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SHORT-PAPER

A FAIR Public Permissioned Blockchain System for monitoring Deforestation in the Amazon

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A FAIR Public Permissioned Blockchain System for monitoring Deforestation in the Amazon

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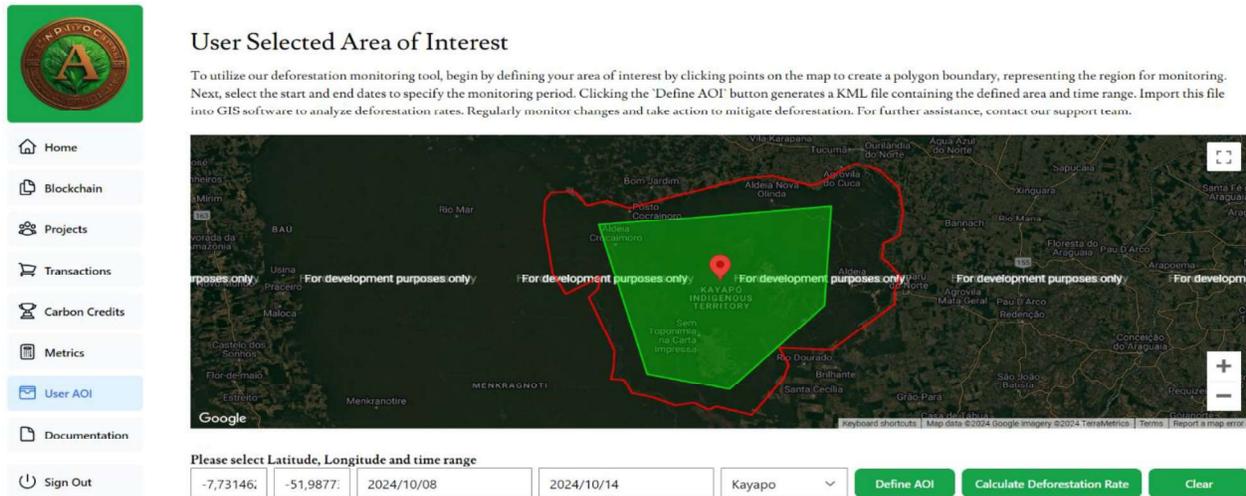


Figure 1: A user-defined AOI as a green triangle, marking the area for analysis. The user can download a KML file by pressing "Define AOI" or trigger satellite image analysis deforestation with "Calculate Deforestation Rate," storing the output on the blockchain.

ABSTRACT

The AetherForest.ai system is a FAIR-based, computer vision-enabled, blockchain-based carbon market infrastructure designed to responsibly track deforestation rates in user-selected geographical areas using satellite imagery while ensuring government oversight. It incorporates accountability through its transparent data storage on a public permissioned blockchain, providing a verifiable record of all analyses. The system is designed with transparency in mind, allowing equal access to data and the ability to review established projects. By using satellite image analysis powered by Google Earth Engine and focusing on Sentinel and Landsat satellites, the system offers transparency in both process and results. Adequacy is ensured through its AI forecasting capabilities for deforestation and afforestation, which provide scientifically verified, actionable insights. Additionally, users can select areas of interest, time points, and access results saved on the blockchain with a unique CID from IPFS, able to replicate findings and thus promoting transparency and long-

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term accountability. Its inclusive approach engages the public, professionals, and researchers in environmental monitoring, fostering a transparent and responsible collaboration for conservation efforts, fostering policy recommendations with openly scientifically verifiable results.

CCS CONCEPTS

•Computing Methodologies → Artificial Intelligence; •Human-centered computing → Ubiquitous and mobile computing → Ubiquitous and mobile devices;

KEYWORDS

blockchain, public permissioned, spatial analytics, FAIR, satellite imagery, deforestation, machine learning

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1. Introduction

Motivation. Deforestation, the extensive removal of forests, has profound consequences spanning from biodiversity loss and the release of stored carbon, to contributing to global warming.

