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Innovative Business Models for Carbon Trading: Integration of AI, Satellite, and Blockchain in REDD+ Scheme in BTS Protected Forest Area

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ABSTRACT

This study describes an emerging business model of carbon trade under REDD+ scheme arrangements by employing Artificial Intelligence (AI), satellite, and blockchain technology in the Bromo Tengger Semeru (BTS) forest protected area. An integrated methodology of GIS-based spatial analysis, stakeholder interview (qualitative), and pilot testing on blockchain was utilized for testing the viability of the model. Results indicate that AI and satellite integration improve the accuracy of carbon stock estimates and deforestation monitoring, while blockchain facilitates transparency and trust in carbon credit transactions. The study identifies the primary barriers, such as cost and capacity-building requirements, and also identifies the potential for scalability and consistency with global climate goals. The findings provide actionable suggestions for policymakers, investors, and environmental managers to enhance forest conservation and carbon market efficiency.

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1. INTRODUCTION

The global requirement to confront climate change has made carbon trading a focus of sustainable development policy [1], [2]. Among the tools applied to confront greenhouse gas (GHG) emissions, REDD+ (Reducing Emissions from Deforestation and Forest Degradation) is a leading mechanism [3], [4]. It aims to create incentives for economic benefits for developing countries to maintain forests, enhance carbon sequestration, and foster sustainable land use. However, the implementation of REDD+ programs is marred by persistent issues, including data inaccuracy, inadequate monitoring, and lack of transparency in carbon credit transactions. These issues necessitate the creation of innovative solutions that can optimize effectiveness and scalability in carbon trading programs [5], [6].

Bromo Tengger Semeru (BTS) conservation forest reserves in Indonesia present a strategic chance to create REDD+ programs. These forests, prized for their high biodiversity value and carbon-sequestering capabilities, are imperiled by land conversion and logging [7], [8]. With the aid of superior technology such as Artificial Intelligence (AI), remote sensing, and blockchain, there exists the prospect for turning forest management in such areas into an carbon-neutral procedure with carbon-trading practices ensured as equitable and open. Artificial intelligence can process massive datasets to improve carbon storage and deforestation risk estimation, satellite technology can deliver accurate forest cover monitoring, and blockchain offers traceability and integrity to carbon credit transactions [9], [10].

This study seeks to develop an innovative business model for carbon trading through the integration of AI, satellite technology, and blockchain in REDD+ programs specifically for the BTS covered forest areas. Applying Geographic Information System (GIS) analysis, the research evaluates the spatial and temporal patterns of forest carbon stock so that decisions and strategic interventions are made in a well-informed manner. With the incorporation of these innovative tools, this model aims to close important gaps in REDD+ implementation, facilitating trust and effectiveness in carbon markets and enhancing international climate mitigation efforts.

Climate change is one of the most pressing dangers of the 21st century, with rising global greenhouse gas (GHG) emissions leading to extreme environmental and socio-economic consequences. Forests are at the heart of mitigating such consequences by serving as carbon sinks, yet deforestation and land degradation continue at alarming rates, particularly in biologically diverse nations like Indonesia. BTS forest locations are no exception, with intense pressures from deforestation, agricultural intrusion, and destructive land use. Aside from inflicting ecological risk to stability, these activities compromise the capacity of the forests to sequester carbon, countering global climate goals.

Existing REDD+ schemes, enforced to promote conservation through carbon markets, have been beneficial. But their rollout has been derailed by inaccuracy of data, inadequate monitoring systems, and a lack of transparency within carbon credit dealings. These pitfalls erode carbon markets' credibility and limit scalability, particularly within regions of strong conservation potential like BTS. To reduce these challenges, it is essential to incorporate innovative technologies—such as Artificial Intelligence (AI), satellite monitoring, and blockchain—to increase the accuracy of information, enhance efficiency in tracking, and offer transparency to carbon trade mechanisms.

1. Editorial: Sustainable Forest management under climate change conditions — A focus on biodiversity conservation and forest restoration
2. Climate-smart forestry: an AI-enabled sustainable forest management solution for climate change adaptation and mitigation
3. Addressing Contemporary Environmental Challenges: A Focus on Climate Change, Waste Management, Biodiversity Conservation, and Sustainable Development
4. Addressing Contemporary Environmental Challenges: A Focus on Climate Change, Waste Management, Biodiversity Conservation, and Sustainable Development
5. Preserving earth's flora in the 21st century: climate, biodiversity, and global change factors since the mid-1940s

Problem Statement

Although REDD+ schemes have promise in curbing deforestation and promoting sustainable development, their application within nations like BTS protected forests remains plagued with a myriad of challenges. These encompass:

1. Inaccuracy of Data: Current methods of forest carbon pool and deforestation pattern estimation are not accurate, and their carbon credit estimates are not reliable.

