Carbono 21: Promoting Forestation Through Digital Assets

Pedro Henrique Barcha Correia[1], **Marcos Antonio Simplicio Junior**[1] **(supervisor)**

[1]Laboratório de Arquitetura e Redes de Computadores (LARC)
Universidade de São Paulo (USP)
Av. Prof. Luciano Gualberto, 158, 05508-010 – São Paulo – SP – Brazil

Abstract. *Despite its environmental benefits, forestation is often overlooked in favor of more profitable crops with negative environmental impacts. In response, this work promotes forestation through tokenization, creating financial incentives for landowners who plant trees. Forested areas and green assets are transformed into Non-Fungible Tokens (NFTs) on a consortium blockchain. Their metadata is automatically updated via satellite-based deforestation tracking systems, something unseen in the literature. The solution also contributes to distributed systems and the environment by proposing several transparency mechanisms – often lacking in forestation efforts and permissioned blockchains –, enabling authorities to audit the transaction and utilization of green assets.*

1. Introduction

To address the pressing climate change issues, several **forestation initiatives** (i.e. efforts to plant and maintain trees or native vegetation) have been proposed in recent decades. Carbon markets are a key example, where certificates representing reductions in CO2 emissions (i.e., carbon units, such as Kyoto Protocol's carbon credits) can often be generated by planting trees. Another initiative is **environmental compensation laws**, requiring entities that cut trees to compensate the environment. In Brazil, this can be done by purchasing compensation rights, certificates issued to landowners who plant and maintain native vegetation.

1.1. Problem definition and motivation

Forestation initiatives present several issues which this work addresses. A common problem is their **low profitability** for landowners [Antunes 2023]. As a result, farmers often neglect forestation in favor of traditional activities like planting sugarcane and soybeans, which, while socially important, have environmental impacts that contradict forestation goals [WWF nd, Ronquim 2010].

Another common issue is the **lack of transparency** in **forestation assets** (e.g., carbon credits, compensation rights). Many assets do not have traceability and audit mechanisms, making it difficult for authorities and other entities to monitor transactions. In the Kyoto Protocol's carbon trading scheme, for example, double counting of carbon credits is a risk due to insufficient detection mechanisms [Franke et al. 2020].

It should be noted that generating carbon credits in an economically viable manner requires thousands of hectares of land, as quantifying the carbon offset potential of an area can be complex and expensive [Haya et al. 2023]. In Brazil, even pools of **forested areas** (i.e., regions designated for planting and maintaining trees and native vegetation) typically require landowners to possess a minimum of 4,000 hectares [Carbonext 2025]. For

individual projects, this requirement may rise to a minimum of 20,000 hectares, making the **carbon credit market inaccessible to small landowners**. In contrast, the Brazilian environmental compensation law allows compensation rights with just 1 hectare, making it more accessible to small farmers. Additionally, unlike carbon credits, compensation rights can be generated through preserving native vegetation in non-forest biomes, like the Cerrado, encouraging forestation in areas unsuitable for traditional crops.

Despite the importance of exploring forestation initiatives beyond carbon markets (especially the carbon credit market), digital platforms that promote forestation often focus on digitizing carbon units for trading [Moss nd, Climatecoin nd, ForestCoin nd, Flowcarbon 2024, OFP 2023]. Some solutions are based on other forestation initiatives, such as environmental compensation [Tustt 2025], but still face challenges like low profitability and **lack of versatility in adopting multiple forestation strategies**, which limits the participation of end users in forestation efforts. Moreover, while many platforms ensure transparency in digital assets, they do not present mechanisms to track the status of the underlying real assets, leading to **digital representations that do not reflect actual assets**, thus creating opportunities for fraud and trading of illegitimate assets.

