Christos Daoulas

A FAIR-based reproducible prototype for Permissioned Public Blockchain Systems: the case or monitoring deforestation on protected Indigenous lands in the Amazon rainforest

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Supervised by Dr. Dimitrios Sacharidis

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Contents

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Abstract

Public permissioned blockchains are a type of distributed ledger technology that aims to bring some of the benefits of decentralization to traditional systems of public administration. These benefits include increased transparency, reduced risk of fraud, and improved efficiency. Transactions on such systems are recorded in a tamper-evident manner, making it easy for anyone to view and verify the accuracy of the record. This can help to build trust between the government and the public, as well as reduce the risk of corruption. Another advantage of public permissioned blockchains is that they can improve efficiency. By automating certain processes and reducing the need for manual intervention, a blockchain-based system can help to streamline the work of government agencies and reduce the risk of errors. These characteristics can be enhanced using FAIR principles, where systems can facilitate transparency, accountability, and collaboration, improving the efficiency and effectiveness of a wide range of processes and operations, while becoming Findable, Accessible, Interoperable, and Reusable. This dissertation will explore the creation of such a public permissioned blockchain template, distributable according to the FAIR principles, that will be applied to a case study focusing on the use of "smart contracts" in order manage land use and resource extraction in the Amazon, as part of a sustainable governmental land governance practice that also ensures indigenous land rights protection; the blockchain will track deforestation rates in protected indigenous areas, using publicly available satellite imagery, and compare the former with the evolution of deforestation in comparable, but non-protected indigenous and non-indigenous land.

1. Introduction

Citizen agency and transparency are particularly salient in contemporary technological civilization, particularly in the context of Big Data and Artificial Intelligence. The use of open data, open code, and transparent methodologies is highlighted as a means for citizens to scrutinize government processes and promote democratic values. The Open Data Movement and Open Science may provide significant means to empower citizens and increase transparency in government decision-making processes. Open-source culture is in effect dictated by the FAIR guiding principles for scientific data management and stewardship, deemed important for ensuring accessibility and interoperability of data, stakeholder engagement and collaboration, and adherence to metadata standards. Citizen agency can thus be empowered by emphasizing the need for transparency and collaboration in government decision-making processes and the potential of open data and open science to promote democratic values, effectively transposing a FAIR-based citizen participation in government processes. The use of information and communication technologies (ICTs) has consequently led to the resurgence of e-Government, which aims to improve the efficiency, transparency, and accountability of government operations and public services. However, e-government platforms are still centralized and vulnerable to external attacks.

An amalgamation of open governance and e-government, supported by innovative technologies like blockchain, may provide accountability and allow citizens to track public governance activities more closely, all while increasing security. Blockchain technology, as a distributed database that allows for the secure and transparent recording of transactions (Nakamoto, 2008), can support a variety of public sectors in this context, including natural resource management. One of the key advantages of blockchain is its ability to provide a tamper-evident record of transactions, which can be useful for tracking the movement of resources and ensuring compliance with regulations, while ensuring the rights of concerned communities, thus granting the technology the potential to revolutionize the way e-government manages and shares data, to encourage the modification of public administration and enable the provision of transparent and secure public services.

Depending on the governance model and the chosen access control mechanism, there is a variety of blockchain architectures that can be employed on an application-basis: public permissionless, public permissioned, and private permissioned. Public permissioned blockchains restrict access to authorized parties who can read and write transactions, while the validation process is limited to authorized nodes. Private permissioned blockchains only permit authorized nodes to read, submit, and validate transactions. Public permissioned blockchains have gained attention as a way to improve the efficiency and transparency of traditional public administration systems while providing transparency and accountability. Using the FAIR principles, a governance model for public permissioned blockchain must ensure non-discriminatory and open access while ensuring decentralization. The benefits of blockchain-based public administration systems include decentralized decision-making, distributed ledgers, increased transparency, and accountability in public administration, which can help reduce corruption.

This dissertation will focus on permissioned public blockchains in the forestry sector, as a very salient contemporary topic is the fight against climate change and its multidimensional implications for human society. Inspired by the latest report from the Intergovernmental Panel on Climate Change (IPCC), the United Nations body for assessing the science related to climate change (Mukherji et al., 2023), the dissertation will explore the benefits of a permissioned public blockchain template for Public Land Governance based on FAIR-principles, applied on a use case pursuing Sustainable Development Goals related to deforestation and indigenous rights. The dissertation aims to contribute to academic literature by addressing a knowledge gap in blockchain template reproducibility. Against the backdrop of climate change, the dissertation details the application of a tailor-made blockchain kernel, in an effort to explore the potential of open-source blockchain templates in the context of robust and efficient public administration systems based on FAIR principles, which can prove decisive in enabling inclusion and providing agency to otherwise unrepresented social strata.

The dissertation is structured as follows: First, I will discuss the latest literature review on blockchain technologies, FAIR principles applied to public permissioned blockchains, deforestation, and how it can be mitigated with blockchain-based public land governance. I will also provide information on the role of indigenous populations as both stewards and recipients of the effort towards, and collateral effects of, the road towards climate change mitigation, respectively. In the third section, I will describe the methodology of the smart-contract based deforestation case study for a small-scale public permissioned blockchain. This will be based on a pipeline combining ETL techniques sourcing data from a publicly available satellite imagery database and applying NDVI-based transformations to determine deforestation rates between comparable samples of pre-determined indigenous, and non-indigenous protected and non-protected areas, focused on the Brazilian Amazon. I will describe how this information will then be fed into a ~~parallel~~ database that will feed smart contract disbursement decisions linked to a proprietary test coin simulating a voluntary carbon market, AZC (AmazonCoin). In the fourth section, I will discuss the results, and in sections five and six, future sector challenges and recommendations for future research respectively. Finally, in section seven I will provide my conclusions, where I will summarize my findings and provide the basis for future research and discussions.

2. Literature Review

2.1 An overview of FAIR-based public permissioned blockchain systems

Innovative Democratic Governance based on FAIR principles

According to Couldry (2014), agency can be understood as " *(...) making sense of the world so as to act within it".* Consequently, one may easily distinguish two notions directly interrelated with agency: knowledge obtained through the ability to "make sense" of the world, and power instrumentalized through the ability to "act within it". In contemporary technological civilization, which is characterized by the constant flow of digitalized information, citizen agency, an important pre-condition for democracy (Imbroscio, 1999), is becoming increasingly salient in an effort to reconcile the societal benefits reaped by the advent of the Internet, Big Data, and Artificial Intelligence technologies, with the challenges naturally arising by the latter as well (Kitchin, 2014). The government data landscape consists of various sources of data, including official records, statistics, user-generated online content, sensory data, tracking data, and transaction data; data can further be categorized by type, such as geographical, economic, or demographic data, and can also be classified as real-time or historical data, as well as by format, such as text, numerical, network, image, and video data (Engin and Treleaven, 2019).

While Big Data and continent technologies have the potential to collect and describe citizens' data in an effort to scrutinize societal behavior as part of ensuring the well-functioning of established governance processes, they often do so without the knowledge or permission of the public, who are additionally not granted the ability to verify the processes undertaken on their data and whether their personal information is being used in a responsible and transparent manner (Dijck, 2014; Mayer-Schönberger and Cukier, 2013). Couldry and Powell (2014), define this limited participation as the danger of Big Data technologies to undermine agency by "*disconnecting system and experience*". A means by which the public may ensure democratic overview of governance is through scrutinizing themselves how their own metadata is being used by public administrations and verify the results of such processes. This would necessitate reproducibility, in this context the ability to verify the results of governmental processes, enabled by the principles of open data, open code, and transparent methodologies (Gandrud, 2018; Ramachandran et al., 2021). Instrumental in this approach is the Open Data Movement, that has the potential to empower citizens and promote transparency in an effort to make governance more collaborative (Bartenberger and Grubmüller, 2014; Gurin, 2015; Ruijer et al., 2017).

