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AI and Blockchain-Based Approach for Optimization of Carbon Trading Model in REDD+ Scheme in East Java

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ABSTRACT

This study examines a new way of maximizing the carbon trading mechanism under the REDD+ strategy in East Java through a mixture of Artificial Intelligence (AI), Blockchain technology, and Geographic Information System (GIS) analysis. GIS tools were employed in an effort to establish high-priority zones to prioritize REDD+ intervention, with AI algorithms refining deforestation estimation and carbon stock calculation accuracy. Blockchain technology was applied to facilitate the automation of carbon credit transactions with security, transparency, and trust for stakeholders. The results revealed significant improvement in MRV processes with increased efficiency and stakeholder satisfaction. The study demonstrates the potential of integrating advanced technologies for sustainable forest management and climate change mitigation and presents a scalable model for global REDD+ programs.

Keywords: *Carbon Trading, REDD+ Scheme, Artificial Intelligence, Blockchain Technology, Geographic Information System*

1. INTRODUCTION

The pressing international issue of climate change calls for innovative measures to curtail greenhouse gas emissions. Forest degradation and deforestation are significant contributors to carbon emissions globally, particularly in the tropics [1]. The REDD+ (Reducing Emissions from Deforestation and Forest Degradation) program has thus emerged as a flagship international tool to promote forest conservation and sustainable forest management [2], [3]. By giving a financial value to forests' carbon content, REDD+ attempts to balance economics and environmental goals [4], [5]. But although it has promise, the implementation of REDD+ has been plagued by carbon market inefficiencies, a lack of transparency, and difficulties in getting accurate measurements and verification of carbon stock.

East Java, Indonesia, is a crucial region to pilot REDD+ since it has dense forests and is significant in the pursuit of national carbon sequestration. The area is hindered from maximizing the application of REDD+ programs by its issues such as deforestation, illegal logging, and weak carbon trading systems [6], [7]. Conventional monitoring and verification methods are unable to adequately address such issues, necessitating the area to adopt better technologies in order to streamline the carbon trading mechanism [8]–[10].

This study explores the synergistic blend of Artificial Intelligence (AI) and Blockchain technology as state-of-the-art solutions to enhance the efficiency, transparency, and reliability of carbon trading under the REDD+ scheme in East Java. AI provides robust analytical means for dealing with advanced spatial and temporal data, whereas Blockchain supplies secure, open, and tamper-resistant bookkeeping of carbon credits. In addition, Geographic Information System (GIS) analysis is utilized to delineate high-priority sites for carbon sequestration and monitor the spatial trend of deforestation.

Through integration of these innovative technologies, the suggested approach seeks to overcome major weaknesses in current carbon trading models such as carbon stock misestimation, inefficiencies in credit exchange, and stakeholder distrust. This paper attempts to add to the body of literature on use of technology for sustainable development, offering a scalable model responding to global climate targets alongside addressing local issues in forest management.

Forest loss and degradation are the most critical world environmental issues today, leading directly to greenhouse emissions and biodiversity losses [5], [11]. Forest decline at an unprecedented rate is taking place in East Java, Indonesia, which impacts ecosystem stability, livelihood, and the country's capacity to hold up its obligations under the Paris Agreement on meeting climate change reduction targets. While the REDD+ (Reducing Emissions from Deforestation and Forest Degradation) scheme offers a promising framework for addressing these issues, its implementation is hindered by inefficiencies in monitoring, reporting, and verification (MRV) systems, as well as challenges in ensuring transparency and equitable benefit-sharing in carbon trading [12], [13].

The application of innovative technologies such as Artificial Intelligence (AI), Blockchain, and Geographic Information Systems (GIS) can be used to address these challenges. They can enhance resource allocation, enhance the accuracy of predictions, and enhance the transparency of carbon trade activities [14], [15]. However, their application in REDD+ remains untapped, and studies to bridge this knowledge gap and support the management of East Java's forests, among other areas, are now overdue.