2. Monitoring Inefficiencies: Traditional Forest monitoring infrastructures are time-consuming and expensive, limiting them from providing real-time feedback on the forests' status.
3. Transparency and Trust Issues: The absence of immutable, secure systems for trading carbon credits erodes trust among stakeholders and ruins market reputation.

2. LITERATURE REVIEW

2.1 REDD+ Schemes Overview

The REDD+ program seeks to mitigate climate change by reducing deforestation and promoting sustainable forest management, particularly in developing countries. However, its success is hindered by transparency issues and limited stakeholder engagement [11]. Effective implementation requires collaboration with local communities, governments, and the private sector while respecting indigenous knowledge [11]. Challenges such as opaque processes, inadequate financial incentives, and political conflicts slow progress [12]. Despite these barriers, REDD+ could significantly reduce greenhouse gas emissions, potentially preventing the release of 1.59 million tCO_2e in Iran's Hyrcanian forests [7]. Given forests' crucial role in carbon sequestration, their conservation is vital for climate mitigation [13].

2.2 Carbon Trading Mechanisms

Carbon trading mechanisms, such as cap-and-trade programs, play a crucial role in incentivizing emissions reductions and promoting climate mitigation. By internalizing the societal costs of CO_2 emissions, these systems create market incentives for reductions [14]. Programs like the Clean Development Mechanism (CDM) and Verified Carbon Standard (VCS) facilitate carbon credit generation, supporting both environmental protection and economic growth in developing nations [15]. Evidence from China demonstrates that carbon trading can effectively reduce industrial emissions by optimizing structures and fostering technological innovation [16], [17]. However, challenges such as variability in carbon stock measurements and skepticism regarding credit verification undermine market integrity (Gupta, 2024). Ethical concerns and the distributional impacts of carbon credits further raise questions about their overall effectiveness [18]. Blockchain technology has emerged as a potential solution to enhance transparency and accountability in carbon trading transactions, addressing these inefficiencies.

2.3 Forest Conservation through Artificial Intelligence

Artificial Intelligence (AI) has become a crucial tool in environmental management, particularly in improving carbon stock estimation accuracy and deforestation monitoring. By leveraging advanced algorithms, AI reduces estimation errors and optimizes resource allocation for interventions. Machine learning models can decrease carbon estimation errors by up to 35%, strengthening the credibility of

REDD+ programs [19]. Techniques like Convolutional Neural Networks (CNNs) and Long Short-Term Memory (LSTM) models enhance land cover classification precision and air quality forecasting [20]. Additionally, AI enables real-time data collection and analysis, facilitating timely responses to deforestation and pollution [21]. The integration of AI with IoT and remote sensing technologies further enhances real-time environmental monitoring capabilities [22].

2.4 *Satellite Technology for Forest Dynamics Monitoring*

Satellite technology is essential for monitoring forest transformation and carbon sequestration through advanced remote sensing methods like LiDAR and hyperspectral imaging. These technologies enable detailed assessments of forest structure and biomass, crucial for understanding deforestation patterns and carbon storage. Remote sensing provides spatially explicit biomass predictions, enhancing forest health monitoring and carbon accounting [23]. Technologies such as LiDAR and satellite imagery significantly improve aboveground biomass (AGB) estimation, which is vital for carbon storage assessments [24]. New-generation satellite systems like GEDI and ICESat-2 offer high-resolution canopy height data, enhancing forest change mapping accuracy by up to 15% [25]. Integrating multiple data sources, including SAR, optical, and LiDAR, further improves the reliability of forest dynamics monitoring [25]. However, high costs and technical complexities limit the accessibility of these advanced remote sensing technologies [26]. Traditional field measurement methods, being labor-intensive and insufficient for large-scale studies, underscore the need for remote sensing integration in effective carbon management [24].

2.5 *Blockchain Technology in Carbon Trading*

Blockchain technology enhances the carbon market by providing a secure, transparent, and efficient framework for carbon credit transactions. Its decentralized nature reduces reliance on intermediaries, lowering costs and fostering trust among stakeholders. Integrating blockchain into initiatives like REDD+ ensures precise tracking of carbon credits, enhancing accountability and traceability to verified conservation efforts. Pilot programs such as KlimaDAO and Regen Network highlight its potential for environmental sustainability. Blockchain's immutable ledger improves transparency, facilitates transaction verification, and detects fraud to ensure compliance [27]. Smart contracts streamline carbon credit issuance and trading, reducing administrative costs and increasing efficiency [28]. Additionally, tokenizing carbon credits creates a more accessible market [29]. By fostering collaboration among NGOs, governments, and the energy sector, blockchain strengthens trust and enables peer-to-peer trading, contributing to a resilient energy grid [30], [31].

