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Digital Transformation in Carbon Trading: Combination of Satellite and Blockchain Technology in REDD+ Schemes

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ABSTRACT

Digitalization has introduced advanced technologies that can potentially revolutionize carbon trading systems, particularly in REDD+ programs. This study examines the application of satellite and blockchain technologies to enhance REDD+ programs. Satellite technology provides real-time, high-resolution forest imagery, ensuring accurate carbon stock measurement, while blockchain offers secure, transparent, and efficient carbon credit exchange platforms. With a combination of GIS analysis, literature review, and expert interviews, the study proposes an integrated framework that automates Monitoring, Reporting, and Verification (MRV) processes and prevents fraud in carbon trading. The findings indicate that combining these technologies can significantly enhance REDD+ credibility and scalability, but challenges such as high implementation costs, loopholes in regulations, and technical complexities must be addressed. This research maps the journey towards incorporating emerging digital technologies in climate change mitigation efforts.

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1. INTRODUCTION

Climate change remains one of the most pressing challenges of the 21st century, necessitating innovative responses to mitigate its effects and increase sustainable development. Among the responses, carbon trading has emerged as a market-based solution to restrict greenhouse gas emissions by assigning economic value to carbon sequestration and emission reduction [1], [2]. In this scenario, REDD+ (Reducing Emissions from Deforestation and Forest Degradation) schemes have become an important tool to combat deforestation, maintain biodiversity, and enhance carbon sequestration in forests [3], [4]. However, despite its potential, REDD+ faces stringent challenges, including the need for accurate monitoring, transparent reporting, and secure verification systems.

The rapid development of digital technologies offers promising opportunities to surmount these challenges and enhance the performance of carbon trading schemes. Satellite technology, through its promise of providing high-resolution spatial and temporal data, has revolutionized forest monitoring by enabling precise estimation of deforestation and changes in carbon stocks [5], [6]. Meanwhile, blockchain technology—a decentralized, immutable ledger system—ensures transparent, secure, and tamper-proof recording of transactions, addressing

salient issues such as data manipulation and fraud in carbon markets [7], [8].

The study investigates the use of satellite and blockchain technologies in REDD+ mechanisms to enhance the overall effectiveness of carbon trading. Through Geographic Information System (GIS) analysis, the study utilizes satellite data to monitor forest cover changes and forecast carbon stocks with precision. Meanwhile, blockchain is utilized in documenting transactions of carbon credits to ensure trust and transparency among actors. This two-fold approach is designed to address the flaws in traditional REDD+ implementations, fostering greater accountability and stakeholder confidence.

Urgency

The increasing impacts of climate change, including rising global temperatures, extreme weather events, and biodiversity loss, emphasize the urgent need for effective mitigation. Deforestation and forest degradation are among the leading causes of greenhouse gas emissions, accounting for around 10-15% of global emissions. REDD+ initiatives were mooted as a solution to such emissions by offering incentives for conservation and sustainable management of forests [9], [10]. But the perennial problems of flawed monitoring, weak reporting mechanisms, and lack of transparency in carbon trading risk derailing the success of such initiatives.

The multibillion-dollar international carbon market needs an efficient mechanism to ensure the integrity of carbon credits. Traditional forest monitoring and carbon accounting methods rely on manual or outdated processes, which are prone to inconsistencies and errors [11], [12]. Furthermore, the absence of secure and transparent mechanisms has led to double-counting of credits, data manipulation, and fraud, eroding stakeholder trust [9], [13]. These drawbacks necessitate the adoption of cutting-edge digital technologies to enhance the reliability, efficiency, and accountability of REDD+ initiatives.

While REDD+ programs have tremendous potential in reducing deforestation and greenhouse gas emissions, their effectiveness is undermined by inherent operational and systemic issues. Traditional forest monitoring approaches often are unable to provide accurate, real-time data on deforestation and carbon stock changes, limiting the ability to assess the true impact of conservation programs. In addition, existing carbon trading systems are opaque and insecure, which not only creates avenues for fraud but also reduces stakeholder confidence.

