Curbing Climate Change: An Analysis of the Blockchain's Impact on the Voluntary Carbon Market

by

Owen Baim

Thesis Advisor: Peter A. Adriaens

A thesis proposal submitted in fulfillment of the requirements of the Michigan Ross Senior Thesis Seminar (BA 480), April 20, 2023.

Abstract

We are currently facing a major global crisis. Climate change is one of the most pressing threats to humanity and yet our system is failing to take the necessary actions to protect our planet from environmental destruction. There is an undeniable coordination issue that has led to ineffective policy, lack of capital, and unsustainable carbon emissions. Deforestation, ocean acidification, glacial retreat, forest fires, heatwaves, droughts, and flooding, among other things, are becoming more prevalent and occurring more often. The voluntary carbon market is one potential solution to help fight climate change, but the current system is plagued with issues that has stifled efforts to scale this market. What if human beings repurpose how we operate to create an environment in which the system itself is regenerating? The movement of rewarding ecological activities with economic incentives has become known as regenerative finance, or ReFi, and is a promising space seeing significant growth. To advance this movement, new technologies are being evaluated as having the potential to fix a lot of the problems existing in the traditional voluntary carbon market. Through the implementation of the blockchain in the voluntary carbon market, there is an opportunity to enhance the current system and help put monetary value on conservation rather than extraction and depletion. Web3 technologies has the potential to act as a contributing force that can make a meaningful and measurable impact in the fight against climate change for individuals, households, and communities across the world. This paper identifies the cutting-edge blockchain-powered technologies and companies optimizing the voluntary carbon market. In doing so, it analyzes whether these nascent innovations can catalyze the ReFi movement to promote and accelerate climate action.

Table of Contents

Introduction

How we interact with the environment and the impact we impose on Earth over the next few decades will be critical in our efforts to save this planet from environmental devastation. Human activities have caused a persistent increase in the concentration of greenhouse gases (GHGs) in the atmosphere, leading to a rise in global atmospheric CO2 levels from approximately 280 parts per million in the 18th century to a record high of around 415 parts per million in 2022, which is more than 50% higher than pre-industrial levels (see Appendix A) (NOAA, 2022). The release of greenhouse gases into the atmosphere due to activities such as burning fossil fuels for energy reduces the planet's ability to release heat, resulting in an increase in global temperatures. This phenomenon, known as global warming, has significant impacts on the planet's ecosystems, human health, and the economy.

Human-induced climate change is affecting weather and climate extremes in every region across the globe (IPCC, 2021). According to NASA, since reliable record-keeping began, global sea levels have risen, the intensity and frequency of hurricanes have increased, wildfire seasons have been longer and more severe, sea ice cover in the Arctic Ocean has decreased significantly, and more species are facing extinction, among many other alarming signs of climate change (Shaftel, 2022). Between 2030 and 2050, 250,000 additional human deaths are projected per year due to climate change (WHO, 2021). The effects of global warming are not limited to humans, as it is projected that one-third of the world's plant and animal species will become extinct by 2050 if current levels of greenhouse gas emissions continue (“Global Warming and Endangered”). The Intergovernmental Panel on Climate Change (IPCC) Working Group II Co-Chair Hans-Otto Pörtner hashly said, “The scientific evidence is unequivocal: climate change is a threat to human wellbeing and the health of the planet. Any further delay in concerted global action will miss a

brief and rapidly closing window to secure a liveable future" (IPCC, 2022). While human activity to date has caused considerable damage, future human activities will determine if the severity and implications of climate change will persist forever.

At the 2015 United Nations Climate Change Conference, 196 parties adopted the Paris Agreement, a legally binding international treaty concerning climate change. Through this landmark agreement, the world set a goal to limit global temperature rise to 1.5 degrees Celsius above pre-industrial levels by the end of the century (United Nations Climate Change, n.d.). Over seven years later, a new report from UN Climate Change shows that the world is far from reaching the 1.5 degree reduction by 2100 and is at risk of irreversible environmental damage (United Nations Climate Change, 2022).

There are many players in the climate space trying to mitigate and prevent the most destructive environmental disasters from occurring including governmental agencies, coalitions, NGO's, startups, corporations, communities, and individuals alike. While there have been countless attempts to organize international diplomatic measures, ineffective policy, unaligned incentives, misallocation of capital, mass bureaucracy, and uneven sharing of this global burden have limited these endeavors. In order to meet environmental goals and help save this planet, many people believe the entire system needs to be realigned to fix this global coordination issue. For this to happen, leaders have urged that differences be put aside and that the world works in unity to solve an issue that is threatening to destroy everything and everyone, regardless of geographic location, income, race, or religion.

With the world struggling to rapidly eliminate GHG emissions, many governments, companies, and individuals are turning to carbon credits. Carbon credits are created through initiatives that decrease, avoid, or eliminate emissions from the atmosphere. One carbon credit

represents one tonne of carbon dioxide or the equivalent amount of another greenhouse gas. The carbon market enables a trading system in which carbon credits are bought and sold, and they are being used by many to offset their emissions and meet ESG demands. As we wait for new environmental technologies to develop, the carbon market offers a way for companies to offset emissions they cannot cut today. While this market has exponentially increased in demand, the legacy system is littered with flaws that are restricting its potential to be one of the most impactful forces in saving the planet.

Regenerative finance, or ReFi, is a promising new movement that is attempting to solve these problems. The goal of ReFi is to transfer control of capital to those looking to solve systematic problems that regenerate and preserve natural environments. More simply, ReFi aims to realign economic incentives in order to promote activities that support regeneration, while discouraging those that contribute to degradation. In theory, this would foster greater economic value to preserve natural resources (e.g. planting trees) rather than extract resources (e.g. cutting down trees for lumber).

At the heart of this movement is the third evolution of the web known as web3. Organizations, communities, and individuals are uniting under a common objective to leverage the blockchain to address the most threatening sustainability challenges. Under this new paradigm, web3 technologies are attempting to reshape the voluntary carbon market (VCM) by creating a more connected, transparent, and accessible ecosystem.

In analyzing how ReFi and the blockchain can be transformative, it is important to first understand the potential of the carbon market and how the current system operates. Accurately describing the shortcomings and inefficiencies of today's voluntary carbon market will be essential to understanding why innovation is necessary. Subsequently, it is important to

understand what is meant by the blockchain, its environmental impact, and how it works. This will help to understand how web3's objectives, values, and ideas align with the ReFi movement. Then, analyzing how the blockchain can add value to the voluntary carbon market and how this new system could contribute to the environment. This includes an evaluation of the pioneering companies disrupting the space and how they are utilizing this technology to enhance the legacy market. Using all of this information, it will be determined whether web3 technologies should be leveraged to promote and accelerate climate action in the VCM.

Overview: Traditional Voluntary Carbon Market

As the fight against climate change heightens, more and more companies and individuals are pledging to do their part in this incessant battle. While some have made progress in reducing their carbon footprint, many have struggled to eliminate their greenhouse gas emissions and are looking for alternative methods to reach carbon neutral[1]. Consequently, public and private companies as well as households and individuals have turned to carbon markets. Carbon markets create a way to buy and sell carbon credits. A carbon credit is produced through projects that reduce, avoid, or eliminate one metric tonne of CO_2–or an equivalent amount of a different greenhouse gas (CO_2e)–from entering the atmosphere. These regenerative projects can range from biodiversity protection to rainforest conservation to renewable energy implementation, among a host of other climate-action initiatives. Governments, companies, or individuals can then fund or purchase these carbon credits through a carbon market to offset emissions. According to the Taskforce on Scaling Voluntary Carbon Markets (TSVCM) which is sponsored by the Institute of International Finance (IIF) with support from McKinsey, "the market for

[1] Carbon Neutral: removing as much carbon dioxide as one emits

carbon credits could be worth upward of $50 billion in 2030" via an estimated 15-fold increase in demand over this time period (Blaufelder et al., 2021).

There are two main types of carbon markets that are helping the world move towards net-zero[2]: mandatory (compliance) carbon markets and voluntary carbon markets. Compliance markets are used by governments and corporations who are legally mandated to offset their emissions. These markets are typically regulated and enforced by internationally, nationally, or regionally qualified organizations and legal systems. The most prominent of these is the Clean Development Mechanism (CDM) in the 1997 Kyoto Protocol, a treaty created by the United Nations that sets binding emission reduction targets for developed nations. The CDM permits countries with emission-limiting commitments to create regenerative projects in developing countries. In turn, these projects earn certified emission reduction (CER) credits for each tonne of CO_2 sequestered or prevented. In order to earn CER credits, a project must pass an intensive public registration and issuance process given by the Designated National Authorities and overseen by the CDM Executive Board. The seven-step process consists of project design, national approval, validation, registration, monitoring, verification, and CER issuance ("United Nations Framework," n.d.). Eventually, the country producing the CER credits can "retire" them and claim the underlying reduction towards their Kyoto Protocol emission commitments. This protocol invented a commodity that helped place a price on carbon and incentivized the reduction of carbon emissions. CER credits became the first standardized emissions offset instrument, a pioneering innovation. While CDM was the first and largest program, carbon credits have been integrated into other regulatory emissions systems as a compliance tool. However, compliance carbon markets cover specific sectors and a limited amount of activities, reducing their ability to scale.

[2] Net Zero: removing as much greenhouse gas as one emits

Rooted in corporate social responsibility, reputational benefits, and altruism, the voluntary carbon market, on the other hand, are utilized by businesses, governments, nonprofits, universities, municipalities, and individuals looking to voluntarily offset their carbon footprint. Since entities can willingly participate in the offset market, there is more potential for scale and thus a larger environmental impact. According to the latest *State of the Voluntary Carbon Markets* report from Ecosystem Marketplace, "the VCM grew in value towards $2 Billion in 2021," up from $520 million in 2020 (The EM Insights Team, 2022).

The key players in the voluntary carbon market consist of financers, project developers, registries, and buyers (see Appendix B). Generally, the process begins with financers such as banks, asset managers, or capital market participants providing capital to project developers to green their portfolio and meet ESG demands. Project developers use that money to build environmentally regenerative projects that reduce, avoid, or eliminate carbon emissions. At the same time, project developers sign up on their preferred credit issuance registry and undergo "know your customer" (KYC). The four largest VCM registries include Verra, Gold Standard, American Carbon Registry, and Climate Action Reserve. Combined, these four markets account for over 1.5bn tons of carbon issued across over 5,000 projects (Macfarlane, 2022). Once a registry is chosen, the project developer must choose the relevant methodology to develop the project. The methodology, which outlines an extensive list of guidelines and procedures for quantifying GHG emissions, typically exists as a pre-approved methodology for project categories such as forestry, agriculture, and waste disposal. Following this, the developer drafts a project specific requirement report, sometimes called a Project Description Document (PDD) or Project Plan, which describes project activity details such as location and size, among all the other necessary details pertaining specifically to that project. The project developer then pays an

approved third-party auditor, sometimes called a validation and verification body (VVB), to assess the documents. As the project matures, which can take years, it undergoes MRV: measuring, reporting, and verification. The project developer is responsible for overseeing the project by following the methodology and PDD to report relevant data about the project. Examples of this may be the height and diameter of trees in a rainforest project or soil samples to measure the carbon sequestration in a soil project. The VVB must visit the project on-site to make sure the procedures outlined were followed and that the data is accurate. The VVB and registry also require proof to ensure the GHG reductions were additional, meaning the elimination of carbon emissions would not have occurred in the project's absence. Once verified, the results need to be approved by the administrators of the registry. If successful, the project developer pays an issuance fee and the carbon credits are issued to the project developer's account and accessible to be held, sold, transferred, or retired. This typically happens via electronic certificates that represent the CO_2 reduction claim, which are then added onto the registry's centralized ledger to be made public along with all the other documents and verifications pertaining to the project. These documents serve as a reference for stakeholders (e.g. investors and buyers) on the caliber of the project. Consumers, such as individuals or organizations looking to offset their carbon emissions, purchase and retire the carbon credits and claim their environmental impact against their own emissions.

