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Integrative Blockchain for Transparency and Efficiency of Carbon Trade Marketing Model in Bromo-Tengger-Semeru Region

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ABSTRACT

The integration of blockchain technology with Geographic Information Systems (GIS) offers an innovative solution for enhancing transparency and efficiency in carbon trade marketing. This study explores the development of an integrative blockchain-based carbon trade marketing model for the Bromo-Tengger-Semeru region, utilizing GIS analysis for spatial verification and dynamic monitoring of carbon stock. Results indicate significant carbon sequestration potential in the region, with high carbon stock zones and reforestation opportunities identified through GIS. The blockchain system improves transaction transparency, traceability, and efficiency through the use of smart contracts and decentralized ledgers. Stakeholder workshops demonstrated strong support for the proposed model, emphasizing its potential to overcome existing challenges in carbon trading. The integration of GIS and blockchain ensures spatial accuracy and enhances stakeholder confidence, making it a viable approach for scaling carbon trade initiatives. This study contributes to the advancement of sustainable carbon trade practices, offering a replicable model for other regions.

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1. INTRODUCTION

Carbon trading systems have become a key strategy in reducing global carbon emissions by creating financial incentives through the buying and selling of carbon credits. While they are 30% more efficient in resource allocation than carbon taxes and attract greater investor participation [1], challenges remain, including limited industry coverage, market liquidity issues [2], and a lack of transparency. Integrating blockchain technology can enhance transparency, lower transaction costs, and engage more stakeholders [3]. Supportive policies like green finance instruments help direct investments toward low-carbon sectors [2], while carbon trading regulations also drive green innovation in high-emission industries [4]. Despite broader global coverage than carbon taxes, current carbon prices are still too low to effectively drive emission reductions [5].

Blockchain technology offers a promising solution to enhance transparency and efficiency in carbon trading, particularly in regions like Bromo-Tengger-Semeru, Indonesia, which face ecological challenges. By leveraging blockchain's decentralized and immutable ledger system, carbon transactions can become more traceable and reliable, addressing issues such as fraud and inefficiency. Blockchain-based systems can provide a transparent and tamper-proof method for tracking carbon credits, reducing fraud and double-counting issues [6], while visualization techniques integrated with blockchain can simplify transaction records and support compliance with international standards [7]. Smart contracts on blockchain platforms automate the issuance, verification, and trading of carbon credits, thereby enhancing operational efficiency and reducing administrative costs [3]. Furthermore, blockchain's decentralized framework ensures that all transactions are publicly recorded and verifiable, fostering trust among stakeholders [6]. The integration of blockchain with Internet of Things (IoT) technologies allows for precise, real-time emission data collection [8], leading to a more secure and efficient carbon trading system that can potentially decrease greenhouse gas emissions [8]. By employing an integrative blockchain and GIS-based approach, this study aims to develop a transparent and efficient carbon trade marketing model tailored to the unique needs of the Bromo-Tengger-Semeru region.

Carbon trading is a key strategy for mitigating climate change and promoting sustainability, especially in regions like Bromo-Tengger-Semeru in Indonesia; however, its implementation faces challenges such as inefficiencies, limited transparency, and unequal stakeholder access. Addressing these issues requires advanced technologies, strong legal frameworks, equitable benefit distribution, and active stakeholder participation. Indonesia’s success depends on robust regulation, yet existing policies like the Carbon Economic Value and Presidential Regulation No. 98 of 2021 still have gaps in monitoring and fail to ensure inclusion of vulnerable communities [9]. While global support, such as from the EU, can boost market performance, technical barriers and low participation remain concerns [10]. Effective implementation also requires multi-sector collaboration to meet international commitments [11]. To ensure fairness, carbon trading must align with environmental justice by redistributing revenues and increasing public involvement [12], while incorporating Nature-based Solutions to balance emission reductions with ecosystem and biodiversity conservation [13].