In his paper, Baack (2015) purports that the open data movement is at the intersection of datafication and open source culture, which have contradictory implications for public agency. According to Baack, datafication, the ubiquitous quantification of social life for which Big Data is the most prominent expression (Mayer-Schönberger and Cukier, 2013), raises concerns about the agency of publics because Big Data technologies might impede our potential to act in an agentic manner; on the other hand, open source culture grants access to the source code of software and incorporates contributions from potentially everyone, emphasizing transparent and collaborative governance that might support agency with very notable examples being Anonymous or Wikileaks (Beyer, 2014). The open data movement can support democratic values when it combines the open sharing of raw data to make decision-making processes more transparent, the direct participation of citizens in the decision-making processes themselves for more collaborative and representative democracy, and the existence of "empowered intermediaries" to make raw data accessible to the wider public (Baack, 2015; Bartenberger and Grubmüller, 2014; Couldry and Powell, 2014; Janssen et al., 2017; Lister, 2019). Open data and open governance are intrinsically interrelated, the former allowing a type of government dictated by the latter to make local and national authorities more transparent about their processes, thus promoting citizen participation and collaboration through the use of new technologies (Hardwick et al., 2018).

Open data combined with open code governance, provide a scientifically sound way to democratize agencies' automated decision-making, by making the algorithmic processes behind regulatory choices visible and thus the involved information systems more transparent, democratic, and legitimate (Citron, 2008). Indeed, whereas science can provide evidence-based solutions to complex problems facing democracies, such as climate change and economic inequality, healthy democratic institutions can help ensure that these solutions are implemented in a fair and equitable manner. Transparency and openness in scientific research through Open Science[1] can help build trust in scientific findings and maintain a healthy democracy in line with societal, ethical and legal considerations, all while reaching and engaging traditionally excluded communities (de Souza de Aguiar Monteiro and Sant'Ana, 2021; Miedema, 2022).

In their seminal paper "*The FAIR Guiding Principles for scientific data management and stewardship",* Wilkinson et al. (2016) discuss the FAIR (Findable, Accessible, Interoperable, Reusable) guiding principles for scientific data management and stewardship, providing insights into the implementation of these principles in open science. The authors highlight the need for clear guidelines and standards to ensure accessibility and interoperability of data along with recommendations for the development of effective FAIR policies and practices, including the need for stakeholder engagement and collaboration and greater attention to metadata standards, findings that are also supported by other researchers (Tschirner et al., 2021; Wuttke et al., 2019).

From digitalizing government documents and services to creating online portals that enable citizens to interact with government agencies, contemporary efforts to make public governance processes transparent and increase citizen participation through innovation, have led to the resurgence of e-Government, the use of information and communication technologies (ICTs) to improve the efficiency, transparency, and accountability of government operations and public services (European Parliament, 2015). Despite recent progress though, e-government platforms are still black-boxes due to their high degree of centralization that warrants heavy reliance on closed governmental oversight, whereas the centralized IT infrastructure used is highly vulnerable to external attacks.

An amalgamation of open governance and e-government, supported by innovative technologies like blockchain, may independently streamline an automatic auditing process to provide accountability and allow citizens and civic organizations to track public governance activities more closely, all while increasing security (Hardwick et al., 2018). In their systematic review of the applicability of blockchain technology to open science, Leible et al. (2019) find that there are several potential benefits that blockchain technology can provide, such as secure recording of transactions and its decentralized nature, which can lead to an increased level of trust. In accordance with FAIR principles, blockchain has the potential to revolutionize the way e-Government manages and shares data, to encourage the modification of public administration and enable the provision of transparent and secure public services (Lykidis et al., 2021).

[1] Open Science is an "international movement of scientific practice based on open publication, open metadata, open data, open source, open educational resources, open peer review, impact and open metrics, open repositories, including data repositories, under FAIR Principles (Findable, Accessible, Interoperable, Reusable)". *Source*: de Souza de Aguiar Monteiro and Sant'Ana (2021)

On Blockchain Technology: an Overview

Blockchain technology has its roots in a number of fields, including cryptography, computer science, and economics (Laatikainen et al., 2023). The origins of Blockchain development can be traced in 1991, when cryptographers Stuart Haber and W. Scott Stornetta proposed the first concept of a secure digital ledger in their paper "*How to timestamp a digital document*", where they discussed how to secure documents against tampering or revision (Haber and Stornetta, 1991). The concept was then furthered and popularized by the individual or group of individuals known as "Satoshi Nakamoto" (2008), in the seminal paper "*Bitcoin: A peer-to-peer Electronic cash system*". The paper described a new electronic payment system that relies on a decentralized network of computers to maintain a shared ledger of all transactions, called the blockchain, secured using cryptographic techniques and used to disrupt traditional financial systems, by reducing transaction costs, ensuring trust without the use of an intermediary like a counterparty, and preventing fraud and double-spending. The technology quickly gained traction and in January 2009, the first block of the Bitcoin blockchain was created, the genesis block, marking the start of the blockchain era (bitcoin.com, 2023). Multiple blockchain-based projects have subsequently been launched, most notably Ethereum in 2014 (Buterin, 2014).

In its essence, Blockchain technology is a database management infrastructure characterized by a digital decentralized and immutable ledger, recording a chronological chain of data transactions contained within "blocks" and maintained on a distributed peer-to-peer (P2P) network of computers called nodes (Zein and Twinomurinzi, 2019). The most important feature of blockchain is decentralization, i.e. the approval of transactions is trustless and not controlled by a single entity or centralized authority, but the verification and addition of transactions in the ledger in the form of blocks, is performed by participating nodes, thus addressing a number of multifaceted issues: network dominance and data stewardship by a centralized authority, single point of failure and high network latency (Ismail and Materwala, 2019; Lykidis et al., 2021). What make blockchains and Distributed Ledger Technologies (DLTs) particularly interesting, also adding an extra layer of security against tampering and revision, are its embedded immutability, transparency and traceability, maintained by using advanced cryptographic techniques that make it virtually impossible to alter or tamper historical data contained within its blocks (Mcquinn and Castro, 2019). This is because each block in the chain is linked to the previous block, creating an unbreakable chain of data that cannot be easily modified by an attacker, without transposing modifications in each consequent linked block in an iterative manner, and consequently necessitating the reversal of a transaction computationally impractical (Nakamoto, 2008).

The workflow is initiated when a network participant wants to perform a transaction, by creating an encrypted copy of the transaction details called a hash, using an encryption function called a hash function e.g., SHA-256 or SHA-1 (Aggarwal and Kumar, 2021). The transaction data in question may refer to a range of assets, such as financial instruments, contracts, records of property ownership, personal medical and educational records, certificates, records of transactions for goods and services, or any other type of asset that can be digitalized (Lykidis et al., 2021). The result is then further encrypted using the user's private key in order to authenticate her identity in the server, and the final output, or the "digital signature" of the ongoing transaction, is then broadcasted to the network (Ismail and Materwala, 2019). Consequently, each block in the blockchain contains a cryptographic hash of the previous block which summarizes the latter's content, along with other information pertinent to the ongoing transaction such as a timestamp and the current list of validated transactions as can be seen in Figure 1.

