Tokenized Carbon Credits

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Abstract

A blockchain turns out to a be natural place to tokenize, trade, and retire voluntary carbon credits. However, tokenized carbon credits are a fractured body of tokens on the blockchain, which hampers some key goals of the industry. Our aim here is to give a detailed exposition of the current state tokenized carbon credits and their surrounding blockchain-based ecosystem, with the goal of clarifying current impediments to token interoperability and trading on-chain with high liquidity.

1 Introduction

A blockchain turns out to a be natural place to tokenize, trade, and retire carbon credits, as recognized by the UN[32], the World Bank[40], the World Economic Forum [44], and others[54, 42, 56, 41, 46, 50]. They offer several advantages to legacy systems, including transparency, traceability, verifiability, and censorship resistance, which lend themselves to robust accounting practices and which can help prevent double counting carbon credits[40, 42]. However, tokenized carbon credits are a fractured body of tokens on-chain, in that they abide by a variety of token standards, feature different metadata formats, and often make distinct judgments on the kind of carbon credits that are acceptable[49]. This hampers token interoperability[42, 49] and on-chain trading with high liquidity[39], both of which are judged to be desirable properties[40, 39, 49].

To address this issue, our aim here is to give a detailed exposition of the current state of tokenized carbon credits to support current efforts in creating standards for the same[14, 7], and to promote interoperability between tokenized carbon credits more broadly, *e.g.* to enable on-chain trading with high liquidity. We operate on the thesis that a reference document containing technical details of tokenized carbon credits can be useful to address the problems due to these tokens being fractured. Thus our purpose is to evaluate tokenized carbon credits from a technical, instead of an economic or climate, perspective, elucidating the foundational mechanics and plumbing underpinning these credits, with an aim of clarifying what it means for them to be interoperable.

1.1 Scope

There are almost too many carbon credit related projects on various blockchains to count. For this survey, we chose to focus on some of the most prominent and highest market cap projects, trying to include projects from as many blockchains as possible, with the aim of giving a series of useful case studies that illuminate the key issues and technical barriers to broad interoperability both of token standards and for low-friction trade. We are fully focused on the nature of the infrastructure underpinning tokenized carbon credits, and thus will not make value judgments on the various methodologies, which quantify carbon capture, and which back tokenized carbon credits, nor on the reputation or reliability of any particular producer of tokenized carbon credits.

We also note that central to the climate debate as it relates to blockchains is the energy expenditure of large proof-of-work chains such as Bitcoin [2, 57]. This included Ethereum up until the so-called *Merge* in September 2022[22]. Since the Merge, all the projects discussed here operate on proof-of-stake chains, which consume negligible amounts of electricity to secure the blockchain[38]. Thus here we will not treat the energy expenditure of blockchains.

1.2 Related Work

Previous work on tokenized carbon credits treats it in the context of so-called *Regenerative Finance* (ReFi), a subset of Decentralized Finance (DeFi) primarily concerned with climate change mitigation through digital financial assets of various kinds[33, 39]. ReFi, taken as a whole, consists of a wide range of applications which can be scrutinized and studied from a variety of disciplines, including business[43], law,[46, 39] economics[48, 47], and (of course) computer science. These include the solutions in the energy industry[35], relating to the transition into sustainable energy[48] and maximizing the efficiency of current grids by allowing for peer-to-peer energy trading[58]; solutions for measurement, reporting, and verification (MRV)[59]; sustainable supply chains [51, 53]; and others. Previous work on tokenized carbon credits includes climate market design[54, 40, 36] and broad surveys of ReFi treating various of its aspects such as the applications[42], organizations and initiatives[43], its impact and efficacy[56, 55, 52], possible fintech applications[41], and from the perspective of legacy voluntary carbon markets[49]. There has also been work in the grey literature on bridging voluntary carbon markets onto blockchains[37], but this approaches the issue from a less technical and more market-driven approach than what we give here.

