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Tokenisation of forest carbon project: a blockchain-based approach for community engagement

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Research Article

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Abstract

Carbon credits have become increasingly important for supporting sustainable forest management and mitigating climate change. However, carbon projects can be challenging for local communities and smallholders to implement due to high expenses and complicated protocols. Forest projects often suffer from inefficiency, lack of transparency, and uneven benefit distribution. This study suggests a blockchain-based framework for aggregating forest carbon projects. This framework is the first in the forest sector to provide a reward mechanism for local communities or smallholders with a direct integration into an accredited registry protocol of Monitoring, Reporting, and Verification. The system combines digital identities, smart contracts, and automated incentives to improve transparency, responsibility, and trust among stakeholders. Two types of tokens are introduced: (i) Carbon Coin represents verified carbon credits within the system; and (ii) Forest Coin functions as a security token used to proportionally distribute project revenue among stakeholders. The revenue distribution was demonstrated in scenarios of afforestation, reforestation, and conservation. In addition, a web application was developed so that users can monitor project details. Unlike most blockchain carbon platforms that focus on investment and trading, this framework addresses upstream challenges, prioritising equitable benefit-sharing. The framework supports project aggregation and prioritises community ownership, advancing inclusive access to the carbon market. This study demonstrates how technological advantages can be transferred to community-driven ecological conservation.

Introduction

Reforestation has been a main approach to reduce biodiversity loss and enhance carbon sequestration (Cunningham *et al.* 2015; Nunes 2023). However, effective reforestation requires not only tree planting but also forest conservation while actively incorporating local communities (Luswaga and Nuppenau 2020). Furthermore, economic incentives are crucial for the success of projects, especially for afforestation, since it takes many years for new trees to generate profits (Hou *et al.* 2019; Akita and Ohe 2021). Forest restoration may serve as a financially viable alternative to conventional land use, especially when supported by an open and transparent carbon market (Jantawong *et al.* 2022). However, traditional forest carbon projects often face structural inefficiencies, including burdensome administration, limited transparency, and exclusionary benefit distribution—especially for smallholders and local communities. Conventional forestry schemes often struggle to engage communities, ensure transparent monitoring, and fairly distribute the benefits of carbon revenues.

Community-Based Forest Management (CBFM) is a financial incentive model that promotes sustainable forest practices by compensating local communities for their stewardship (Purnomo *et al.* 2020). Community-engaged initiatives include REDD+ (Reduced Emissions from Deforestation and Degradation) and Payment for Ecosystem Services (PES). These programmes aim to reward communities in proportion to their contributions to ecological services—for example, preventing deforestation and maintaining carbon stocks (Robinson *et al.* 2013; Derissen and Latacz-Lohmann 2013; Acharya, Maraseni, and Cockfield 2019). Although the CBFM rules help provide access to rights, their implementation often faces practical barriers, particularly when it comes to ensuring transparent and equitable distribution of financial benefits (Kosoy and Corbera 2010; Vatn 2010).

Forest conservation and carbon credit programmes are fundamentally based on trust among stakeholders, particularly local communities (Luswaga and Nuppenau 2020; Akita and Ohe 2021). However, forest management is typically bureaucratic and often excludes local participation (Pirard 2012). In particular, forests under community management have shown lower deforestation rates than strictly protected ones (Agarwal *et al.* 2022; Porter-Bolland *et al.*

2012). Local communities continue to be marginalised in terms of management authority and benefit-sharing (Purnomo *et al.* 2020; Gross-Camp 2017). In many national REDD+ projects, communities report that government agencies retain most financial benefits, depriving them of meaningful returns (Balderas Torres and Skutsch 2012). Centralised policy frameworks further weaken local property rights, incentives, and tenure—factors that contribute to forest degradation (Webb and Shivakoti 2006). Economic incentives remain a powerful motivator for community involvement in forest conservation (Luswaga and Nuppenau 2020). Carbon credits can provide one such financial mechanism. For instance, the Kasigau Corridor REDD+ Project in Kenya channels revenue from carbon credits directly into conservation and local development (Kill 2017). Although carbon credits offer strong potential, they are not easy to access.

Challenges include complex accounting, high transaction costs, and the administrative burden of Monitoring, Reporting, and Verification (MRV). Furthermore, the costs of forest management often exceed the financial returns from carbon sales (Pirard 2012; Moser, Windmuller-Campione, and Russell 2022). These challenges are even more acute for smallholders and local communities with limited resources (Agrawal and Gibson 1999; Pirard 2012). Manual administration of carbon credit using spreadsheets induces slow processing, high audit costs, and the risk of double-counting (Ashley and Johnson 2018; Effah *et al.* 2021). Such manual processes are error-prone and inefficient, reducing credit quality. High-quality carbon credits must demonstrate additionality, accuracy, permanence, exclusivity, and regulatory compliance (Swinkels 2024). An optimal system should therefore automate credit issuance, support secure trading, and maintain transparent, auditable records (Ashley and Johnson 2018). One viable solution for forest carbon credit management is through project aggregation. It combines small forest plots in a larger project area to improve efficiency and increase total carbon sequestration (Students of Research for Environmental Agencies and Organizations, Department of Earth and Environment, Boston University, 2018). This approach reduces risk and entry barriers, allowing small-scale actors to access carbon markets (Climate Action Reserve 2024). For example, the Cold Hollow initiative allowed a collective of landowners to participate in the American Carbon Registry (ACR). Similarly, the Australian Clean Energy Regulator enables small carbon projects to be grouped under a single registration (Clean Energy Regulator 2024).

Carbon credit management can be further improved via recent technologies. Among them, blockchain technology has characteristics—such as traceability, transparency, and security—that are highly applicable to carbon projects (Woo *et al.* 2021). Already adopted in the supply chain and energy sectors (Sanda, Pavlidis, and Polatidis 2022; Boumaiza and Maher 2024; Woo *et al.* 2020), blockchain enables immutable data storage and smart contract functionality. Regarding the carbon market, blockchain has been applied in various initiatives—such as Veritree, GainForest, Vlinder, and Open Forest Protocol. These platforms often prioritise transparency or traceability over equitable benefit-sharing. For instance, GainForest links donations to forest health metrics without issuing formal credits. Vlinder tokenises mangrove offsets, but does not include financial governance for community distribution. Regen, built on the Cosmos SDK, offers methodological rigour but poses adoption barriers for land stewards. Silvi focuses on smallholder regeneration through tokenised impact certificates, but remains in the early stage and lacks DeFi or registry integration.