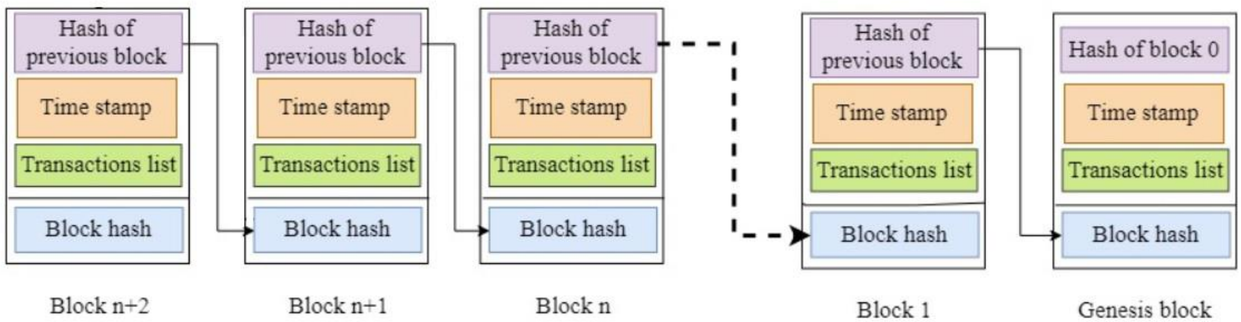

Figure 1: Overview of Blockchain Architecture

Source: Ismail and Materwala (2019)

Each new block containing the network's latest transactions is validated through the consensus mechanism, which is the procedure of an asynchronous messaging communication between a number of nodes in the network, such the broadcasting of a transaction representing an event in the system and containing application-specific details (Pîrlea and Sergey, 2018). The addition of new blocks of transactions broadcasted to the blockchain network is confirmed through a process called "mining", performed by mining nodes (or block generators), that are a subtype of full nodes – i.e. nodes able to store a full copy of the ledger and validate a transaction, in contrast to light nodes who can only send and receive transactions (Belotti et al., 2019). A full node's work is twofold and precedes that of the miners: first, it is responsible for verifying the identity of the user wanting to append her transaction, to the rest of the network, by decrypting the user's digital signature through the latter's public key; secondly, a full node checks data integrity by evaluating the correspondence between its own version of the user's encrypted/hashed transaction details, and the equivalent obtained after decrypting the user's signature (Ismail and Materwala, 2019).

The protocols used to achieve consensus in Blockchain-based DLTs can be based on computing power, non-computing capabilities and voting algorithms used to validate a transaction. Currently the most commonly used consensus algorithms are Proof-of-Work and Proof-of-Stake. The Proof-of-Work (PoW) is a compute-intensive consensus protocol, in which miners compete with each other to solve a cryptographic problem of manageable computational complexity in order to verify the transaction's pertinence to a specific block (i.e., find the hash of the block in question), with the first miner to do so obtaining a reward (a transaction and mining fee, which act as the incentive for their computational power used) after a significant pool of miners validate the transaction from their side as well (Nakamoto, 2008). The Proof-of-Stake (PoS) is a more secure, environmentally friendly and non-computing capability based consensus mechanism, developed as a less energy-consuming alternative to PoW (Belotti et al., 2019). In PoS, instead of miners, validators are responsible for adding new blocks to the blockchain, with their voting power based on the amount of cryptocurrency they hold or "stake" in the network, whose duration determines rewards (Laatikainen et al., 2023). Validators are either chosen randomly, or based on the number of days they have been "staking". To validate a block, a validator puts up some of their cryptocurrency as a stake, which can be temporarily frozen if they attempt to cheat the system (Tan et al., 2022). Validators are incentivized to validate transactions honestly because if they act maliciously or try to double-spend, their stake will be lost (Zhao et al., 2021). Primary enabled by PoS, Ethereum introduced the innovation of smart contracts in 2015 (Shermin, 2017). Smart contracts are digital self-executing contracts that can automate business operations based on predetermined terms of agreement between buyer and seller included in the code. Smart contracts automatically execute the concerned transaction when the coded clauses are met and without the need of an intermediary or entity (Buterin, 2014).

Blockchain technology has seen significant growth and transformation since its inception, and its potential for disruption and innovation continues to be explored across multiple fields. Although often associated with cryptocurrencies, such as Bitcoin and Ethereum, blockchain has many applications beyond finance, including, but not limited to: social impact, natural resource management, supply chain management, healthcare, voting systems, e-Government, and digital identity verification (Bustamante et al., 2022; He and Turner, 2022; Laatikainen et al., 2023; Mcquinn and Castro, 2019). It is considered a disruptive technology because it has the potential to fundamentally change the way data is stored, shared, reviewed and managed across a wide range of applications in the public and private sector, supporting trust, efficiency, transparency, security, and accountability without the need of intermediaries, thus potentially benefitting many established monitoring and bureaucratic processes. The early days of blockchain were marked by scalability, energy consumption and security issues, but as more individuals, groups and entities began working on blockchain projects, these issues have been addressed to a considerable extent (Amiri et al., 2021; Belotti et al., 2019; Ismail and Materwala, 2019). Research on layer-1 and layer-2 blockchain technologies has iterated continuously improved architectures over the years, to better suit different use cases[2] (Gudgeon et al., 2020). Ongoing development has currently led to various types of blockchain protocols depending on the access control mechanism required, from

[2] A layer-1 network, or Mainnet, is the base level of the blockchain architecture in charge of on-chain transactions, like Bitcoin or Ethereum, and is responsible for hosting the immutable append-only chain of blocks that accumulates transactions from parties in a network for public verifiability. A layer-2 network like smart contracts, is an external, parallel off-chain network built on top of layer-1 in order to improve the latter's performance e.g., by increasing scalability. *Source*: https://academy.binance.com/en/articles/blockchain-layer-1-vs-layer-2-scaling-solutions

public and private blockchains to permissionless, permissioned and even hybrid ones, each with its own set of features and benefits (Helliar et al., 2020).

Permissioned vs permissionless blockchains and traditional systems for public administrations

Depending on the access control mechanism, there is a distinction between public permissionless, public permissioned, and private permissioned systems. First, in *public permissionless* blockchain systems, any user can join the network and participate in the data reading, writing, and validation process, and the users can remain anonymous. Second, in *public permissioned* blockchains, every node can read and write transactions, but the validation process is restricted to authorized nodes. Third, in *private permissioned* blockchains, only authorized nodes can read, submit and validate transactions. In permissioned systems, the validation of transactions happens using selective endorsement (i.e., by a small number of authorized actors) instead of a consensus mechanism that is applied to a permissionless system. In permissioned systems, the actors' identity is typically not hidden (Laatikainen et al., 2023).

Public permissioned blockchain technology has especially gained increasing attention in recent years as a potential solution for improving the efficiency and transparency of traditional public administration systems. In permissioned public blockchain systems, access to the blockchain is restricted to certain trusted parties. Participants have either restriction on writing (validation) rights only, or on both reading (access) and writing rights. Usually, this participation mode leads to less decentralised blockchains (Belotti et al., 2019). Whenever a system requires public verifiability, i.e., it lets anyone in the public community observe the system's state and verify its correctness, writing rights may be kept restricted but at the same time everyone is free to observe the ledger state in open permissioned blockchains (INATBA and Climate Ledger Initiative, 2020). This means that the data stored on the blockchain should be easily discoverable and accessible to those who have permission to view it, but only specified nodes that have been trusted by the network are able to validate transactions and enable their addition to the network. Such systems also are interoperable as they may be integrated with other systems and data sources, and it should be able to be reused for a variety of purposes (citation).

One key benefit of reproducible permissioned public blockchain systems is their ability to prove the tamper-evident record quality of transactions and other events by third parties, who have not been involved in the initial registration process of such transactions. This is essential in industries such as finance, where the integrity of records and the avoidance of double-spending practices compliance with AML are of the utmost importance. In addition, these systems can help to facilitate collaboration and information sharing, as they allow multiple parties to access and contribute to a shared record of data, improving ecosystem health and supporting the fight against crime in a coordinated international manner (citations).

