Blockchain's potential in forest offsets, the voluntary carbon markets and REDD+

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Abstract

Increasing net-zero commitments by individuals, companies and governments have been accompanied by the growth of the voluntary offset market, including Reducing Emissions from Deforestation and Forest Degradation (REDD+). Technologies, notably blockchain, are starting to enter the REDD+ space, and may have the potential to address issues such as additionality, permanence, leakage and property and community rights. In this Perspective we first examine voluntary markets and the role forest carbon offsets have played within them, highlighting the evolution of REDD+ and the issues that have hindered its development. We then examine the potential of blockchain to address each of the issues, using literature and emerging experience from the use of blockchain in forestry space. We find that the technology may have the potential to improve verifiability and reduce transaction costs, and to a lesser degree aid in addressing additionality and permanence concerns. However, greater learning from the emerging use of blockchain in pilot projects is needed to fully assess and maximise its potential.

Introduction

Business, governments and individuals are increasingly recognising the urgency of climate change, leading to a growing net-zero 'club' of countries (e.g., UK 2021) and companies (e.g., BP 2020). Financial regulators are also discussing how to drive the transition to net-zero financial systems (NGFS 2021, UNFCCC 2021).

Pathways to net-zero require a portfolio of technologies, ranging from established (e.g. renewables), to emerging (e.g. inert anodes for aluminium), to negative emission technologies such as afforestation and reforestation. Emerging technologies are needed to decarbonise heavy industrial sectors like cement and steel, which generate nearly 20% of global emissions (de Pee et al. 2018), yet few are available at commercial scale. This implies such industries will need to use offsets: credits for sequestering carbon or reducing emissions. Amongst offsets, forestry activities are perhaps the most mature and readily available, with activities such as afforestation and avoided deforestation historically being regarded as viable and cost-effective options to address climate change (Eliasch 2012).

This drive to net-zero, along with the large sums of money being mandated to meet the challenge, brings increased attention to offset markets. In 2020, the Taskforce on Scaling Voluntary Carbon Markets (TSVCM) released recommendations to improve the voluntary carbon trade (TSVCM 2020b), based on a projected 15-fold scale-up in offsetting by 2030 (TSVCM 2020a). The history of the voluntary market, inclusive of the market for forestry-related offsets via Reducing Emissions from Deforestation and Forest Degradation (REDD+) has however been beset by limiting issues such as transparency, additionality, permanence and credibility. REDD+ developed out of a contextual underpinning of Payment for Environmental Services (PES) schemes, that have increased in scale and scope worldwide in recent years (Ferraro, 2011 Kaczan et al. 2017). Many issues that have affected REDD+ also impact PES and indeed REDD+ could be conceived of as a special type of PES.

Into this mix has come an acceleration of digital technologies (McKinsey 2020), including artificial intelligence (AI), big data and blockchain, with the latter mushrooming in financial services, supply chain management (BiTA 2017) and proxy voting and elections (Broadbridge 2018). Notably blockchain has also started to enter the climate change space, especially in the integration of renewable energy into grids (IRENA 2019), with its applications proposed for international climate policy (Reinsberg 2021), carbon markets and offsets (Chen 2018, Howson 2019, Hartmann and Thomas 2020), and REDD+ (Howson et al. 2019).

The advantages of the use of digital technologies are potentially multifaceted. In the context of the use of blockchain for foreign aid, Reinsberg (2019) identified twin benefits of validating transactions and transparency. For international climate policy, Reinsberg (2021) highlighted areas in which blockchain could contribute: new information through blockchain prediction markets, eliminating coordination problems between actors, and guaranteed execution of smart contracts. We focus on the potential for blockchain to increase transparency, provide automatic validation, and reduce transaction costs between buyers and sellers within REDD+ projects. By building on the existing literature on challenges of REDD+ (e.g., Oberhauser 2019), we examine whether blockchain could help in solving those issues through examination of current projects utilising blockchain in the forestry space.

Voluntary market: Growth, Issues and Opportunities

Carbon offsets operate in compliance and voluntary markets, with the former subject to regulation by national and international bodies. In contrast, voluntary markets are not defined by specific caps and firms are free to choose whether, and in which projects, they wish to invest. Even though the voluntary market has historically been small, it has started to grow driven by company commitments and anticipation of future regulation (Figure 1), and is expected to grow over 300-fold by 2030 (Shankleman and Rathi 2021).