Despite their contributions, existing platforms primarily focus on the offset or trading stages of the carbon market. They often overlook the upstream challenge of aggregating small forest plots into a verifiable and registry-compliant project. Most systems also do not prioritise revenue distribution or the ownership of carbon assets. To address this gap, this study proposes a blockchain-based framework for aggregating smallholder forest projects into registry-compliant carbon projects. The system combines digital identities, smart contracts, and a dual-token model—Forest Coin (FC) for benefit-sharing and Carbon Coin (CC) for marketable carbon credits. The system ensures transparent and MRV-aligned credit issuance. It also promotes local stewardship and equitable participation, advancing climate goals and social equity.

Methodology

Proposed framework

Figure 1 illustrates the proposed framework that integrates blockchain technology into the forest carbon aggregation project. The left column presents a typical life cycle of a carbon credit project that is in line with the MRV protocol (Broekhoff *et al.* 2019). A typical life cycle of a carbon credit project involves four key stages:

1. **Methodology Development:** The development of the methodology ensures that the reductions in greenhouse gases (GHGs) meet the quality criteria. Most credit registries provide approved methodologies that are specifically designed based on project types.
2. **Project Development, Validation & Registration:** The project undergoes development, validation, and registration processes. The projects are designed by developers, financed by investors, validated by independent verifiers, and registered with carbon credit registries.
3. **Project Implementation, Verification, & Credit Issuance:** This stage involves continuous monitoring and periodic verification of emission reductions. Upon verification, carbon credits can then be issued and deposited into the developer's account in a registry.

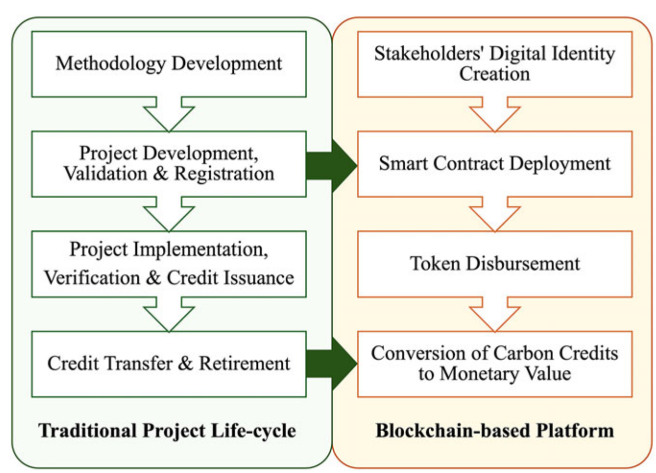

Figure 1. Proposed framework for the tokenisation of forest carbon projects. The left column illustrates the conventional carbon credit project life cycle aligned with the Monitoring, Reporting, and Verification (MRV) protocol. The right column presents the proposed blockchain-based platform, which enables transparent tracking and equitable distribution of carbon revenues to all relevant stakeholders, including local communities.

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4. **Credit Transfer & Retirement:** The credits obtained can be traded, transferred, or retired within the registry system. Retirement removes credits from circulation in the carbon market.

The right column introduces the proposed blockchain-based framework, complementing the MRV protocol through four key stages:

1. Stakeholders' Digital Identity Creation: Relevant stakeholders (e.g., forest caretakers, landowners, and project developers) are assigned digital identities to verify and authenticate their roles within the system.
2. Smart Contract Deployment: Smart contracts are deployed to automate agreements, defining the conditions under which tokens are distributed and revenue is shared.
3. Token Disbursement: Once carbon credits are verified, they are tokenised into digital assets (CC tokens), enabling secure and transparent trading.
4. Conversion of Carbon Credits to Monetary Value: When these credits are sold, the smart contract automatically converts the proceeds into monetary value and distributes payments proportionally to all stakeholders according to their holdings of FC tokens.

Platform design

A blockchain-based carbon credit platform was designed to track and distribute benefits, improving transparency and efficiency in the carbon credit ecosystem. Two tokens are employed in the proposed system: (i) CC token represents verified carbon credits, and (ii) FC token functions as a security token used to proportionally distribute CC tokens among stakeholders. CC tokens can be held, traded, or retired by users on the platform. FC tokens are exclusively allocated to project contributors (e.g., forest caretakers, landowners, and developers) and represent fractional ownership in aggregated small-scale forest projects. FC tokens are issued at the start of the project and distributed according to pre-agreed terms (e.g., land area, level of participation, or conservation performance). FC tokens entitle holders to an automated, proportional share of CC tokens. FC tokens serve multiple purposes within our ecosystem beyond their primary function of distributing CC token revenue shares. These tokens can be traded on secondary markets to attract environmentally conscious investors who seek opportunities in sustainable business ventures. Furthermore, FC tokens provide a mechanism to incentivise broader stakeholder participation through structured loyalty programmes. For example, participants who maintain minimum token holdings for extended periods, such as three years or longer, become eligible for complementary environmental services, including guided nature excursions. This approach creates long-term engagement while aligning investor interests with environmental conservation objectives.

The dual-token design separates functionality and stakeholder roles. CC tokens act as a currency for carbon markets and DeFi platforms, facilitating the trading and retirement of verified credits. FC tokens function as equity shares, representing ownership in the project, and enabling smart contract-based dividend-like payouts. Local communities may hold both tokens depending on pre-project agreements; FC tokens for stewardship and revenue sharing, and CC tokens for direct ownership of issued carbon credits.