Apart from evident traditional finance applications though, there are several scientific studies that have demonstrated the importance of reproducible permissioned public blockchain systems in a variety of sectors. For example, such systems can improve the transparency and accountability of supply chain management (citations), whereas another study found that permissioned blockchain systems can be used to track and verify the origin of agricultural products, helping to ensure their quality and authenticity (citations). In the healthcare industry, a study published in the journal "Blockchain in Healthcare Today" found that these systems can be used to securely and transparently share patient data and medical records, improving the efficiency and effectiveness of healthcare delivery (citations).

Using the FAIR principles as a guide, public permissioned blockchain systems can further facilitate a level of transparency and accountability that is essential for public administrations. A governance model meriting both, the “Public” and “Permissioned” designations, has to ensure non-discriminatory and open access on one hand, i.e. inclusion, fair access, usage and sustainability of the network, while ensuring decentralization on the other by open participation in the construction, operation, provision and governance of the infrastructure on the other (Navarro, 2018). In the context of e-Governments, as a decentralized, distributed and secure network, public permissioned blockchain can allow citizens to easily find their on metadata, improve data accessibility, provide a standardized and interoperable data format between stakeholders, and enable easier data audit, verification, and reusability by overseeing authorities (Moura et al., 2020). As a result, this blockchain governance model is particularly well suited to empower citizen participation in the democratic process through greater transparency, accountability, and efficiency in government services, benefiting citizens and stakeholders alike, while improving trust in public governance (Bustamante et al., 2022; Pauletto, 2021; Poblet et al., 2020; World Economic Forum, 2020).

The technology behind the system, grants a number of inherent comparative advantages in relation to more traditional centralized, but closed public administration systems. First, public permissioned blockchain technology allows for decentralized decision-making and distributed ledgers, which can increase transparency and accountability in public administration. This quality of a blockchain based public administration system has important repercussions against systemic institutional corruption, as this database type can increase the trust of the civil society on terms of the veracity and fairness of public transactions, both at a higher administrative level and at a lower citizen-centric one (citation). Traditional public administration systems often rely on central authorities to make decisions, which can be subject to corruption and manipulation. In contrast, public permissioned blockchain allows multiple parties to validate transactions and make decisions, reducing the risk of corruption and increasing transparency. For example, a study by Li et al. (2019) found that using a public permissioned blockchain in a government procurement process led to increased transparency and reduced corruption compared to a traditional procurement process.

Second, public permissioned blockchain technology can improve efficiency in public administration. Traditional public administration systems can be slow and bureaucratic, with multiple layers of approval and documentation required for each transaction. In contrast, public permissioned blockchain technology allows for automatic and real-time validation of transactions, reducing the need for manual approval and documentation processes. As an example, a study by Zhang et al. (2018) found that using a public permissioned blockchain in a government land registration system led to a significant reduction in processing times compared to a traditional system.

Third, public permissioned blockchain technology can improve security in public administration. Traditional public administration systems are vulnerable to cyber attacks and data breaches, which can result in the loss or theft of sensitive information. In contrast, public permissioned blockchain technology uses advanced cryptographic techniques to secure transactions and data, making it more resistant to cyberattacks. For example, Nakamoto (2008) found that using a public permissioned blockchain in a government voting system led to increased security and reduced the risk of fraud compared to a traditional voting system.

Compared to permissionless systems, permissioned Blockchains can process transactions much faster without compromising network security. The sacrifice of decentralization in favor of security and scalability is particularly attractive to networks with pre-defined stakeholders acting within specific boundaries. It leverages the technology's cryptographic features and still ensures scalability to meet the needs of high transaction throughputs (Braden, 2019).

2.2 A case study on reducing deforestation rates in protected indigenous Amazonian lands using blockchain

In this review, we will explore the potential of permissioned public blockchain systems for monitoring deforestation on public land, as a very salient contemporary topic is the fight against climate change. We summarize the current state of the art in this area and briefly discuss the findings of relevant peer-reviewed studies, along with some notable real-world applications.

Deforestation and Blockchain-based Public Land Governance

According to the IPCC (Mukherji et al., 2023), the emissions of greenhouse gases, coupled with unsustainable land use practices, have undeniably led to global warming, resulting in significant economic harm; these effects are felt most acutely by vulnerable communities who are disproportionately affected and have historically contributed the least to the problem of climate change. A major contributor to climate change is deforestation, the conversion of forests to non-forest land, often for agricultural or urban development; deforestation constitutes a significant ecological challenge as it can lead to soil erosion, water shortages, and other environmental problems with far-reaching consequences, not only for biodiversity, but also for human well-being in general (Foley et al., 2005; Gibbs et al., 2010). The role of forests in the fight against climate change is evidently very significant, due to their vital role as carbon sinks and their consequent potential to release large amounts of carbon dioxide into the atmosphere following their destruction (Chazdon et al., 2016; DeFries et al., 2010; Foley et al., 2005).

Afforestation and avoided deforestation are historically considered as reliable and cost-effective methods in the fight against climate change (Eliasch, 2008). Public land, which is owned and managed by governments, represents a significant portion of the world's forests and is a key focus of efforts to address deforestation (Agrawal et al., 2008). As such, public land governance including conservation on one hand and restoration of forests on the other hand through monitoring and management of deforestation, especially in tropical regions such as the Amazon, have the highest total mitigation potential (Carvalho et al., 2019; Nepstad et al., 2014; Reydon et al., 2020). Effective public land governance requires robust systems for monitoring and managing natural resources, including forests. These systems allow for the collection and verification of data from multiple sources, including satellite imagery and ground-based observations (Asner and Mascaro, 2014; Carvalho et al., 2019). Additionally in land administration, the question of who has what rights and to which land parcel is very critical, and therefore makes it important to be able to know participants' identity as property law in many legal systems may require some property rights to be formalized in a notarial deed (Ameyaw and de Vries, 2020; Garcia-Teruel and Simón-Moreno, 2021);

In recent years, there has been increasing interest in the use of blockchain technology for the management of natural resources, including the monitoring of deforestation by embedding remote sensing technologies, with considerable literature (Braden, 2019; Chen, 2018; Corrêa Tavares et al., 2021; He and Turner, 2022; Howson, 2019; INATBA and Climate Ledger Initiative, 2020; Khandelwal and Nair, 2022; Kotsialou et al., 2022). The key feature of blockchain is its ability to provide a tamper-evident record of transactions, which can be useful for tracking the movement of resources and ensuring compliance with regulations (Allena, 2019; Bottoni et al., 2020). In addition, blockchain systems can improve the efficiency of land governance by reducing the time and administrative resources required to process land transactions, as the latter can be processed electronically thus greatly reducing the time and resources required (Ameyaw and de Vries, 2020).

Given the nature of challenges facing effective and efficient land governance, permissioned public blockchain systems specifically have a high potential for managing public forested land in an effort to mitigate climate change (INATBA and Climate Ledger Initiative, 2020). A study by Shang and Price (2019), found that the use of a permissioned blockchain-based system for land registration in Georgia resulted in a significant reduction in the time and cost of the registration process. In Indonesia, two studies proposed permissioned blockchain-based framework for land ownership tracking, which can help achieve and validate the integrity of changes in land ownership and can enhance the transparency of land administration processes (Christine et al., 2022; Thamrin et al., 2021).

In permissioned public blockchain systems, access to the blockchain is restricted to certain trusted parties, and such systems have been proposed as a potential solution for monitoring deforestation on public land, as they allow multiple parties to securely and transparently record transactions and can thus be employed to track and verify the use of public land, including activities related to deforestation (INATBA and Climate Ledger Initiative, 2020; Moura et al., 2020; Ruiz, 2020; UNECE, 2022). The permissioned entry to a blockchain is required in cases where activities should be associated with a specific legal identity (Braden, 2019), making this specific blockchain architecture particularly appealing for land governance applications (Garcia-Teruel and Simón-Moreno, 2021).