Issues: Traditional Voluntary Carbon Market

While this process may sound relatively straightforward, the journey of a carbon credit from inception to retirement is incredibly complex, bottle-necked, and siloed. The lack of transparency and trust significantly contributes to the issues and risks of these legacy systems.

According to BloombergNEF, the voluntary carbon market could be valued at $1 trillion annually by 2037 “if several fundamental issues are addressed” (BloombergNEF, 2023). Many of these issues stem from the insufficient quality of carbon credits which affect every stakeholder and stage in the value chain. An inadequate market can lead to poor demand, less supply, and false claims of carbon offsetting. This may stifle climate action and innovation, overstate the progress on climate change mitigation, and even add to the climate crisis.

The way the current system is set up requires a significant number of forms and paperwork including:

- Methodology type
- Project Description Document
- Contracting an approved auditing body
- Validation and verification assessment
- MRV data tracking
- Additionality report
- Carbon credit issuance
- Historical tracking of credits (sold, transferred, retired)

The current process to collect and distribute all this data is slow and not scalable. With the outdated infrastructure and tools used by legacy registries, “Current measurement, reporting and verification (MRV) methodologies are numerous, require significant manual work, are slow to follow and measure against and are often redundant. Many methodologies for the collection, analysis and distribution of data remain non-digital and lack machine-readable auditability” (World Economic Forum, 2023). Additionally, the necessary data for any given credit can substantially differ based on the registry, project type, methodology, vintage[3], location, scale, and

[3] Vintage: the year the credits were issued

complexity, contributing to a lack of credit standardization. With multiple registries and protocols, the traditional carbon market is complex and fragmented, requiring “the onerous processing of disparate and heterogenous data sources" (Wolfberg & Adriaens, 2021). Consequently, data made available to public and private sectors can have a large latency to be aggregated, grouped together, and standardized. Even Gold Standard, one of the largest registries, said in a public consultation that “The conventional verification process is costly and time consuming due to the lack of appropriate automation (digitalisation) and so it cannot be done in ‘real-time’ and therefore periodic delays are the norm, often verification starts after a year of data monitoring and reporting” (Gold Standard, 2023). Legacy systems lack the technological infrastructure to collect, process, and disseminate real-time data which has resulted in a core issue with traditional carbon markets: quality.

With a lack of real-time data, accurate tracking and transparency diminish. The system suffers from quality control issues and thus struggles with proper governance and enforcement. This can lead to double counting which occurs when the same emission reduction or removal is claimed and counted towards multiple mitigation targets or goals. Carbon Direct says that, “In most cases, retiring parties can purchase offset tons and account for the carbon offset without oversight” (Macfarlane, 2022); to make matters worse, there is little to no responsibility for the quality of those offsets. This is a significant problem as it undermines the environmental integrity of the carbon market and can lead to an overestimation of emission reductions.

This is known as greenwashing, which can occur when stakeholders make false claims about the benefits of their carbon emission reductions. These misleading claims can derive from purchasing carbon credits of poor quality or that face issues with additionality, leakage[4], or

[4] Leakage: project directly or indirectly displaces greenhouse gas emissions outside of the project boundary

permanence[5]. Companies and individuals buy these inferior credits, which are typically cheaper, and insist that they have reduced their carbon emissions more than they actually have. Recently, a nine-month investigation into the world's leading carbon standard found that "more than 90% of their rainforest offset credits – among the most commonly used by companies – are likely to be 'phantom credits' and do not represent genuine carbon reductions" (Greenfield, 2023). When the quality of projects and their carbon credits are questioned, project financers may be more reluctant to provide capital and buyers may resist purchasing to avoid involvement in risky projects or being scrutinized for greenwashing. This harms project developers who require both funding and purchasers to participate in the market.

Moreover, due to the distinctive attributes of each project and its carbon credits, credits are "traded and sold like differentiated products (e.g. wine) rather than like commodities (e.g. corn or rice)" ("Introducing Carbon Pools", n.d.). With limited standardization, it is difficult for project developers to know how much to list their credits and for buyers to know how much to spend on credits. Consequently, around 75% of voluntary carbon credits are bought and sold over the counter (OTC) (Yin, 2022). OTC markets operate through a network of dealers or market makers who facilitate the trades. Carbon credit OTC markets lack real-time data, liquidity, and price transparency. As written in a McKinsey carbon market report, "Transparent reference and market data are not readily available now because access to data is limited and the OTC market is difficult to track" (Blaufelder et al., 2021). Less-resourced project developers and buyers rely on intermediaries, such as a broker or consultant, to navigate the OTC market. Project developers typically sell their carbon credits to an intermediary who purchases the credits at one price, takes

[5] Permanence: maintaining GHG emission reductions or removals; not allowing carbon to be released back to the atmosphere

a large fee, and then resells the credits for more. This system is inefficient and reduces the financial return for project developers while increasing the price for buyers.

This decreased financial reward is amplified by the high costs charged to project developers. Throughout the development of a carbon offset project, project developers are required to pay a myriad of fees. These can differ based on the registry, methodology, and project type, but generally include:

- Account opening fees
- Annual registry account fees
- Methodology approval fees
- Certification review fees
- Validation and verification fees
- Carbon credit issuance fees
- Transaction/transfer/delisting fees
- One-off fees (e.g. additional rounds of review or design change)

A major contributor of these high fees are from registries relying on manual, human processes. This was made evident through Gold Standard's public consultation as "There is growing interest among stakeholders to accelerate progress on the journey from today's conventional MRV, roughly characterised as 90% manual and 10% digital, to transition towards more digital MRV, roughly characterised as 10% manual and 90% digital" (Gold Standard, 2022). These high costs make the current system exclusive and disincentivizes project developers from participating.

In all, when evaluating the flaws in traditional carbon markets, the core issues compound and produce more problems (see Appendix C). Disparate and siloed data with high latency

generates issues with data accessibility, transparency, and tracking. When key players in the value chain struggle with this, integrity and trust diminish and so does quality. This increases the cases of double counting and greenwashing in the market, which has a negative environmental effect. Lack of quality causes project financers to provide less capital, decreases the number of end buyers, increases costs, and thus reduces the supply of project developers. This is detrimental to a market that is necessary for reducing greenhouse gas emissions and accelerating the transition toward a low-carbon economy.

What is Web3 and the Blockchain

In understanding how web3 technologies can be advantageous in the voluntary carbon market and curbing climate change, it is important to first understand what is meant by web3 and the blockchain. Web3, also known as web 3.0, is the third iteration of the World Wide Web. With its inception in 1989, web1 gave rise to the internet in a "read-only" fashion, providing the infrastructure for static, non-interactive websites. While revolutionary, it was web2 that helped shape the internet as we know it today– an interactive platform that allows for user generated content and engagement. This life-changing innovation helped onboard billions of people onto the web and gave birth to "big tech" such as social media and conglomerates like Google and Amazon. Over time, power distilled into the hands of centralized organizations and concerns over data privacy and censorship have increased. Web3 is a transformative technological development that gives ownership to the user in a decentralized manner via the blockchain.

The blockchain is the underlying technology that powers all of web3. It is a chain of linked blocks that each contain data and forms a collection of records on a digital ledger. Each block has a limited amount of data storage, so once a block reaches capacity it is added to the

chain of other blocks via a shared network of computers. Since the blockchain is a string of interconnected data structures, it is immutable– any modification to one block would necessitate changes to all subsequent blocks.

The blockchain is often viewed as having a negative impact on the environment and as a technology that exacerbates climate change. While this may be true in some instances, what determines this is the type of blockchain and its consensus mechanism[6]. There are a host of different consensus mechanisms, but the two most common are called Proof-of-Work (PoW) and Proof-of-Stake (PoS). This matters because PoW, which powers the popular blockchain known as Bitcoin, is extremely energy intensive while PoS, which powers the second largest blockchain known as Ethereum, uses little energy. This is because Proof-of-Work requires powerful, energy-intensive computers to power the blockchain. Essentially, tens of thousands of computers race to be the first to solve a complex math problem, which enables the winner to confirm the block and add it to the network where it's distributed to the rest of the miners[7]. These computers are operated all over the world by many individuals and organizations, giving the blockchain its decentralized nature. Miners are incentivized to do this work through the reward of newly created cryptocurrency coins and transaction fees. This also acts as compensation for their efforts in maintaining the blockchain network and ensuring its security, which includes expenses such as energy bills, computer hardware, maintenance, and time.

Contrast this PoW model with the PoS consensus mechanism which reduced Ethereum's annualized electricity consumption by more than 99.988% ("Ethereum Energy Consumption," 2022). In Proof-of-Stake, validators are required to have minimal hardware and stake money as collateral to secure the network. Instead of running thousands of energy-intensive computers,

[6] Consensus Mechanism: a standardized method for computers to agree and verify the data in each block
[7] Miner: individual or organization that validates transactions on a blockchain network

validators can operate the necessary software on an ordinary computer. And instead of consuming loads of energy to solve a complex problem, validators are randomly chosen to add a new block to the network and confirm its validity. In all, users can operate on and benefit from the blockchain without negatively affecting the environment through Proof-of-Stake blockchains such as Ethereum, Polygon, and NEAR, among many others.

Overview: Blockchain Carbon Market Ecosystem

In order to understand the innovation occurring in the blockchain-powered voluntary carbon market, it can be helpful to distinguish the aspects of the digital carbon market ecosystem. At the base layer is infrastructure, which is driven by the type of blockchain, carbon bridges, exchanges, and market data providers. Ethereum, Polygon, Celo, NEAR, Cosmos, and Bitgreen consist of some of the most popular blockchains that carbon companies are using to build. These blockchains may differ based on their consensus mechanism, smart contract language, and transaction processing capacity, fees, and execution times. While these nuances make each blockchain appealing for various reasons, every blockchain listed above is eco-friendly and energy efficient. Carbon bridges built on the blockchain are used to convert already issued, off-chain carbon credits into on-chain digital tokens. Exchanges, on the other hand, enable carbon credit users to interact with the DeFi ecosystem. Market data providers aggregate, analyze, and provide data about carbon markets, allowing anyone to easily access and verify market data.

Applications built on top of the infrastructure layer consist of three key components: project financing, on-chain retirement, and marketplaces. To aid in the supply side of this market, companies have built unique applications to innovatively deploy capital to project developers.

On the demand side, various protocols facilitate on-chain credit retirement. Marketplaces provide the platform for suppliers to list credits and buyers to purchase credits.

Built on the blockchain and used within applications are carbon assets including tokenized carbon credits, crypto-native credits, and NFTs. Tokenized credits consist of carbon credits that originate from off-chain registries and are bridged on-chain. Crypto-native credits, on the other hand, are issued directly on-chain. Other pioneering companies are leveraging the properties of non-fungible tokens (NFTs)[8] to innovate carbon on the blockchain. In discovering novel use cases within the infrastructure, application, and asset stack, new blockchain carbon companies are pioneering the space.