A salient theme from previous work is that interoperability and trading with high liquidity is an explicit goal of governments, agencies, and researchers writing about blockchain-based carbon markets. As we will see, for producers of tokenized carbon credits this is also an explicit and central goal. Part of the issue is that tokenized carbon credits are expected to behave like commodities[54, 40], and therefore be fully fungible on-chain as an asset class. However, each credit has its own distinct, granular data which makes it difficult to do so in practice. Despite this, there has not yet been an exposition of the technical details of carbon credits with the aim of supporting interoperability, mutual fungibility, and unified token standards. It is our view that the research presented here could be useful in unifying a fractured marketplace and achieve the goals of the industry.

1.3 Outline

Our first priority (§2) is to survey some key examples of tokenized carbon credits, understanding methodologies used to back them, how they are tokenized, and understanding the characteristics of the token contracts, including their fungibility status. We also look briefly at projects which don't tokenize carbon credits explicitly, but do things adjacent to it. We will then look at some key auxiliary components of tokenized carbon credits relevant to their interoperability, looking first at methods to trade tokenized carbon credits (§3) via various decentralized and automated mechanisms; then at blockchain-based applications built on top of carbon credits (§4); and finally at climate data availability (§5), which is highly relevant to the carbon credit tokenization process. We finish by looking at different organizations and collectives which aim to promote the usage of blockchains for carbon trading, some of whom are attempting to make standards for tokenized carbon credits (§6). Our aim is to provide an accurate, concise, and useful reference document to the technical plumbing of tokenized carbon credits as they stand at the time of writing; we conclude (§7) with our insights into standards that could address interoperability issues that we see today.

2 Tokenized Carbon Credits

Tokenized carbon credits vary in the wild in at least two ways: in what justifies their value and in the implementation details of the token contract. The first relates to interoperability from a qualitative perspective. Tokens that, roughly speaking, represent equivalent things are easier to interoperate than tokens which represent distinct things—and even if they are distinct qualitatively, if we can compare them easily they may also be easily interoperable. The second relates to interoperability from a more technical and engineering perspective. A token's fungibility status, metadata, and entrypoints—and how well they conform to established standards—may affect how easy or difficult it is to write applications for these tokenized carbon credits technically. Because our goal is to study tokenized carbon credits as it relates to issues of interoperability, we will write about tokenized carbon credits in these broad categories: first, in what justifies their value (*i.e.* in what is backing them as a legitimate carbon credit), and second, in the implementation details of their token contracts. Let us elaborate slightly on each of these categories.

First, tokenized carbon credits must be substantiated in some way as airborn carbon dioxide rigorously captured and stored, or something similar to it (*e.g.* avoided emissions). This requires a methodology, of data collection and processing, to accurately quantify the amount of carbon stored. As with any discipline, such methodologies can vary in nature, rigor, and reliability. Some tokenized carbon credits draw on established methodologies, as they are backed by carbon credits on legacy ledgers. Others are minted natively on the blockchain, using new methodologies, often based on machine learning on satellite data. In either case we encounter the problem of tokenization, which is how one accurately represents some off-chain asset or data on the blockchain, in such a way that transactions on the blockchain correctly govern any corresponding real-world asset or event. More subtly, every producer of tokenized carbon credits makes a choice on criteria for acceptable carbon credits. For tokenized carbon credits backed by a legacy-ledger carbon credit, criteria have to be set for which carbon credits from the legacy ledger are allowed to be tokenized. The most common guards relate to vintage, *e.g.* that credits must be less than ten years old, or relate to a class of carbon credit, *e.g.* restricting to nature-based credits or requiring that credits be from carbon sequestration rather than prevented deforestation. The reason for these choices can vary greatly, from a value judgment on the quality of some credits, to the specific ethos and goals of a particular team. For tokenized carbon credits which employ their own methodology to verify captured carbon and mint credits, the methodology itself makes a judgment on what constitutes rigorous carbon capture, and thus a carbon credit, and what does not. These are specific details we'll look at as it relates to what substantiates a tokenized carbon credit, though we reiterate that we are not in a position to make value judgments on one methodology over another.