Figure 1: Annual Voluntary Carbon Offset Issuances and Retirements, 2005-2020

Net-zero targets met through offsetting are credible only if the credits involved are valid, permanent and additional, requiring transparency over the nature of the project, its performance and continuing impact. Should doubts arise then offsets lose credibility and net-zero is undermined. What is therefore required is transparency, both for purchasers and for stakeholders (including shareholders) monitoring net-zero targets. Transparency brings credibility and helps to boost demand for offsets helping companies and countries meet ambitious net-zero goals.

Forest carbon offsets within voluntary carbon markets

Forestry activities for offsetting include afforestation, reforestation, improved forest management, avoided deforestation and forest degradation, all grouped together into the basket of REDD+. REDD+ was institutionalised through the UNFCCC Conference of Parties (COP) to cover actions taken by national governments, guided by the 2013 Warsaw Framework for REDD+ (WFR).

In practice, REDD+ bifurcated into two streams: (*i*) national or jurisdictional programs (e.g. in Guyana and Brazil), funded by multilateral or bilateral donors and governed by the UNFCCC and (*ii*) project-level activity. These two scales emerged to tackle different aspects of reducing deforestation – requiring both changes to national-level policies and local incentives, and to leverage different sources of finance. It is the latter, sub-national projects, that is the focus of the offset market.

Forest projects accounted for 38%, or almost 41.5 $MtCO_2e$ of all voluntary offset projects in 2019, with avoided unplanned deforestation initiatives alone accounting for more than 22 $MtCO_2e$ (Figure 2).

However, forest offsets suffer from challenges pertaining to verifiability, permanence, additionality and leakage (Angelsen 2010), as well as insufficient financial transparency, vague and expensive standards (Laing et al. 2016) and high transaction fees (Nantongo and Vatn 2019).

Figure 2: Top 10 Project Types by Volume and Price: Voluntary Carbon Credits, 2019

Blockchain technology

A blockchain is a (distributed) ledger that records exchanges of ownership (via transactions) of assets in a transparent and permanent manner. Systems powered with blockchain consist of an interconnected network of nodes (computers) that interact with each other (see Figure 3(a)) to decide which information they receive is valid and permanently stored in the ledger. To reach such decisions, nodes strictly follow a publicly accessible set of rules, known as consensus protocols (e.g. proof-of-work or proof-of-stake – with the latter generally requiring greatly less computational power and energy).

Figure 3: A Blockchain Network

When a node receives new data, it checks the data's integrity and, if it concludes that it is valid, the data is shared across the network in the form of a block (Figure 3(b)). If all nodes agree, data is immutably stored using advanced cryptography. For each new set of data stored, the updated ledger is distributed across the network, so every participant has access to the same data (Figure 3(a)). These processes make it extremely difficult to modify the ledger, when compared to other storage methods such as in central or distributed databases, and thus blockchain offers advantages of transparency and validity.

(De)centralisation

Blockchain can either follow a centralised model where a central authority supervises the ledger's incoming data, which is more suitable for international or national level forestry schemes, or a decentralised platform that is shared, held and updated by multiple nodes (Figure 3(a)), theoretically allowing remote buyers and sellers of forest offset credits to connect.

Two options are available for accessibility: a permissionless network where every node can join, and a permissioned network where only nodes with special authorisations are allowed. Permissioned networks are proposed where there is a desire to decentralise control to only some degree; this is perhaps more useful for government-backed forestry schemes. Permissioned networks can be further broken down into public and private permissioned, to indicate who can read the data on the blockchain. Alternatively, a permissionless network is suggested where an open system with maximum possible decentralisation is required, for example allowing easier connection between remote offset buyers and sellers, thus offering transparency benefits as any citizen can access information, allowing independent parties to validate offsets for example. In cases where the full transparency of transactions plays a key role in the application of interest, then a permissionless network is recommended.

Smart Contracts

Smart contracts are programs stored on the blockchain, self-executed when certain conditions are met, automating standard tasks. In this way they could serve to automatically validate contractual provisions in forest offsets that would otherwise require large amounts of manual input.