As per environmental law, very salient notable positions from the Rio Declaration on the Environment and Development drafted during the U.N's "Earth Summit" in 1992, and the United Nation Economic Commission from Europe's Aarhus Convention, emphasize the need to involve the general public in decision making processes and the management of related problems, through "*appropriate access to information concerning the environment that is held by public authorities*.." ("United Nations Conference on Environment and Development," 1992) to enable "*public participation in decision-making enhance the quality and the implementation of decisions, contribute to public awareness of environmental issues, give the public the opportunity to express its concerns and enable public authorities to take due account of such concerns*" (Stec et al., 2000).

It is this author's view that when an "open" public permissioned blockchain system acts as an immutable record of land ownership and transactions, it may offer an innovative solution that is well-placed to ensure the integrity of public land governance. According to Allena (2019), such a "middle solution" between a fully permissionless system that would be more decentralized on one hand, and a permissioned system that is safer and more scalable given current levels of protocol security, may be more appropriate, as it only involves concerned parties satisfying the compliance requirement on terms of transparency on the legal identity of the participants in a land transaction, while allowing any user to anonymously view registered transactions (Braden, 2019; Garcia-Teruel and Simón-Moreno, 2021; INATBA and Climate Ledger Initiative, 2020). More specifically, land management is open to consultation to the general public which would be able to usufruct the process' full transparency by witnessing maximum visibility of the data registered on the blockchain (INATBA and Climate Ledger Initiative, 2020), but would allow closer scrutiny and active participation in the data registration and verification process only from groups and individuals constituting directly involved parties in such land transactions, as well as NGOs and other environmental and civic associations representing social interests, in order to satisfy compliance requirements while ensuring a minimum degree of involvement from concerned public and notarial authorities to ensure legitimacy (Allena, 2019; Garcia-Teruel, 2020).

Under this light, blockchain's nature as a distributed database that allows for the secure and transparent recording of transactions, offers for the potential to revolutionize natural resource management (Braden, 2019; Kotsialou et al., 2022). The role of innovative, robust and efficient public permissioned administration systems based on FAIR principles, can thus prove decisive in pursuing the Sustainable Development Goals (citation).

The role of indigenous peoples in protecting forest land in the Amazon

The Amazon rainforest is one of the most biodiverse and important ecosystems on the planet, providing a critical habitat for an estimated 400 billion individual plants and animal species; the Amazon also is the home and hunting ground for many indigenous communities providing them with vital resources in a symbiotic relationship that has lasted for many centuries (Pérez and Smith, 2019; Plotkin, 2020). Unfortunately, the region is also facing a serious threat from deforestation human activity, including illegal logging, mining, and land clearance for agricultural development (Baragwanath and Bayi, 2020; Plotkin, 2020; Prioli Duarte et al., 2023; Reydon et al., 2020). The rapid deforestation of the Amazon has become a major global concern, as it not only destroys the natural habitat of countless species, but also contributes to climate change and undermines the livelihoods of local communities (Mukherji et al., 2023).

There is ample compelling academic research that the protection of indigenous forest lands by governments and conservation organizations, can ensure that these areas remain intact and serve as a barrier to further deforestation and the mitigation of consequent climate change (Baragwanath and Bayi, 2020; FAO, 2021; Mukherji et al., 2023; Prioli Duarte et al., 2023; Reydon et al., 2020; Robinson et al., 2014). Indigenous communities can provide a buffer zone for the forest; such peoples have lived in the Amazon for generations, and have developed a deep understanding of the forest and its ecosystems, obtaining a traditional role as stewards and protectors of the rainforests they have been living for generations in. Indigenous areas in Latin America have fewer forest fires than other areas, and there is solid data from the Amazon Basin and most other forested areas in Latin America that the CO2 emissions from Indigenous and Tribal territories are much lower than those of other areas with similar ecological conditions and remoteness (Nelson and Chomitz, 2011; Walker et al., 2020). Many indigenous territories prevent deforestation as well or better than non-indigenous protected areas - for example, a study from the *Conservation biology* journal, found that deforestation was 1.7 to 20 times higher along the buffer zone, versus the inside of the indigenous reserve perimeters, using satellite-based maps of land cover (Nepstad et al., 2006).

One way in which protecting indigenous forest lands can help with deforestation is by promoting traditionally established sustainable land use practices that have helped maintain the forest's biodiversity. Indigenous and tribal communities often hold more knowledge about medicinal plants, forest fruits and vegetables, fire and forest management, knowledge that is lacking in communities with less experience living and working in forests (Blackman et al., 2017; Pérez and Smith, 2019; Plotkin, 2020; Posey, 1985). Practices like these allow indigenous communities to live in harmony with the forest and prominently include agroforestry, swidden agriculture, and hunting and gathering. These practices not only help to conserve the forest, but also provide the communities with a livelihood. By promoting these practices, governments and conservation organizations can help to reduce the pressure on the forest from land use change (González and Kröger, 2020; Plotkin, 2020).

A second way in which protecting indigenous forest lands can help with deforestation is by providing an alternative to commercial logging. Commercial logging is a major driver of deforestation in the Amazon, as it is often done without regard for the forest's ecosystems or the rights of indigenous communities. By protecting indigenous forest lands, governments and conservation organizations can ensure that logging is done in a sustainable way, and that the rights of indigenous communities are respected (De La Rosa Tincopa, 2009; FAO, 2021; González and Kröger, 2020; Silva-Junior et al., 2023).

Finally, the remoteness of indigenous lands in the Amazon can help against deforestation as these areas are typically better preserved due to limited accessibility (Oliveira et al., 2007). These lands are often located in areas that are difficult to access, making it challenging for loggers and other extractive industries to operate, and as such, any attempts to enter these areas can be detected and prevented by indigenous communities, who have the knowledge and experience to protect their lands (Finer et al., 2008). In their study, Nepstad et al. (2006) found that indigenous lands in the Brazilian Amazon had lower deforestation rates compared to other land-use categories, including protected areas, private lands, and agrarian reform settlements, among others, suggesting that this is in part due to the fact that indigenous lands are usually located in more isolated areas, and have strong legal protection against external threats.

One of the main challenges in protecting indigenous forest lands in the Amazon is the lack of clear land ownership and management systems (Baragwanath and Bayi, 2020; BenYishay et al., 2017; Oliveira et al., 2007). This can lead to illegal logging, mining, and other activities that destroy the forest and harm local communities. With formal recognition of their territorial rights and support for their livelihood activities, they can demarcate their forests to monitor illegal invasions, coordinate with authorities to have intruders removed, engage in various types of forest management activities to keep their forests in good condition and finally, so that outsiders know they cannot use that land (FAO, 2021; Reydon et al., 2020).

The main advantage of permissioned public blockchain systems is their ability to increase transparency and accountability in the land governance process. In traditional systems, it can be difficult for individuals to access information about land ownership and transactions, leading to a lack of transparency and lower trust. In many legacy systems, land records are often stored in a centralized location and are thus more vulnerable to fraud and corruption (citation). Additionally, in traditional systems, the process of transferring land ownership can be slow and cumbersome, requiring the involvement of multiple parties and the exchange of physical documents. On the contrary, within a permissioned public blockchain system, all parties involved in a land transaction have access to the same information, increasing accountability and reducing the potential for corruption, as they are able to replicate the whole land title registration process on their own machines by running open code.