The framework intends to engage a wider range of participants, from individuals to large corporations, that is, forest caretakers, project developers, and landowners. Figure 2 illustrates the key steps of the framework:

1. **Forest Management:** All stakeholders must agree to participate and hold FC tokens to receive incentives from carbon credit sales. Forest caretakers are responsible for maintaining and protecting the forest to ensure optimal carbon sequestration. A project developer manages the coordination between stakeholders.
2. **Verification:** Carbon credits must be issued by a trusted organisation, that is, carbon credit registries. After issuance, the carbon credits are tokenised in CC. This is to ensure that

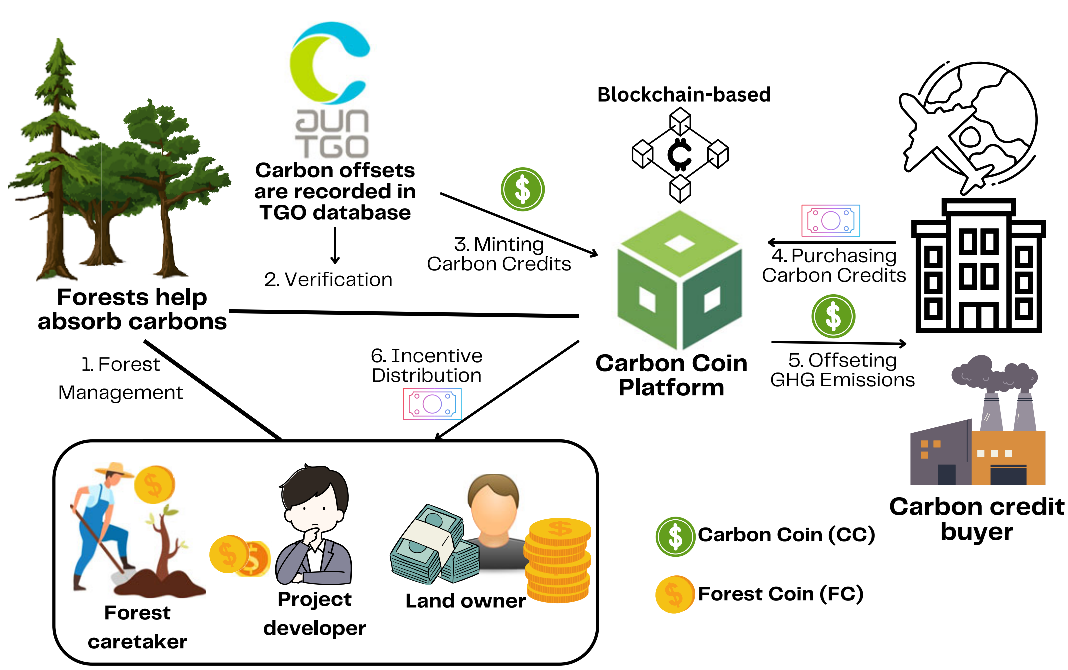

Figure 2. Blockchain-based carbon credit system begins with (1) forest management activities that enhance carbon sequestration, followed by (2) verification and recording of carbon offsets in the database of a carbon registry, e.g., the Thailand Greenhouse Gas Management Organization (TGO). (3) Verified credits are then tokenised as Carbon Coins (CCs) through the CarbonCoins Platform. (4–5) These tokens can be purchased by carbon credit buyers to offset their greenhouse gas (GHG) emissions. (6) Incentives from the sales are automatically distributed to stakeholders—including forest caretakers, project developers, and landowners—based on their holdings of Forest Coins (FCs).

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only verified carbon credits are tokenised. This role can be performed by government institutes. For example, in Thailand, it is an action of the Thailand Greenhouse Gas Management Organization (TGO). The CC tokens are then deployed on the blockchain, making them available for trading.

3. **Minting Carbon Credits:** Upon successful verification, the registry authorises the platform to mint carbon credits, ensuring that the number of CC tokens issued corresponds to the verified carbon sequestration capacity of the forest. The CC tokens are assigned to stakeholders based on their FC token holdings ratio. For example, if a forest caretaker has one FC token, a project developer has two FC tokens, and a landowner has seven FC tokens, CC tokens will be allocated in 10%, 20%, and 70% ratios, respectively.
4. **Purchasing Carbon Credits:** Carbon credit buyers can purchase CC tokens directly from the platform. The platform acts as an intermediary between the registry and the digital marketplace, facilitating the seamless transition of verified credits into tradable tokens.
5. **Offsetting GHG Emissions:** Buyers can purchase CC tokens to offset their GHG emissions. The blockchain system ensures the integrity and transparency of the offset process, preventing double-counting and ensuring verifiable emissions reductions.
6. **Incentive Distribution:** Revenue from CC token sales is distributed among stakeholders based on who is the CC token holdings. We design to give CC tokens to stakeholders after minting for the reason that they can decide when to sell the CC tokens for their profits since they are CC token owners. A smart contract executes the automated distribution mechanism.

CC tokens can be traded on CarbonCoins, an on-chain platform that permanently records all transaction data. The registry also stores detailed metadata about the originating forest project, including verification data from sources such as satellite monitoring and remote sensing. Once the final holder uses a CC token to offset emissions, the corresponding carbon credit is retired within the registry ecosystem (e.g., removed from the TGO system). Simultaneously, the CarbonCoins platform executes a smart contract that permanently removes the CC token from circulation. To prevent double-counting, each CC token is embedded with a unique digital fingerprint. It links to a specific geographic location, time period, and forest measurement dataset. The registry also records the unique ID of the token, the retirement timestamp, and the organisation responsible for its retirement. This mechanism ensures that each carbon credit is fully verifiable, non-replicable, and cannot be reused across different platforms or registries.

Platform architecture

The proposed platform, CarbonCoins, uses current Web technologies and blockchain to verify, mint, and trade carbon credits. Figure 3 shows the components of this platform. Cryptocurrency wallets authenticate users and function as safe access points to mint, transfer, and trade carbon credits. The responsive frontend is constructed with a user-friendly interface using Next.js, a framework for server-side rendering and statically generated React apps. The frontend provides users with an interactive dashboard, displaying real-time carbon pricing via a REST API.