Tokens

Tokenisation is the process of assigning meaning to a particular type of object or data, including assigning value to a physical coin (e.g. currency) and connecting the ownership certificate of an asset to a piece of data. In the first example, the token is interchangeable with other tokens, known as fungible tokens (FTs). People can use FTs to decentralise ownership of assets such as land, rights and shares of a company, for example a land block can be overlayed with a system of FTs, where each token represents only a fraction of the land's total value on the market, hence empowering participation of smaller investors. Alternatively, non-fungible tokens (NFTs) derive their value from the unique asset they represent – they are not easily interchangeable, and owners retain the whole value of an asset, such as a forest, or tree.

Oracles

An oracle is a connection that allows data transfers from external sources to a destination, blockchain-based system. Oracles work according to triggers (e.g., a transaction on the blockchain), gathering external data (e.g., satellite data on forest clearance) and placing it into transactions subsequently added to the blockchain (e.g., the purchase of a forest offset), allowing externally retrieved data to be internally read and processed (e.g., by smart contracts).

Modern technologies in forestry offset projects

The integration between carbon markets and blockchain has already begun. Forestry projects utilising blockchain technology, in proposal and pilot stages, are increasing (Table 1). This trend is unsurprising as the technology offers decentralized communication and cooperation between parties, building an infrastructure that could provide a transparent means for an automated, decentralised verification process of issuing, monitoring and even revoking credits.

Carbon offsets generate emissions 'savings' through activities, such as planting trees. These savings are then sold to buyers creating a carbon market, using carbon credits as its native 'currency'. With the use of blockchain, information of what type of asset a credit represents is added to the users' blockchain accounts (wallets) in the form of tokens (Figure 4). Tokens can then be sold to other users, creating a market. The value of each token depends on the underlying asset, such as size of emissions savings. Using blockchain can transparently process and securely store every token transaction. In addition, a wide range of information pertaining to the underlying asset (emissions, legal status, or associated environmental and social performance) can follow the token from seller to buyer – and be updated as the status of the asset changes. All initiatives in Table 1 adopt this general underlying idea of integrating carbon markets with blockchain.

Table 1: Blockchain-led Carbon Credit Project Initiatives

Figure 4: Issuing Carbon Tokens through Smart Contracts

Projects using blockchain vary significantly depending on what technologies are used, how they are used, the scale of projects, and target groups. The largest investors such as large corporations (e.g., Samsung) will likely invest in projects that provide legitimate and credible offsets and therefore require transparency over underlying processes, along with tackling technical issues associated with REDD+ as do for example Veritree and Treecycle (Table 1). Alternatively, others may be willing to fund offset activities irrespective of strict requirements and expectation of profiting from their investments, as in EcoMatcher and ForestCoin.

Treecycle is a reforestation program with the aim of planting 10 million trees on fallow land in Paraguay (Treecycle 2019). It is not currently offering offsets but is monitoring the evolution of the market and may adjust its business model. Treecycle sells tokens, referred to as TREE, tied to actual trees, built on a proof-of-stake blockchain. The token provides holders with 40% of the net profit generated. Treecycle has also developed an additional token called TXC gifted to investors free of charge and constituting a bonus to supplement purchase of TREE tokens. The sale of tokens however is open only for investors from certain jurisdictions.

Veritree is a blockchain-based platform, offering various projects with different impacts on climate change from Nepal (habitat and soil restoration) to Madagascar (carbon sequestration with mangrove trees) and Indonesia (carbon sequestration and coastal erosion). Veritree claims to address issues pertaining to REDD+ including double-counting, additionality, permanence and transparency. There is however no detail on how they plan to do that (potentially due to industry access), although Samsung (Sherr 2022) and Cardano (Malwa 2022) are planning to collaborate with the company.

EcoMatcher aims to tackle climate change and offset by planting new trees. Companies and consumers can either 'adopt' single trees or whole forests. When trees are planted, users can track the location, species, and CO_2 emissions reductions associated with their growth. Data is stored on a cloud-based platform, and companies can purchase the data but the scheme is unlikely to be suitable for carbon offsetting by companies.

