affordability: "Small-scale stakeholders can't afford blockchain solutions. The government or international donors need to subsidize these costs to make it feasible." These concerns suggest that equitable access and financial support are crucial to ensuring that blockchain benefits all stakeholders, not just large institutions.

In addition to infrastructure and cost-related challenges, the blockchain expert stressed the importance of regulatory clarity: "Without a strong regulatory framework, blockchain adoption will face legal uncertainties. We need clear guidelines to protect data privacy and security." This underscores the need for comprehensive policies that not only facilitate blockchain integration but also address ethical and legal concerns surrounding data governance. Without supportive infrastructure, funding, and regulation, blockchain's transformative potential in carbon trade management may remain largely untapped.

Discussion

1. Enhancing Transparency and Stakeholder Trust

The findings align with existing literature on blockchain's potential to enhance transparency and accountability in carbon markets [4], [23]. In Indonesia, where mistrust and opacity have hindered the success of REDD+ schemes, blockchain could play a transformative role by providing an immutable and accessible ledger for carbon credit transactions. However, ensuring that local stakeholders can access and interpret blockchain data remains a challenge that must be addressed through capacity-building initiatives.

2. Revolutionizing MRV Processes

Blockchain's integration with advanced technologies such as satellite imagery and IoT offers a powerful solution to inefficiencies in MRV processes. By automating and standardizing data collection and reporting, blockchain can enhance the credibility of emissions reductions reported under REDD+ schemes. This aligns with studies highlighting blockchain's potential to streamline environmental monitoring systems [5], [6], [24].

However, the reliability of blockchain-based MRV systems hinges on the quality of data inputs. The inconsistencies noted by the conservationist reflect a broader issue in Indonesia's environmental data infrastructure, which requires significant investment and capacity building to ensure the accuracy and integrity of data.

3. Addressing Implementation Barriers

The barriers identified in this study highlight the practical challenges of implementing blockchain technology in developing countries. Infrastructure and cost-related concerns resonate with findings from [25], who noted that blockchain adoption is often limited by resource constraints. In Indonesia, addressing these barriers requires a phased approach that begins with pilot projects in regions with adequate infrastructure and gradually expands as capacity improves.

Policy alignment is another critical factor. The absence of clear regulatory frameworks for blockchain adoption in carbon markets creates uncertainty for stakeholders. Policymakers must develop guidelines that balance innovation with safeguards against misuse, ensuring that

blockchain technology is leveraged effectively to meet REDD+ objectives.

4. Implications for REDD+ and Carbon Trade in Indonesia

This study contributes to the growing body of knowledge on blockchain's role in carbon trade management, emphasizing its relevance to Indonesia's REDD+ initiatives. By addressing transparency, MRV inefficiencies, and trust issues, blockchain has the potential to enhance the effectiveness and credibility of carbon markets. However, realizing this potential requires concerted efforts to overcome the identified barriers.

Collaborative partnerships between government agencies, private sector stakeholders, and international organizations are essential to ensure the successful integration of blockchain technology. Pilot projects, capacity-building initiatives, and regulatory reforms will be crucial in creating an enabling environment for blockchain adoption in Indonesia's carbon trade systems.

5. CONCLUSION

This study highlights the transformative potential of blockchain technology in addressing systemic inefficiencies and trust deficits in Indonesia's carbon trade management and REDD+ schemes. Blockchain provides a transparent, tamper-proof system that enhances stakeholder trust and improves the accuracy of MRV processes when integrated with technologies like IoT and satellite imagery.

However, significant challenges persist, including infrastructure limitations in remote areas, financial barriers for small-scale stakeholders, and the lack of a robust regulatory framework. Addressing these issues requires a collaborative approach involving government agencies, private stakeholders, and international organizations. Capacity building and targeted subsidies are essential to ensure inclusivity and effectiveness.

Blockchain is not a standalone solution but a valuable tool that, when strategically implemented, can significantly contribute to achieving Indonesia's carbon reduction and sustainability goals. Future research should focus on scaling blockchain applications and evaluating their long-term impacts on environmental and economic outcomes.

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