2. Goals

This study aims to build Carbono 21, **a technological platform that promotes forestation through digital assets**. Particularly, the work seeks the digitization of forestation-related assets, such as compensation rights. The proposal is built on two key pillars that address gaps identified in related works. Given the complexity of the project, these pillars were designed primarily to overcome the challenge of demonstrating the system's overall benefits, allowing us to present them in a modular manner. **The pillars represent both our main contributions and the specific objectives of the project**, guiding the construction of the solution and enabling its concrete evaluation:

- **Pillar I - Transparency mechanisms** to ensure proper implementation of forestation efforts. This corresponds to: (a) Utilizing systems that provide transparency of real-world data by reporting on the status of forestation assets and detecting deforestation events; and (b) Providing transparency of the digital data on the platform, including digitized assets and their real-world status.
- **Pillar II - Versatile mechanisms**, adaptable to a plurality of forestation initiatives and capable of creating incentives to encourage users to participate in efforts beyond carbon credit markets. For users interested in forestation initiatives, this means ease in discovering and acquiring digitized assets. For landowners, this translates, for instance, into increased profits from forestation, allowing small farmers to participate in forestation efforts, and providing opportunities for them to profit from maintaining native vegetation on lands unsuitable for other purposes (due to legal restrictions or infertility).

This work proposes, implements, and tests a solution based on the aforementioned pillars, focusing on the Brazilian context. Nevertheless, Pillar II should allow for adaptation to other scenarios.

3. Method

To achieve the proposed goals, we examined related works in both the literature and industry, outlining their main contributions and limitations, as presented in Section 4. It is

worth mentioning that the pillars of the project, described in the previous section, were created based on the gaps identified in the related works, aiming to address them.

Seeking to comply with the proposed pillars, we defined the system players, their interactions, and use cases. Based on that, we identified functional and non-functional system requirements. Following that, we determined technologies to meet these requirements and compared them. In particular, InterPlanetary File System (IPFS), blockchain, and smart contracts stood out among the considered options since the first two allow for the transparent storage of data, potentially meeting Pillar I, while the last one presents flexibility in adapting the business logic of the platform to the rules of forestation initiatives, therefore possibly addressing Pillar II. By employing these technologies, we created an architecture that aggregates the benefits of related works while introducing nouveau mechanisms to overcome the identified limitations.

Subsequently, we built a Proof of Concept (PoC) to validate the proposed approach. We evaluated the solution in two stages:

1. **Feasibility:** We analyzed the feasibility of the project by benchmarking its performance w.r.t. the latency and throughput of the implemented operations. Additionally, we conducted scalability tests by adding nodes and organizations to the blockchain network, to evaluate how the system responds to different network configurations.
2. **Compliance with the pillars:** We assessed the adequacy of the solution to the two pillars that represent our specific goals and main contributions. Regarding Pillar Ia (real-world data transparency), we analyzed if the adopted mechanisms are capable of identifying deforested lands and tracking the state of forestation assets. Concerning Pillar Ib (digital data transparency), we evaluated if the proposed transparency mechanisms can properly inform about the processes of creating and operating digital assets in the system, allowing for the auditing of such data and detection of irregularities in Carbono 21's activity. As for compliance with Pillar II (versatile mechanisms), we analyzed the platform's ability to create incentives for users and to encompass forestation initiatives from the related works.

The rationale behind this two-step analysis is to assess whether the proposed solution can be used by multiple users simultaneously and whether it meets Carbono 21's goals. These goals, in turn, support a broader objective: promoting forestation.

4. Related works

Several blockchain-based platforms promote forestation using Fungible Tokens (FTs) and Non-fungible Tokens (NFTs), which can help: (a) make forestation-related assets and their transaction transparent; and (b) create financial incentives for landowners to plant trees. Table 1 presents outstanding examples, like MOSS [Moss nd]. This project buys, tokenizes, and resells carbon credits on the public Ethereum network, making transactions publicly visible [Etherscan 2025]. However, there are no mechanisms to track the status of underlying carbon units, leading to potential double counting problems (i.e., consuming the same asset twice, within and outside the platform) [Chakraborty et al. 2022, Franke et al. 2020]. Other solutions, like EcoRegistry [EcoRegistry 2025], FlowCarbon [Flowcarbon 2024], ClimateCoin [Climatecoin nd], and BITMO [Bitmo 2025] also tokenize and sell carbon credits. Such platforms often exclude small landowners,

as carbon credit generation is typically viable only for properties of thousands of hectares [Carbonext 2025].