Blockchain technology, is thus well poised to help with a clear demarcation of indigenous lands, as it can be used to create a secure and transparent land registry that can clearly identify the indigenous ownership and management of these lands (Daniel and Ifejika Speranza, 2020; Keilitz and Wiipongwii, 2017; Mata et al., 2022; Palau-McDonald, 2022; Soner et al., 2021). Through the "*tokenization*" land rights[3] offered by blockchain, indigenous communities would be able to more easily and securely transfer ownership and use of their land. This would make it more difficult for outside actors to exploit or take advantage of these communities and their land, thereby reducing the risk of deforestation (Villares, 2021). This digital registry can be used to create a transparent and tamper-proof record of land ownership, making it more difficult for illegal actors to claim ownership of forest land, thus preventing illegal activities and ensuring that only authorized individuals or organizations have access to these areas. By using blockchain to create a digital registry of indigenous forest lands, we can ensure that these lands are protected and that the rights of the indigenous communities are respected (Corrêa Tavares et al., 2021; Villares, 2021).

The literature is currently limited on ongoing blockchain applications focused on the protection of indigenous land rights specifically in the Amazon. The most ambitious initiative in the region of its kind was a $12 million project by the National Indian Foundation of Brazil (FUNAI), aimed at creating a cryptocurrency for Amazonian natives that would back a number of projects for the protection of indigenous land rights, but was halted in 2019 by then Brazilian President Jair Bolsonaro (UFJF, 2019). Similarly, a national land registry project launched by the Colombian government's National Land Agency (ANL) on the blockchain in partnership with Ripple Labs, aiming to help legally solidify highly contested indigenous land rights, was halted due to political reasons after the change of government (Linares, 2022). These failed blockchain projects highlight both, the significant potential of, and the complex political environment underpinning, tech innovation for indigenous land protection in the Amazon region.

The Rainforest Foundation US has found more success, having launched a blockchain platform aiming to help indigenous communities in the Amazon Basin and most notably in Peru, to secure their land rights and protect their lands from deforestation (Rainforest Foundation US, 2023). The platform uses blockchain technology to create a secure and transparent land registry system that can be used to authenticate land ownership and

[3] Tokenization is the process of representing a real-world asset, such as land, as a digital token on a blockchain (Garcia-Teruel and Simón-Moreno, 2021).

provide a fixed ledger of land use rights transactions. Finally, the YUXIBU project, developed by Canopée Ambiental (Canopée, 2023), has been proving successful in its endeavor to preserve protected areas of the Huni Kuin indigenous people in the Mucuripe Farms complex in Brazil using blockchain technology, helping increase transparency and accountability in the management of their land rights (Cenário Agro, 2022).

Apart from the Amazon, there are already a number of very notable initiatives underway using blockchain to protect indigenous property rights across the globe. In Ghana, Bitland – a blockchain-based land registry startup – aims to promote secure land rights, creating tamper-proof land titles, which can help protect the land rights of Ghanian indigenous people against fraud and corruption (Keilitz and Wiipongwii, 2017; Smart Africa Secretariat, 2020). In the Honduras, the PATH Land Administration Project focusing on updating cadastral information and land titling for indigenous communities and financed by the World Bank and FAO, teamed with Epigraph (a blockchain solutions company) in 2015 to reform and modernize PATH's systems, manage government data and build a digital land title registry (Graglia and Mellon, 2018). It is worth noting the plethora of startups working on blockchain-based land registries that may also indirectly benefit indigenous communities, with initiatives in India, Ukraine, Netherlands, the United Kingdom, Saudi Arabia, Kenya, Honduras, Bermuda, Mexico, St. Kitts and Nevis, Rwanda, Zambia, Liberia, India, Ethiopia and Papua New Guinea (Mousseau F. et al, 2020).

Smart Contracts for the disbursement of funds for indigenous protection against deforestation

A final method, which will also be the focus of this paper, is the disbursement of funds for the successful land management of protected indigenous ecosystems collectively to such communities, using smart contracts. Before proceeding with the description of the employed underlying blockchain technology, it is important to properly define a number of notions contingent on collective payments, in order to better understand how smart contract clauses can assist funding schemes' monitoring efforts.

Collective payments, where forest users receive benefits conditional on group, rather than individually-tied performance in relevant projects[4], are a known method to enhance forest protection on a local level, ensuring both the self-determination of the involved communities, as well as tropical ecosystem preservation against deforestation (Naime et al., 2022). Although individual payments have shown to also contribute to countering deforestation, they are less promising as they adhere to the free-rider problem compared to the collective alternative (Hayes et al., 2019). In this context, collective payments for

[4] i.e., each individual observes other people's choice, sanctions when deforesting, community sanctions by other members. *Source*: https://forestsnews.cifor.org/78046/collective-payments-for-ecosystem-services-a-promising-policy-tool-to-reduce-deforestation?fnl=en

ecosystem services in local communities, have shown promising results against individual payments, as a method to counter the free-rider problem, as they offer stronger monitoring and enforcement, albeit at higher implementation costs (Börner et al., 2014). According to research, the best middle solution entails a hybrid approach of the attribution of sanctions by the government acting as an "external enforcer", as part of a comprehensive policy-mix scenario adjacent to collective payment systems, on terms of effectiveness, efficiency and equity/fairness (Hayes et al., 2019; Naime et al., 2022). In this sense, government sanctioned indigenous territorial rights, offering payments for environmental services such as the land management of protected indigenous lands, and community forestry, have all been shown to effectively reduce deforestation and forest degradation in indigenous territories (Baragwanath and Bayi, 2020; Montero-de-Oliveira et al., 2023; Reydon et al., 2020; Robinson et al., 2016).

Collective payments become very salient when considering the drive to net-zero SDGs and the large sums of money increasingly being mandated to meet the challenge. To sustainably reduce the impact of deforestation, it becomes apparent that humanity needs to employ a variety of very low or zero carbon emitting technologies, which unfortunately are not yet available at commercial scale. In the meantime, carbon offsets can be obtained through government-sanctioned voluntary carbon markets, in the form of credits for either reducing emissions or sequestering carbon (McKinsey, 2020; Mukherji et al., 2023). Such efforts directly garner attention towards the voluntary carbon markets that will supply carbon offsets to meet SDG goals, in the framework of forestry-related offsets via Reducing Emissions from Deforestation and Forest Degradation (REDD+)[5] (Kotsialou et al., 2021).

Carbon markets can be either compliance – strictly supervised by national and international authorities – or voluntary, a largely unregulated and mainly consisting of private actors that buy carbon offsets to voluntarily mitigate the effects of their choices on the climate, contributing to activities including improved forest management and avoided deforestation and forest degradation, grouped under REDD+; carbon offsets generate emissions savings that are then sold to willing buyers that create effectively a carbon trading market, using carbon credits as a native currency (Battocletti et al., 2023; Kotsialou et al., 2021). Such activities pertain to the Payment for Environmental Service Framework (PES), with communities such as indigenous populations, that are remunerated for activities that help enhance or preserve their local ecosystems, for which they are awarded carbon credits (Montero-de-Oliveira et al., 2023; UNFCCC, 2023).

According to a report by the Food and Agriculture Organization (2021), "*At the current price paid by the Green Carbon Fund of $5 per ton of CO2-equivalent of reduced emissions, investing in the territories of Indigenous and tribal communities could save $570 million US per year in carbon emissions*"; this entails not only lower costs for the recognition of indigenous property

[5] REDD+ is a framework created by the UNFCCC Conference of the Parties (COP) to guide activities in the forest sector that reduces emissions from deforestation and forest degradation, as well as the sustainable management of forests and the conservation and enhancement of forest carbon stocks in developing countries (UNFCCC, 2023)

rights, but a number of socio-environmental benefits as well, because funding can be directed to securing indigenous property rights, conservation projects under PES schemes, support community forestry, and revitalize indigenous cultures and traditional knowledge.