These challenges are also exacerbated by the lack of integration between transaction platforms and monitoring systems, which leads to inefficiencies and increased administrative costs. These problems not only threaten the integrity of REDD+ schemes but also their uptake and scalability globally. These challenges demand a revolutionary approach that combines innovative monitoring technologies with transparent and secure transaction systems to build an efficient and credible carbon trading system.

The objectives of this paper are threefold: (1) to explore the role of satellite technology in improving forest monitoring and carbon stock estimation, (2) to analyze the application of blockchain technology in increasing transparency and security in carbon credit trading, and (3) to propose an integrated system combining these technologies for facilitating REDD+ programs. The findings aim to contribute to the growing body of knowledge on digital transformation in climate change mitigation and offer practical information for policymakers and practitioners involved in carbon trading and forest conservation.

2. LITERATURE REVIEW

2.1 REDD+ Schemes: Aims, Issues, and Prospects

The REDD+ framework incentivizes developing countries to protect forests while providing economic benefits to local communities and promoting biodiversity conservation. However, challenges such as

limited financial resources, governance issues, and inadequate Monitoring, Reporting, and Verification (MRV) systems hinder its effectiveness. REDD+ projects typically offer a mix of monetary and non-monetary benefits, with over 75% providing employment opportunities, along with infrastructure development and public services that enhance local livelihoods [14]. However, financial constraints and governance problems remain significant barriers to implementation, particularly in Phase 1 countries still developing their MRV capacities to meet UNFCCC standards [15], [16]. Robust MRV systems are essential for ensuring REDD+ credibility, yet traditional methods are costly and error-prone [17]. Technological advancements in MRV can improve efficiency and accuracy, potentially enhancing project outcomes [16]. This necessitates urgent need for sophisticated technological solutions for improved accuracy and efficiency in forest monitoring and carbon accounting.

2.2 The Use of Satellite Technology in Forest Monitoring

Satellite technology is crucial for monitoring deforestation and estimating forest carbon stocks using advanced remote sensing techniques. High-resolution imagery and machine learning algorithms enable accurate land cover tracking, supporting REDD+ initiatives and improving forest management decisions. Methods like Random Forest and Extreme Gradient Boosting enhance carbon stock estimation from satellite data [18], while high-resolution images facilitate deforestation monitoring for timely conservation efforts [19]. LiDAR and hyperspectral imaging further refine biomass measurement and carbon sequestration estimates [20]. Integrating multi-source data, including SAR and optical imagery, significantly improves forest change mapping accuracy [21]. These advancements strengthen forest management and climate mitigation efforts [22], though real-time monitoring systems remain essential for adaptive policy responses. However, the problem of high cost, limited access to high-resolution data, and technical expertise remains significant barriers to large-scale adoption, particularly in developing countries.

2.3 Blockchain Technology in Carbon Trading

Blockchain technology is transforming carbon trading by enhancing transparency, security, and efficiency. Its decentralized and tamper-proof nature addresses issues like double-counting and fraud, fostering trust among stakeholders. An immutable ledger ensures accurate carbon credit tracking, preventing discrepancies and boosting market confidence [23], [24]. Smart contracts automate transactions, minimizing human error and fraud while reducing administrative costs [25]. Real-time data visualization further supports decision-making and operational efficiency [24] However, challenges such as scalability, high energy consumption, and regulatory complexities hinder widespread adoption [26], [27], posing obstacles to full blockchain integration in carbon markets.