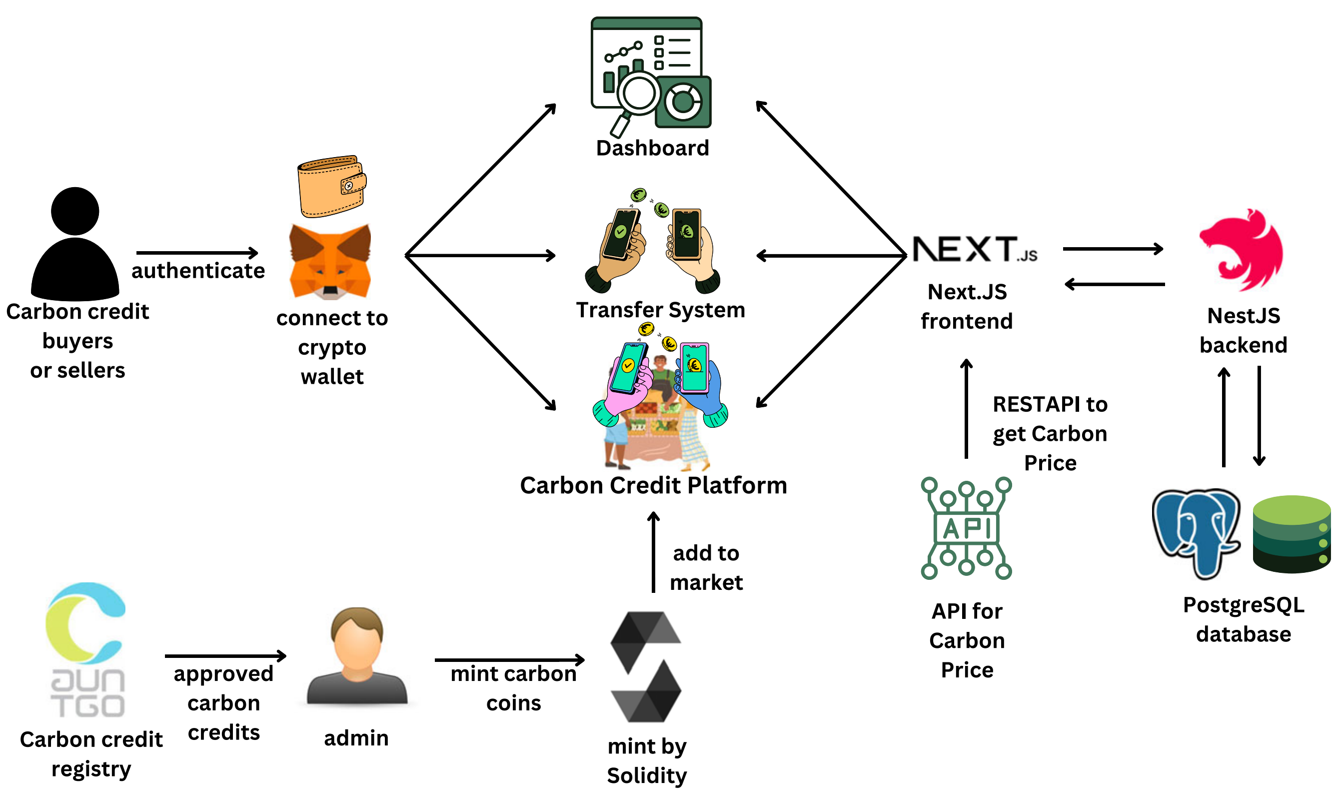

Figure 3. The CarbonCoins platform is designed to accommodate users who are carbon credit buyers or sellers. Users must authenticate via crypto wallet connections before accessing the platform's dashboard and transfer system. The platform's frontend is built with Next.js and communicates with a NestJS backend, supported by a PostgreSQL database. Verified carbon credits from a trusted registry are approved by an admin and minted as carbon tokens using Solidity smart contracts. The minted tokens are then added to the market and traded via the platform. REST APIs facilitate carbon price retrieval and integration with external registries.

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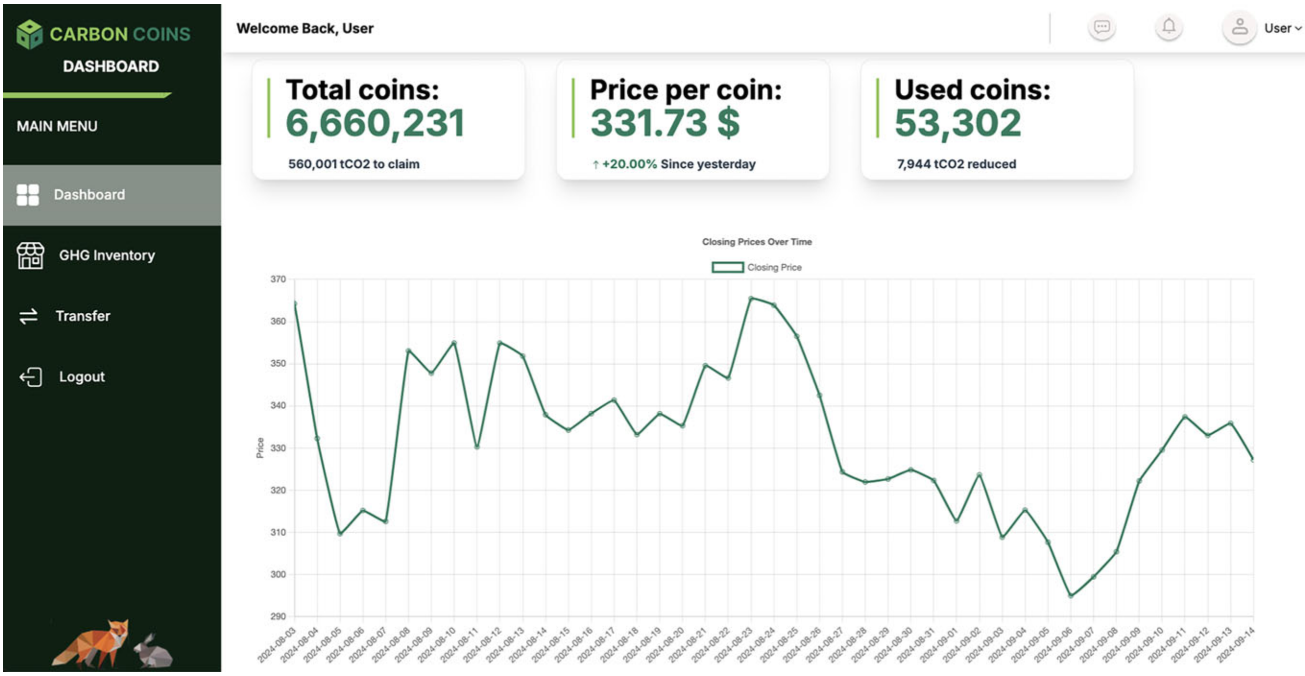