Advantages: Blockchain-Powered Carbon Market

There are a few key characteristics of the blockchain that make it a valuable technology to implement in the voluntary carbon market (see Appendix D). A blockchain is decentralized, meaning transactions are verified by a network of users and nodes and enforced using cryptographic trust. The decentralization of data storage and uptime removes concerns about a single point of failure in maintaining VCM database records. Additionally, the legitimacy of the data is required to be approved by various entities and doesn't rely on a central authority. This reduces the chances of a bad actor and eliminates the power of a single entity making decisions for the entire system.

One use-case prompted by the blockchain's decentralizion is the ability for pre-approved validators with a range of relevant expertise to verify the data being captured on projects[9]. For example, the validators could consist of tech companies, development agencies, environmental

[8] NFT: represents ownership of a unique item stored on the blockchain; not interchangeable
[9] This method is being implemented by Open Forest Protocol, a company that is analyzed later in this paper

NGOs, government agencies, VVBs, and research institutions who vote on the legitimacy of the cross-examined data provided by the various validating bodies. A native token[10] can be issued on the blockchain and used as payment for validation, acting as an incentive that rewards truthful verification and a financial dissuader for doing otherwise.

Another essential characteristic of the blockchain is its immutability. Once code has been programmed into smart contracts and data has been recorded on the blockchain, it cannot be changed. This tamper-proof system increases trust by eliminating the fear of data manipulation.

The blockchain is also interoperable, making for a more connected and holistic market. This enables the integration of carbon credits from multiple registries into a single interconnected marketplace. Instead of having siloed data on various platforms, it can all be aggregated on a single platform and accessed by anyone. This interoperability also allows data from various sources and technologies to easily connect to the blockchain and be made available to the public, providing real-time information on the MRV of projects.

Given the programmability of the blockchain, human processes can be replaced with code and increase the efficiency of the system while also cutting costs. Smart contracts[11] make the payment process more desirable because they facilitate faster transactions by automatically executing when conditions are met. For project developers that require payment in a timely manner, immediate payment and reduced fees can incentivize continued participation in the market. Smart contracts also open new forms of innovation that can positively impact project funding. One example is recurring royalties which entitle project developers to a percentage of each subsequent carbon credit transaction in perpetuity[12]. Additionally, risk-averse financers

[10] Native Token: represent the value of the ecosystem
[11] Smart Contract: programmed with "if-then" statements to enforce an agreement; once conditions are met, the contract automatically executes
[12] This would be the case if the tokenized carbon credit is resold and not immediately retired

have the opportunity to provide upfront funding to projects requiring capital, while also ensuring that these projects are adhering to the standards to issue high-quality credits. Financers can pool money into smart contracts that restrict access to the funds until predetermined criteria are met. If the milestones are reached, the smart contract executes and provides the money to project developers. For example, a forestry project could receive $10,000 of funding if the trees mature to a specific height predetermined by the participating parties. Once the trees are verified to have reached that height and the data is uploaded to the blockchain, the smart contract will execute and the capital will be released to the project developer.

Transparency and traceability are also key features that provide value to a carbon market that is often criticized for being opaque and prone to fraud. All transactions and activities are visible on a public ledger and accessible by anyone. If users have full access to data about carbon credits including their issuing registry, project type, vintage, trading activity, and retirement status, buyers can better understand the quality of the different credits. Having insight into the quality of credits help determine their appropriate value and alleviates concerns about purchasing inferior credits or greenwashing. This combined with an auditable log of activity, such as the costs of comparable credits that have already sold, can significantly help with price transparency and discovery.

Typically, those on both the demand and supply side of carbon credits rely on brokers and consultants to help them find the appropriate counterparty. Now, both buyers and sellers can seamlessly partake in the market. Having a marketplace to directly buy and sell on is an important innovation that cuts out fee-taking intermediaries who are typically required in the complex, opaque, and restrictive OTC markets. The log of activity can also help prevent double counting and ensure that carbon credits are only sold once. Eliminating the double spend

problem has been core to blockchain technology since its inception. As written in the original Bitcoin whitepaper from 2008, “we propose a solution to the double-spending problem using a peer-to-peer distributed timestamp server to generate computational proof of the chronological order of transactions” (Nakamoto, 2008).

Financers benefit from the transparency and traceability too as it significantly improves visibility into project developers, project history, and project plans. Having this information reduces time-consuming and costly due diligence, increases trust in the investee, and allows financers to feel more confident in the integrity of the project. This also alleviates the fear of being scrutinized for double counting or greenwashing and can simplify the reporting process. As governments move forward with requiring the public sector to comply with ESG regulations and report disclosures (e.g. Task Force on Climate-Related Financial Disclosures), it will become more critical for these stakeholders to reliably invest in high-quality carbon credits.

Once carbon credits are tokenized on the blockchain via a carbon bridge or natively issued on-chain, a host of other innovations add new novelties that can transform how this system operates and what can be accomplished. Through the programmability of the blockchain, tokenomics can be “baked into a particular cryptocurrency’s computer code by its founding developers” (Stevens, 2022). Tokenomics enable a protocol’s native tokens to take on different properties and functions such as a fixed or unlimited supply, divisibility into smaller units or bundling into standardized units, specific rules for transfer and ownership, or granting access to certain services and platforms. Supply of tokens can have a major impact on scarcity and thus price. Having the flexibility to determine this supply can influence incentives to buy and hold tokens. Additionally, enabling tokens to be purchased in fractional quantities can make carbon credits more affordable and scalable. Instead of people needing to offset full tonnes of CO_2, they

can purchase smaller quantities. Through fractionalized tokens and an application programming interface (API), any company in any industry can provide a checkout option for customers to offset the emissions of their purchase (e.g. paying extra to offset the emissions released from getting groceries delivered). Standardizing carbon credits, on the other hand, is also enabled through tokenization. According to Nori, "To accomplish scalability, carbon markets will have to look more like commodities markets" (Nori, n.d.). This can be achieved through the bundling of tokens. Criteria gates implemented by protocols grant access to different carbon credits with similar attributes from varying projects, registries, and vintages to be bundled into a carbon pool. In exchange for a credit that matches the pool's criteria, the supplier receives a standardized credit that acts like a commodity. Having various carbon pools set by distinct criteria establishes different classes of carbon assets. This helps the market determine the price of each asset class and creates a standardized asset that is composable with the emerging decentralized finance (DeFi) ecosystem (more on this below). Lastly, tokens can be used as a governance mechanism through a decentralized autonomous organization (DAO). Ownership of the protocol's native token delegates voting power in community-led decisions such as the types of projects accepted on the platform (e.g. only carbon removal projects), criteria for different carbon pools (e.g. only forest projects issued credits within the last five years), and which entities to approve as validators (e.g. an accredited tech company), among others. Voting power is typically distributed by a person's percentage of the overall supply of tokens which can also incentivize the holding of the token.

Decentralized finance (DeFi) is a new and rapidly evolving ecosystem that uses blockchain technology to provide financial services and products. Given that the fight against climate change is global, it is extremely advantageous that DeFi operates on a permissionless

blockchain and is accessible to anyone with internet access. According to the World Bank, around 1.4 billion adults globally remain unbanked (World Bank Group, 2022). DeFi, however, eliminates many of the barriers that traditional financial institutions impose. Individuals who don't have access to normal financial services can use cryptocurrencies to send remittances, buy stablecoins in times of fiat volatility, and easily send cross-border payments. Decentralized financial markets are also open and accessible 24/7 and enable instant transactions. These benefits increase the appeal of DeFi and can onboard millions of people to participate in the voluntary carbon market. DeFi also provides opportunities to interact with decentralized exchanges (DEXs)[13], different currencies, lending, borrowing, and staking. Trading tokenized carbon credits on a DEX enables order matching engines known as automated market makers (AMM) to pair buyers and sellers in real-time without the need for intermediaries. It enables individuals to pay or receive payment in their preferred currency, lend money and accrue interest, borrow money to participate in the market, or stake money to validate the blockchain. These DeFi applications help address the major liquidity and efficiency issues in the legacy VCM. All this to say, DeFi can enable greater access and innovation for both suppliers and buyers. It can help project developers get their credits to market faster and more cost-effectively while also providing additional financing opportunities and flexibility to buyers. DeFi can enable a small land steward in Copenhagen to directly list their project on a blockchain-powered marketplace, and an individual in a developing nation to purchase those carbon credits. DeFi opens access to liquidity from everywhere in the world and financing from investors globally. The blockchain powers DeFi and DeFi is one part of ReFi's wider tech stack. ReFi builds on the movement of DeFi by taking some of its key building blocks and applying them to the most urgent global challenge: climate change.

[13] A DEX is a platform that allows users to buy, sell, and trade cryptocurrencies without intermediaries

Pioneering Blockchain-Based Carbon Companies

The 1997 Kyoto Protocol was the official formation of a carbon trading market. Since then, various players have entered the space to iterate, transform, and improve the system. When Bitcoin was issued in 2008, blockchain technology came into public view. As people uncovered the capabilities of the blockchain, its applications expanded. By the mid-2010s, the blockchain began to be viewed as a technology with the potential to positively disrupt the climate space. From approximately 2017 onward, new organizations have joined the ecosystem as first-generation blockchain carbon companies. Today, we are witnessing the evolution of these pioneering companies as well as the emergence of the next generation of blockchain carbon innovations. Although still considered a nascent space, additional organizations continue to enter the domain.

I had the opportunity to engage in conversations with companies widely regarded as some of the most disruptive and revolutionary in the space. These include:

- Toucan
- Chainlink
- KlimaDAO
- Open Forest Protocol
- Moss
- Nori
- Thallo
- Blockchain Triangle
- Flow Carbon

- Regen Network

Throughout this process, I had the privilege of conversing with individuals occupying diverse positions ranging from CEO to Chief Blockchain Officer to Head of Carbon and Sustainability Solutions. These insightful conversations consisted of general questions about the space as well as company-specific questions[14]. This provided a range of perspectives on the legacy system, the impact of blockchain technology, and the future of the space. Below are writeups of each company based on the conversations and other information collected via company websites, whitepapers, and documentation[15].

Toucan

Founded in 2020, Toucan is an infrastructure provider built on Polygon and Celo that utilizes a carbon bridge, carbon pools, and a blockchain-based registry database for users to easily and transparently buy, sell, transfer, retire, or hold tokenized carbon credits.

Toucan's carbon bridge allows anybody to bring a group of verified carbon credits on-chain as a carbon batch NFT. These NFTs can be sold on marketplaces, used as collateral, or fractionalized and turned into an equivalent amount of fungible[16] carbon credit tokens called TCO2 ("Toucan" or "tonne" or "tokenized" carbon credits). Although fungible, the attributes of the original carbon credit, including project and vintage, are attached and viewable by anyone.

Once carbon credits are bridged and fractionalized, the TCO2 token can be deposited and locked into carbon pools. Each pool (e.g. BCT and NCT) contains different attribute gating criteria that the TCO2 token must satisfy in order to receive a corresponding carbon reference

[14] Questions: What does your company believe are the key challenges with the traditional voluntary carbon market? How is your company using the blockchain to solve these issues? What are some of the biggest challenges and barriers your company is facing and how are you addressing these pain points? How do you envision this space taking shape in the short term and long term?
[15] Please note that this space is iterating at rapid speed; new updates are constant and current company offerings change
[16] Fungible Token: represents ownership of a interchangeable or identicle item stored on the blockchain

token. For example, BCT (Base Carbon Tonne) pool criteria is a credit issued from Verra with a vintage of 2008 onwards; NCT (Nature Carbon Tonne) pool criteria is a credit issued from Verra through a nature-based methodology and from a vintage of 2013 onwards (with a ten year rolling acceptance window). This homogenizes the credits and can help address the liquidity issues that stem from varying credit traits. Reference tokens can be traded on DEXs or used in other blockchain applications that accelerate climate action. Carbon reference tokens can be exchanged back into TCO2 tokens and retired on Toucan's platform. Accurate carbon accounting is maintained by redeeming and burning the TCO2 tokens locked in the carbon pool, which is then recorded on the public blockchain forever.