ForestCoin encourages individuals to plant trees and receive tokens in exchange for uploaded photos or other data, with tokens able to be sold or spent at participating merchants. Environmental benefits from ForestCoin and EcoMatcher (Table 1) are likely to be small and ignore the importance of differing forest types, and addressing permanence or additionality. Both ForestCoin and EcoMatcher could however encourage environmentally-friendly behaviour and are potentially well-suited to individuals and companies wishing to become visibly more sustainable through transparent tree-planting.

Verifiability, financial transparency and transaction costs

Supply chains for forest-offset credits are often filled with intermediaries and national or international organisations overseeing distribution or redistribution of funds [Oberhauser, 2019), often retaining administrative fees, creating transaction costs and disconnects between buyers and sellers. Lack of financial transparency is coupled with insufficient standardisation of the market. Currently, most credits are issued through unique processes between suppliers, making it difficult to objectively measure credit quality, leading to suggestions for voluntary markets to establish a 'fungible currency' with universally acceptable standards (Streck 2020). Standards such as Verified Carbon Standard (VCS) and Gold Standard exist but are far from ubiquitous, and it is unclear how they will respond to rapid demand increases. Along with the challenge of measuring quality, checking whether contracts are fulfilled may become particularly cumbersome and require significant finance (Streck 2020). Different approaches have been developed to bring standardisation to the market, but often rely on manual labour in verifying performance. The labour involved in measuring and monitoring REDD+ (Oberhauser 2019) makes supervision and implementation of initiatives relatively expensive, evidenced by the average costs of forestry offsets exceeding renewable energy projects more than three times (Figure 2). Transparency is needed to ensure credits are verifiable, to avoid 'double-counting' and exploitation by 'carbon cowboys' seeking to gain from supplying credits of dubious quality (Maguire 2011).

Blockchain can ensure the efficient exchange of tokens without intermediaries, reducing inefficient use of labour and creating rapid low-cost exchanges. Such platforms also provide an infrastructure for the development of innovative applications. For example, blockchains allow smart contracts to be deployed, allowing connection via oracles with outside data collection sources (as proposed by GainForest 2019), for example data on forest cover, land-use changes from drones, satellites or on-ground verifiers (Figure 5). Other data concerning legal tenure and social and environmental safeguards could also be included (Veridium 2016). However, to accurately combine such data, additional technology is needed including artificial intelligence (AI)(GainForest 2019 Vlinder 2019 Pachama 2020). Their approach allows the receipt of decentralised data and the use of smart algorithms to reach a conclusion on credits. If conflicts arise, for example where one source reports ‘yes’ and another ‘no’, the system can either assign a higher weight to the more commonly accepted source or request additional data from on-ground inspections. The latter is preferable when multiple entities with conflicted interests report conflicting data, to minimise the possibility of biased decisions, further conflict, and collusion.

Opportunities offered by blockchain could become more attractive by adopting NFTs, priced differently based on the carbon content of the tree. ‘Adopt-a-tree’ style schemes have mushroomed (e.g., Green Initiative Foundation’s projects in Indonesia) as they give the ability and motivation for the public to be directly involved in forest protection. Blockchain-based platforms such as Forestcoin and EcoMatcher utilise this feature of the technology. Although not part of these companies’ proposals, blockchain gives users the ability to destroy or virtually lock NFTs away from the market, avoiding double-counting.

Permanence, leakage and additionality

Smart contracts enabled by blockchain, used in concert with technologies such as AI, offer potential solutions to issues pertaining to permanence, leakage and additionality (Palmer, 2011 Atmadja and Verchot 2012, Chiroleu-Assouline et al. 2018). Permanence is ‘the longevity of a carbon pool and the stability of its stocks’ (Watson et al. 2000). Forest carbon is inherently unstable due to reversals through forest fire or land-use changes, raising the possibility that carbon savings can be reversed, negating the validity of previously issued credits. These challenges could be mitigated through blockchain providing validated, transparent information to buyers, especially when coupled with smart contracts to provide automatic validation. Updated data on the forested area’s status, to the level of individual trees, can be associated with the token, and should the status of the carbon sequestered change, the value of the offset can be adjusted. If the token is sold on, then relevant information would follow it along with future changes in the information (e.g., Treecycle). The usefulness of blockchain is predicated upon there being suitable information from external sources, such as through the increasing availability of satellite data (e.g. in Brazil, Moutinho 2021) along with project level data from drones (Mitchell et al. 2017).