	Tokenization of forested areas	Tokenization of carbon sequestration assets	Tokenization of other forestation assets	General tokenization of forestation assets	Trees or forested areas generate tokens	Automatic detection of deforestation events	Transparency of real data using reliable sources	Transparency of digital data
Moss	-	●	-	-	-	-	-	●
Treedefi	-	●	-	-	●	-	-	●
ForestCoin	-	-	-	-	●	-	-	-
Open Forest Protocol	●	●	-	-	●	-	-	●
Trustt Green	-	-	●	-	-	-	-	●
Carbono 21	●	●	●	●	●	●	●	●

● = supported; - = unsupported

Table 1. Comparison of related works

Treedefi [Treedefi nd] has a similar proposition, enabling the transaction and auditing of tokenized carbon units on the public Binance Smart Chain (BSC) network [BscScan 2025]. However, initially, the company's business model involved tokenizing individual trees into NFTs (NFTrees), with owners receiving carbon tokens periodically based on their trees' CO2 sequestration capacity.

In ForestCoin, on the other hand, users earn cryptocurrencies (FTs) by providing evidence that they have planted trees [ForestCoin nd]. Therefore, rather than tokenizing individual trees, ForestCoin generates tokens based on trees planted. The goal is to plant one tree for every person on the planet, totaling 7.59 billion tokens. This approach contrasts with Open Forest Protocol (OFP) [OFP 2023], a competitor critical of the scalability of blockchain systems that work with individual trees. Instead, OFP tokenizes entire forested areas, reducing the number of tokens and improving network performance, scalability, and storage efficiency.

In both ForestCoin and Open Forest Protocol, the users themselves register trees or forested areas, respectively. To do so, they use a mobile application to capture pictures and input information about the planted trees, which are then validated by other users through a voting process. Validators are rewarded with cryptocurrencies for voting consistently among them. In ForestCoin, tree planters receive FTs immediately after validation. In contrast, OFP requires ongoing photo submissions for sustained verification before tokens are issued, based on carbon sequestration. While OFP's model is more robust, it still relies on photos and text, which can be manipulated, e.g., by using outdated photos. Conversely, to improve reliability and agility in the verification process, it would be possible to integrate real-time data from Internet of Things (IoT) sensors [Figorilli et al. 2018], drones [Harfouche and Nakhle 2023, Vilkov and Tian 2023], and satellites [Ministério da Justiça e Segurança Pública nd, MapBiomas nd]. Nevertheless, none of the solutions listed in Table 1 currently incorporates such approaches. Furthermore, none presents mechanisms to automatically detect deforestation events and block

corresponding tokens and their benefits, which would encourage landowners to maintain the planted trees.

Regarding transparency of digital data, most solutions presented in Table 1 use public blockchain networks to that end. However, ForestCoin employs a permissioned blockchain with private read access, requiring company authorization to join the network. An alternative would be to adopt a public read access policy and publish signed append-only logs of the blockchain data on IPFS [Kimura et al. 2024] or on a second blockchain [Robinson and Brainard 2019] for further transparency.

Finally, it is important to emphasize that, to our knowledge, existing blockchain-based forestation solutions, both commercial and in the literature, do not propose the adoption of forestation actions in a generalized manner. While related works tokenize forestation assets, they typically focus on carbon units, thus limiting the possibilities for end users to participate in forestation efforts. Trustt Green [Tustt 2025] stands out by tokenizing and selling compensation rights, but like others, it tokenizes only one type of forestation asset, lacking a flexible architecture to incorporate other asset types over time.

5. Scenario and solution overview

The system involves five key players: Carbono 21, the Federation, Monitors, Landowners, and Buyers, as detailed in Table 2. Based on their interaction, an overview of the system design is presented below, along with the main use cases.