Toucan's Open Climate Registry (OCR) contains tokenized credits that are either natively issued directly on-chain by registries or brought on-chain via Toucan's carbon bridge. The OCR is a connected, transparent database that aggregates the information and trading history of all recorded carbon credits. This accessible and traceable database can enhance the buying and selling of credits and help the carbon market scale. Through increased price discovery, buyers can make more informed decisions and suppliers have more negotiating power.

Through Toucan's infrastructure, other climate-positive products and protocols can be easily built using the company's software developer kit (SDK) and API. Real-world tokenized carbon credits are made available to be utilized in web3 markets and leveraged throughout the DeFi ecosystem, generating an amplified effect (see Appendix E).

Chainlink

Founded in 2014, Chainlink is a decentralized oracle network. Oracles provide the infrastructure that transfer off-chain data (e.g. energy data) onto a blockchain and enables connectivity between blockchains. While it may not directly impact the carbon markets,

Chainlink plays a key role in providing tamper-proof and reliable information, such as price feeds and trading activity, to carbon companies operating on-chain. Given that there are various carbon credit standards and registries each with its own data quantification requirements and verification processes, Chainlink's decentralized oracle network helps aggregate the data and provide a single source of truth for carbon market participants. This makes it possible to access accurate and up-to-date information, helping improve latency and information asymmetry. This technology enables key players in the system to modernize their infrastructure and provides a more transparent, efficient, and cost-effective system.

KlimaDAO

Founded in 2021 and built on the Polygon blockchain, KlimaDAO is working to democratize access to carbon markets through its core infrastructure. By enabling organizations to build products and features on top of its infrastructure, Klima is trying to create a virtuous cycle of growth. The company has also created its own marketplace where already-issued credits can be easily and transparently bought, swapped, and retired. In addition, Klima has built a carbon dashboard that acts a market data provider.

Partnering with carbon bridge companies such as Toucan and Moss, stakeholders can transfer verified off-chain credits onto KlimaDAO’s on-chain platform. With on-chain carbon credits, users can choose from a host of carbon pools built by various blockchain carbon companies and receive different fungible base tokens in return. These base tokens can either be sold or converted into KLIMA, the protocol’s native token. KLIMA can be used in numerous ways including as payment to retire tokenized credits on the blockchain. KlimaDAO’s retirement certificate is ingrained with essential information that confirms the retirement and operates as proof that the tonnes have been offset, eliminating the potential for double counting. KLIMA can

also be locked up to accrue rewards or held and used as a voting mechanism. KlimaDAO is a community-led initiative that allows KLIMA token holders to participate in the decision-making process and help shape the direction of the organization (e.g. propose and vote on the carbon pools available to users). Leveraging its infrastructure and the DeFi stack, KlimaDAO is opening avenues of innovation that connects the market and drives funding to sustainability projects worldwide (see Appendix F).

Open Forest Protocol

Founded in 2020, Open Forest Protocol (OFP) is an accessible platform that enables forest projects of all sizes from around the world to accurately measure, report, and verify (MRV) their forestation data on the blockchain. OFP is built on the energy-efficient NEAR blockchain, a proof-of-stake network that allows OFP to be open-sourced and scalable.

First, project developers[17] register and upload basic information about their forestry land plots on the Open Forest Protocol platform. OFP's Project Operator Dashboard uses this information to generate geolocated NFTs for each designated forest plot. These NFTs serve as a virtual representation of land ownership and permanently store and update every project detail in the token's metadata. The dashboard also randomly assigns field agents, responsible for monitoring the progress of the forest project, to sample different plots. Through the simplicity of a smartphone, field agents can use OFP's Forester app to collect and upload data from their assigned sample plots. Due to the ease of this MRV process, data is collected more often and for cheaper, occurring every six months for the first two years and then annually moving forward. The field data obtained can be accessed on a dashboard by approved validators and undergoes rigorous testing using a variety of distinctive capabilities, data sets, and remote-sensing technologies provided by each validator. Validators combine this with their forest expertise to

[17] Project developers are referred to as operators on the OFP platform

review and vote on the data for each project. The communal network of validators verifies or rejects uploaded project data which is stored in a transparent manner on the blockchain. This generates an unalterable ledger of forest activity, along with a continuously expanding data pool for validators to analyze and compare against (see Appendix G).

In exchange for their verification and to incentivize truthful actors, validators earn OPN (Open) tokens which are automatically distributed via smart contracts. Live projects can then be viewed on the OFP Project Explorer where anyone can access general information (e.g. location, description, goals), uploaded MRV data, and validation history of each project.

While currently in development, Open Forest Protocol has plans to expand project categories beyond forest projects[18], issue its own on-chain credits, create a wallet to hold, transfer, or retire tokenized credits, build a digital wholesale offramp for OFP-supplied credits, pre-fund projects, and make decisions governed by a DAO in part through OPN tokens. With the power of blockchain technology, these initiatives will continue to increase transparency and access, helping to improve liquidity and price discovery.

Moss

Founded in 2020, Moss is a carbon platform that makes it simple and transparent for businesses and individuals to offset their emissions by supporting Amazon REDD[19] projects. Moss buys credits from Verra certified environmental preservation projects and uses a carbon bridge to add them to the blockchain. Each carbon credit is tokenized on a one-to-one basis via the issuance of fungible MCO2 (Moss Carbon Credit) tokens on the Ethereum blockchain. MCO2 is meant to be “primitive” to allow for other innovators to leverage the token for new functionalities, products, and services. MCO2 is listed on global exchanges and can be bought on

[18] such as mangroves and biodiversity projects
[19] REDD: Reducing Emissions from Deforestation and forest Degradation

Coinbase and Gemini[20]– the only carbon credit company in the world with tokens listed on these platforms. Once purchased, MCO2 can be sent by users to an Ethereum address designated by Moss who then retire the corresponding carbon credits.

While Moss also sells non-tokenized credits, the company's reasoning for tokenization is primarily for security purposes. Their securely programmed smart contracts create a layer of safety that lead to high credibility, transactability, and low transaction costs. Additionally, by tokenizing this process, activity can be publicly traced and audited, generating a faster and more secure transfer of carbon credit legal ownership (VERPA). By having carbon credits on the blockchain, real-time data such as total supply, price, and unique holders can be viewed through Ethereum's block explorer and analytics platform Etherscan or KlimaDAO or Dune Analytics.

Lastly, Moss offers Amazon NFTs, allowing easy access to purchase the rights of the property and protection of forested land. Through these NFT sales, owners implicitly sign and agree to keep their area of the Amazon Rainforest preserved. To properly maintain the area's security, a 30-year forest protection fund was established by Moss from a portion of the NFT revenue.

Nori

Founded in 2017, Nori has created a carbon removal marketplace on the Polygon blockchain. The company works directly with carbon removal project developers to issue NRT (Nori Carbon Removal Tonne) tokens directly on-chain via their in-house methodology processes. By focusing on carbon removals as opposed to avoidances or reductions, MRV is easier, more effective, and reduces concerns about additionality (see Appendix H). One NRT represents one tonne of CO_2 removed and stored for at least ten years, with re-verification every

[20] Based on current trading volume, Coinbase and Gemini rank as the second and twelfth largest centralized exchanges (CEX) in the world, respectively

three years. These NRT tokens get listed on Nori's marketplace and can be directly bought by users via the NORI native token. A portion of NORI's token supply is automatically withheld and used as an insurance reserve and warranty to remunerate buyers should carbon be lost before the end of ten years.

NORI functions as a fungible digital currency within Nori's marketplace and can be exchanged for NRT tokens on a one-to-one basis. Acting as a commodity that can be actively traded on exchanges, the NORI token can help scale markets and provide market pricing. Once NRT tokens are sold on the marketplace, the credits are retired immediately, eliminating intermediaries and preventing double counting. NRT tokens are minted as NFTs that contain details on the carbon removal data. When purchased, the NFT is updated to include a unique certificate that confirms the buyer's ownership, sale price, and date of retirement, helping to promote transparency.

Given that NORI is a crypto token, it can be purchased in fractional amounts. With this in mind, Nori is building an API that can be integrated into platforms so carbon removals can be purchased as part of other transactions (e.g. buying a plane ticket).

Thallo

Founded in 2021, Thallo aggregates carbon credits from project developers in one easy-to-use marketplace built on the Polygon blockchain. Thallo's two-way carbon bridge allows project developers to transfer issued credits from major registries to the blockchain. Thallo's bridge can successfully store critical information about a project such as its vintage and serial numbers, and create a log of activity that is easily traceable through a single click function. These carbon credits can be transferred on and off the blockchain in a manner that maintains accountability. All events conducted on the underlying registries are reflected on-chain and all

activity on-chain is accounted for on the underlying registry. By ensuring that every transaction is recorded and traceable, Thallo can help prevent issues of double counting.

The process for project developers is simple and consists of joining the platform and undergoing KYC, transferring carbon credits onto the platform, and receiving instant payment upon sale. Project developers can easily set a price based on real-time data and receive passive income through royalties from the credits' secondary sales. Providing direct access to a transparent market can help cut out intermediaries, making it more profitable for project developers and less costly for buyers.

For businesses and individuals, Thallo's platform has advanced project filters for easy carbon credit exploration. Through Thallo's dynamic pooling, buyers can specify credit attributes (e.g. project type, vintage, location) and create their own pool of fungible tokens that match the criteria (see Appendix I). This blockchain-enabled innovation can help solve the liquidity issue that exists from selling widely heterogenous credits. The platform also helps with price discovery on the demand side by providing critical information such as the listed price of each project and the price history of sold credits.

By leveraging the public, immutable, and distributed nature of the blockchain, Thallo makes it possible for anyone to access this data at any time, thereby promoting transparency and trust in the system. As a result of Thallo's modern architecture and blockchain execution, the platform charges a lower-than-average flat fee of 3% for all transactions. Enabling higher margins encourages project developers to continue to participate in the market by reinvesting in existing or new project operations.

Blockchain Triangle

Founded in 2018, Blockchain Triangle is a digital finance platform that enables real-time data feeds for banks, asset managers, and capital market participants to help with climate compliance, performance, and benchmarking. The company combines financial asset information with smart meter and IoT sensor data and links them to create a digital asset on the blockchain (see Appendix J). More specifically, assets that can be tracked through these devices are recorded on the blockchain where the various data points are embedded, aggregated, and organized for various stakeholders in the financing value chain to easily understand. Through the blockchain, these unalterable tokenized assets are updated in real-time, which is more dependable, trustworthy, and consistent than its non-digital equivalent. Providing timely and detailed information enhances liquidity while minimizing risk.

The ability to represent numerous tokenized assets in a single portfolio of assets also decreases the inefficiencies that come with reporting disclosures and regulatory compliance, making green financing more appealing to capital providers. This automated, low-cost software approach can significantly reduce the cost of capital and the cost of administration. This reduction has a two-fold effect: it democratizes access to projects for smaller investors which in turn provides funding to additional projects.