Leakage occurs when 'interventions to reduce carbon emissions in one place causes carbon emissions in another' (Atmadja and Verchot 2012). Dealing with leakage is a thorny issue with solutions focusing on buffer-zones and nesting project-based approaches within country-level programmes (Atmadja and Verchot 2012, Streck 2021,). This is not an issue that can be solved using digital technologies alone. Blockchain could though provide a conduit for information pertaining to the problem, allowing for amendments or revocation of credits relating to leakage, although this could also be done through non-digital techniques. For example, a smart contract could contain a provision that deforestation in a buffer zone must not rise above a threshold. By capturing and processing this information via AI or similar, blockchain could amend the credit accordingly should the threshold be breached (Regen Network 2018). This process could assist in addressing issues of local leakage but is unlikely to address regional leakage, that requires wider policy action.

Additionality of offsets relates to whether carbon savings would have arisen anyway in the absence of projects (Valatin 2011). Blockchain cannot eliminate the problem but could provide a tool to capture and process relevant information (via smart contracts) that could validate associated credits. For example, blockchain, using oracles, could capture, process and communicate information about the prices (and thus profits) of drivers of deforestation, such as of soya, beef or palm oil. Rises (or falls) in prices imply that the economic returns from deforestation are greater or smaller; thus projects are likely to be additional (or not).

Local communities' involvement, property rights and governance

Under a decentralized blockchain model, local communities could, in theory, play bigger roles and reap greater benefits from carbon markets. There is an increasing need to design adequate requirements to ensure the UNDRIP adoption and other related standards when developing offset projects (De la Fuente and Hajjar 2013, Timperley 2019). Such standards could be translated and programmed as conditions into smart contracts. The exact mechanism through which relevant information would be collated and added to the blockchain would vary between jurisdictions but likely involve some burden-of-proof on behalf of credit-sellers that provisions regarding property rights are met, including the lack of pre-existing conflicts and the upholding of community rights.

The use of blockchain in this way, on its own, cannot resolve property right issues. However, it could: (*a*) ensure that where conflicts occur, parties with more power cannot exploit those with less rights by selling credits for projects impacting them; and (*b*) incentivise actors to resolve conflicts in order to access finance (Regen Network 2018). Blockchain can also add security to buyers that, should conflicts arise, credits would be adjusted accordingly, removing the validity of credits, ensuring that reputational risks are minimised. Blockchain's advantages are likely to be larger where community rights are more established. In areas such as central Africa where communities' rights have historically been weak (Barrow et al. 2016), advantages may be more on the buyer's side, helping to either avoid buying into areas with conflicts or offering safeguards about their future discovery. This raises the danger that actors with greater power may be more likely to exploit advantages of blockchain, risking disenfranchising communities without power further from international climate change architecture.

For communities for which property rights are secure, blockchain may have an important role in achieving easier access to buyers in the carbon market (GainForest 2019, Universal Carbon 2019, Vlinder 2019), with local communities directly selling climate services through tokens. By dealing directly with communities, buyers may connect better with projects, finding those that fit their motivations. A potential question-mark over the viability of blockchain is the capacity of communities to engage in such technology. There is evidence that local communities may have the capacity to engage in technologies such as blockchain through devices such as smartphones. For example, in Guyana, a Community-Based Monitoring (CBM) System for REDD+ required communities to utilise GPS software, with evaluations highlighting the capacity of the communities involved (Bellfield et al. 2015). Rainforest Foundation's MappingForRights project also demonstrates this capacity, with communities in the Democratic Republic of the Congo using GPS-enabled tablets to map customary lands and resources (Handja 2014). Local community partners of Veritree are already collecting data on trees and co-benefits in real time and uploading to investors using mobile phones. Furthermore, the adoption of mobile phones in developing countries, in conjunction with poor banking infrastructure, has been a key driver of digital payments (Ammous 2015, Flore, M. 2018,). The emerging infrastructure of blockchain-based payments could be utilized and integrated with systems of payments for environmental services and other forest offset projects.