Player	Operation	Description
Landowner	Asset proposal & sale	User requests the tokenization of forested areas and forestation assets
Carbono 21 (admin.)	Asset creation	Validates Landowner requests and mint tokens for them
Buyer	Asset purchase	User interested in consuming, holding or reselling tokenized assets
Federation	Data management	Executes, validates, and stores the transactions
Monitor	Platform auditing	Audits operation and transactions

Table 2. System players and their roles

As illustrated in Table 3, Carbono 21 employs its own FTs (i.e., cryptocurrencies), one type of NFT for forested areas, and one for each kind of forestation asset adopted in the platform. Based on that, Landowners can transform real-world assets into digital assets, which can be financially beneficial for them, as explained in Section 5.1. To obtain an NFT, they must request the registration of a land or forestation asset to Carbono 21. This requisition must include basic information, such as the size, location, and registration number of the asset, along with documentary evidence supporting these details and demonstrating compliance with forestation laws.

As for Carbono 21 (the system administrator), it is responsible for approving or denying the Landowners' requests after verifying submitted data and documentation. Carbono 21 uses governmental transparency systems and satellite-based deforestation tracking platforms to that end [IBAMA nd, MapBiomas nd]. Once validated, Carbono 21 generates and sends the requested digital asset to the owner, as seen in Figure 1. Specifically,

Asset	Description	Generation
Land NFT	NFT representing a forested area (i.e., an area with preserved vegetation)	Landowner requests tokenization. Carbono 21 generates the token
Forestation Asset NFT	NFT representing a forestation asset. One type for each kind of asset (e.g., carbon credits, compensation rights)	Landowner requests tokenization. Carbono 21 generates the token
Fungible Token (FT)	Cryptocurrency that enables the sale and puchase of NFTs, as well as financial incentives for Landowners	Automatic generation though the dividends mechanism (see Section 5.1)

Table 3. Types of tokens available in the Carbono 21 ecosystem

since it is a unique good, an NFT is minted, containing metadata that correspond to its real status. This information is then updated automatically over time, based on deforastation events issued by specialized third-party systems [MapBiomas nd].

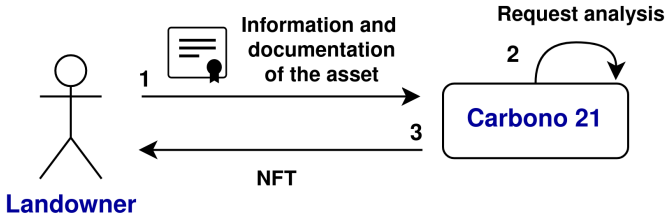

Figure 1. Diagram representing the registration of a valid asset

Landowners can sell their NFTs in exchange for FTs through the marketplace, as shown in Figure 2. Buyers who acquire NFTs, can resell them, benefit from dividends (see Section 5.1), or consume them if they are forestation assets (e.g., use compensation rights or carbon units for legal purposes).

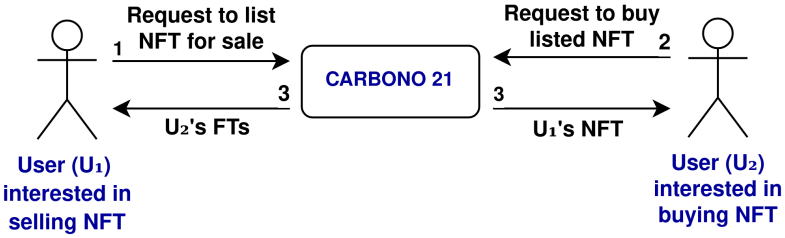

Figure 2. Diagram representing the purchase and sale of an NFT, where "Carbono 21" is the intermediary system

Every operation is executed and validated by the Federation, a consortium of organizations involved in the platform's data management. The Federation operates as nodes of a consortium blockchain, maintaining a consistent storage of transactions. It is also responsible for executing the smart contract, which defines token types and permitted operations. Carbono 21 is a mandatory member, while other organizations like universities, non-governmental organizations (NGOs), and environmental authorities (e.g., Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) and Environmental Company of the State of São Paulo (CETESB)) may join if approved by the network members. The blockchain allows these entities to supervise one another.