Carbon credit markets awarding PES schemes though, are characterized by a complex infrastructure: a high number of intermediaries, such as conservation business and international organizations, that increase transaction costs on the disbursement of funds between social actors, placing a hurdle in the fluidity of the concerned REDD+ projects; the lack of transparency on the benefit distribution, coupled with the lack of a commonly agreed framework for the issuance of carbon credits from different suppliers, inhibits an objective assessment of carbon credit quality (Kotsialou et al., 2021; Oberhauser, 2019). One way to address this issue, is the establishment of a harmonized "fungible" currency, but the high number of heterogenous approaches – spearheaded by Verra's Carbon Verified Standard and the Gold Standard – along with a need to ensure compliance between the verification of fulfillment of voluntary carbon project agreements amongst concerned parties on terms of avoided deforestation, entail high financial and labor costs in regards to supervision and implementation, which are passed on the price of carbon credits themselves, which also have to be verifiably non "double-counted" (Maguire, 2011; Oberhauser, 2019; Streck, 2020).

Blockchain thus inevitably enters the picture, due to the synergies between its technical fundamentals of decentralization without the need of intermediaries, that are well suited to enable both, more efficient and effective low-cost financial transactions on one hand, and transparent forest monitoring on the other (Hartmann and Thomas, 2019; Kotsialou et al., 2021). Using blockchain, information on the asset type a carbon credit represents, for example tons of CO_2 emissions avoided or captured, is added to the user's blockchain accounts (wallets) in the form of tokens, digitalized value equivalents in the form of a native currency within the system – that may also provide information on other metrics such as legal status and associated environmental and social performance– whose value is redeemable by the actors funding the carbon market (Kotsialou et al., 2021).

Blockchain's underlying technology that makes this possible are smart contracts: self-executing contracts with the pre-defined terms of the agreement written directly into the code, i.e. they are digital agreements that are encoded on a blockchain automatically and directly execute certain actions when certain conditions in the terms of their coded contract agreements are met. Smart contracts allow for the automation of a variety of processes, including the transfer of assets and the enforcement of agreements. Like conventional blockchain architectures, the key advantage of smart contracts is that they are highly transparent and tamper-proof, which can help to prevent fraud. Additionally, smart contracts can be easily scaled and replicated (Buterin, 2014; Lipton and Levi, 2018). In the context of REDD+ projects related to carbon markets, smart contracts can be connected to innovative cloud-based data collection sources (IoT), measuring a variety of indicators such as forest cover, land-use changes, satellite imagery, legal tenure and socio-environmental safeguards (GainForest, 2023; He and Turner, 2022; Veridium, 2023). The impact of blockchain technology on forest cover monitoring can be maximized when integrating

Artificial Intelligence (AI) algorithmic models based on probabilistic theory (Blockchain 4.0), whose inputs can feed automated real-time smart-contract decisions, without the need of human intervention (Angelis and Ribeiro da Silva, 2019; Ismail and Materwala, 2019). The application of AI for forest monitoring already has a variety of use cases, with evident synergies in terms of real-time decision making that can boost environmental protection (GainForest, 2023; Pachama, 2023; Vlinder, 2023).

The combination of AI enabled smart-contracts, may also help curb other issues endemic to REDD+ projects: permanence, "the longevity of the carbon pool and stability of its stocks", meaning the potential of reversibility of eventual carbon emission savings, due to human and non-human stressors (Watson et al., 2000); leakage, occurring when "interventions to reduce carbon emissions in one place, causes carbon emissions in another" (Atmadja and Verchot, 2012); and additionality, i.e. the counterfactual possibility of having achieved carbon sequestration even in the absence of REDD+ activities in the same area (Valatin, 2011). Permanence can be achieved through the blockchain by ensuring that the constant flow of IoT data related to the ecosystem's state, consistently reflects the carbon savings achieved, taking into consideration metrics of forest degradation, either respectively adjusting the carbon credit value or even breaking the smart contract altogether, with the appropriate devolution of the associated carbon credits (TreeCycle, 2023). Additionality, although it cannot be directly solved with blockchain, smart contracts could nevertheless capture a proxy based on information of indicators for key deforestation drivers in the area, such as commodity prices: a drop in the prices beyond a specific threshold for example, could signal reduced production and thus less carbon emissions/higher carbon savings, prompting the smart contracts to cancel the additionality of the project in terms of carbon savings and respectively adjust carbon credits (Kotsialou et al., 2021). Leakage can be addressed by smart-contract provisions that deforestation to the project's contingent buffer zone cannot exceed a specific level, and if this clause is breached carbon credits are amended accordingly (Booman et al., 2021).

As seen in the previous section, indigenous communities in the Amazon face challenges in proving their ownership of land and resources, which can make it difficult for them to enforce their rights and protect their land from illegal logging and other forms of exploitation. Even though is lies outside the scope of this dissertation, it is worth mentioning that smart contracts can additionally further enforce indigenous land rights by providing a digital record of land ownership that is tamper-proof and easily accessible to all parties involved, as they automatically verify the terms of land use agreements based on pre-determined clauses, a necessary and replicable prerequisite for the disbursement of carbon credit funds (Makala and Anand, 2018). They thus offer further legal ground for restrictions on logging or other activities that could harm the forest, by solidifying verifiable land ownership proof embedded in the consensus mechanism of the chosen architecture. This would provide another powerful tool for preventing illegal deforestation and ensuring that the rights of indigenous communities are protected at the same time, as they are able to assert their rights on one hand promoting their inclusion, and scale the protection of their land through carbon market disbursements on the other (Corrêa Tavares et al., 2021; Moura et al., 2020; Open Forest Protocol, 2023).

These characteristics make smart contracts an ideal cost-effective solution for use in land management and conservation efforts, that can be used across large areas of the Amazon. On terms of indigenous protection, for example, a smart contract could be created to automatically release funds to indigenous communities who meet certain sustainability criteria, such as maintaining a certain amount of forest cover or protecting certain species. Thus, the forest is protected by providing financial support to indigenous communities, as smart contracts can automate the process of disbursing funds based on predefined conditions. For example, a smart contract can be set up to disburse funds to an indigenous community only if they can prove that they have protected a certain area of the forest. In this way, smart contracts can provide a transparent and efficient way to disburse funds to indigenous communities, as they ensure that benefits are used for their intended purpose and consequently directed only to those who are truly committed to protecting the forest (Chapron, 2017; Howson et al., 2019), as indigenous communities are rewarded for ecosystem enhancing activities through direct automated fund disbursements by participating actors (Oberhauser, 2019; Stuit et al., 2022). Smart contracts can thus be used to track the progress of conservation efforts, making it easier to monitor and evaluate the effectiveness of the carbon credit programs. In what follows is a non-exhaustive list of several notable smart contract-based initiatives:

- Veridium helps the indigenous people in the Amazon with carbon credits tokenized by their CARBON coin using the smart contract-based Hyperledger Fabric blockchain architecture, to support forest conservation efforts that generate carbon credits under the Verified Carbon Standard. The Veridium ecosystem includes a platform for managing and trading carbon credits, which provides proof of the carbon reduction impact of its projects to buyers of carbon credits while upholding the rights of local communities and the integrity of the ecosystem (Veridium, 2023).
- The ForestCoin project, which uses blockchain technology to create a digital token that can be used to incentivize sustainable land use practices. Landowners who participate in the program are rewarded with ForestCoins for activities such as reforestation and conservation, which can be exchanged for goods and services or used as collateral for loans. This provides a financial incentive for landowners to protect the forest, while also creating a market for conservation-friendly products and services (ForestCoin, 2023).
- Directly relevant to indigenous communities, GainForest "*entails a smart contract between the donor and the community (provided by GainForest) that uses machine learning and satellite imagery to trigger periodic payments if given levels of forest cover are maintained*" (Stuit et al., 2022); the Kayapo project is very notable, as it has already significantly helped the indigenous peoples of the same name protect their territory in the Amazon rainforest, contributing to the avoidance of emissions to the equivalent of 3,793,648 tonnes of CO2 per year (GainForest, 2010).