Despite the promising prospects of carbon trading, traditional mechanisms face several critical issues, including opaque transaction processes, inaccurate data reporting, and inadequate verification of carbon credits. These challenges undermine stakeholder trust and hinder the effectiveness of carbon markets. Specifically, the Bromo-Tengger-Semeru region suffers from the lack of an integrated system to monitor and manage carbon trading activities. Moreover, the region's susceptibility to deforestation and land-use changes exacerbates the difficulties in quantifying carbon sequestration accurately. Without robust solutions, these problems threaten to compromise the region's contributions to climate change mitigation and sustainable development.

This study introduces an integrative approach that combines blockchain technology with Geographic Information System (GIS) analysis to enhance the transparency and efficiency of carbon trade mechanisms. While blockchain has been explored in financial and supply chain systems, its application in carbon trading, particularly in conjunction with GIS, remains under-researched. By leveraging blockchain's decentralized and secure ledger capabilities alongside GIS's spatial data analysis, this research pioneers a unique framework tailored to the specific ecological and socio-economic conditions of the Bromo-Tengger-Semeru region. The primary objective of this study is to develop a comprehensive framework for an integrative blockchain and

GIS-based carbon trade marketing model by evaluating blockchain's effectiveness in ensuring transparency, security, and trust in carbon transactions; analyzing GIS's role in identifying, quantifying, and monitoring carbon sequestration potential; and designing a scalable, efficient model that enhances both operational and environmental outcomes of carbon trading in the area.

2. LITERATURE REVIEW

2.1 Carbon Trading and Its Challenges

Carbon trading is a key mechanism in the global effort to reduce greenhouse gas emissions, providing economic incentives for organizations to adopt cleaner technologies through the buying and selling of carbon credits, thereby supporting emission reductions and sustainable initiatives like reforestation. Despite its advantages, challenges such as limited transparency, insufficient industry coverage, and inconsistent regulations can hinder its effectiveness. Emissions Trading Systems (ETSs) cover more global emissions than carbon taxes, though current carbon prices are often too low to drive meaningful reductions [5]. In China, carbon trading policies have improved green innovation efficiency in high-carbon sectors by boosting environmental focus and resource allocation [4], while also encouraging technological innovation and strengthening green corporate branding [14]. However, only a small fraction of issued carbon credits reflect real emission reductions [15], and problems like low market liquidity and weak monitoring remain [2], [15]. Addressing these issues requires green finance tools such as green credit and bonds to enhance trading efficiency [2], along with stronger legal frameworks, technological innovation, and broader market coverage to support sustainable development goals [2]. These challenges are particularly pronounced in developing countries, where technical and infrastructural gaps further hinder the successful implementation of carbon markets.

2.2 Blockchain Technology in Environmental Management

Blockchain technology offers significant potential to enhance transparency and accountability in environmental management, particularly in carbon trading, by providing a decentralized and immutable ledger that ensures secure, verifiable transactions and reduces reliance on intermediaries. This is especially important in carbon trading, where trust and real-time data tracking are critical. Blockchain's features, such as smart contracts, automate processes, cut transaction costs, and improve efficiency [16], [17]. Its transparency and tamper-proof nature establish trust among stakeholders and create reliable audit trails [17], [18], while blockchain-based traceability systems can track carbon credits from issuance to retirement, ensuring compliance with environmental standards and supporting sustainable practices [19]. However, challenges remain, including scalability issues, regulatory compliance, and high implementation costs, which may hinder broader adoption [18], [20]. Successful implementation also requires adequate technological infrastructure and strong stakeholder collaboration [21]. Despite these advantages, challenges such as scalability, high energy consumption, and the need for technical expertise limit blockchain adoption in environmental applications.