2.6 *Integration of Technologies in REDD+ Schemes*

The integration of AI, satellite technology, and blockchain offers a transformative approach to addressing the REDD+ challenge by enhancing carbon accounting, fraud prevention, and stakeholder engagement. These technologies collectively improve the accuracy and transparency of carbon credit systems, enabling more effective climate action. AI algorithms analyze satellite data to provide precise carbon stock measurements, improving deforestation and land-use monitoring, while real-time satellite imagery ensures continuous observation for timely REDD+ interventions. Blockchain further strengthens transparency and security through an immutable ledger that records carbon credit transactions in a tamper-proof manner, reducing fraud and double-counting [28], [32]. Smart contracts automate the issuance and trading of carbon credits, enhancing operational efficiency and accountability [27], [28]. Additionally, blockchain facilitates decentralized platforms where stakeholders, including governments and NGOs, can access transparent data, fostering trust and collaboration [29].

2.7 *Gaps in Existing Literature*

Although there has been significant progress in each of these technologies separately, scientific research on their integrated application in REDD+ projects is limited. Existing studies mostly focus on pilot tests or conceptual models, and without records of actual implementation. Socio-economic impacts of such technologies on regional populations, particularly in developing countries, are another untapped subject area.

This study incorporates existing research in proposing an integrated model that merges AI, satellite technology, and blockchain for REDD+ programs' carbon trading. The proposed model addresses some of the most pressing issues such as carbon stock estimation accuracy, deforestation detection, and transparency in carbon trading. By using and verifying this model within the BTS forested landscapes under protection, this study aims to promote the utilitarian application of technology-driven REDD+ initiatives and offer an imitable model for future projects globally.

3. METHODS

3.1 Research Design

The research is structured into three general phases. Data collection and analysis include the procedure of gathering primary as well as secondary data regarding carbon stocks in the forest, deforestation trends, and stakeholders' opinions on REDD+ programs. While developing a technology integration framework, AI, satellite technology, and blockchain technology are studied in an effort to come up with an integrated system to boost the process of carbon trading and forest conservation. The third phase, GIS-based spatial analysis, uses Geographic Information System (GIS) methods to map and evaluate forest carbon sequestration and deforestation threats. Studies are conducted in the BTS protected forests of Indonesia, chosen for their environmental significance and deforestation risk. High-resolution satellite images and GIS software are utilized to analyze carbon stock distribution and forest cover change, which are critical sources of information for conservation planning and REDD+ implementation.

3.2 Data Collection

The study utilizes both primary and secondary data to comprehensively assess the implementation of REDD+ schemes. Primary data are collected through interviews and questionnaires with the stakeholders like the local communities, forest management agencies, and policymakers to get the information regarding challenges and opportunities of REDD+ implementation. Secondary data are available datasets on carbon stock, forest cover, and deforestation rate in the BTS region, procured from government reports, NGOs, and research studies. This combination of data sources gives a balanced view, presenting qualitative and quantitative information regarding forest conservation and carbon trading activities.

3.3 Tools and Technologies

The study combines Artificial Intelligence (AI), Satellite Technology, Blockchain Technology, and Geographic Information System (GIS) to enhance REDD+ implementation and carbon trading efficiency. AI algorithms sort through large sets of data, predict deforestation trends, and optimize carbon stock estimations using historical learning in order to make the predictions as accurate as possible. Satellite capabilities enable real-time monitoring of forest cover, deforestation, and land use cover, and remote sensing techniques provide accurate spatial details regarding forest vigor. Blockchain applications are used in developing a traceable and reliable platform for management of carbon credit transactions to increase trust and establish stakeholder trust. While this is accomplished, GIS integrates spatial and non-spatial data for visualization and analysis of forest carbon distribution and deforestation hotspots. Integration of these technologies enhances the monitoring power, predictability, and integrity of carbon credit markets.

3.4 Data Analysis

The study employs a multi-method approach with a mix of spatial, qualitative, and quantitative analysis to evaluate REDD+ implementation and carbon trading markets. Spatial analysis employs GIS to overlay satellite imagery with deforestation and carbon stock information to identify high-risk areas and opportunities for targeted intervention. Qualitative analysis involves content analysis of stakeholder interviews and surveys to identify primary facilitators and inhibitors of REDD+ implementation, providing contextual insights into policy and operational challenges. Quantitative analysis employs statistical techniques to cross-validate carbon stock estimates and assess the effectiveness of the integrated technologies. This holistic framework provides a strong assessment of REDD+ approaches, enabling data-driven decision-making towards sustainable forest management.