2.4 Integration of Satellite-Blockchain

The integration of satellite and blockchain technologies offers a transformative approach to enhancing REDD+ programs by improving monitoring and transaction transparency. Satellite technology enables real-time tracking of forest changes, providing continuous updates on forest cover and serving as verifiable evidence for carbon credit claims, thereby strengthening emissions reduction credibility. Meanwhile, blockchain ensures secure and transparent carbon credit transactions through its decentralized ledger, reducing fraud and double-counting risks [8], [28]. Smart contracts further enhance cost efficiency by automating processes and lowering administrative costs [25], [29]. This synergy fosters accountability and trust among stakeholders, including governments, NGOs, and the private sector, while promoting a collaborative ecosystem that encourages sustainable practices and compliance with environmental regulations [28], [30]. Effective application of these technologies, however, requires overcoming

interoperability, data privacy, and access to technical skills problems.

2.5 Research Gaps

While considerable research has been undertaken on the application of blockchain and satellite technologies to carbon markets, there are gaps that can be identified. Little research is carried out on their application to practice in the case of REDD+ projects, particularly in developing countries. It has also been the practice for research to focus on individual technology without attention given to how a synergy of using them collectively would impact outcomes. This research attempts to fill these gaps by crafting an integrated framework that integrates satellite and blockchain technologies to facilitate improved REDD+ delivery and carbon markets.

3. METHODS

3.1 Study Design

The study employs an exploratory study design to investigate the feasibility of integrating advanced digital technologies into REDD+ programs. A combination of qualitative GIS analysis and literature review is employed to analyze the feasibility, advantages, and limitations of this integration.

3.2 Data Collection

The study utilizes secondary data from peer-reviewed journals, UNFCCC reports, and blockchain-based carbon trading platforms through academic journals, reports, and case studies of REDD+ implementation, satellite technology, uses of blockchain for carbon trading, and climate change mitigation. High-resolution satellite data from NASA's Earth Observatory, Copernicus Sentinel satellites, and Google Earth Engine are used to quantify changes in forest cover, deforestation patterns, and carbon stocks. In addition, semi-structured interviews of climate policy, blockchain, and forestry experts like policymakers and technology developers provide information on opportunities and challenges related to the integration of the technologies.

3.3 Data Analysis

The data are processed and analyzed using GIS tools to investigate forest cover change monitoring, deforestation rates, and carbon stock estimation with a focus on those areas with active REDD+ projects to illustrate the application of satellite technology to enhance MRV systems. Thematic analysis is employed to integrate literature and expert interview qualitative data through coding and categorizing information to identify recurring themes that relate to the integration of blockchain and satellite technologies in carbon trading. Based on GIS and thematic analysis findings, a conceptual model is generated to illustrate how these technologies integrate into REDD+ programs, such as key components such as data collection, verification, issuance of carbon credits, and transaction tracking.

4. RESULTS AND DISCUSSION

This elaborates on the implications of integrating satellite and blockchain technologies in REDD+ initiatives. The results are discussed in three main areas: the efficacy of satellite technology in monitoring forest cover change, the use of blockchain to enhance carbon trading, and the proposed framework for integrating these technologies to improve REDD+ implementation.

4.1 Efficacy of Satellite Technology in Monitoring Forest Changes

The GIS analysis using satellite imagery indicated significant improvement in monitoring deforestation and forest degradation in REDD+ scheme areas. Some of the key results include high-resolution forest cover data from Sentinel-2 and Landsat platforms, which provided reliable information on forest cover change and deforestation hotspots. Temporal analysis from time-series data enabled deforestation trends to be monitored over time, giving information on seasonal and human-induced forest cover changes. In addition, estimation of the carbon stock was improved by merging LiDAR and hyperspectral data so that carbon accounting and above-ground biomass could be assessed better.

These findings support that satellite technology is a good way to enhance the Monitoring, Reporting, and Verification (MRV) systems required for REDD+ implementation. There remain limitations, however, particularly regarding access to data and the need for technical know-how to analyze and process satellite data, which could prove a weakness for developing countries.