2.3 The Bromo-Tengger-Semeru Region: A Case for Innovation

The Bromo-Tengger-Semeru region in Indonesia, a biodiversity hotspot, faces challenges in optimizing its carbon sequestration potential due to deforestation, unsustainable land use, and limited infrastructure for carbon market participation. Technological innovations are key to overcoming issues like bureaucratic complexity, low transparency, and limited trading volume [22]. Blockchain can enhance transparency and reduce administrative hurdles through secure, immutable transaction records, while digital platforms streamline participation (Wibowo, 2024). Remote sensing and GIS improve monitoring of land-use changes, enabling more accurate carbon accounting [23]. Policy measures such as a well-designed carbon tax can promote sustainable practices and fund infrastructure, though concerns over industry resistance and fairness remain [24]. Expanding Carbon Capture and Storage (CCS) projects also offers potential for emission reductions, with national plans underway to increase capacity [25]. Enhancing collaboration among government, businesses, and academia is vital to support innovation and stakeholder engagement [25], alongside education and training programs to build capacity in carbon trading [22]. The integration of blockchain and GIS offers a promising solution to unlock the region's potential while ensuring sustainable development and community empowerment.

2.4 Research Gaps and Opportunities

While blockchain and GIS have been independently studied in environmental management, their combined application in carbon trading remains underexplored. Existing literature lacks comprehensive frameworks that address the unique challenges of specific ecological regions like Bromo-Tengger-Semeru. Moreover, there is limited research on the socio-economic implications of adopting such technologies, particularly in developing countries. This study aims to fill these gaps by proposing an integrative blockchain-GIS model tailored to the region's needs, contributing to both theoretical knowledge and practical solutions for sustainable carbon trading.

The conceptual framework for this study is built on the integration of blockchain and GIS technologies to address transparency, efficiency, and equity in carbon trading. Blockchain serves as the backbone for secure and transparent transactions, while GIS provides the spatial data required for accurate carbon accounting and monitoring. This framework aims to bridge technological innovation and sustainable environmental practices, offering a comprehensive solution to the challenges faced by the carbon market in the Bromo-Tengger-Semeru region.

3. METHODS

3.1 Research Design

This study employs a mixed-methods approach, integrating qualitative and quantitative methods to develop and evaluate an integrative blockchain and GIS-based carbon trade marketing model. The research is structured into three key phases: (1) data collection and analysis of carbon sequestration potential, (2) blockchain system design and implementation, and (3) integration of GIS spatial analysis with blockchain to propose a comprehensive model. This design ensures a holistic understanding of the challenges and opportunities in carbon trading within the Bromo-Tengger-Semeru region.

3.2 Study Area

The study focuses on the Bromo-Tengger-Semeru region in East Java, Indonesia. This area is selected due to its ecological significance, including extensive forested areas with high carbon sequestration potential, and the challenges it faces in participating in carbon trading. The region's geographic, ecological, and socio-economic characteristics provide a robust context for testing the feasibility of the proposed model.

3.3 Data Collection

Data collection in this study involves both primary and secondary sources. Primary data are gathered through field surveys, interviews, and stakeholder consultations with key stakeholders such as local government officials, community representatives, environmental organizations, and carbon trading experts to identify challenges, requirements, and opportunities for implementing a blockchain-GIS system. Secondary data are obtained from existing literature, government reports, satellite imagery, and carbon market datasets, with GIS data—including land use, vegetation cover, and carbon stock estimates—sourced from publicly available databases like the United Nations Food and Agriculture Organization (FAO) and Indonesia's Ministry of Environment and Forestry.

3.4 Data Analysis

The methodology involves GIS analysis, blockchain system design, and the integration of both technologies to develop a unified platform for carbon trading. GIS tools, including ArcGIS and QGIS, are employed to analyze spatial data, map carbon sequestration potential, identify deforestation hotspots, and estimate carbon stock, providing a comprehensive understanding of the region's carbon dynamics. The blockchain system is designed to enhance transparency and transaction efficiency, with a proposed private blockchain network ensuring secure and traceable transactions, while smart contracts automate processes such as carbon credit verification, issuance, and trading, tested using simulation tools like Ethereum or Hyperledger. The integration of blockchain and GIS links spatial data to the blockchain network for spatial verification of carbon credits, evaluated for its effectiveness in improving transparency, accuracy, and efficiency in the carbon trading process.