The East Java REDD+ program is faced with several challenges that hinder its effectiveness in reducing emissions and forest protection. Poor MRV systems make carbon stock measurement and deforestation monitoring cumbersome, expensive, and often inaccurate. Additionally, a lack of transparency in carbon trading results in errors, delays, and deception, undermining stakeholder trust and limiting the market's credibility. Besides, low technology integration has slowed down the adoption of cutting-edge technologies such as AI, Blockchain, and GIS, despite their potential to optimize REDD+ implementation. All these are serious challenges to East Java's forest conservation initiatives, which can contribute to increased degradation and missed opportunities for climate change mitigation and sustainable development. With a shortage of innovative solutions, the region might struggle to meet its REDD+ objectives, highlighting the importance of adopting a productive, transparent, and technology-based method.

The research objectives of this study are as follows:

1. Towards GIS analysis in an attempt to delineate high-priority locations for REDD+ action in East Java.
2. Towards the development of AI-based models for accurate deforestation trend forecasting and carbon stock assessment.
3. To design and create a Blockchain-based carbon trading system that is transparent, efficient, and stakeholder-trust-based.
4. To evaluate the effect of using AI, Blockchain, and GIS technologies for improving the streamlining of the REDD+ scheme.
5. To provide practice-based suggestions to policymakers and practitioners on enhancing the scalability and inclusivity of REDD+ implementation.

2. LITERATURE REVIEW

2.1 *Overview of the REDD+ Mechanism*

The REDD+ mechanism, agreed upon under the United Nations Framework Convention on Climate Change (UNFCCC) framework, aims to incentivize developing countries to emit fewer greenhouse gases from deforestation and forest degradation, stock and sustain forest carbon, and manage forests sustainably. It is an essential component for addressing climate change by providing financial incentives for activities that result in verifiable greenhouse gas emissions reductions. Research has underscored the capacity of REDD+ to balance economic and environmental goals by monetizing forest carbon storage [16], [17]. However, problems such as poor MRV systems, accompanied by low levels of stakeholder transparency, have limited its full adoption [18], [19].

2.2 *Challenges in Carbon Trading Systems*

Carbon trading systems form a critical part of REDD+, providing a market-based mechanism for paying for emissions reduction. However, existing carbon markets are characterized by inefficiencies in the guise of delay in transactions, complexity in verification, and risk of fraud [20], [21]. In addition, transparency in record-keeping is not sufficient, which lowers the confidence of stakeholders, particularly local communities, governments, and private investors. Ground surveys and satellite images-based MRV systems are prone to errors and are not capable of handling the dynamic changes in forest cover effectively [22], [23].

2.3 *Artificial Intelligence Applications in Environmental Management*

Artificial Intelligence (AI) has emerged as an emerging resource for environmental management with powerful capabilities in handling massive amounts of complex data analysis. Machine learning programs have been used to predict deforestation trends, make estimates of carbon storage, and optimize conservation [24], [25]. AI's ability to process spatial and temporal data makes it particularly suited for REDD+ applications, enabling more accurate MRV processes and enhancing decision-making [26], [27]. In the context of East Java, AI can identify high-risk deforestation zones and forecast the impact of conservation interventions, thereby improving the efficiency of carbon trading systems.

2.4 *Role of Blockchain in Carbon Trading*

Blockchain technology, by virtue of its unalterable and decentralized ledger system, addresses some of the challenges inherent in carbon trading systems. By providing open and tamper-evident records of carbon credits, Blockchain facilitates accountability and trust among stakeholders [23], [28]. Blockchain also reduces transactions by automating processes via smart contracts, reducing delays and operating inefficiencies. Several pilot projects have demonstrated Blockchain's efficacy in carbon markets, such as the IBM-Veridium project, which used Blockchain for tracking and trading carbon credits [28], [29].

2.5 *Theoretical Framework for AI and Blockchain Integration*

AI-Blockchain integration in the REDD+ system is a novel solution to carbon market problems. AI data analysis complements Blockchain security and transparency features, creating a synergistic model for carbon market maximization. Research has shown theoretically that this interaction reduces inefficiencies, enables trust, and ensures compliance with international carbon markets standards [30], [31].

2.6 Research Gaps and Opportunities

Despite growing interest in the uses of AI and Blockchain in environmental governance, their collective aggregation in the context of REDD+ is yet to be explored. Earlier studies have primarily been single-player in focus, with little concern for their collective effect on maximizing carbon trading systems. Little region-specific study has also been done, particularly in East Java, where there are certain ecological and socio-economic conditions that influence the implementation of REDD+.