Another player motivated by distrust in the system is the Monitor, which can be any entity, e.g., governmental agencies and users (Landowners and Buyers). Monitors can identify misconduct by Carbono 21 or the Federation without joining the blockchain network. Their role can be one-time (e.g., validate a transaction) or ongoing (e.g., validate every block). They can detect alterations to the blockchain, approved invalid transactions, smart contract backdoors and illegitimate creation of NFT, thus enhancing the trustworthiness of the network.

5.1. Incentives

The main goal of this work is to promote forestation (i.e., planting and maintaining trees or native vegetation). To achieve that, we employ smart contract technology to create clear financial incentives for Landowners: (a) A marketplace where Land NFTs and Forestation Asset NFTs can be traded; and (b) A mechanism for periodic generation of cryptocurrencies to holders of Land NFTs, so that Landowners are entitled to this passive income as long as they hold this token and preserve the corresponding forested area.

Carbono 21 aims to adopt inclusive forestation initiatives, encouraging small and big Landowners to sell their forestation assets through mechanism (a). Buyers are also encouraged to acquire one of the many possible forms of NFTs available. Among the forestation strategies that the platform can adopt, environmental compensation stands out for enabling revenue generation from maintaining native vegetation on lands unsuitable for other uses. This approach supports even small Landowners who cannot plant traditional crops due to limited areas, legal restrictions, or infertility, allowing them to profit from mechanisms (a) or (b).

Regarding mechanism (b), its functioning is illustrated in Figure 3. Owners of Land NFTs are entitled to receive FTs generated periodically (i.e., monthly) and automatically by the smart contract. The distributed tokens represent dividends relative to the profits earned by Carbono 21 during the period. This approach contrasts with related works that pay landowners once [Treedefi nd] or yearly [OFP 2023]. By making farmers earn dividends every month, Carbono 21 seeks to encourage farmers to keep the trees standing.

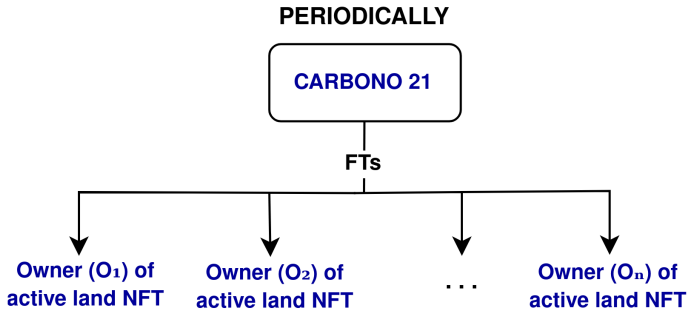

Figure 3. Periodic generation of cryptocurrencies for owners of Land NFTs

The total dividends to be paid are distributed proportionally to the size of each forested area. This approach aims to reward the forestation activity itself, ensuring that those who contribute more to the environment receive greater rewards. This is not an effort to quantify carbon offsetting, which can be an extremely complex task [Haya et al. 2023].

It is important to note that the generation of cryptocurrencies only occurs for NFTs with active status, as an NFT can be blocked if any irregularity is detected in the corresponding property. This approach incentivizes the Landowner to maintain their trees or native vegetation, as deforestation would result in the loss of the ability to receive periodic FTs.

6. Results

To assess the feasibility of the proposed solution, a PoC was developed using Hyperledger Fabric 2.5 [Androulaki et al. 2018] and benchmarked under several setups. As shown in Table 4, the implementation is capable of achieving up to 768 transactions per second (TPS) (about 66 million daily transactions) with 2s latency for Land NFT creation transactions. It can also reach up to 1400 TPS (roughly 121 million daily transactions) with 0.01s latency for Land NFT read transactions. Even with 4 organizations taking part in the blockchain, the PoC can create nearly 39 million Land NFTs daily (450 TPS). Considering that Brazil had around 8.1 million active rural properties in 2020 [Brazilian Government 2020], these results satisfy our feasibility requirements, as explained in Chapter 6.1.1 of the Master's thesis [Correia and Simplicio 2024]. Details of the implementation and testbed are presented in Chapter 5.