4. RESULTS AND DISCUSSION

4.1 Carbon Stock Assessment

The synergy of AI and satellite enhanced the estimation capacity of carbon stock in BTS forest reserves significantly. GIS analysis validated that carbon stock in the region is approximately 15 million tons, with dense carbon concentrations found in areas of intact patches of forests. AI models, which were trained on historical and real-time satellite data, provided precise predictions of carbon sequestration capacities, reducing error rates by 30% compared to the traditional method.

4.2 Monitoring of Forest Dynamics

Remote sensing techniques and satellite imagery effectively identified deforestation zones, reporting a loss of around 1,200 hectares over the past five years. Deforestation was mostly due to illegal logging and agricultural intrusion. AI helped monitor land-use change in real-time, allowing proactive intervention measures.

4.3 Blockchain for Carbon Trading

The blockchain-based carbon trading platform was extremely reliable in offering safe and transparent transactions. The stakeholders felt increased trust stemming from the immutable nature of blockchain data, which documented the source, ownership, and transport of carbon credits. The system supported 15 secure carbon credit transactions during the pilot period, with 5 minutes average time per transaction, compared to several days in traditional systems.

4.4 Stakeholder Engagement

Stakeholder and local community surveys revealed increased awareness and acceptability of REDD+ initiatives through the transparent models offered by blockchain technology. 80% of the respondents indicated the combined approach eliminated significant challenges such as equitable benefit sharing and carbon trading responsibility.

Discussion

The integration of AI, satellite imaging, and blockchain in REDD+ initiatives addresses the most serious challenges in forest protection and carbon trading. AI's predictive abilities enhance the quality of carbon stock estimates and ensure efficient monitoring of deforestation trends. Satellite imaging provides real-time, accurate information required for forest mapping and management of forest resources, while blockchain ensures transparency and accountability in carbon trading. The integration of these technologies forms a robust platform for REDD+ program scaling, particularly in sectors like BTS, where traditional methods have not been able to deliver reliable results. Minimization of data errors and transaction duration emphasizes the potential of technology-driven solutions in optimizing operational effectiveness and stakeholder trust [33], [34].

One of the key obstacles to successful REDD+ has been distrust among stakeholders due to processes lacking transparency and unequal benefit-sharing. The blockchain platform addresses this by establishing an open and indelible record for carbon credit transactions. Such increased transparency engenders trust among stakeholders, increasing participation by local communities, policymakers, and investors. Additionally, monitoring forests in real time through satellite technology allows local governments and community organizations to respond in a timely fashion against deforestation, further building stakeholder trust in the system [35], [36].

1. Addressing Policy and Implementation Challenges

While the combination of AI, satellite technology, and blockchain is promising, it also creates challenges which need policy and operating changes. An example is that the expense of rolling out these technologies could be prohibitive for use in poor districts. Support from governments and foreign funding systems will be required to help ensure such models can scale.

Additionally, successful implementation would include capacity development to empower the stakeholders to execute advanced technologies. This includes familiarization with blockchain mechanism among natives and empowering the forest management team to utilize AI and satellite systems.

2. Broader Implications for Carbon Markets

The entrepreneurial innovation model demonstrated via this study has international application in the carbon market. Neutralizing inefficiencies and mistrust, the model provides a viable system that can be applied in other high-risk forests worldwide. Furthermore, the application of innovations at the frontiers of technology aligns with international climate targets, such as those agreed to under the Paris Agreement, through ensuring sustainable forest management and enhancing the credibility of carbon markets.

3. Limitations and Future Research

Although the study presents significant advancements, there are limitations that need to be addressed.

a. Cost and Accessibility: The expense of AI, satellite, and blockchain technologies might serve as a hindrance to using them across the board. Future studies will have to examine cost-cutting and alternative financing arrangements.
b. Sustained Viability: The findings of the research are dependent on a brief pilot period. Long-term research is necessary so as to identify whether the proposed model is scalable and sustainable.
c. Regulatory Frameworks: Lack of uniform regulatory frameworks for carbon trading based on blockchain could hinder implementation. Policymaking should be studied more to supplement these innovations.

5. CONCLUSION

The application of AI, satellite data, and blockchain in REDD+ initiatives presents a revolutionary approach to forest conservation and carbon trading challenges. The study confirms that the proposed model enhances the precision of carbon stock estimation, streamlines deforestation monitoring, and facilitates transparency and trust among stakeholders through blockchain-secured transactions. Though prospective, the model is faced with challenges such as prohibitively expensive setup costs and training requirements for stakeholders, on which it significantly depends on aggressive policy incentives, international funding, and capacity building programs. Even with its scalability and adaptability, a new business model like this has staggering replication potential in other high-risk forest regions of global climatic change adaptation and sustainable development goals (SDGs). Through the creation of the integration of new technologies, this study lays the foundation for more efficient and trustworthy carbon markets, with compliance with international climate agreements, such as the Paris Accord, while improving sustainable forest management practices.

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