- On the same lines, Rainforest Foundation US in collaboration with Regen Network, "*use blockchain technology to track, verify and reward communities for protecting and regenerating forests in a pilot project in the indigenous community of Buen Jardin de Callaru, Peru*" (Macqueen, D. and Mayers, J., 2020). As part of the project, the Ticuna people who inhabit the aforementioned region are collectively protecting 1000 acres of Amazon rainforest in their territory from illegal logging, by patrolling the territory with the use of drones and signal possible breaches; in return the community receives direct disbursements for maintaining net zero deforestation in a "tree account" (Regen Network, 2023). The Rainforest Foundation US also uses smart contracts to automate the process of land titling and reduce the risk of fraud in Peru (Rainforest Foundation US, 2023).
- The Amazon Environmental Research Institute (IPAM), is using smart contracts to help protect the rights of indigenous communities in the Amazon. Through the use of blockchain technology, IPAM is able to create secure and transparent land registries that can help to prevent land grabbing and ensure that the rights of local communities are respected. This can help to ensure that the forest is managed in a sustainable and equitable way, benefiting both local communities and the environment. As the registry allows for better monitoring and enforcement of protected areas, helping to ensure that these areas are not exploited for commercial purposes (Froehlich et al., 2022).
- Finally, notable examples include Single.Earth's MERIT token and Moss' MCO2 token. MERIT is based on Solana[6] and is issued to local communities for "*maintaining and increasing their land's ecological value*" – a very relevant salient REDD+ project is the protection of the Santa Natalia Plot in the Brazilian Amazon, home to the indigenous Kawahiva (Single.Earth, 2023). Similarly, the MCO2 Ethereum-based utility token, underpins digital carbon credit certificates that can be used by investors to finance forest preservation projects in indigenous communities in the Amazon (Moss, 2023).

3. Methodology

The Contribution of this paper will be a focus on a final method, using smart contracts for the disbursement of funds in the form of a native fungible token, through the monitoring of a decrease in deforestation rates, comparing protected indigenous land along with non-protected indigenous territories, against a baseline established by non-indigenous settled public land. This section will describe the architecture of a machine-learning based ETL pipeline prototype, that will disburse collective funding through smart contracts through a

[6] Solana is a programmable blockchain protocol which is based on Ethereum's smart contracts. *Source:* https://docs.solana.com/

proprietary test coin, AmazonCoin (AZC) that tokenizes the carbon credits earned through avoided deforestation.

[.....]

4. Results

[...]

5. Limitations and challenges

[....]

6. Recommendations for future work

In the context of Open/Public Permissioned blockchain systems, DAOs can be a very interesting enhancement. Decentralized Autonomous Organizations (DAOs) can be built on top of existing permissionless or permissioned blockchain systems, and can be considered as new forms of decentralized governance. Managed by a group of people who share the same interests and goals, DAOs are the most complex form of a smart contract. DAOs act decision-making systems that enable for example, transparent decision processes, automation of certain operations, formalized rules, and decentralization of power, among others. They rely on the collective agreement of its members that is achieved and maintained via voting. DAOs run according to a set of token governance rules written in code of the application layer, obviating the need for human management involvement. These token governance rules, of the blockchain layer and the application layer alike, have the potential to disrupt governance as we know it. (Shermin, 2017). Governance tokens implement a voting logic where the token holders can express their intention for the protocol development in majority-voting schemes in various protocol-specific voting mechanisms. Governance tokens typically follow the principle of one token, one vote, providing means for decentralized governance by distributing the voting power evenly to the community.

DAO members can vote for example, to the allocation of the DAO resources, changes in the DAO code, etc. Some of the DAO platforms that facilitate the creation of DAOs are Aragon, DAOstack, and DAOhaus. In some blockchain systems, token holders are allowed to vote on issues that govern the development and operations of a blockchain system (e.g., adjusting fees, appointing team members, and adopting new rules). In some systems, (e.g., LUNA, BNB), tokens can be used for several purposes besides voting. In other systems, especially in DAOs and DeFi applications, there are specific governance tokens for this purpose.

One of the earliest governance tokens was issued by MakerDAO, an Ethereum-based DAO underpinning the stablecoin DAI, while other examples include Compound, Uniswap, and Curve DAO. For blockchain systems that do not want to invest in implementing their own voting system themselves, there are some decentralized voting tools (e.g., Snapshot) where it is possible to choose a suitable voting strategy and system (e.g., single choice, approval voting), and the system provides the holders the possibility to vote (in case of Snapshot, off-chain), and easy-to-verify results. (Laatikainen et al., 2023).

In the context of public administrations, DAOs can be used to manage the rules and policies of an open permissioned blockchain, as well as to make decisions about the allocation of resources and the distribution of rewards. By using a DAO, open permissioned blockchains can become more decentralized, transparent, and democratic, which can help to improve their security and efficiency. Under these considerations, it would be interesting for future research to consider the expansion of open permissioned public administration systems with share-based DAOs which are more permissioned compared to governance-token based ones, and allow a trust-based involvement in the protocols and arrangements governing the associated public governance processes.

7. Conclusion

This dissertation has demonstrated a use case for the deployment of a FAIR-based open permissioned blockchain for public governance, applied to a multifaceted case study in the intersection of climate change, natural resource management and indigenous peoples' rights. The use case has two implications. Firstly, it provides further evidence that the use of open-source innovative technologies such as blockchain may empower legitimized collective action in an effort to protect the rights and land of minorities that are not properly represented in democratic systems. This particular use case application highlights the potential of blockchain to empower both, climate action and indigenous communities facing deprecation of their rights and land due to deforestation, through initiatives ensuring that the forest remains under the control of the people who live in it. Indigenous communities have a vested interest in protecting the forest, as it is their home and source of livelihood, and by giving them a say in how the forest is managed, governments and conservation organizations can ensure that the forest is protected for future generations.

Secondly, the results further support the academic literature with reproducible evidence, by underlining that public permissioned blockchain technology has the potential to significantly improve the efficiency, transparency, and security of traditional public administration systems, while safeguarding citizen agency through direct involvement and oversight in public processes enabling the deterministic attribution of a wide spectrum of fundamental civic rights. The proposed system's decentralized decision-making and distributed ledger structure can increase transparency and accountability, while its ability to automate and streamline processes can improve the efficiency of public administration processes. The advanced cryptographic techniques of open permissioned systems can also improve security, reducing the risk of cyberattacks and data breaches. Therefore, public permissioned blockchain technology is a superior alternative to traditional public administration systems and permissionless systems in the context of public administration.

These advantages can be extended to a variety of public sectors, but would find fertile ground particularly on public land governance initiatives that are salient SDG precursors, as the inherent increased security, transparency, accountability, and efficiency of the systems have the potential to significantly improve the way that land is managed and governed. Public land governance is traditionally plagued by challenges facing forest management and conservation practices, which can be improved through the use of permissioned public blockchain systems. The findings are supported by several peer-reviewed scientific studies that have demonstrated the potential of permissioned public blockchain systems in improving public land governance and reducing deforestation rates. Such systems provide a secure and transparent methodology to track the use of public land, ensuring that forests are managed sustainably and protected for future generations.

Finally, it is worth considering the limitations of blockchain technology applied to public administration systems. These range from power consumption issues, that can be addressed head on by choosing an appropriate consensus algorithm, to scalability, governance framework and confidentiality restrictions. The latter may particularly hamper the collective participation of citizens in the validation of transactions in open permissioned systems, due to the performance issues identified with permissionless systems. Future research in share-based DAO applications may address these concerns, by reconciling governmental legitimacy with unobstructed citizen participation, thus enabling increased transparency in the determination of the underlying protocols and contingent liabilities to any participant in the underlying public permissioned network, and not just the selected consortium of nodes operated by the trusted network of public authorities, NGOs and other civic organizations.

Appendix

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