Benchmark	Scenario	Avg. Read	Avg. Write
Baseline	2vCPU/4GB per node, 1 node per org., 2 orgs.	400 TPS, 0.01s	577 TPS, 2s
Hardware	6vCPU/12GB per node	1050 TPS, 0.01s	**768 TPS, 2s**
Nodes	4 nodes (endorsers) per organization	**1400 TPS, 0.01s**	379 TPS, 4.7s
Organizations	4 organizations	450 TPS, 0.01s	512 TPS, 6.2s

Table 4. Best average transaction throughput and latency for each phase of the benchmarking

7. Contribution and final considerations

Given the importance of planting trees, especially considering the urgency of mitigating global warming, several digital platforms that promote forestation have been proposed in recent years [Moss nd, Climatecoin nd, ForestCoin nd, Flowcarbon 2024, OFP 2023]. Although most of them provide transparency of their digital assets, they frequently lack mechanisms to ensure transparency regarding the underlying assets. This might imply outdated content and, potentially, ineffective forestation strategies. Furthermore, these solutions are typically based on the carbon market, which presents low profitability for landowners, and, in the case of carbon credits, restrictions for small farmers. Moreover, the carbon market does not apply to biomes that are not tree-covered, like the Cerrado, and, thus, do not promote the maintenance of native vegetation in such areas.

In response, we designed Carbono 21, a digital platform capable of adopting various forestation initiatives, enabling the digitization, purchase, sale, and use of forestation assets. The platform features a flexible architecture that adapts to different forestation initiatives and legislation across countries – an approach not identified in related Computer Science works. Smart contracts facilitate the digitization of forestation assets, including those accessible to small farmers, into NFTs. Through these technologies, Carbono 21 proposes mechanisms that aim to enhance the profitability of tree planting, thereby making this activity more attractive to landowners.

Regarding transparency, we propose the use of technologies capable of providing real-world data about forested areas and forestation assets. While related Computer Science works propose unreliable and poorly scalable methods to track such assets (e.g., vegetation monitoring via pictures taken by users) [ForestCoin nd, OFP 2023], Carbono 21 supports the use of governmental databases and high-resolution satellite imagery. Such methods ensure that forestation efforts are implemented correctly by keeping digitized assets up-to-date and automatically aligned with their real-world counterparts.

As for the transparency of the digital assets, their creation and operation are managed by a consortium blockchain. Its data are publicly accessible and signed append-only logs of them are regularly uploaded to the IPFS network, as described in details in Chapter 4.2.1.3 of the Master's thesis [Correia and Simplicio 2024]. This mechanism allows Monitors (i.e., non-members of the blockchain network) to share the signed blockchain log and use it to verify the system's correct operation over time. Furthermore, the proposed approach enables any entity to audit not only the digitized assets and their transactions, but also Carbono 21's business logic – like the implemented types of assets and permitted operations – as explained in Chapter 4.2.3.3 of the Master's thesis [Correia and Simplicio 2024]. To our knowledge, such transparency in permissioned blockchain networks has not been achieved in related works, thereby representing **a significant contribution to the field of distributed systems**.

As a final contribution, this work implements and tests the proposed solution. Its source code is available at `https://github.com/Carbon-21/4orgs-ERC1155` (requesting access to the author may be necessary). The results show that the system meets its versatility and transparency goals (Pillars I and II) and performs adequately, being capable of creating over 700 digital assets per second, and reading over 1400 assets per second, depending on the setup.

References

Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., Christidis, K., De Caro, A., Enyeart, D., Ferris, C., Laventman, G., and Manevich, Y. (2018). Hyperledger Fabric: A distributed operating system for permissioned blockchains. In *Proc. of the 13th EuroSys Conference*, pages 1–15.