Ecosystems are disrupted, impacting water cycles, soil fertility, and overall environmental resilience. Accurate monitoring of deforestation rates is crucial for maintaining ecological balance, mitigating climate change, and fostering sustainable development. Traditional systems such as secured databases rely on a central authority to manage and verify data. While these databases can be highly secure, they are prone to tampering or errors if the central authority is compromised [1]. Instances where satellite data was manipulated or falsified are not uncommon: for example, in 2019, Brazil faced allegations that deforestation rates were underreported, distorting the actual extent of deforestation in the Amazon¹. Tampering with or falsifying satellite data is also becoming increasingly concerning, especially as AI technologies advance. A study by Zhao et al. (2021) [2] highlights how "deepfake geography" is used to manipulate satellite imagery, posing significant risks for data integrity. These challenges underscore the urgent need for robust, unbiased, and tamper-resistant monitoring systems to inform evidence-based decision-making, and aid in biodiversity preservation and the protection of ecosystem services [3]. In this regard, the integration of blockchain technology and zero-knowledge proofs (ZKPs), provide an essential layer of trust that traditional systems cannot offer. Blockchain creates a decentralized, immutable, and verifiable record for afforestation/deforestation monitoring through satellite imagery analysis, ensuring that all data is public, tamper-evident, and transparent. In this capacity, blockchain technologies can act as a safeguard against sophisticated tampering attempts, by making any data modifications publicly visible and instantly verifiable, building public trust and holding stakeholders accountable [4]. ZKPs add an extra layer of security to blockchains by allowing the verification of deforestation data without revealing sensitive information², ensuring privacy is maintained [5]. Consequently, these technologies jointly enhance transparency, fostering public trust and accountability [6]. Decentralized data access empowers various stakeholders, promoting collaboration in forest monitoring and ensuring that no single entity controls the system [7]. Smart contracts on the blockchain automate sustainable forestry agreements, incentivizing afforestation and discouraging illegal logging [8]. This transparency encourages public participation in supporting sustainable practices, ensuring a secure and decentralized system for environmental data integrity [9]. The integration of deforestation monitoring with a blockchain based voluntary carbon market allows for better oversight and management of carbon credits, optimizing the benefits of voluntary carbon markets on fighting against climate change [10 – 12].

Our Approach. In this paper we introduce a decentralized application (dApp)³ designed to define deforestation rates on captured geographical user input or established Payment for Ecosystem Services (PES) Projects' surveillance, through the application of machine learning algorithms. The system upholds accountability by ensuring that the results directly inform the disbursement of an attached carbon market's credits, with all transactions and data transparently stored on a peer-reviewed

¹ More information on the alleged Amazon deforestation data manipulation may be found at this link

² This is particularly important in regions where land disputes or illegal logging occur. In these cases, revealing sensitive geographic information can escalate conflicts or expose vulnerabilities. Using ZKPs, involved parties can securely demonstrate compliance or verify activities without revealing specific details, maintaining the balance between transparency and privacy.

and openly accessible blockchain. This guarantees transparency by providing equal access to information and ensuring that the credit allocation process is both unbiased and verifiable. The platform's integration of projections and relevant metrics ensures adequacy, offering stakeholders clear, data-driven insights that are easily comprehensible. Transparency is further reinforced by the open accessibility of both the results and the methodology used, enabling stakeholders to independently verify the findings and participate in an equitable and accountable carbon market.

2. System Architecture

In this section we demonstrate AetherForest.ai's underlying system architecture and a description of relevant functionalities aimed to interested academics, organizations, and the public.

The proposed public permissioned blockchain architecture aims to provide a decentralized and transparent system template for managing voluntary carbon markets [13]. This blockchain system will leverage FAIR principles to ensure that it is Findable, Accessible, Interoperable, and Reusable [14]. The system consists of six layers, addressing the following components [15]: (i) **blockchain**, (ii) **network**, (iii) **data**, (iv) **Api**, (v) **applications** and (vi) **governance**.

In the heart of the **Blockchain Layer** lies the consensus mechanism, choosing a suitable one for a public permissioned blockchain [15]. Smart Contracts guide blockchain decision making aimed at managing land use and resource extraction processes. These contracts are designed to be transparent, auditable, and secure and are Solidity based. Transactions are facilitated through a native test token, "AetherCoin" (ATC), instrumenting carbon credits in a virtual environment, ensuring easy transferability and traceability of pertinent transactions. The tokens are awarded either to the public as an incentive to contribute towards environmental monitoring, towards beneficiaries of PES schemes with the added benefit of proving land ownership, or finally traded between sponsors of the aforementioned schemes aiming to offset their carbon emissions by participating in Voluntary Carbon Credit markets with the embedded smart contracts proving respective resource extraction permits. Finally, a robust identity management system is used to ensure that participants on the blockchain are authorized entities. This can involve integration with existing government identification systems, that also facilitate administrative and regulatory oversight of the blockchain's transactions.

The **Network Layer** is a peer-to-peer network enabling decentralized communication between nodes. This enhances fault tolerance and ensures that the system operates without a central point of failure. Robust encryption and security protocols are used to protect the integrity and confidentiality of data on the blockchain.