Local community involvement raises the question of power and governance, issues central to the effectiveness, equity and efficiency of forest offset activity. The increasing application of blockchain has prompted nuanced debates on the socio-economic implications of technology relating to global political economy and governance (Zwitter 2015, Just & Latzer 2017, Zwitter & Hazenberg 2020). Existing studies suggest that blockchain may empower historically less privileged actors (e.g. cross-border remittances), with potential to address unequal access to financial services (Ammous 2015, Flore 2018), and enhancing the effectiveness of existing institutions, for example improving aid delivery (Reinsberg 2019). Blockchain technologies however could also be destructive to existing governance structures and diminish roles of centralized authorities that traditionally underpin global governance. These divergent insights suggest that analysis from different contexts is needed to understand how technologies impact multifaceted relationships between actors and processes at each governance level: local, national or global.

Within the forest sector, there are social contexts where centralized actors could benefit from introducing blockchain to reduce transaction costs by facilitating direct relationships between centralised donors and beneficiaries of REDD+ finance, automatically settling transactions and sharing information across organisations. This could enhance functioning of existing centralized systems, making them more efficient, increasing trust and credibility. Such a system is relevant when international organizations and donors are at the centre of REDD+. This application would benefit from permissioned blockchain, with central authorities administering systems, selecting and validating participants (both donors and beneficiaries) and their behaviours. An example is the proposal of digitization of all of Europe's trees using a private permissioned blockchain (Bartoszek 2021). Although such a model could bring efficiencies to centralised systems, it could reinforce existing power dynamics and risk locking those without power out of systems, exacerbating challenges that have created pressures on the forest in the first place.

In contrast, for pilot and small-scale projects and mirroring the use of blockchain in tree growth, different governance structures may be more suitable. Interaction here would need to be decentralized and most likely be beneficial if it capitalizes on the inherent decentralized features of the technology. The system should be more flexible, allowing inclusion of various actors at different levels (mirroring multi-level governance conceptualisations of REDD+). Such applications should utilise permissionless blockchains, facilitating access to all. Although in theory this could solve aspects of power dynamics, it depends on wider circumstances such as access to technology.

Discussion

Blockchain, due to its decentralised and transparent nature, has an ability to enforce verifiable smart contracts and provide systems for reducing transaction, monitoring, and verification costs. But questions and research gaps remain.

First, with blockchain emerging in offset projects, and with potentially many different options for users of offsets, it becomes difficult to understand which company provides credible credits. In an industry built on network effects, it is crucial that offset projects attract strong developers, with adequate understanding of forestry projects and their challenges, and a large capital-rich userbase.

Second, if the space becomes dominated by few players with a large number of small blockchain-based projects, important innovations would be required, for example by having the ability to seamlessly transact value across different blockchain platforms. This idea is conceptually similar to 'linking carbon markets' (Doda et al. 2019, Doda and Taschini 2017). 'Traditional' blockchain solutions such as Cosmos (Kwon and Buchman 2016), Polkadot (Wood 2017) and Overledger (Verdian et al. 2018) already have this ability built into their design, allowing multiple blockchains to be connected. Future research needs to understand if similar integration of various offset platforms is feasible and desirable.

Third, continued learning from pilot activities is needed as to the usefulness of the technology, along with a deeper understanding of technical, social and cultural barriers. NFTs and offset tokens could be accompanied with social tokens empowering local communities. This could change the relationship between forestry communities and their local economies, and between forest communities and international donors and investors. Field experiments with social tokens could help with integrating of forest tokens into social aspects, and the technology/education needed for local communities. More broadly, further understanding of the pre-conditions for the use of blockchain is needed, including the resolution of rights and the technological capacity and availability required.

At COP26, donors committed to deliver at least US$1.7 billion of financing to local communities. Yet, there are no good mechanisms in place to deliver funding to the ground. Blockchain in combination with mobile phones and emerging digital payment structures offer intriguing possibilities for donors to transfer directly to recipients, while tracking funding.

Finally, despite its potential, existing blockchain technologies can not entirely address additionality, leakage and permanence. More challenging is property rights –a major driver in deforestation (Cotula and Mayers 2009, Palmer et al. 2010). Blockchain is only likely to be effective in geographies where property rights are clear and conflicts absent, while power dynamics are favourable to either centralised or limited decentralised approaches. The technology could, however, provide assurance to buyers that rights issues are resolved and community rights upheld along with providing incentives for conflict resolution. The fact that benefits may not accrue to communities involved in rights disputes, or that could be locked out of centralised systems, where finance may be of most use, is a downside - with further research needed on how emerging technologies can assist.