Flow Carbon

Founded in 2021, Flowcarbon is focused on creating a liquid and transparent carbon market by bringing nature-based (e.g. conservation, reforestation, nature restoration) carbon credits onto the blockchain. Users can initiate a transfer of issued credits from one of the four market-recognized registries into a special purpose vehicle (SPV) that is overseen by a reputable third-party and frequently audited. Batches of off-chain credits, unique to a project and vintage year, are then bridged on-chain as GCO2 tokens. Each batch of GCO2 tokens is unique and

equivalent to the number of credits transferred (see Appendix K). Flowcarbon's two-way bridge allows for autonomy in the preferred configuration of the credit, giving users the option to switch back and forth between off-chain tokens and different on-chain tokens. On account of the blockchain, reliable accounting can be verified through a publicly accessible registry that uses unique identifiers to ensure that the credits are legitimate.

These unique GCO2 tokens can then be combined with other GCO2 tokens of similar attributes and converted into an equivalent amount of fungible bundle tokens. The GNT (Goddess Nature Token) is the first bundled token created on Flowcarbon. To obtain a GNT, Flowcarbon requires users to exchange a nature-based GCO2 token that is issued by a market-recognized standard and has a vintage within five years of the current year. This commoditization can help create liquidity and optionality in the market.

Due to the interoperability enabled by the blockchain, bundled tokens can be leveraged in liquidity pools, lending protocols, and other DeFi applications. The tokens can also be retired on-chain where they are stored transparently in the contract until they accumulate to a full batch. Flowcarbon then retires the corresponding credits in the carbon credit registry and records a tamper-proof checksum for auditing purposes. Through smart contracts and the blockchain, these full-functionality tokens expand the innovative possibilities, democratizing access to carbon credits and increasing price discovery in a safe and trackable way.

Regen Network

Founded in 2017, Regen Network operates through three intertwined functions: Regen Ledger, Regen Marketplace, and Regen Registry. The Regen Ledger, developed with the Cosmos SDK, is a Proof-of-Stake blockchain that provides a decentralized, transparent, and immutable infrastructure. This blockchain infrastructure facilitates communication and transactions among

multiple registries, resulting in the creation of a transparent accounting system that is accessible to the public.

The Regen Marketplace, powered by the Regen Ledger, is a platform used to create, bundle, and sell on-chain carbon credits called ecocredits. Ecocredits get issued through the Regen Registry, which develops its own methodologies for nature-based projects. The Regen Registry is a decentralized registry operated by experts and earth stewards that works to lower the barriers for project developers through more approachable processes, less costly onboarding, and community-driven decisions. The Regen Network is governed by REGEN token holders, allowing the community to determine how the network evolves and functions. Unlike centralized carbon registries, decisions such as new project standards and peer review processes are decided upon and approved by the community. To carry out transactions on the Regen Marketplace, users pay a small quantity of REGEN as a fee to compensate the validators who enable the continued uptime of the Regen Network blockchain.

Using Toucan's two-way bridge, NCT tokens can also be brought onto Regen's blockchain. NCT tokens can be redeemed for ecocredits, which can then be retired on the Regen Ledger. Conversely, eligible ecocredits can be exchanged for NCT tokens and bridged off Regen's blockchain and onto the Polygon blockchain.

The interchangeability and interoperability enabled by the blockchain allow for credits on the Regen blockchain to be used across DeFi applications and in a more liquid manner. As a result, Regen's infrastructure can help project developers gain greater access to buyers while also avoiding fees charged by intermediaries. On the buyer side, high-quality carbon credits can be purchased, traded, and retired with greater transparency and accountability, eliminating the fear of double counting and greenwashing.

Limitations: Blockchain-Powered Carbon Market

While technology may make something possible, it may not necessarily be the right fit for implementation. While the blockchain can and is being used in the voluntary carbon market, it is important to understand whether it should be used in the VCM.

The blockchain can facilitate data through its interoperable system, but it critically depends on other technology to digitally monitor, report, and verify (dMRV) that data. New and developing technology such as geospatial analysis, remote sensing, drones, big data, and artificial intelligence are being used to collect data in a more efficient and effective way, helping to modernize GHG methodologies and streamline verification. The blockchain can play a complementary role in facilitating a connected, holistic market, however, this is not possible without accurate, real-time data about the projects via dMRV.

Moreover, smart contracts have a lot of upside, but they are only as secure as the code they are built on. In the event that there are vulnerabilities present in the code, malicious actors can exploit the smart contract to steal funds or disrupt the network. This can be problematic as attackers could steal or transfer tokenized carbon credits without authorization. This can damage the integrity of the carbon market by undermining the trust of investors and participants. Furthermore, given the blockchain's interoperability and building block infrastructure, more touchpoints become accessible for hacks to occur; this can take place via cross-chain bridges, hot wallets, or DeFi protocols. With 2022 being the biggest year ever for crypto hacking (Chainalysis, 2023), this is a major concern that needs to be considered when bringing any component of the carbon market on-chain.

Another important thing to consider is where in the value chain it would make most sense to implement the blockchain. Tokenizing off-chain issued credits does not fix the problems that currently exist with the issuing process such as inefficiencies, high-costs, and questionable credit approval. Verra, Gold Standard, American Carbon Registry, and Climate Action Reserve are all formed as nonprofits. Nonprofits typically focus on operational stability over profit and can sometimes suffer from a lack of resources and complex regulatory compliance. This may contribute to why legacy registries have historically been expensive and slow to adopt new technologies, hampering the space from achieving efficiency and scale. Consequently, project developers have suffered from high registry costs and bottlenecks. Additionally, if legacy registries are issuing low-quality credits, which many reports have indicated, their on-chain equivalents are also inadequate. According to Carbon Direct's *2022 Commentary on the Voluntary Registry Offsets Database*, "Rather than sourcing high-quality credits, blockchain buyers have been retiring credit categories at most risk of being low quality" (Carbon Direct, 2022). One reason for this is the gating criteria in carbon pools, allowing for low-quality credits to be standardized and sold to less knowledgeable buyers. If carbon pools enable users to exchange poor-quality credits such as from faulty carbon avoidance projects or old vintages, it can create demand for non-additive credits and promote greenwashing.

While the supply of faulty credits on the blockchain may come from individuals looking to game the system, the demand is likely coming from naive individuals. This is another potential issue with the implementation of blockchain technology. Navigating the carbon market is already difficult for the average company or person. Adding an additional layer of complexity via web3 can be even more problematic. Gilles Dufrasne, the policy officer for a watchdog NGO called Carbon Market Watch, bluntly described this new market saying, "It may be transparent,

but it's not accessible because nobody understands how it works apart from the fintech people" (Lo, 2022). Using a web3 wallet, bridging credits on-chain, exchanging credits in carbon pools, fractionalizing credits, and interacting with the DeFi ecosystem all require high tech literacy. Even those who are tech-savvy may struggle to understand these features. This can turn away various stakeholders from getting involved in the voluntary carbon market and have a negative effect on the overall system.

There are also general concerns about the web3 space as a whole. Given the youth of this technology, there is both regulatory and legal uncertainty that exists. Many governments are unsure about the blockchain and have yet to establish the proper frameworks to create regulation and legal clarity around its use. The anonymity of web3 is a contributing factor to this skepticism and another concern in the voluntary carbon market. At present, the registries require all account holders to undergo KYC verification, comply with anti-money laundering (AML) regulations, and agree to their "Terms of Use". There is concern that the anonymity of web3 can bypass these mandates. Failure to conduct these safeguards on holders of tokenized credits could provide an avenue for malicious actors to acquire these assets and heighten the risk of fraud.

There are other features enabled by the blockchain that could contribute to instability in the market. Given a protocol's ability to issue a native token, a lot of value is determined by the token's price. Many times, profits are based on the value of the token which, in the web3 ecosystem, can be very volatile (see Appendix L). If a protocol relies on the value of this token, a decrease in its price due to a market crash, speculation, or any other reason, can be detrimental to the platform and its impact on the carbon market.

It is also worth examining whether certain features need to be powered by the blockchain or if they can simply be carried out by traditional, centralized organizations. In Moss'

whitepaper, they state that the MCO2 token was purposely designed to be “primitive” and that the company is not trying to create a new market in primary or secondary trading or in fractional or whole trading because all of it exists already (“Moss Whitepaper”, n.d.). As the leading global spot trading platform for voluntary carbon credits, Carbon Trade eXchange (CTX) does have some comparable features that make it appealing. The platform is available 24/7 and claims to offer reports with live market pricing. There is also the Global Emissions Offset (GEO) future market, the first voluntary carbon market standardized contract launched by the Chicago Mercantile Exchange (CME Group) on Xpansiv market CBL. This platform commoditizes carbon credits and can be seen as a centralized equivalent of carbon pooling. Another example is U.C. Berkeley’s Voluntary Registry Offsets Database (VROD) which presents data on all carbon projects, credit issuances, and credit retirements listed globally by the four main registries.

It is also important to consider that some of the issues with the current voluntary carbon market may not be directly solved with the implementation of blockchain technology. Currently, 97% of all projects issuing credits over the past two years were reductions, not removals, which typically have few durable storage options and are more at risk of reversal (Carbon Direct, 2022). Additionally, while credit supply has been increasing, retirements fell in 2022 for the first time since 2016 (see Appendix M). And with the credits that are being retired, buyers are retiring older credits. The average age of retired credits rose to 7.3 years in 2022 compared to 6.1 years in 2021 and 5.3 years in 2020 (Carbon Direct, 2022).

History: Blockchain in the Voluntary Carbon Market

Considering the advantages, applications, and limitations listed above, it is important to understand how the space has played out to date. Beginning around 2017, blockchain carbon

innovations started to launch, and consequently, a few of the registries started to explore the blockchain's potential. In January of 2021, Regen Network sold the first natively blockchain-produced carbon credits to Microsoft, a convincing signal of demand for tokenized credits. In October of 2021, Toucan released BCT, one of the first bundled carbon tokens. By the end of the year, around 15 million carbon credits had been tokenized and deposited into the Base Carbon Pool (Khodai, 2022).

In April of 2022, CarbonPlan, a nonprofit organization that produces research on the data and science of carbon removal, released the *Zombies on the blockchain* article (Badgley & Cullenward, 2022). This report highlighted the artificial success of carbon credit tokenization and halted the momentum that was being driven by BCT tokens. The article explained that with the initial rollout of projects like Toucan, the crypto market assigned a greater value to carbon credits in tokenized form compared to their off-chain equivalents. This created an arbitrage opportunity that attracted a significant influx of credits to be bridged on-chain. However, the report claimed that most of the activity generated was for low-quality, neglected credits that had experienced little demand over recent years. CarbonPlan proved this claim through "projects like VCS191 that hadn't seen a single retirement prior to Toucan. Although this hydropower project started operating in 2006 in Yunnan, China, its first retirement on Verra's system occurred in late December 2021 as part of a bridge transaction to Toucan. Since then, Toucan-based transactions have retired over 2 million credits from the project" (Badgley & Cullenward, 2022). In response to this report, Toucan COO Robert Schmitt said, "The only reason CarbonPlan was able to do this analysis is because it's on-chain. They could never have done this in the traditional market" (Calma, 2022).