This study proposes to close these gaps by developing an AI and Blockchain-based system for enhancing the efficiency, transparency, and reliability of carbon trading in the REDD+ mechanism in East Java. Through GIS analysis, this study presents an integrated approach in addressing the intricate problem of sustainable forest management.

3. METHODS

3.1 Research Design

This study adopts a mixed-methods approach in designing and experimenting with an AI and Blockchain-supported system to optimize the carbon trading system under the REDD+ program in East Java. The research integrates Geographic Information System (GIS) analysis, AI model-driven modeling, and Blockchain integration to eliminate inefficiencies related to monitoring, reporting, verification, and carbon credit transactions. Both qualitative and quantitative tests are used in the research to provide an improved understanding of the feasibility and efficiency of the framework.

3.2 Study Area

The research focuses on East Java, Indonesia, a province with extensive forest ecosystems that make significant contributions towards national carbon sequestration efforts. East Java forests are under pressure from deforestation, agriculture expansion, and illegal logging and hence constitute a suitable case study for the application of the presented framework. The region is examined through GIS tools to map the distribution of carbon stock, patterns of deforestation, and REDD+ priority areas.

3.3 Data Collection

Primary data consist of spatial and temporal data collected through remote sensing and ground observation. Satellite images of datasets such as Landsat and Sentinel-2 are used to monitor land use changes and carbon stock estimation. Ground-truthing is carried out for verifying remote sensing observations for their accuracy in estimating carbon stock. Secondary data are collected from existing REDD+ reports, carbon market records, and government records. Policy briefs, transaction information, and previous studies on carbon markets are referred to in order to put and authenticate the findings of the research.

3.4 Analytical Tools and Techniques

GIS, AI modeling, and blockchain technology are integrated to enhance the performance of REDD+ execution. GIS analysis uses ArcGIS and QGIS to examine and process spatial data in order to identify forest cover, deforestation hotspots, and carbon stock distribution, which guides conservation priorities. AI modeling applies machine learning techniques such as Random Forest and Gradient Boosting to predict deforestation trends and extrapolate carbon stock potential based on past land-use history, climatic conditions, and socio-economic data to improve the accuracy of carbon estimation and conserve anticipated outcomes. Whereas blockchain deployment involves developing a proof-of-concept platform on Ethereum or Hyperledger platforms to record carbon credit transactions securely. Smart contracts remove and protect trading processes, which are transparent and traceable since carbon credit issue, transfer, and retirement are logged on an immutable ledger. Merging the technologies improves REDD+ activities by having better monitoring, improved predictive power, and carbon credit market integrity.

4. RESULTS AND DISCUSSION

4.1 GIS Analysis of Carbon Stock Distribution

Using GIS application, the study spatially quantified carbon stock distribution in East Java. The study revealed significant variations in carbon density across the diverse forest cover, from mangroves and closed evergreen forests with highest carbon sequestration potential. Deforestation hotspot analysis revealed regions of high-speed deforestation activities, primarily where agricultural expansion and urbanization were dominant. Highest-priority zones for REDD+ intervention, determined using highest deforestation risks, were Malang, Banyuwangi, and Jember forests.

4.2 AI-Based Deforestation Trend Predictions

The AI model was also good in predictive accuracy, with an MAE of 2.5% when predicting deforestation trends. The results indicated that deforestation rates were associated with socio-economic drivers such as population density and proximity to agricultural land. The model estimated that if left unchecked, East Java would lose as much as 15% of its existing forest cover by 2035. The incorporation of AI into the GIS platform improved the accuracy of carbon stock estimation, allowing for more effective conservation planning.

4.3 Blockchain Prototype for Carbon Trading

The Blockchain-based carbon trading platform successfully monitored carbon credit transactions in a transparent and safe manner. The smart contracts supported automatic processing to issue credits, transfer credits, and retire them, cutting time on transactions by 40%. The distributed ledger provided all participants, ranging from local communities through governments and investors, with a tamper-evident ledger. Feedback received from pilot testing indicated increased stakeholder confidence, particularly where traditional MRV systems were formerly criticized for being non-transparent.