Figure 4. The CarbonCoins dashboard displays key metrics—total coins, current price, and used coins—with a line graph showing market trends. A sidebar provides access to Dashboard, GHG Inventory, Transfer, and Logout. The interface offers a clear overview of credit holdings and market activity.

The backend, designed using Nest.js, controls business logic and stores the data on a Postgres database. The backend also hosts a manager dashboard that informs market trends, user interaction, and system activities. The administrative dashboard is equipped with tools to control the platform, grant carbon credit rights, and monitor market activity. Solidity, a programming language for Ethereum smart contracts, is used to mint carbon credits. Smart contracts guarantee that, depending on certain criteria, transactions are carried out automatically and transparently. The records on a blockchain are permanent, thus guaranteeing the credits' traceability and safety.

Before being traded on the market, carbon credits must be verified and issued, a process that the carbon credit registry performs fundamentally. This certification procedure guarantees credibility and maintains the integrity of the platform. The carbon credits issued are made accessible for trading within the platform's market system, where buyers and sellers can trade them at open market rates. The platform employs peer-to-peer transactions to ensure the transparency and accountability of carbon credits. The platform is designed to be scalable so that external features—that is, other APIs to retrieve real-time carbon credit price—can be added without interfering with current capabilities.

Figure 4 shows a screenshot of the dashboard where users can monitor their assets and historical price data. The frontend (Next.js)[1] and backend (Nest.js)[2] source codes of this platform are available in the GitHub repository. The platform comprises an inventory page to track and calculate the reduction in GHG. It allows users to input data and automatically compute GHG emissions for compliance and sustainability reporting. Additionally, the functional prototype of the platform is currently deployed and accessible online.[3] This proof-of-concept validates our technical architecture and demonstrates the platform's feasibility for real-world deployment.

[1] https://github.com/KGDss/carbonCoins.
[2] https://github.com/KGDss/carbonCoins-api.
[3] https://carbon-coins.vercel.app.

Results

Integration with A/R projects

Blockchain technology can help to enhance afforestation and reforestation (A/R) initiatives by assigning distinct digital IDs to sites, enabling continuous monitoring, ensuring reliability and efficiency. Smart contracts automate rewards, where tokens are distributed upon reaching milestones. Forests can then be assessed for carbon credit issuance, allowing credits to be traded on carbon markets. Integrating blockchain with traditional A/R efforts creates a transparent, equitable, and sustainable framework for forest management.

One strategy for formulating a reward system for an A/R project involves using the growth rate, γ, which can be predicted via the logistic function (Gregorczyk 1991; Petsri *et al.* 2007; Castellanos-Acuña *et al.* 2022):

$$\gamma(t) = \frac{A}{1 + b\ exp^{-rt}} \tag{1}$$

where γ is the growth size (e.g., dry weight or aboveground carbon content), t is the age of the plant, A is a maximum growth value, and the rest are constants ($b > 0$ and $r > 0$).

At the beginning of the project, there is a mutual agreement between the community and the project developer about the provision of specific awards if the growth rate remains within a predetermined range. Stakeholders should reach an agreement on particular allometric equations at the beginning of the project, with species-specific models strongly recommended for precise and accurate estimation of carbon stocks (Makungwa *et al.* 2013).

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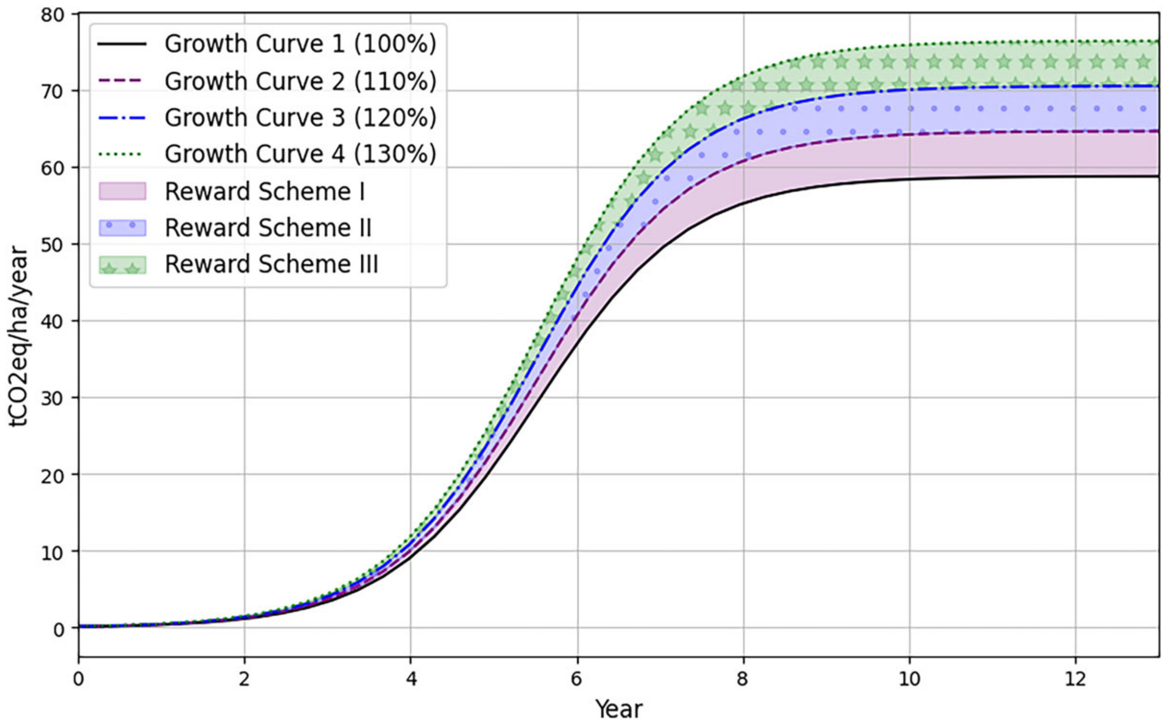