In May, Verra responded to CarbonPlan's groundbreaking report by issuing a statement that "Verra will, effective immediately, prohibit the practice of creating instruments or tokens based on retired credits" (Verra, 2022). Gold Standard, American Carbon Registry, and Climate Action Reserve also followed suit, releasing similar reports restricting the tokenization of their issued credits. While this was a stifling shift for blockchain innovation, "it also created an opportunity for the development of digitally native methodologies, registries and digital environmental assets" (Nesbitt, 2023). There was also some optimism within the blockchain carbon space as Verra, Gold Standard, and American Carbon Registry launched public consultations and working groups in the months following, showing that registries recognized the potential and demand generated by the blockchain's implementation.

In December of 2022, the World Bank's Climate Warehouse program, the Government of Singapore, and the International Emissions Trading Association (IETA) developed the Climate Action Data Trust (CAD Trust), a blockchain-powered platform that aggregates and synchronizes carbon credit data from all major registries; this was an exciting announcement for the space given the commitment of governmental entities to leverage the blockchain.

In January of 2023, Verra published its public consultation and is currently finalizing its approach. In February, Carbonplace, a blockchain-based carbon marketplace that was formed by a group of banks, raised $45M from nine leading global banks ("Carbonplace Announces", 2023). This was an indication that banks prefer their clients to transact carbon credits on a more secure system, and was a market signal of corporate demand.

In March of 2023, Gold Standard used the information collected from their public consultation and working groups to initiate a readiness phase. Consulting with five blockchain

carbon companies including Toucan, Flowcarbon, Thallo, Earthchain, and Bitgreen, the registry has plans to issue tokenized carbon credits for the first time in May of 2023 (Velev, 2023).

Recommendation

After examining all the information presented through an objective lens, it is evident that the voluntary carbon market can make the greatest environmental impact by adopting a comprehensive strategy that includes several different approaches. These approaches include digitizing the system through dMRV, fostering collaboration among legacy registries and blockchain carbon companies, and promoting continuous education and regulatory reform. By taking this multi-faceted approach, the voluntary carbon market can be strengthened and improved to make a meaningful contribution towards reducing carbon emissions and mitigating the impacts of climate change.

While the blockchain offers significant value to the voluntary carbon market, the latest dMRV developments must also be incorporated to ensure maximum growth in the VCM. While this does take time, costs money, and differs based on the project, the long term value outweighs these concerns. By integrating the most advanced dMRV technology and connecting them to the blockchain, the system will benefit from improved data collection and quality. This will help speed up methodology quantification and streamline the verification process, making the system more connected, efficient, and cost-effective. It is expected that the implementation of this approach will enhance the quality of the carbon credits that are issued, thus reducing the prevalence of low-quality credits brought on-chain.

Moreover, it is recommended that blockchain carbon companies adopt a collaborative approach with existing registries and support their evolution instead of creating entirely new

systems from scratch. Given that current registries have existed for decades, they have established a governance process and reputation that many stakeholders have come to trust. By working in conjunction with web3 companies, registries can reap the benefits provided from the blockchain while maintaining credibility. This harmonization will help drive innovation and foster a seamless transition towards a more efficient and effective carbon market.

While collaboration between registries and blockchain carbon companies is essential, there are some fundamental aspects that both parties must agree upon and uphold. It is imperative that the companies bridging credits on-chain prioritize security and conduct regular audits to identify and address any vulnerabilities in smart contracts. Additionally, for users to join these platforms and interact with tokenized carbon credits, companies should mandate that customers go through KYC and AML to prevent bad actors from disrupting the market. This will ensure that credits can be tokenized at scale with the appropriate safeguards to ensure market integrity, regulatory compliance, and consumer protection.

Additionally, the data traced and made available to stakeholders via blockchain's digital ledger needs to be detailed yet standardized, organized into a human-readable format, and crafted with a non-technical interface. It is critical that the web3 space continues to increase its user interface and experience. In order for this technology to be adopted and used by the masses, it needs to function seamlessly enough that users can benefit from its capabilities without knowing that the blockchain is powering the backend.

Despite an enhanced user interface serving as a partial solution, it should be noted that the use of crypto involves a steep learning curve. Therefore, there is a pressing need for education and regulatory reform in both the web3 space and the voluntary carbon market. Considering that the carbon market has existed for nearly two decades, it is recommended that

stakeholders rely on experienced working groups to further its development. A few groups working to improve the VCM include the Voluntary Carbon Markets Integrity Initiative (VCMI), the Taskforce on Scaling Voluntary Carbon Markets (TSVCM), and the Integrity Council for Voluntary Carbon Markets (ICVCM), among a host of others. On the web3 side, groups like the Crypto Sustainability Coalition, the Climate Collective, and the Crypto Impact & Sustainability Accelerator (CISA) will also be critical in bridging the educational and technological gaps.

In addition, it is imperative that stricter regulations and oversight mechanisms are continually assessed and implemented by government bodies. This is exemplified by Article 6 of the Paris Agreement and the guidelines established by CORSIA, which both serve to enforce the inclusion of high-quality credits in the carbon market. Providing comprehensive education and establishing supportive regulation can help minimize the difficulties associated with implementing the blockchain while facilitating the growth of the VCM in a safe manner.

Lastly, although certain modern centralized applications may be useful in addressing some of the present challenges, it is clear that they do not offer the same comprehensive benefits as applications built on the blockchain. For example, joining the Carbon Trade eXchange is a tedious process and comes with high membership fees and restrictions in the types of credits and payment options. The GEO futures market utilizes an antiquated application process and restricts non-wholesale clients from joining. VROD's database, on the other hand, is simply a downloadable Excel sheet with outdated data that is updated to a new file version every few months.

While there will undoubtedly be challenges and limitations with the voluntary carbon market moving forward, a multifaceted strategy is essential to maximize its environmental impact. Incorporating advanced technology for dMRV, promoting collaboration among existing

carbon registries and blockchain companies, and prioritizing continuous education and regulatory reforms are all vital components of this approach.

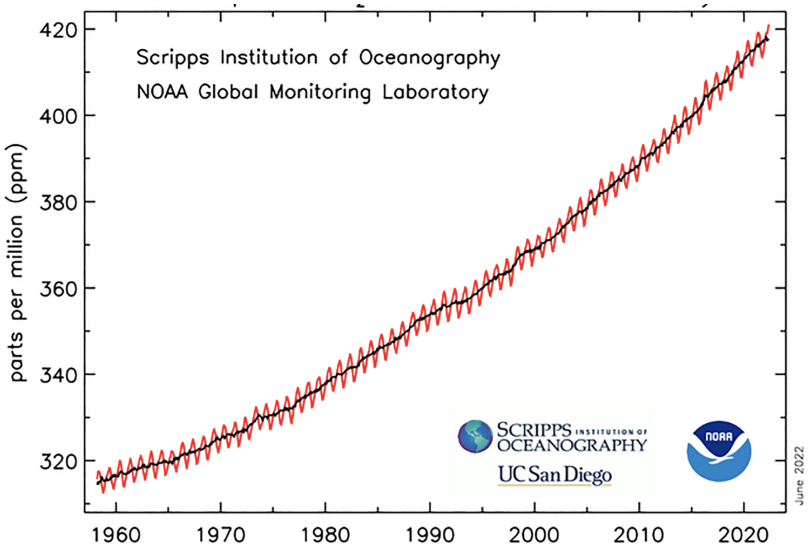
Conclusion

In conclusion, the blockchain's integration into the voluntary carbon market provides a promising avenue to enhance ReFi and amplify the VCM's impact on the environment. By leveraging blockchain's unique features such as immutability, interoperability, and traceability, we can create a more trusted, connected, and transparent VCM that aligns economic incentives with activities that support regeneration. However, it is essential to acknowledge that the voluntary carbon market is only one part of a larger movement to fight climate change. We must continue to explore and implement innovative solutions, while also addressing systemic issues such as overconsumption and environmental degradation. By working together and committing to a sustainable future, we can create a world where economic prosperity and environmental sustainability go hand in hand.

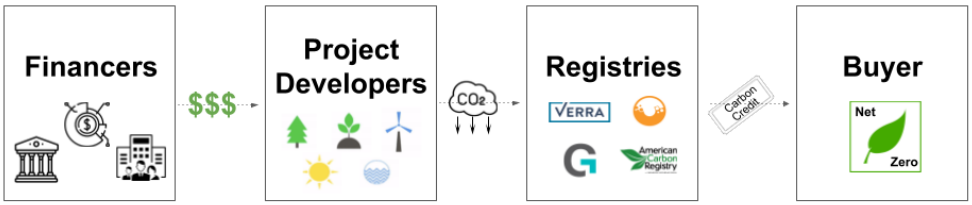
Stopping climate change is crucial to ensure a sustainable future for our planet and all the people, animals, and living organisms that inhabit it. The consequences of inaction are dire, and we are already seeing the effects of climate change today, including rising sea levels, more frequent and intense natural disasters, and irreversible damage to ecosystems. If we continue on this path, we risk catastrophic consequences that will impact not only our generation but generations to come. This requires a global collective effort from all sectors, including governments, businesses, and individuals, to implement innovative solutions and reduce our carbon footprint. Ultimately, the goal is not only to stop climate change but also to create a world that is more resilient, equitable, and prosperous for all.

Appendix:

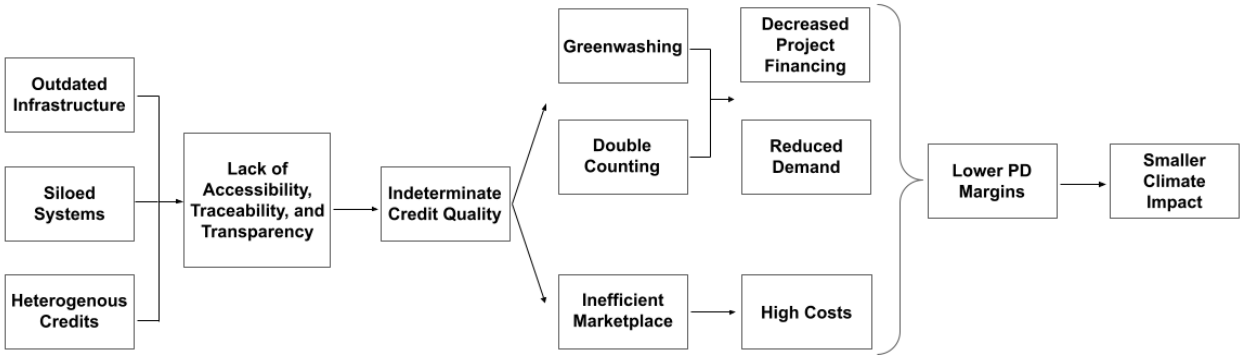
Appendix A: Atmospheric CO_2 by Year



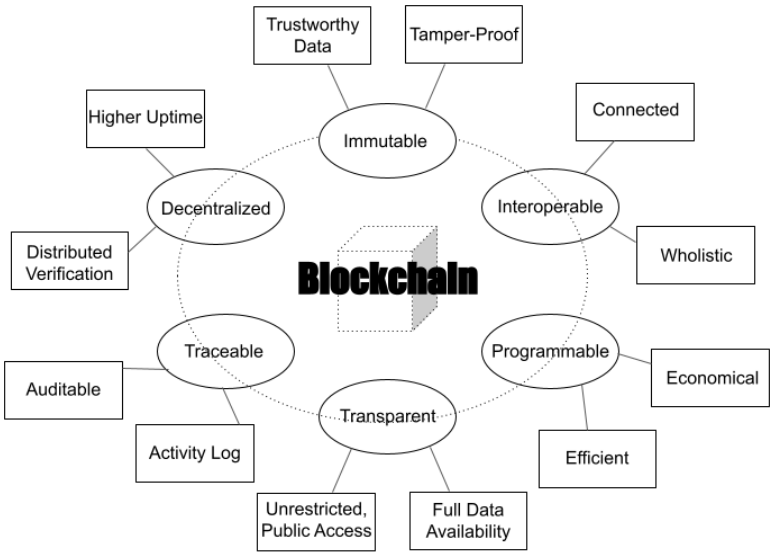
Appendix B: Voluntary Carbon Market - Carbon Credit Lifecycle