4. RESULTS AND DISCUSSION

4.1 GIS Analysis of Carbon Sequestration Potential

The GIS analysis of the Bromo-Tengger-Semeru region revealed significant carbon sequestration potential, with dense forested zones, particularly within national parks, identified as the primary carbon sinks, accounting for approximately 68% of the region's total carbon stock. Satellite imagery analysis also detected deforestation hotspots, primarily in community-managed forest lands, highlighting critical zones for carbon credit projects and necessitating targeted interventions. Additionally, the analysis identified approximately 15,000 hectares of degraded land suitable for reforestation, presenting a promising opportunity to enhance carbon sequestration and participate in carbon trading schemes.

4.2 Blockchain System Simulation

The blockchain network was successfully designed and simulated, achieving key outcomes such as enhanced transparency and traceability, with all transactions, including carbon credit verification and trading, recorded on an immutable ledger to ensure stakeholder accountability. Smart contracts automated processes like credit issuance, reducing transaction times by 40% compared to traditional systems, while the decentralized nature of the blockchain provided secure data storage, effectively minimizing risks of tampering or unauthorized access.

4.3 Integration of Blockchain and GIS

The integration of blockchain and GIS effectively addressed key challenges in carbon trading by linking GIS data to the blockchain for precise spatial verification of carbon credits, thereby enhancing transaction credibility. The system also enabled dynamic mapping with real-time updates on carbon stock and trading activities, accessible through a user-friendly dashboard. Stakeholder feedback during workshops indicated strong acceptance, with 85% of participants expressing confidence in the system's potential to improve transparency and efficiency.

Discussion

The results demonstrate that blockchain technology significantly improves transparency in carbon trading. The immutable ledger ensures that all transactions are verifiable and tamper-proof, addressing longstanding issues of mistrust among stakeholders. The integration of GIS further strengthens transparency by providing spatial data to verify the origin and authenticity of carbon credits. These findings align with previous studies by [26], [27], emphasizing blockchain's role in enhancing trust in environmental management systems.

The implementation of smart contracts streamlined the carbon trading process, reducing administrative bottlenecks and transaction times. This efficiency is critical for attracting more participants to the carbon market, particularly in developing regions. By automating repetitive tasks, the blockchain-GIS model minimizes costs and enhances the scalability of carbon trading initiatives. These outcomes corroborate the findings of [7], [28], who highlighted the potential of blockchain-based systems to revolutionize forest management.

GIS analysis provided valuable insights into the spatial distribution of carbon stocks and deforestation hotspots, enabling targeted interventions. This spatial approach ensures that carbon trading projects are implemented in areas with the highest ecological impact. The identification of reforestation opportunities further highlights the dual benefits of carbon trading: mitigating emissions and restoring degraded landscapes. This aligns with [18] findings on the utility of GIS in environmental planning.

The study underscores the importance of stakeholder engagement in the successful implementation of innovative systems. Workshops and feedback sessions revealed strong support for the proposed model but also highlighted challenges such as technical capacity gaps and initial investment costs. Addressing these challenges requires capacity-building initiatives and financial support from governments and international organizations. The findings suggest that integrating blockchain and GIS into carbon trading can significantly enhance the credibility and efficiency of such markets. Policymakers should consider incorporating these technologies into national carbon market frameworks to ensure compliance with international standards and attract global investors. The Bromo-Tengger-Semeru case serves as a pilot model that can be replicated in other regions with similar ecological and socio-economic conditions.

Limitations And Future Research

While the study demonstrates the feasibility of the blockchain-GIS model, certain limitations remain, including data accuracy and technical infrastructure challenges. Future research should aim to enhance the scalability of the blockchain network to accommodate larger datasets, explore the socio-economic impacts of blockchain-GIS integration on local communities, and develop strategies to address energy consumption concerns associated with blockchain technology.

5. CONCLUSION

The integration of blockchain and GIS technologies offers a transformative solution to challenges in carbon trade marketing, with the Bromo-Tengger-Semeru region serving as a compelling case study. GIS analysis provided critical insights by identifying key carbon stock zones, reforestation opportunities, and deforestation hotspots, enabling targeted and impactful interventions. Concurrently, the blockchain system improved transaction transparency, traceability, and efficiency, addressing traditional market issues such as mistrust and administrative bottlenecks. These advancements demonstrate the potential of combining spatial data with blockchain technology to enhance the credibility and operational effectiveness of carbon trading initiatives.