4.2 Blockchain's Role in Enhancing Carbon Trading

The analysis of the application of blockchain in carbon trading revealed several benefits. Blockchain's distributed ledger technology delivered security and transparency by rendering all carbon credit transactions unalterable, putting an end to fraud and double counting issues in traditional carbon markets. Smart contracts also enabled automatic transfer and issuance of carbon credits based on validated satellite data, reducing transaction time and expense significantly. Furthermore, the irrevocability of blockchain records established greater trust among stakeholders like governments, investors, and host communities.

Despite these advantages, there are difficulties, namely the scalability, inordinate energy consumption, and uncertainty regarding regulations that discourage large-scale uptake. The overcoming of such difficulties is necessary to unlock the full potential of blockchain technology within carbon markets as well as ensure its successful assimilation into the global climate reduction agenda.

4.3 Integrated Framework for REDD+ Schemes

Satellite and blockchain technologies being combined is offering a paradigmatic approach to addressing the flaws in the implementation of REDD+. The planned framework consists of several key components: data gathering and validation, where satellite technology gathers real forest data, processed and validated with GIS software; carbon credit issuance, where validated data is used for calculating carbon sequestration and issuing carbon credits through automated blockchain smart contracts; tracking of transactions, where all carbon credit transactions are stored securely on the blockchain in order to enhance transparency and fraud prevention; and stakeholder engagement, where arrangements to involve local communities and governments in tracking and decision-making processes.

This unified platform highlights the way these technologies support each other. Satellite technology improves the accuracy and reliability of forest monitoring, while blockchain provides a secure yet effective method of carbon trading. By combining these innovations, REDD+ initiatives can enhance their Monitoring, Reporting, and Verification (MRV) systems to build trust and efficiency in carbon markets.

4.4 Discussion

Satellite and blockchain integration has immense potential for the facilitation of REDD+ implementation, in line with previous research that emphasizes the need for improved Monitoring, Reporting, and Verification (MRV) systems. Satellites have been shown to enhance the accuracy of forest monitoring, while blockchain ensures maximum transparency and security in carbon credit transactions. The proposed framework boosts REDD+ credibility by applying accurate data gathering and secure transactions, reducing administrative costs through automation, and offering scalability for increased participation in global carbon markets. These advantages align with earlier studies that emphasize the potential of digital innovations in enhancing environmental governance and facilitating efficient carbon trading mechanisms [8], [31], [32].

Challenges remain, however, as observed in earlier studies on technology adoption in climate finance. Deploying these technologies to success hinges on overcoming technical and cost challenges, particularly in the developing world where capacity and investment may be constrained. Interoperability between blockchain platforms and satellite data systems is also a key technical challenge that requires further

research and development. Uncertainty regarding regulations is another challenge, as the lack of standardized frameworks for carbon trading on blockchain affects market stability and legal recognition. Mitigating such issues is central to realizing the full potential of satellite and blockchain use in REDD+ and its sustained effectiveness in global climate change mitigation efforts.

4.5 Policy and Practical Implication

The findings underscore the need for supportive policies to facilitate the efficient use of satellite and blockchain technology in REDD+ projects. Governments and multilateral organizations should prioritize capacity building by providing training programs to stakeholders, legislative reforms to establish legal frameworks for blockchain-based carbon markets, and joint platforms to facilitate collaboration between technology providers, governments, and local communities in order to bridge the gaps of implementation. These technologies are a major milestone toward making REDD+ more efficient and scalable. With the overcoming of present barriers, this solution has the potential to be a crucial contribution towards global action against climate change as well as sustainable forest management.

5. CONCLUSION

Satellite and blockchain conjoinment is a groundbreaking opportunity to enhance the rollout and effectiveness of REDD+ initiatives. Satellite technology allows for precise and current forest cover and carbon stock mapping, addressing some of the key MRV process hurdles. Blockchain improves these features by ensuring safe, clear, and efficient carbon credit trading, establishing stakeholder confidence. The model presented in this paper shows how these technologies can be integrated to automate the majority of procedures, reduce administrative costs, and enhance the validity of REDD+ activities. However, despite such advantages, financial costs, technical expertise, and regulatory uncertainty are significant challenges to widespread adoption.