The **Data Layer** consists in a Distributed Ledger used to record transactions in a tamper-proof manner. This ensures that data is

³ A decentralized application (dApp) is a web-based app powered by blockchain within the Web3 framework (Web3 refers to the decentralized internet infrastructure built on blockchain technology). It uses smart contracts to automate tasks and record actions transparently on the blockchain, ensuring security and verifiability without central control. This decentralized structure allows for peer-to-peer interactions and tamper-proof execution of operations [15].

immutable and transparent, as well as standardised in accordance with FAIR principles, making it easier to Find, Access, Interoperate, and Reuse data, and employing open standards for data representation. Data Privacy ensures the protection of sensitive information, using zero-knowledge proofs to enable data verification without revealing the actual data. Results are visualized on a dashboard, saved on the blockchain, and can be retrieved using a unique Content Identifier (CID) from IPFS.

The **API Layer** ensures Interoperability and Accessibility as APIs allow seamless integration with external systems, enabling collaboration between different government agencies, consortiums, or stakeholders such as the public and beneficiaries.

The **Application Layer** features a decentralized application (dApp) framework built on Django, Next.js, and React.js, providing a web-based dashboard or mobile application interface. This user-friendly interface (UI) allows government officials, Indigenous communities, and other stakeholders, such as the public, to seamlessly interact with the blockchain. On the backend, satellite imagery is integrated through Python-enabled Google Earth Engine APIs triggered by a Django API to monitor deforestation rates through satellite image analysis, where user-defined Areas of Interest (AOI) are pre-processed using NDVI and cloud mask filters. The data is then split into training and test sets for Random Forest Algorithm analysis, identifying deforestation and afforestation between two user-specified points in time. The processed data is then fed into the blockchain, ensuring transparency, result verifiability, and accountability. For this purpose, a Solidity smart contract is deployed on a local Hardhat blockchain to manage the issuance of carbon credits based on predefined clauses overseen by a regulatory authority. An SQL database handles the flow of carbon credits, while an IPFS database stores metadata for each automated carbon credit issuance. On the front end, the Next.js and React.js app visualizes metrics through a Power BI dashboard, providing easy access to the platform's functionalities.

Finally, the **Governance Layer** involves a mock governance framework used for decision-making processes related to system's source code, complying with relevant legal and regulatory frameworks.

3. System Functionality

UI Functionalities. The system is a Decentralized Web App and following a login landing page, is comprised of two panes: one including a routing of eight sections and the other demonstrating relevant content:

1. **Home**, providing an overview of the app's functionality.
2. **Blockchain**, showing the blockchain containing the carbon market functioning with relevant timestamps and hashes.
3. **Projects**, providing an overview of the registered projects of the platform.
4. **Transactions**, allowing for the carbon market's functionality on terms of carbon credit emission and carbon offsets claimed by participating actors;
5. **Carbon Credits** provides an SQL table with all the blockchain carbon credits automatically emitted through the satellite analysis per project.

6. **Metrics**, showing a quantification of selected participating projects' relevant indicators.
7. **User AOI** (Figure 1), for the user identified Area of Interest (AOI)⁴; and Documentation, providing links to the whitepaper and open source GitHub code as per the FAIR principles.

The platform, consisting in a public permissioned blockchain has three access levels:

1. **Public**, allowing any member of the public to interact with the app, with the exception of the Transactions section.
2. **Beneficiaries** who are able to access all areas of the app with the exception of some Transaction section functionalities; and
3. **Consortium**, which are the governing body of the dApp and have unrestricted access to all levels.

A. Beneficiary Perspective: Indigenous Community

Scenario: Sustainable Fund Disbursement – The Indigenous community, as beneficiaries, access AetherForest.ai through a user-friendly interface tailored to their local context and language. The community navigates to the “Projects” tab and chooses their respective land management project. Here, they submit evidence of their ongoing conservation efforts, such as maintaining specific forest cover. The smart contract, integrated with IoT devices and AI models, validates the submitted data in real-time. This includes metrics like forest cover, land-use changes, and satellite imagery, ensuring the accuracy of the information. Upon successful validation, the smart contract automatically triggers the disbursement of funds to the Indigenous community. The transparent and tamper-proof nature of the blockchain ensures that the funds are allocated solely for their intended purpose. Finally, the community receives real-time updates on the blockchain regarding the fund disbursement by navigating to the “Blockchain” tab and searching the hash number of their submitted transaction, enabling them to track their progress and the impact of their conservation efforts. This fosters trust and accountability. If they wish to trade their gained carbon credits to a corporation financing their Payment for Ecosystem Service scheme, they can do so in the “Transactions” section through the “Transfer Triggered AetherCoin Carbon Credits” functionality.