Figure 5. Growth curves of mangrove forests over an age range of 0 to 13 years. Shaded regions represent different reward tiers based on deviations from the baseline (Growth Curve 1), which corresponds to carbon sequestration rates (tCO2eq/ha/year). Each curve represents a different growth performance scenario for community incentive modelling.

Table 1. Example of a reward scheme based on % deviation from the predetermined range of predicted growth rate

Scheme	Predetermined Range (% of predicted carbon sequestration rate)	Reward (% Carbon credits, tCO2-eq)
0	< 100%	5%
I	100–110%	10%
II	110–120%	15%
III	120–130%	20%
IV	> 130%	25%

Table 2. Reward scheme based on the predetermined range of NDVI

Predetermined Range of NDVI	Reward (% Carbon credits, tCO2-eq)
< 0.6	10%
0.6–0.8	20%
> 0.8	25%

An example of the reward scheme is illustrated in Figure 5. It is a reforestation scheme in which a project developer is a collection of several local communities. Each community will earn a reward based on the achieved γ. For instance, regarding the scenario of a mangrove forest, A can be assumed to be 58.75 tCO2-eq/ha/year (Thailand Greenhouse Gas Management Organization 2024). The rest of the parameters for Equation (1) are taken from the study of carbon sequestration of a mangrove forest planted in Thailand (Kridiborworn *et al.* 2012). The variables b and r are assumed to be 462 and 1.11, respectively. The resulting predetermined range is labelled in Table 1.

Integration with REDD+ projects

The proposed framework can be applied to REDD+ projects using token-based incentives to support conservation efforts. Tokens are issued when conservation milestones or carbon sequestration targets are verified. If a designated forest area remains intact and satellite imagery confirms its condition, smart contracts automatically distribute rewards to responsible communities or organisations. Incentive levels can also be adjusted based on forest health conditions. Remote sensing data from satellites or drones enables forest health assessments by analysing spectral reflectance bands (Abad-Segura *et al.* 2020). These bands are combined to generate vegetation indices that reflect ecosystem health and productivity. The carbon sequestration potential can be inferred from these indices.

An example of a reward scheme is presented in Table 2. The example utilised the Normalised Difference Vegetation Index (NDVI). It is widely adopted, easy to compute, and strongly correlated with vegetative health and canopy structure. However, it may saturate in dense tropical forests (Mutanga, Masenyama, and Sibanda 2023; Haque *et al.* 2024; Ju *et al.* 2024). It is calculated as:

$$NDVI = \frac{R_{NIR} - R_{Red}}{R_{NIR} + R_{Red}} \tag{2}$$

where R_{NIR} and R_{Red} refer to spectral reflectance in the near-infrared and red bands, respectively (Gessesse and Melesse 2019). Alternative indices such as the Enhanced Vegetation Index (EVI), which mitigates atmospheric and saturation effects, or the Leaf Area Index (LAI), which offers more structural information, could be explored in future versions of the framework (Huete *et al.* 2002).

An example of this approach is illustrated in Figure 5, depicting a hypothetical reforestation scheme involving several local

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Table 3. Comprehensive comparison of blockchain-based carbon credit platforms

Feature	CarbonCoins (CC&FC)	Toucan (BCT)	MOSS (MCO2)	KlimaDAO (KLIMA)
Integration Scope	End-to-end (project → tokenisation)	Post-verification only	Post-verification only	Treasury management
Community Incentive Model	Direct FC rewards for CC sales	None	None	Staking rewards
MRV Integration	Built-in workflow	External dependency	External dependency	Not applicable
Primary Beneficiaries	Local communities + traders	Traders/institutions	Traders/institutions	Token stakers
Credit from Trusted Source	Supported	Supported	Supported	Supported
Dashboard for Users	Supported	Supported	Supported	Supported
Marketplace Access	Supported	Supported	Supported	Supported
Emission Reporting	Supported	Supported	Supported	Not supported
GHG Inventory Management	Supported	Supported	Not supported	Not supported

communities under the supervision of a project developer. Each community earns a reward based on its achieved γ—the estimated carbon sequestration for a given year, expressed in tonnes of $CO2$ equivalent per hectare per year (tCO2eq/ha/year). This example is based on a hypothetical mangrove reforestation project. For example, in this scenario, A is assumed to be 58.75 tCO2eq/ha/year (Thailand Greenhouse Gas Management Organization 2024), while the parameters b and r in Equation (1) are derived from a study of mangrove forests in Thailand (Kridiborworn *et al.* 2012), with values of 462 and 1.11, respectively. The logistic growth function is used to simulate various growth performance outcomes under the same conditions. Each shaded region in the figure represents a reward tier, where a higher actual carbon sequestration (that is, higher values on the y axis) results in a higher proportion of carbon credits allocated as incentives. This model is purely illustrative and is not based on any regulatory standard.

The reward tiers are summarised in Table 1. The criteria are based on the observation that the NDVI of healthy, dense vegetation typically exceeds 0.6 (Kocur-Bera and Małek 2024; Gidey *et al.* 2018). This scheme is hypothetical and developed for demonstration purposes only. In this example, local communities can earn up to 25% of the carbon credits issued, depending on NDVI-derived forest health metrics. Unlike conventional REDD+ benefit-sharing schemes that rely on administrative allocation, this framework links incentives to near-real-time satellite data, enabling automated, transparent, and performance-based reward distribution.