To realize the full potential of these technologies, collaboration among policymakers, technology firms, and international organizations is essential. Capacity building, the establishment of regulatory environments, and the development of innovative financing tools for implementation should be prioritized. By addressing these challenges, the intersection of satellite and blockchain technologies can contribute significantly to global action against deforestation, greenhouse gas emissions reduction, and sustainable development goals.

REFERENCES

for Carbon Trading," in *2024 IEEE International Conference on Blockchain and Distributed Systems Security (ICBDS)*, IEEE, 2024, pp. 1–6.

[3] M. M. Keerthi, "Innovative Approaches to Carbon Sequestration Emerging Technologies and Global Impacts on Climate Change Mitigation".

[4] S. Dixit and S. Bardiya, "Carbon Trading in Developing Economies: Challenges, Opportunities, and Best Practices," *International Journal For Multidisciplinary Research*, 2024, [Online]. Available: https://api.semanticscholar.org/CorpusID:274047746

[5] S. Chiquier, A. Gurgel, J. Morris, Y.-H. H. Chen, and S. Paltsev, "Integrated assessment of carbon dioxide removal portfolios: land, energy, and economic trade-offs for climate policy," *Environmental Research Letters*, vol. 20, no. 2, p. 024002, 2025.

[6] S. Mondal and D. Palit, "Climate Change Mitigation Through Sustainable and Climate-Smart Agriculture," *Ecosystem Management: Climate Change and Sustainability*, pp. 23–54, 2024.

[7] H. Shu, "Research on Innovation Mechanism and Realization Path of Carbon Finance under the Goal of 'Double Carbon,'" *Economics, Law and Policy*, 2024, [Online]. Available: https://api.semanticscholar.org/CorpusID:273094678

[8] 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.

[9] K. K. Hira, "Climate mitigation and adaptation with challenges, opportunities, and solutions," *International Journal of Advanced Mass Communication and Journalism*, 2025, [Online]. Available:

https://api.semanticscholar.org/CorpusID:275475597
[10] K. Psistaki, G. Tsantopoulos, and A. K. Paschalidou, "An overview of the role of forests in climate change mitigation," *Sustainability*, vol. 16, no. 14, p. 6089, 2024.
[11] J. Kurniawan, A. Razak, N. Syah, S. Diliarosta, and A. Azhar, "Pemanasan Global: Faktor, Dampak dan Upaya Penanggulangan," *INSOLOGI: Jurnal Sains dan Teknologi*, vol. 3, no. 6, pp. 646–655, 2024.
[12] A. A. Qutbi, M. Sarjan, and T. Sjah, "Dampak Perubahan Iklim terhadap Keanekaragaman Hayati dan Kesehatan Lingkungan," *Lamda: Jurnal Ilmiah Pendidikan MIPA dan Aplikasinya*, vol. 4, no. 2, pp. 113–119, 2024.
[13] A. R. Mostafa, A. M. Owes, and S. Ghoniem, "Interconnected Impacts of Climate Change on Biodiversity, Agriculture, and Human Health," *Advances in Basic and Applied Sciences*, 2025.
[14] V. Theresia, S. S. Atmadja, and E. Lieberherr, "Global analysis of the proposed benefits from REDD+ projects," *Environmental Research Letters*, 2024.
[15] H. Yang, M. Song, H. Son, R. Kim, and E. Choi, "Evaluating REDD+ Readiness: High-Potential Countries Based on MRV Capacity," *Forests*, vol. 16, no. 1, p. 67, 2025.
[16] E.-K. Jang, D. Kwak, G. Choi, and J. Moon, "Opportunities and challenges of converging technology and blended finance for REDD+ implementation," *Frontiers in Forests and Global Change*, vol. 6, p. 1154917, 2023.
[17] A. N. Mwambala, "Carbon and Biodiversity Co-benefits in Tropical Forest and Agroforestry Ecosystems: A review," *Tanzania Journal of Science*, vol. 50, no. 4, pp. 724–736, 2024.
[18] A. Nguyen and S. Saha, "Machine Learning and Multi-source Remote Sensing in Forest Carbon Stock Estimation: A Review," *arXiv preprint arXiv:2411.17624*, 2024.
[19] C. W. Rawarkar and S. Agrawal, "Analyzing the Role of Machine Learning and Satellite Image Processing in Predicting Deforestation," in *2024 2nd DMIHER International Conference on Artificial Intelligence in Healthcare, Education and Industry (IDICAIEI)*, IEEE, 2024, pp. 1–6.
[20] B. Hosseiny, M. Zaboli, and S. Homayouni, "Forest Change Mapping using Multi-Source Satellite SAR, Optical, and LiDAR Remote Sensing Data," *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, vol. 10, pp. 163–168, 2024.
[21] I. R. McGregor, G. Connette, and J. M. Gray, "A multi-source change detection algorithm supporting user customization and near real-time deforestation detections," *Remote Sens Environ*, vol. 308, p. 114195, 2024.
[22] S. Illarionova, P. Tregubova, I. Shukhratov, D. Shadrin, A. Efimov, and E. Burnaev, "Advancing forest carbon stocks' mapping using a hierarchical approach with machine learning and satellite imagery," *Sci Rep*, vol. 14, no. 1, p. 21032, 2024.
[23] 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," *International Journal of Research and Innovation in Applied Science*, vol. 9, no. 12, pp. 688–714, 2024.
[24] Y.-C. Tsai, "Enhancing Transparency and Fraud Detection in Carbon Credit Markets Through Blockchain-Based Visualization Techniques," *Electronics (Basel)*, vol. 14, no. 1, p. 157, 2025.
[25] S. Saraji and M. Borowczak, "A blockchain-based carbon credit ecosystem," *arXiv preprint arXiv:2107.00185*, 2021.
[26] 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 at SSRN 5082355*.
[27] P. K. Patro, R. Jayaraman, A. Acquaye, K. Salah, and A. Musamih, "Blockchain-based solution to enhance carbon footprint traceability, accounting, and offsetting in the passenger aviation industry," *Int J Prod Res*, pp. 1–34, 2024.
[28] S. A. Kalaiselvan, J. S. P. Venkatesh, A. M. V. Kumar, and K. R. Karthik, "Blockchain Powered Carbon Credit Marketplace," in *2024 10th International Conference on Communication and Signal Processing (ICCSP)*, IEEE, 2024, pp. 582–585.
[29] S. Jawalkar, R. Shende, R. Selokar, S. Sendre, and R. Vairagde, "Carbon Credit Transfer System using Blockchain," in *2024 Third International Conference on Intelligent Techniques in Control, Optimization and Signal Processing (INCOS)*, IEEE, 2024, pp. 1–6.
[30] Y. Wen, J. Li, and Y. Chen, "Design and Implementation of Carbon Accounting Information System Based on Blockchain," in *2024 Second International Conference on Cyber-Energy Systems and Intelligent Energy (ICCSIE)*, IEEE, 2024, pp. 1–6.
[31] J. Reiche *et al.*, "Integrating satellite-based forest disturbance alerts improves detection timeliness and confidence," *Environmental Research Letters*, vol. 19, no. 5, p. 054011, 2024.
[32] H. He, Y. Shang, X. Zhang, J. Yin, S. Deng, and M. Han, "The Application of Blockchain Technology in the Area of Satellite Remote Sensing Data," in *2024 12th International Conference on Agro-Geoinformatics (Agro-Geoinformatics)*, IEEE, 2024, pp. 1–6.