B. Consortium Perspective: Government and Conservation Organizations

Scenario: Transparent Monitoring and Governance - Government and conservation organizations log in to AetherForest.ai using their credentials to access the blockchain-based consortium's data securely. The consortium reviews smart contracts governing land management projects directly from the dApp's backend with the help of a developer and auditor. They assess the sustainability criteria defined within each contract and verify the data submitted by involved communities in the “Projects” tab, such as the public, first nations or researchers. Consortium members then utilize the transparent and real-time information provided by the blockchain to make informed governance decisions. This may include adjusting funding through carbon token emission or implementing sanctions through the smart contract. Finally, the

⁴ Area of Interest or AOI, refers to a geographical region that is being examined or studied for satellite imagery analysis.

consortium collaborates seamlessly through the attached blockchain's social media platform (commonly [Discord](#)), exchanging insights, making announcements to stakeholders, and collectively contributing to the effective governance of associated land management projects.

C. General Public Perspective: Environmental Enthusiast

Scenario: Transparent Carbon Credit Market Exploration – A public user interested in environmental conservation explores AetherForest.ai. The user accesses the blockchain's user-friendly interface to learn about carbon credit projects in the Amazon or define their own area of interest to determine relevant deforestation rates. The user can explore specific smart contracts related to carbon credit initiatives through the open-access GitHub repository in the dApp's "Documentation" section. The blockchain provides detailed information on each project's emitted tokens, including metrics on avoided deforestation, carbon sequestration, and community impact, which the user can download through IPFS with a CID code per project transaction. The user can gain insights into transactions within the carbon credit market and metrics and projections on associated projects in the "Metrics" section, which includes graphs and projections generated through an interactive PowerBI embedded app. Transparent, replicable, and traceable information on credit distribution and utilization helps the general public understand or verify the impact of their potential contributions by running the code on their machines and cross-checking the results. The blockchain platform also offers educational resources and links to external data sources in the "Documentation" section, enhancing the user's understanding of environmental challenges, Indigenous rights, and the role of blockchain in sustainable practices.

4. CONCLUSION

This paper presents AetherForest.ai, a dApp infrastructure, which can determine deforestation rates across user-selected geographical locations using publicly available satellite imagery. It facilitates a blockchain-based integrated carbon market with government and regulatory oversight. The system promotes transparency and accountability through its FAIR-based public permissioned blockchain-powered voluntary carbon market in public governance, illustrating a case study at the crossroads of climate change, natural resource management, and Indigenous rights. By entrusting the public and beneficiaries with environmental monitoring for forest and land management, the technology enables transparency and responsibility. The study affirms the transformative impact of public permissioned blockchain technology on traditional administrative systems, bolstering existing literature. Attributes like decentralized decision-making, distributed ledgers, and advanced cryptography enhance efficiency in public administration. These qualities make public permissioned blockchains superior and adequate alternatives for sectors like public land governance, aligning with United Nations Sustainable Development Goal (SDG) objectives for enhanced security, transparency, and efficiency. Future research, particularly in share-based Decentralized Autonomous Organization (DAO) applications⁵, holds promise for reconciling

government legitimacy with citizen engagement, enhancing the potential of public permissioned blockchain systems. However, it is crucial to acknowledge the limitations inherent in applying blockchain technology to public administration. Challenges, including power consumption, scalability, governance frameworks, and confidentiality restrictions, demand careful consideration. Addressing these concerns, particularly in terms of scalability and governance, is vital for fostering citizen participation and ensuring transparency in the determination of underlying protocols within public permissioned networks. Finally, AetherForest.ai is versatile and adaptable, monitoring predefined indicators from public and private data sources. It supports diverse applications across private enterprises, public institutions, and government organizations. AetherForest.ai offers a robust template tailored to various sectors and use cases, from overseeing industrial production and land use to managing real estate and optimizing logistics. As per the author's commitment to FAIR principles, a working template and more screenshots can be found on GitHub⁶.

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⁵ DAOs are built on top of existing blockchain systems, both permissioned and permissionless, and represent new forms of decentralized governance. Managed by a collective of individuals with shared interests and goals, DAOs are complex smart

contracts that enable transparent decision-making processes, automation of operations, formalized rules, and decentralization of power.

⁶ <https://github.com/chrisdaoulas/AetherForest.ai>