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Figure legends

Figure 1: Annual voluntary carbon offset issuances and retirements, 2005-2020 (Source: Ecosystem MarketPlace, 2021)

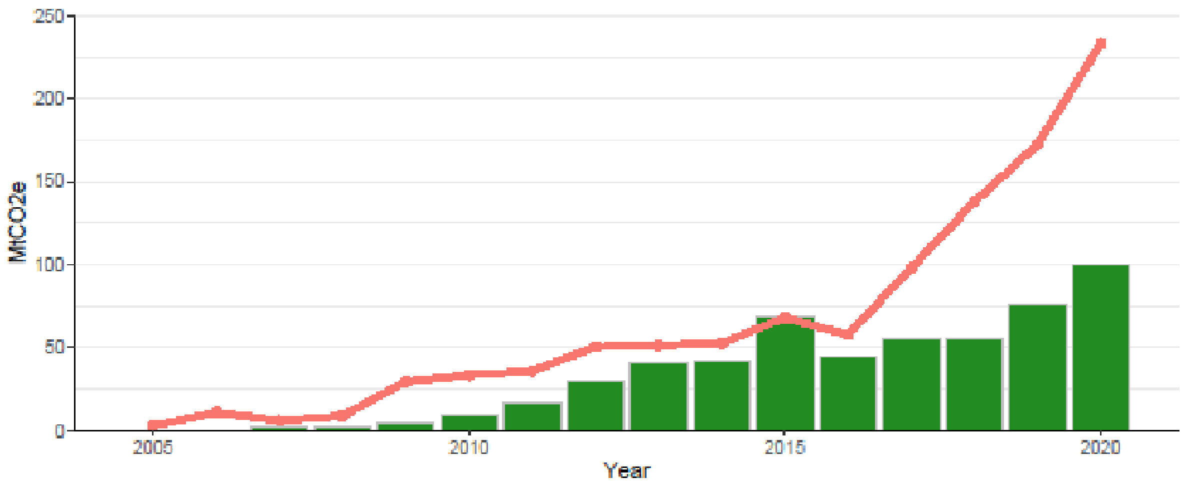
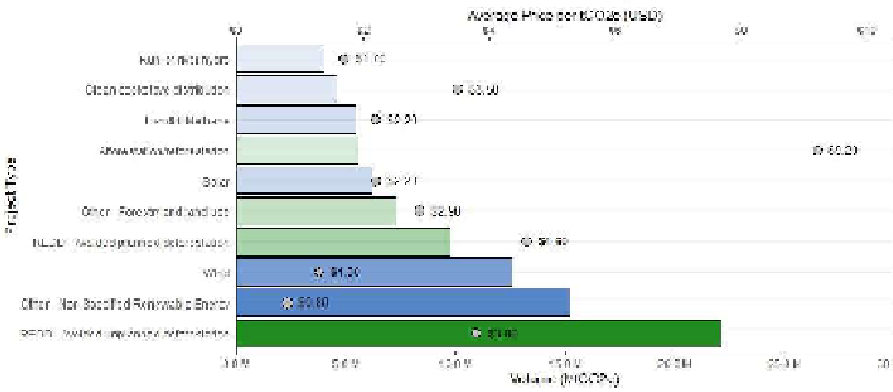