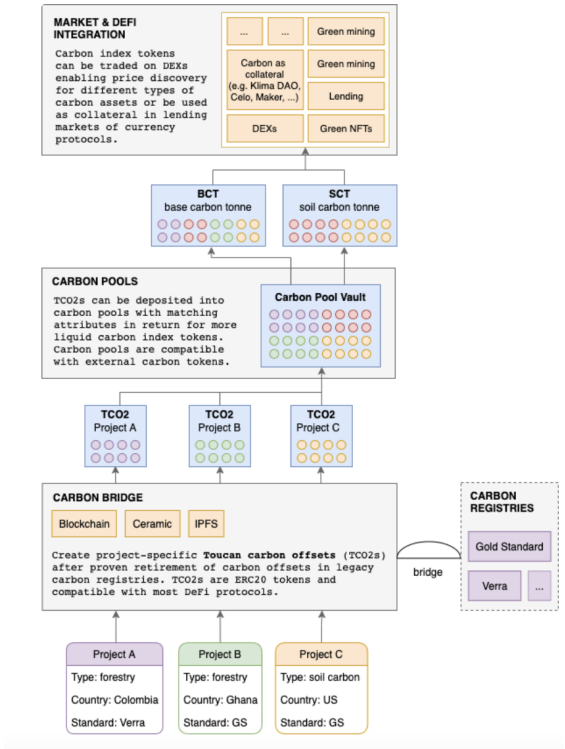
Appendix C: Issues with the Voluntary Carbon Market



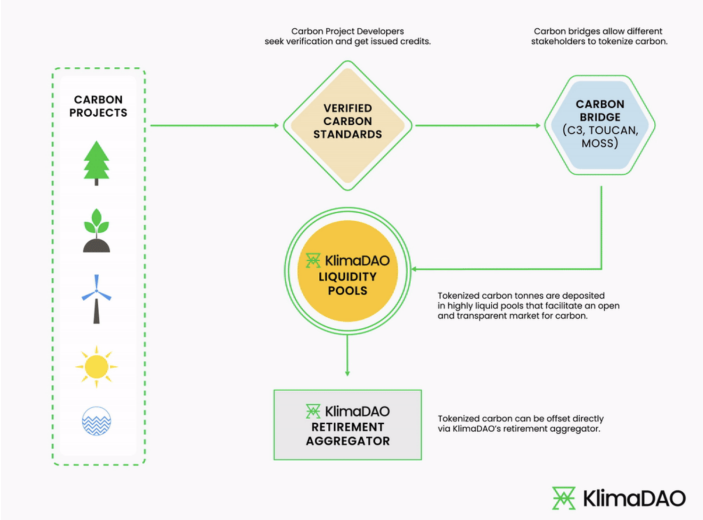
Appendix D: Blockchain Key Properties



Appendix E: Toucan Digital Asset Creation



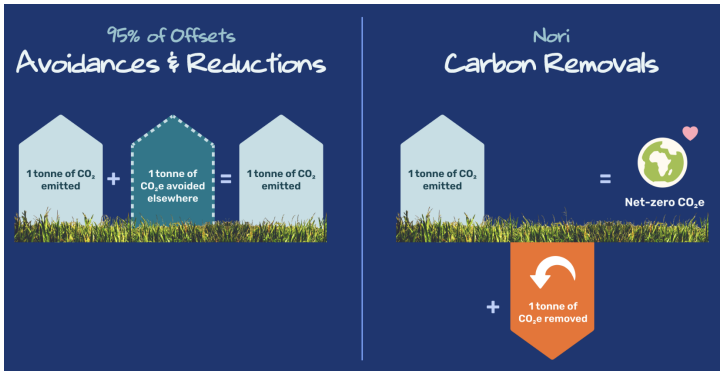
Appendix F: KlimaDAO Digital Asset Creation



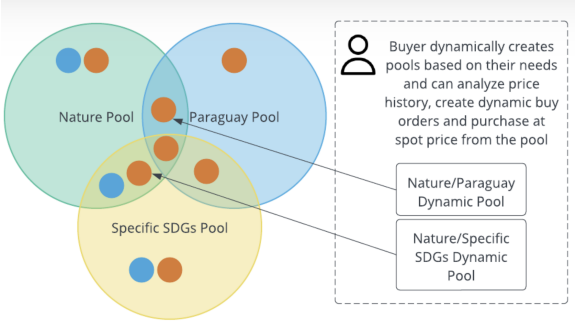
Appendix G: Open Forest Protocol Validation Process

Figure 1: OFP's validation process

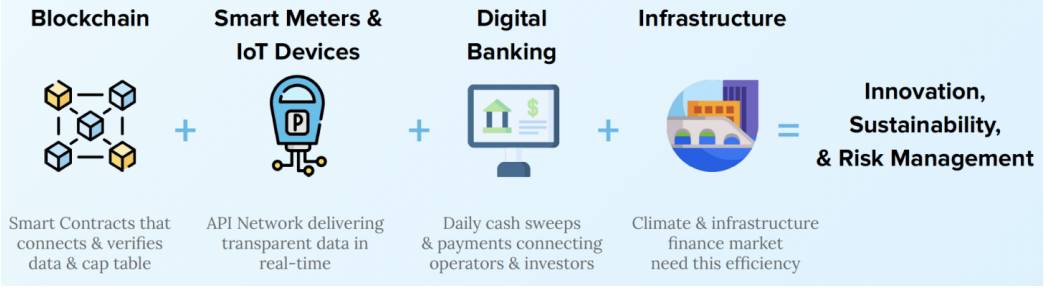
Appendix H: Carbon Avoidance & Reduction vs Carbon Removal



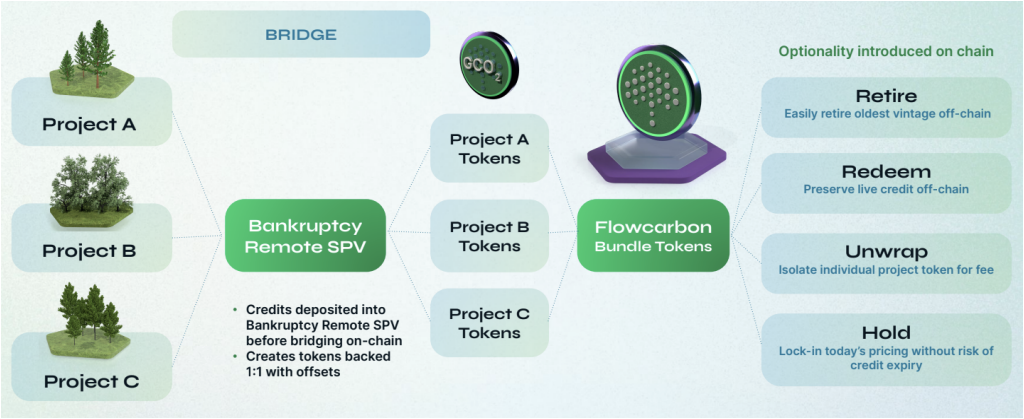
Appendix I: Thallo's Dynamic Pooling



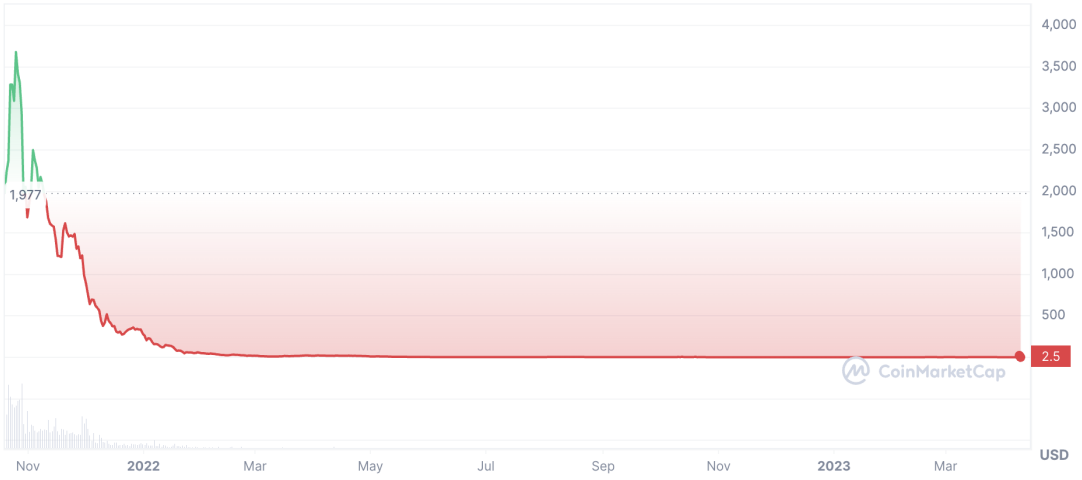
Appendix J: Blockchain Triangle Digital Asset Creation



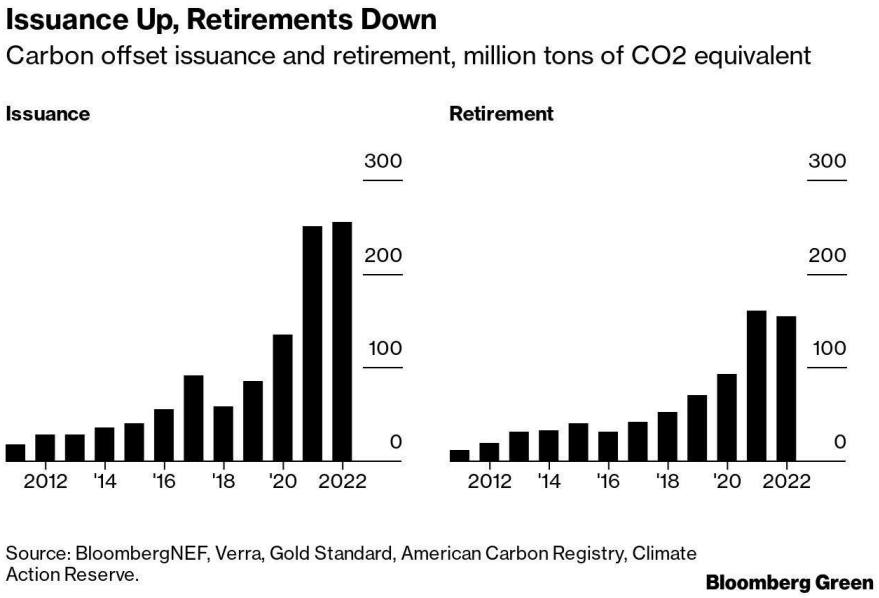
Appendix K: Flowcarbon Digital Asset Creation



Appendix L: KLIMA All-Time Token Price



Appendix M: Carbon Issuance vs Retirement



References

A blockchain-based marketplace for removing carbon dioxide. Nori. (2019, February 18). Retrieved April 17, 2023, from https://nori.com/resources/white-paperf