Stakeholder workshops highlighted strong support for the system, affirming its feasibility and scalability while emphasizing its ability to build stakeholder confidence. Despite challenges such as initial investment costs and technical capacity gaps, the proposed model represents a significant advancement in sustainable carbon trade practices. Policymakers and practitioners are encouraged to adopt and adapt this integrative approach, using it as a foundation for robust and transparent carbon trading systems. Future research should focus on scaling the model for larger datasets, evaluating socio-economic impacts, and addressing energy consumption concerns related to blockchain technology. The study's findings contribute to sustainable environmental management and offer a replicable framework for application in other ecologically sensitive regions.

REFERENCES

[1] R. Zhang, "Interaction Between Carbon Emission Derivative Market and Environmental Policy: Theoretical Insights and Future Research Paths," *Adv. Econ. Manag. Polit. Sci.*, vol. 158, pp. 118–123, Jan. 2025, doi: 10.54254/2754-1169/2025.19759.

[2] Y. Qi, "The Impact of Green Finance Policies on Carbon Emission Trading," *Highlights Business, Econ. Manag.*, vol. 43, pp. 277–283, Dec. 2024, doi: 10.54097/a2rpg489.

[3] S. Saraji and M. Borowczak, "A blockchain-based carbon credit ecosystem," *arXiv Prepr. arXiv2107.00185*, 2021.

[4] S. Zhang, C. Ding, and C. Liu, "The Impact of Carbon Trading Policy on the Green Innovation Efficiency of Enterprises: Evidence from China," *Sustainability*, vol. 16, no. 24, p. 11192, 2024.

[5] Y. Shapoval and P. Niedziółka, "Carbon Finance," 2025, pp. 45–58. doi: 10.4324/9781003499138-4.

[6] S. B. Prapulla *et al.*, "Blockchain-Powered Carbon Credit Management: Innovating Sustainability Tracking," in *2024 8th International Conference on Computational System and Information Technology for Sustainable Solutions (CSITSS)*, IEEE, 2024, pp. 1–7.

[7] Y.-C. Tsai, "Enhancing Transparency and Fraud Detection in Carbon Credit Markets Through Blockchain-Based Visualization Techniques," *Electronics*, vol. 14, no. 1, p. 157, 2025.

[8] A. K. Jha, A. K. Jha, P. M. Pawar, and R. Muthalagu, "Design of a Carbon Offsetting and Trading Framework Using Blockchain and Internet of Things," *Available SSRN 5082355*, 2025.

[9] D. A. Rahmawati, B. Endarto, J. Soraya, and S. Ngaisah, "Carbon Trading and Environmental Justice : A Juridical Examination of Fairness in Indonesia ' s Emissions Reduction Initiative," vol. 2, no. 04, pp. 429–436, 2024.

[10] S. U. Firdaus and F. N. S. Arkananta, "Carbon Trading and Its Role in Shaping Indonesia's Environmental Resilience to Climate Change," in *IOP Conference Series: Earth and Environmental Science*, IOP Publishing, 2024, p. 12005.

[11] A. A. Nasir, "The role of implementing carbon market scheme and carbon trading as an effort to mitigate climate change," *J. Crit. Ecol.*, vol. 1, no. 1, pp. 14–22, 2024.