Antunes, C. (2023). Caubóis do carbono loteiam a amazônia. *Sumaúma*.

Bitmo (2025). Bitmo. `https://www.bitmo.org/`.

Brazilian Government (2020). Estatísticas e Dados Abertos dos Imóveis Rurais. `https://tinyurl.com/mvy6rn3v`.

BscScan (2025). Treedefi token. `https://tinyurl.com/2ksutunp`.

Carbonext (2025). Seja produtor. `https://tinyurl.com/6f35x5p7`.

Chakraborty, S., Anand, A., Kalash, D., and Srivastava, A. (2022). Transparency in carbon credit by automating data-management using blockchain. In *2022 IEEE ICBDS*, pages 1–5.

Climatecoin (n.d.). White paper. `https://tinyurl.com/2vyy3s6m`.

Correia, P. H. B. and Simplicio, M. A. (2024). Carbono 21: Promovendo florestamento utilizando tokenização. Master's thesis, University of São Paulo.

EcoRegistry (2025). EcoRegistry. https://www.ecoregistry.io/.

Etherscan (2025). Moss. https://tinyurl.com/mtjsrkys.

Figorilli, S., Antonucci, F., Costa, C., Pallottino, F., Raso, L., Castiglione, M., Pinci, E., Del Vecchio, D., Colle, G., Proto, A. R., et al. (2018). A blockchain implementation prototype for the electronic open source traceability of wood along the whole supply chain. *Sensors*, 18(9):3133.

Flowcarbon (2024). Flowcarbon. https://www.flowcarbon.com/.

ForestCoin (n.d.). White paper. https://tinyurl.com/4baxhbph.

Franke, L., Schletz, M., and Salomo, S. (2020). Designing a blockchain model for the Paris agreement's carbon market mechanism. *Sustainability*, 12(3):1068.

Harfouche, A. and Nakhle, F. (2023). Artificial intelligence, blockchain, and extended reality: Emerging digital technologies to turn the tide on illegal logging and illegal wood trade. *Ann. of Silvicultural Res.*, 48(1):12–21.

Haya, B. K., Evans, S., Brown, L., Bukoski, J., Butsic, V., Cabiyo, B., Jacobson, R., Kerr, A., Potts, M., and Sanchez, D. L. (2023). Comprehensive review of carbon quantification by improved forest management offset protocols. *Frontiers in Forests and Global Change*, 6:958879.

IBAMA (n.d.). Consulta de autuações ambientais e embargos. https://tinyurl.com/3zs83357.

Kimura, L. T., Shiraishi, F. K., Andrade, E. R., Carvalho, T. C. M. B., and Simplicio, M. A. (2024). Amazon biobank: Assessing the implementation of a blockchain-based genomic database. *IEEE Access*, 12:9632–9647.

MapBiomas (n.d.). MapBiomas Alerta. https://plataforma.alerta.mapbiomas.org/mapa.

Ministério da Justiça e Segurança Pública (n.d.). Programa Brasil Mais. https://plataforma-pf.sccon.com.br/.

Moss (n.d.). White paper. https://tinyurl.com/bdh756x6.

OFP (2023). White paper. https://tinyurl.com/nt533b8a.

Robinson, P. and Brainard, J. (2019). Anonymous state pinning for private blockchains. In *2019 TrustCom/BigDataSE*, pages 827–834.

Ronquim, C. C. (2010). Queimadas na colheita da cana-de-açúcar: Impactos ambientais, sociais e econômicos. *Embrapa*.

Treedefi (n.d.). White paper. https://tinyurl.com/muyabc5r.

Tustt (2025). Trustt green. https://tinyurl.com/3n5k8xu3.

Vilkov, A. and Tian, G. (2023). Blockchain's scope and purpose in carbon markets: A systematic literature review. *Sustainability*, 15(11).

WWF (n.d.). Soy. https://tinyurl.com/5374v9xc.