Badgley, G., & Cullenward, D. (2022, April 7). *Zombies on the blockchain*. CarbonPlan. Retrieved April 21, 2023, from https://carbonplan.org/research/toucan-crypto-offsets

Blaufelder, C., Levy, C., Mannion, P., & Pinner, D. (2021, January 29). *A blueprint for scaling voluntary carbon markets to meet the Climate Challenge*. McKinsey & Company. Retrieved December 8, 2022, from https://www.mckinsey.com/capabilities/sustainability/our-insights/a-blueprint-for-scaling-voluntary-carbon-markets-to-meet-the-climate-challenge

Calma, J. (2022, August 18). *Crypto can't fix carbon offsets - but crypto fans are trying anyway*. The Verge. Retrieved April 21, 2023, from https://www.theverge.com/2022/8/18/23310254/carbon-offset-credits-crypto-tokens-adam-neumann-wework

Carbonplace Announces New CEO; Secures USD 45 Million in Funding . Cision PR Newsletter. (2023, February 8). Retrieved April 21, 2023, from https://www.prnewswire.com/news-releases/carbonplace-announces-new-ceo-secures-usd-45-million-in-funding-301741174.html

Chainlink 2.0: Next steps in the Evolution of Decentralized Oracle Networks. Chainlink Labs. (2021). Retrieved April 21, 2023, from https://research.chain.link/whitepaper-v2.pdf?%5C_ga=2.193233451.740500264.1661436925-2037660992.1657727189

Climate change and health. World Health Organization. (2021, October 30). Retrieved April 12, 2023, from https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health

Climate change: A threat to human wellbeing and health of the planet. Taking action now can secure our future. Intergovernmental Panel on Climate Change. (2022, February 28). Retrieved April 12, 2023, from https://www.ipcc.ch/2022/02/28/pr-wgii-ar6/

Ethereum Foundation. (2022, December 2). *Ethereum Energy Consumption*. Retrieved December 8, 2022, from https://ethereum.org/en/energy-consumption/

Five Need-to-Knows About the Future of Voluntary Carbon Offset Markets. BloombergNEF. (2023, January 26). Retrieved April 21, 2023, from https://about.bnef.com/blog/five-need-to-knows-about-the-future-of-voluntary-carbon-offset-markets/

Flowcarbon Docs. Flowcarbon. (n.d.). Retrieved April 21, 2023, from https://docs.flowcarbon.com/introduction/context

Flowcarbon Lite Paper. Flowcarbon. (n.d.). Retrieved April 21, 2023, from https://docs.google.com/viewerng/viewer?url=https%3A%2F%2Fuploads-ssl.webflow.com%2F625db0bad5cfd681bd654bd8%2F634ef8738e897575871e586d_Flowcarbon%2520Lite%2520Paper%252010.22.pdf

Global atmospheric carbon dioxide levels continue to rise. National Oceanic and Atmospheric Administration. (2022, November 15). Retrieved April 21, 2023, from https://research.noaa.gov/article/ArtMID/587/ArticleID/2914/No-sign-of-significant-decrease-in-global-CO2-emissions#:~:text=The%20publication%2C%20produced%20by%20an,percent%20above%20pre%2Dindustrial%20levels.

Global warming and endangered species initiative. Center for Biological Diversity. (n.d.). Retrieved April 12, 2023, from https://www.biologicaldiversity.org/campaigns/global_warming_and_endangered_species/index.html#:~:text=Global%20warming%20is%20projected%20to,human%20societies%20across%20the%20globe.

Greenfield, P. (2023, January 18). *Revealed: More than 90% of rainforest carbon offsets by biggest certifier are worthless, analysis shows*. The Guardian. Retrieved April 21, 2023, from https://www.theguardian.com/environment/2023/jan/18/revealed-forest-carbon-offsets-biggest-provider-worthless-verra-aoe

Introducing Carbon Pools. Toucan. (n.d.). Retrieved April 21, 2023, from https://docs.toucan.earth/toucan/pool/pools

Introducing KlimDAO. KlimaDAO. (n.d.). Retrieved April 21, 2023, from https://docs.klimadao.finance/

IPCC 2021, *Climate Change 2021: The Physical Science Basis, the Working Group I contribution to the Sixth Assessment Report*, Cambridge University Press, Cambridge, UK.

Khodai, E. (2022, January 4). *Base carbon tonne (BCT): A new web3 Building Block*. Toucan Protocol. Retrieved April 21, 2023, from https://blog.toucan.earth/base-carbon-tonne-bct-a-new-web3-building-block/

Lindsey, R. (2022, June 23). *Climate change: Atmospheric Carbon Dioxide*. National Oceanic and Atmospheric Administration. Retrieved April 21, 2023, from https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide#:~:text=June%2023%2C%202022-,Highlights,2021%3A%20414.72%20parts%20per%20million.

Lo, J. (2022, August 19). *World Bank backs carbon credit blockchain registry to attract crypto investors*. Climate Home News. Retrieved April 21, 2023, from https://www.climatechangenews.com/2022/08/19/world-bank-launches-carbon-credit-blockchain-registry-to-attract-crypto-investors/

Macfarlane, M. (2022, May 6). *Assessing the State of the Voluntary Carbon Market in 2022*. Carbon Direct. Retrieved April 21, 2023, from https://www.carbon-direct.com/insights/assessing-the-state-of-the-voluntary-carbon-market-in-2022#footnoteList2

Moss. (n.d.). Moss White Paper.

Nakamoto, S. (2008). *A peer-to-peer electronic cash system*. Bitcoin. Retrieved April 21, 2023, from https://bitcoin.org/en/bitcoin-paper

Neelakanti, N. (2022, August 23). *Regenerative finance 101: A guide to crypto's refi movement*. CoinCentral. Retrieved April 21, 2023, from https://coincentral.com/regenerative-finance-101/

Nesbitt, A. L. (2023, March 9). LinkedIn. Retrieved April 21, 2023, from https://www.linkedin.com/posts/anna-lerner-nesbitt-0569111_blockchain-vcm-carbonmarkets-activity-7039633025994752000--70Z?utm_source=share&utm_medium=member_desktop

Nori Litepaper. Nori. (n.d.). Retrieved April 21, 2023, from https://nori.com/litepaper

Nori Whitepaper- The Path to Reversing Climate Change with Carbon Removal and Blockchain. Nori. (n.d.). Retrieved April 21, 2023, from https://nori.com/whitepaper

Open Forest Protocol Whitepaper. Open Forest Protocol. (2023, January). Retrieved April 21, 2023, from https://static1.squarespace.com/static/606cb05a7a012f3e0371e0a4/t/63c5157c1aa905392bdf6ba0/1673860510286/2023-01_OpenForestProtocol_WhitePaper.pdf

Public Consultation Draft White Paper on Digitising Verification For Climate Markets. Gold Standard. (2023, January 20). Retrieved April 21, 2023, from https://www.goldstandard.org/sites/default/files/public_consultation_draft_white_paper_for_digitising_verification.pdf

Recommendations for the Digital Voluntary and Regulated Carbon Markets. World Economic Forum. (2023). Retrieved April 21, 2023, from https://www.weforum.org/whitepapers/recommendations-for-the-digital-voluntary-and-regulated-carbon-markets

Regen Network Whitepaper. Regen Network. (2021). Retrieved April 21, 2023, from https://regen-network.gitlab.io/whitepaper/WhitePaper.pdf

Shaftel, H. (2022, November 8). *The Effects of Climate Change*. NASA. Retrieved November 10, 2022, from https://climate.nasa.gov/effects/

Springer Nature. (2009, November 19). *Measuring the Daily Destruction of the World's Rainforests*. Scientific American. Retrieved November 30, 2022, from

https://www.scientificamerican.com/article/earth-talks-daily-destruction/#:~:text=Pinning%20down%20exact%20numbers%20is,day%20on%20top%20of%20that.

Stevens, R. (2022, November 11). *What is Tokenomics and Why Is It Important?* CoinDesk. Retrieved April 21, 2023, from https://www.coindesk.com/learn/what-is-tokenomics-and-why-is-it-important/

Thallo Two-Way Carbon Bridge - Litepaper. Thallo. (n.d.). Retrieved April 21, 2023, from https://docs.thallo.io/

The EM Insights Team. (2022, August 3). *VCM reaches towards $2 billion in 2021: New Market Analysis published from Ecosystem Marketplace*. Ecosystem Marketplace. Retrieved December 8, 2022, from https://www.ecosystemmarketplace.com/articles/the-art-of-integrity-state-of-the-voluntary-carbon-markets-q3-2022/

Tiseo, I. (2023, February 6). Annual carbon dioxide (CO_2) emissions worldwide from 1940 to 2021. Statista. Retrieved April 12, 2023, from https://www.statista.com/statistics/276629/global-co2-emissions/

United Nations Climate Change. (n.d.). *The Paris Agreement*. Unfccc.int. Retrieved November 10, 2022, from https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement#:~:text=Its%20goal%20is%20to%20limit,neutral%20world%20by%20mid%2Dcentury.

United Nations Climate Change. (2022, October 26). *Climate Plans Remain Insufficient: More Ambitious Action Needed Now*. Unfccc.int. Retrieved November 10, 2022, from https://unfccc.int/news/climate-plans-remain-insufficient-more-ambitious-action-needed-now

United Nations Framework Convention on Climate Change. (n.d.). *CDM project cycle*. Clean Development Mechanism. Retrieved December 8, 2022, from https://cdm.unfccc.int/Projects/diagram.html

Velev, V. (2023, March 2). *Gold Standard Set To Issue Tokenized Carbon Credits In May*. Carbon Herald. Retrieved April 21, 2023, from https://carbonherald.com/gold-standard-set-to-issue-tokenized-carbon-credits-in-may/

Verra Addresses Crypto Instruments and Tokens. Verra. (2022, March 25). Retrieved April 21, 2023, from https://verra.org/verra-addresses-crypto-instruments-and-tokens/

Wolfberg, D., & Adriaens, P. (2021, November 4). *Blockchain Triangle Whitepaper*. Blockchain Triangle.

World Bank Group. (2022, July 21). *COVID-19 Boosted the Adoption of Digital Financial Services*. World Bank Group. Retrieved April 21, 2023, from

https://www.worldbank.org/en/news/feature/2022/07/21/covid-19-boosted-the-adoption-of-digital-financial-services#:~:text=Globally%2C%20some%201.4%20billion%20adults,go%2C%20much%20more%20is%20needed.

Yin, I. (2022, November 17). *Interview: Voluntary Carbon Market Trade Volume May Grow On Year in 2022 despite headwinds, says CBL.* S&P Global Commodity Insights. Retrieved April 21, 2023, from https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/energy-transition/111722-interview-voluntary-carbon-market-trade-volume-may-grow-on-year-in-2022-despite-headwinds-says-cbl

2022 Biggest Year Ever For Crypto Hacking with $3.8 Billion Stolen, Primarily from DeFi Protocols and by North Korea-linked Attackers. Chainalysis. (2023, February 1). Retrieved April 21, 2023, from https://blog.chainalysis.com/reports/2022-biggest-year-ever-for-crypto-hacking/

2022 Commentary on the Voluntary Registry Offsets Database (VROD). Carbon Direct. (2022). Retrieved April 21, 2023, from https://d13en5kcqwfled.cloudfront.net/files/Commentary-on-the-Voluntary-Registry-Offsets-Database-VROD-2022.pdf