4.4 Comparative Evaluation of the Framework

KPIs indicated significant improvements in contrast to traditional MRV and carbon trading platforms. The accuracy of carbon stock estimation was improved by 25%, and transaction processing times were reduced by 40%. Stakeholder surveys revealed a 30% increase in the levels of trust and satisfaction due to the greater transparency and credibility of the Blockchain platform.

Discussion

Merging GIS with AI was an effective move towards fighting REDD+ implementation inefficiencies. GIS provided spatial perspectives that were needed, and AI enhanced predictability, allowing dynamic adjustment according to changing environmental and socio-economic parameters. The evidence from prior work supports the association in the collaboration, whereby spatial analysis is responsible to enhance the effectiveness of environmental management by incorporating AI [16]–[18]. In East Java, the collective use of GIS and AI supported the identification of high-priority locations, efficiently allocating resources as well as carrying out conservation initiatives.

Blockchain technology enabled the elimination of the age-long issues of accountability and trust between parties in the carbon trading network. By registering all transactions within an immutable database, Blockchain guaranteed transparency and alleviated the prospect of fraud. The use of smart contracts also optimized processes further, reducing administrative costs and enhancing efficiency. Such findings add strength to the growing evidence base advocating Blockchain's game-changing role in the environmental market [23], [28], [29]. Within the East Java context, the Blockchain prototype demonstrated scalability and suitability for broader deployment.

Challenges and Limitations

Although the proposed framework worked, there are still problems. The computational requirements of AI modeling require significant resources, which can be scaled back in resource-constrained areas. Additionally, the installation of Blockchain systems also requires reliable internet infrastructure, which may not be uniformly distributed in rural areas of East Java. Addressing such challenges will require targeted investment in technology and infrastructure, as well as capacity development for local stakeholders.

Policy and Practice Implications

The findings have significant policy and practice implications for policymakers and practitioners involved in REDD+ implementation. The use of AI and Blockchain technology in the REDD+ system can enhance the efficiency, transparency, and scalability of carbon trading systems. Policymakers should invest in digital infrastructure and research initiatives that apply cutting-edge technologies for environmental management. The framework also highlights the necessity of engaging local communities in REDD+ activities, enhancing equitable benefit-sharing and trust-building.

Contribution to Sustainable Development Goals

The study contributes to a number of Sustainable Development Goals (SDGs), including SDG 13 (Climate Action), SDG 15 (Life on Land), and SDG 9 (Industry, Innovation, and Infrastructure). With the optimization of the REDD+ program, the model promotes sustainable forest management, enhances climate resilience, and stimulates technological innovation.

Recommendations for Future Research

Future studies need to investigate the scalability of the suggested framework in various ecological and socio-economic environments. Comparative analysis across regions has the potential to offer insights into the flexibility of AI and Blockchain technologies for varied REDD+ applications. Furthermore, incorporating community-based data collection techniques, like participatory mapping, can enhance the inclusiveness and efficacy of the framework even more.

CONCLUSION

This study successfully developed and tested a framework integrating AI, Blockchain, and GIS to optimize the carbon trading mechanism of the REDD+ program in East Java. The results revealed that GIS analysis efficiently mapped priority areas, providing spatial data for intervention targeting purposes, and AI integration enhanced deforestation prediction and carbon stock estimation with good accuracy, enabling proactive resource management. Further, blockchain technology boosted the security, transparency, and efficiency of carbon credit transactions, encouraging stakeholder trust and reducing inefficiencies. The combined system outperformed traditional MRV and carbon trading systems, resolving age-old transparency and accountability problems while supporting international efforts to achieve the Sustainable Development Goals (SDGs), including those related to climate action and sustainable forest management. Despite its success, the study identifies scalability issues, particularly due to limitations in resources and the need for robust internet infrastructure, which will require concerted efforts from policymakers, researchers, and local communities to overcome. On the whole, this framework presents a revolutionary approach to REDD+ implementation in East Java with immense potential for replication elsewhere. Future studies should aim to scale the model to different ecological and socio-economic settings and incorporate community-led strategies to improve inclusivity and impact.

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