The integration of blockchain into forest carbon projects supports transparent monitoring, automated incentives, and equitable revenue sharing via tokenised systems. Token-based approaches eliminate intermediaries, enhance trust through immutability, and allow fine-grained, fractional revenue distribution. Nonetheless, practical challenges such as digital literacy, infrastructure access, and token volatility should be addressed. By combining satellite-based monitoring with blockchain automation, the proposed framework offers a scalable, real-time solution for REDD+ incentive allocation.

Comparison of carbon credit platforms

While several blockchain platforms have emerged in the carbon credit space, most are designed primarily for tokenising already issued carbon credits and enabling trading or retirement in decentralised finance (DeFi) ecosystems. These systems typically assume that credits are already verified and registered. In contrast, our proposed platform integrates upstream processes—such as project aggregation, MRV alignment, and registry-compatible token generation—into a unified workflow as shown in Table 3. The blockchain-based carbon credit market has seen significant growth. In addition to our proposed tokens, CC and FC, several carbon credit tokens are currently active in the market. Toucan and KlimaDAO emerge as the most liquid and widely adopted projects (Toucan 2024; KlimaDAO 2024). These tokens are listed on *CoinMarketCap*,[4] the largest platform for cryptocurrency trading information. Toucan is a pioneer in bridging real-world carbon credits, such as Verified Carbon Units from Verra, onto the blockchain as Base Carbon Tonne (BCT) tokens.

These tokens can be traded, retired, or integrated into DeFi applications. KlimaDAO uses KLIMA tokens to incentivise the retirement of carbon credits. KLIMA is backed by a treasury of BCT tokens sourced from Toucan. Together, Toucan and KlimaDAO lead the sector in liquidity and trading innovation. However, KLIMA incentivises token holders through staking mechanisms, which contrasts with our FC tokens that directly reward contributors when CC tokens are sold. MOSS Earth, an Amazon reforestation initiative, tokenises credits under the MCO2 label. These tokens are tradable on Ethereum and Celo platforms (MOSS 2024). The initiative has garnered attention through partnerships with major corporations and a commitment to transparency. C3 is another ecosystem that enables the trading and retirement of its native Carbon Credit Coin (C3 2024). Its blockchain infrastructure is designed for scalability, allowing broader participation in the expanding carbon market.

In addition to the major systems mentioned above, there are other options with lower liquidity but which are highly regarded for their uniqueness in environmental solutions. Flowcarbon, for example, offers institutional-grade carbon credits via GNT tokens (Flowcarbon 2024). Regen Network focuses on regenerative agriculture and issues REGEN tokens (Regen Network 2024). Veritree promotes reforestation efforts using TREES tokens (Veritree 2024). Carbonland Trust emphasises nature-based solutions and biodiversity, representing credits through CLT tokens (Carbonland Trust 2024). Save Planet Earth is a community-oriented project equipped with SPE tokens, which finance large-scale reforestation initiatives (Save Planet Earth 2024).

[4]https://coinmarketcap.com/.

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Table 3 compares the functionality of the leading blockchain-based carbon credit platforms, highlighting the distinct features and limitations of each. The comparative analysis reveals distinct approaches among the leading carbon credit platforms, each offering varying degrees of functionality and community engagement mechanisms. Whereas most blockchain-based carbon credit platforms primarily focus on trading tokenised, verified credits, the CarbonCoins platform introduces three key innovations: (i) upstream integration from project development through tokenisation, (ii) a dual-token system in which FC tokens directly reward community participation in carbon credit sales, and (iii) full MRV compatibility embedded within the tokenisation workflow.

CarbonCoins platform demonstrates integration in all key operational areas, encompassing trusted credit sourcing, user dashboards, marketplace access, emission reporting, and GHG inventory management. What fundamentally distinguishes CarbonCoins from its competitors is its innovative implementation of FC tokens, which facilitate direct, proportional rewards to local communities and project contributors. Through this mechanism, when CC tokens are sold, FC token holders automatically receive payments through smart contracts, establishing a systematic approach that ensures that stakeholders actively involved in forest conservation efforts benefit financially from their participation. This design addresses a critical gap prevalent in existing platforms by creating alignment between financial incentives and grassroots-level climate stewardship activities.

Toucan Protocol presents a comprehensive suite of tools through its integration with verified credits sourced from established registries, including Verra and Gold Standard. The platform offers user-friendly dashboards, maintains high-liquidity marketplaces, and provides complete support for both emission reporting and GHG inventory management. Despite these robust capabilities, the Toucan protocol notably lacks mechanisms designed to directly incentivise local community participation in conservation efforts.

MOSS Earth demonstrates similar core capabilities, incorporating trusted credit sourcing, dashboard functionality, and marketplace integration into its operational framework. The platform maintains support for emission reporting while maintaining a primary focus on practical carbon offset solutions. However, MOSS Earth's functionality limitations become apparent in its absence of tools for GHG inventory management and lack of mechanisms for rewarding community stakeholders who contribute to project success.

KlimaDAO operates with fundamental functionalities that include integration with trusted registries, dashboard systems, and marketplace access capabilities. The distinctive approach of the platform centres on treasury-backed staking mechanisms that serve to incentivise community-driven climate action initiatives. However, KlimaDAO's operational scope does not extend to direct emission reporting capabilities, GHG inventory management, or the implementation of token-based mechanisms similar to FC tokens for distributing project-level rewards to participants.

Unlike KlimaDAO's treasury-backed approach, where KLIMA tokens derive value from accumulated carbon credits, our FC tokens create direct economic incentives for community participation. When communities sell CC tokens, FC token holders receive proportional rewards, aligning community interests with market performance. This mechanism addresses a critical gap in existing platforms where local communities often remain disconnected from the financial benefits of their conservation efforts. Our analysis reveals that existing platforms address only a few stages of the carbon credit life cycle (verification, tokenisation, trading), while our integrated approach covers six stages, including project aggregation, community coordination, MRV alignment, tokenisation, incentive distribution, and market facilitation. Furthermore, we are the first to implement a dual-token system in which community participation is directly monetised through secondary token rewards.