250
200
150
100
50
0
MtCO2e
2005
2010
2015
2020
Year

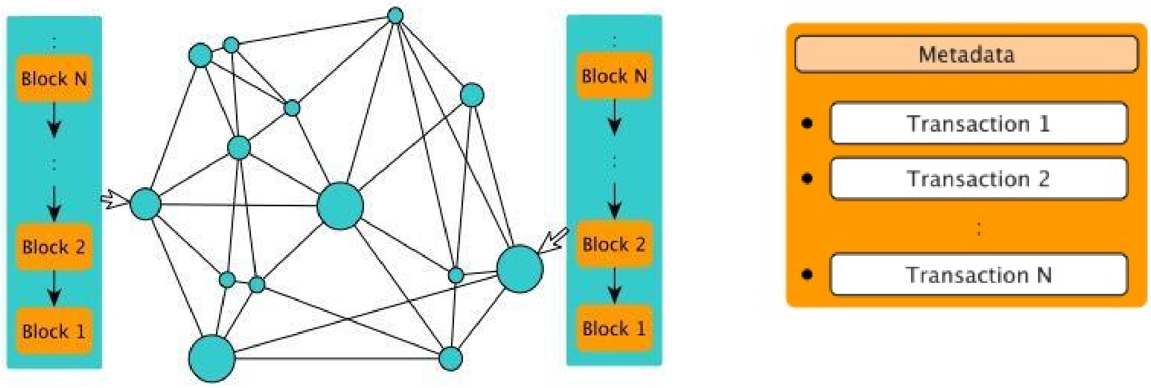
Figure 2: Top 10 project types by volume and price: voluntary carbon credits, 2019 (Source: Ecosystem MarketPlace, 2021

Figure 2: Top 10 Project Types by Volume and Price: Voluntary Carbon Credits, 2019



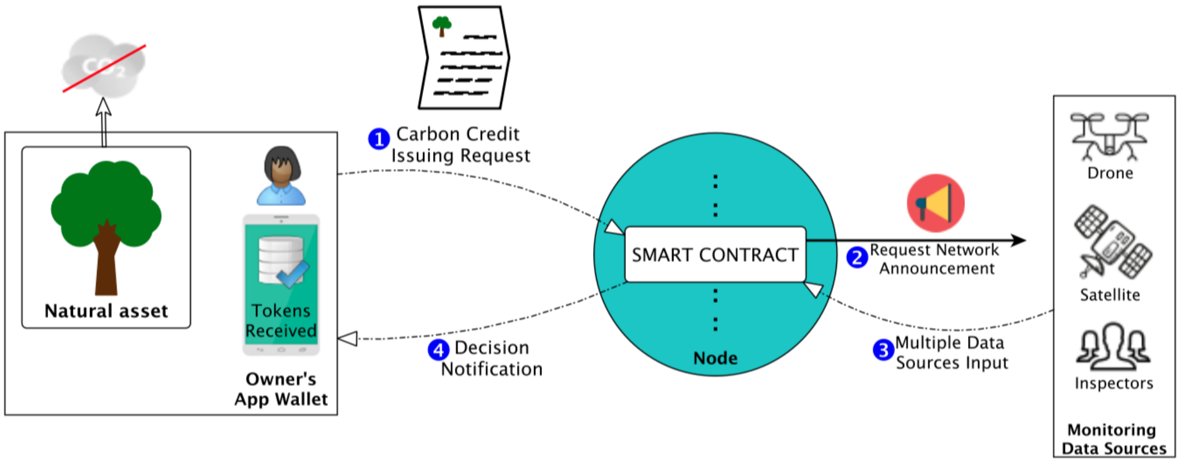
Source: Ecosystem MarketPlace, 2021

Figure 3: (a) Each node in the network eventually receives the updated ledger, (b) a block mainly consists of validated pieces of transaction data, together with the cryptographic link (in the metadat a section) that secures the bond with its predecessor (the previously validated and shared block).



(a) (b)

Figure 4: Smart contracts are deployed within transactions sent to the blockchain network, thus they are immutably stored in the ledger once confirmed. When a new transaction requires the service of a particular smart contract, say the Issuing Carbon Credits smart contract, the transaction calls that smart contract's function and gives it an input to process. For example, a tree owner submits all necessary information to request the carbon credits her tree generates. The smart contract algorithm announces this request to the network. External data sources connected to the blockchain receive this announcement and each one of them submits its own information with respect to that request. The input from all data sources is automatically evaluated by the smart contract. Global standards for issuing carbon credits can be added as conditions into the algorithms of smart contracts. If verified, tokens are issued to the wallet of the owner, who can then start trading in the blockchain-powered carbon market. If declined, the smart contract can return the reasons for rejection or request further information.


CO2
Natural asset
Tokens
Received
Owner's
App Wallet
1 Carbon Credit
Issuing Request
SMART CONTRACT
Node
2 Request Network
Announcement
3 Multiple Data
Sources Input
4 Decision
Notification
Drone
Satellite
Inspectors
Monitoring
Data Sources