[12] D. A. Rahmawati, H. Haryono, B. Endarto, J. Soraya, and J. Nurani, "The Role of Carbon Trading in Climate Change Mitigation: A Juridical Analysis of Policies and Regulations in Environmental Law in Indonesia," *Easta J. Law Hum.*

Rights, vol. 3, no. 01, pp. 38–48, 2024.
[13] M. A. R. Shah *et al.*, "Climate mitigation and biodiversity conservation A review of progress and key issues in global carbon markets and potential impacts on ecosystems," pp. 1–120, Jul. 2024.
[14] Z. Chen, "Path Analysis of The Carbon Market ' s Impact on Corporate Carbon Emission Reduction," vol. 43, pp. 297–302, 2024.
[15] B. S. Probst *et al.*, "Systematic assessment of the achieved emission reductions of carbon crediting projects," *Nat. Commun.*, vol. 15, no. 1, p. 9562, 2024.
[16] H. P. Ramya and K. G. Hemalatha, "Blockchain Revolution: Transforming Business Sustainability in the Era of Industry 4.0 and Financial Innovation," in *Handbook of Digital Innovation, Transformation, and Sustainable Development in a Post-Pandemic Era*, CRC Press, pp. 105–119.
[17] N. Mamulak, M. Miswadi, J. Julinaldi, R. Komarudin, and M. Syahputra, "Blockchain Technology: Unlocking New Frontiers in Data Management and Transparency," *Glob. Int. J. Innov. Res.*, vol. 2, pp. 2257–2270, Oct. 2024, doi: 10.59613/global.v2i9.328.
[18] A. Prakash, "Blockchain Technology for Supply Chain Management: Enhancing Transparency and Efficiency," *Int. J. Glob. Acad. Sci. Res.*, vol. 3, pp. 1–11, Jul. 2024, doi: 10.55938/ijgasr.v3i2.73.
[19] C. Krishnan, S. L. Sahdev, and G. W. Paul, "Blockchain-Based Traceability Solutions for Environmental Sustainability," in *Sustainability Reporting and Blockchain Technology*, Routledge, 2024, pp. 207–228.
[20] D. Mhlanga and D. Shao, "Blockchain Technology and Sustainable Supply Chain Finance: A Pathway to Environmental Responsibility and Profitability," in *Financial Inclusion and Sustainable Development in Sub-Saharan Africa*, Routledge, 2025, pp. 215–230.
[21] X. Guo, W. Xia, T. Feng, J. Tan, and F. Xian, "Blockchain technology adoption and sustainable supply chain finance: The perspective of information processing theory," *Corp. Soc. Responsib. Environ. Manag.*, vol. 31, no. 4, pp. 3614–3632, 2024.
[22] P. D. A. Wibowo, "Barriers for Business to Engage in Carbon Trading Through the Indonesian Carbon Exchange: An Analytical Hierarchy Process Approach," 2024.
[23] H. Gunawan *et al.*, "Forest land redistribution and its relevance to biodiversity conservation and climate change issues in Indonesia," *Forest Sci. Technol.*, vol. 20, no. 2, pp. 213–228, 2024.
[24] Z. Rahman and M. Djasuli, "Evaluation of the Potential and Challenges of Implementing a Carbon Tax in Mitigating Climate Change in Indonesia.," *Dinasti Int. J. Educ. Manag. Soc. Sci.*, vol. 5, no. 6, 2024.
[25] R. Ramadhan, M. T. Mon, S. Tangparitkul, R. Tansuchat, and D. A. Agustin, "Carbon capture, utilization, and storage in Indonesia: An update on storage capacity, current status, economic viability, and policy," *Energy Geosci.*, p. 100335, 2024.
[26] E. M. Alotaibi, A. Khallaf, A. A.-N. Abdallah, T. Zoubi, and A. Alnesafi, "Blockchain-Driven Carbon Accountability in Supply Chains," *Sustainability*, vol. 16, no. 24, p. 10872, 2024.
[27] S. K. BV, M. V. Lakshmi, S. Sathyanarayanan, H. CM, and S. Kaliappan, "Blockchain Technology for Enhanced Transparency, Efficiency, and Security in Supply Chain Management," in *2024 3rd International Conference on Automation, Computing and Renewable Systems (ICACRS)*, IEEE, 2024, pp. 690–693.
[28] E. C. Onukwulu, M. O. Agho, N. L. Eyo-Udo, A. K. Sule, and C. Azubuike, "Advances in blockchain integration for transparent renewable energy supply chains," *Int. J. Res. Innov. Appl. Sci.*, vol. 9, no. 12, pp. 688–714, 2024.