Discussion

Blockchain-based carbon credits provide great advantages in ensuring transparency, efficiency, and fairness. The smart contract enables the revenues to be automatically distributed as per the prior agreement. Smart contracts also ensure correct and timely revenue allocation. Its automation also reduces transaction costs and the need for intermediaries. FC tokens representing ownership ensure compliance with financial regulations while fostering trust among stakeholders. Furthermore, blockchain's immutable nature guarantees that the entire process is transparent and auditable, eliminating the risk of fraud and mismanagement. The tokenisation of forest carbon projects offers significant advantages for local communities, particularly in terms of financial inclusion, transparency, and long-term sustainability. This framework ensures that the revenue generated from carbon credits is distributed more equitably among stakeholders. Unlike traditional carbon credit systems, which often lack transparency and are dominated by large corporations, tokenisation allows for real-time tracking of transactions, reducing the likelihood of financial mismanagement or exploitation. This system fosters trust and integrity in carbon credits, ensuring that locals receive their fair share of carbon credit revenues. The FC and CC token system makes it easier for small communities to earn revenue from forest conservation by reducing traditional entry barriers. For example, instead of needing a minimum of 100 ha to cover the high costs of consultants and documentation, a village can tokenise just 10 ha of restored mangroves in FC tokens and earn CC tokens from their forest. Communities can flexibly allocate FC tokens, rewarding members based on tree planting efforts or forest monitoring contributions. Instead of waiting for credit validation and payment, communities begin receiving CC tokens—proportional to their FC tokens—once the mangroves reach maturity.

In addition, tokenisation empowers local communities by providing them with greater autonomy over resource management. Many small-scale forest conservation projects struggle to gain recognition in conventional carbon markets due to high entry costs and bureaucratic barriers. Tokenisation simplifies participation, enabling smaller projects to receive validation and certification through decentralised mechanisms. This accessibility can encourage more communities to engage in reforestation, conservation, and sustainable land-use practices, ultimately contributing to both climate mitigation and local economic development. Another key benefit is improved financial liquidity. Tokenised carbon credits can be fractionalised—allowing smaller investors, organisations, and even individuals to participate in the market. This lowers the financial barriers for local communities, enabling them to monetise carbon sequestration efforts without waiting for bulk transactions. In addition, smart contracts can automate the distribution of funds, ensuring that payments reach communities on time, which is particularly valuable for those in regions with limited banking infrastructure.

The framework offers a promising solution to integrate forest carbon projects into digital markets. However, its implementation comes with challenges that require thoughtful consideration. Blockchain technology is complex and has not been widely adopted in the forestry sector (He and Turner 2022). Many remote communities may have limited Internet access and digital literacy, which could hinder their ability to engage with the platform effectively. Addressing this will require targeted investment in training, capacity building, and accessible digital tools. By integrating user-friendly interfaces and offering technical support, the framework can become more inclusive and allow greater participation of grassroots stakeholders.

This work introduces the first blockchain-based carbon credit platform featuring a novel dual-token system that directly incentivises local community participation through automated, transparent reward distribution. Unlike existing platforms that focus primarily on trading and offsetting, the proposed framework offers full integration from project aggregation to market access. It supports fractional tokenisation of smallholder forest parcels and embeds MRV-aligned processes to reduce bureaucratic constraints. Importantly, it is the first implementation of a secondary token (FC) to monetise and distribute community contributions in carbon projects. The framework enables forest caretakers and landowners to form aggregated carbon projects while retaining individual ownership via tokenised shares. For example, five villagers each contributing 10 ha can form a 50 ha project, with FC and CC tokens distributed proportionally according to their input.

Despite these advantages, the proposed framework can face difficulties in practice. The system depends mainly on the integrity and proper coding of smart contracts. Any vulnerability in the code can cause system failure or unintended exploitation. Developing robust fraud prevention protocols can enhance investor confidence and credibility in tokenised carbon credits. Furthermore, the adoption of blockchain and tokens requires technical expertise, which can be challenging for small organisations or less technologically advanced stakeholders. Local communities may struggle to understand the framework, including the concept of carbon credits and blockchain technology. Therefore, continuous communication throughout the project life cycle is essential (Holmes, Potvin, and Coomes 2017). Energy consumption must be carefully considered when implementing blockchain technology. Using energy-efficient consensus mechanisms, such as Proof-of-Stake, is crucial to maintaining environmental sustainability (Sedlmeir *et al.* 2020). The implementation of blockchain may also be constrained by regulatory and legal uncertainties. Policymakers, industry experts, and local communities must collaborate to establish clear, supportive policies that facilitate adoption in the forestry sector. Future research should focus on refining the system's stability, user accessibility, and interoperability with existing carbon market registries. Furthermore, additional monitoring technologies such as satellite imaging, UAV data, and IoT sensors can be integrated to strengthen MRV processes and improve the credibility of carbon credit issuance. With continued innovation and collaboration, tokenisation has the potential to transform forest carbon markets into a more transparent, inclusive, and sustainable financial mechanism.

Conclusion

This study developed the blockchain-based framework for aggregating forest carbon projects. Blockchain technology can help reduce the administrative and financial complexity of carbon credit projects. Technology can also improve access for small-scale project developers and participation in local communities. The developed framework combines smart contracts, tokenisation, and digital identities. It was intended to increase transparency and automate the profit distribution. The novelty of this framework is to facilitate the aggregation of forest projects and the integration with accredited carbon registries. Unlike most existing platforms that focus on post-verification credit trading or investor-driven token models, our approach integrates community engagement, automated MRV alignment, and equitable benefit-sharing from the outset. The contribution of the proposed framework can be concluded in three ways. First, it guarantees safe, unchangeable, and verifiable transactions—enhancing transparency and trust in carbon credit systems. Second, the use of FC tokens can create a fair profit-sharing system for local communities and smallholders—prioritising direct revenue distribution to those actively involved in forest conservation. Third, it improves accessibility to carbon markets through the aggregation of smaller forest projects, thereby increasing community forest engagement. Future research should explore the scalability and practical implementation of the framework to assess its effectiveness in real-world scenarios.

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