Secondly, tokenized carbon credits differ in their implementation details, in particular in their token contracts and their characteristics. To our knowledge, tokenized carbon credits all conform to token standards typical for the blockchain on which they are deployed. For Ethereum, these are the ERC20 and ERC721 standards, and for Binance, these are the BEP20 and BEP721 standards for, respectively, fungible and non-fungible tokens. Standards for fungible and non-fungible tokens tend to be highly compatible, though not exactly the same. For example, tokens on separate blockchains will require bridging, and are secured by distinct consensus algorithms. However, these technical differences are not insurmountable. Setting standards aside, tokenized carbon credits differ in several other ways, including the degree to which they are fungible, where some are natively fungible, while others are NFTs which can be fractionalized or traded for a fungible token. Those that are NFTs are non-fungible because they contain granular data on the carbon credit or carbon project backing it in their metadata. Finally, tokens can differ in how much carbon one token represents, *e.g.* 1 ton per token. These are the sorts of technical details which we are interested in as it relates to the implementation details of a carbon credit.

With this broad framework in mind, we will consider several tokenized carbon credits which are currently live on various blockchains, highlighting their features as it relates to these two categories of variability. We will start with carbon credits which are backed by credits on a legacy ledger, moving afterward to those which mint tokens natively on-chain backed by their own methodologies. For each of these tokens, we follow their technical structure starting with the ledger or methodologies that back the tokens, how they are bridged or minted onto the blockchain, and then moving to the token type and how they address issues of fungibility and liquidity.

2.1 Toucan

Toucan[31] tokenizes Verra credits onto Polygon via their *Carbon Bridge*. Anyone who owns a Verra credit can use the Carbon Bridge, subject to two criteria: the backing methodology of the Verra credit must not be on their blocklist, and the credit's *vintage* (the difference between the date of verification and the date of issuance) must not exceed ten years. The blocklist currently only has one methodology, AM0001, which relates to refrigerant manufacturing, and which Verra stopped producing in 2014[20]. The bridging process is elaborate, one-way, and non-custodial. To bridge, users create a BatchNFT token contract into which the credits can be bridged. They then retire the credits on Verra with specific information about their NFT contract, and then update their contract with the Verra serial number. Users then await approval from Toucan, where Toucan checks that the token contract and retirement on Verra align. If approved, Toucan mints the carbon credits into the NFT contract.

Once bridged, the NFT can be fractionalized using a token contract from Toucan's TCO2 class of ERC20 (fungible) token contracts. Each TCO2 token contract faithfully preserves the metadata of the NFT it fractionalizes, so distinct TCO2 contracts are not mutually fungible. However, the Toucan team has the explicit goal of enabling on-chain trading with high liquidity (as we have mentioned), so they have a pooling mechanism which acts as a fungibility layer on top of the TCO2 contracts. Each pool allows users to deposit TCO2 tokens in exchange for a fungible pool token which is backed by other TCO2 tokens that meet the pool's acceptance criteria. At the time of writing there are two pools, BCT (Base Carbon Tonne) and NCT (Nature Carbon Tonne), each of which has a list of approved methodologies of Verra credits which are allowed in the pool. BCT and NCT tokens can also be bridged from Polygon onto Celo.

2.2 Flowcarbon

Flowcarbon[13] tokenizes carbon credits from recognized, non-profit registries onto Celo. They handle the entire tokenization process themselves, at the request of a user. Someone wishing to tokenize a carbon credit submits a request, after which the credits are transferred to and held custodially with a bankruptcy remote special purpose vehicle (SPV). Flowcarbon then mints a token for the user. The credits remain on the registry *unretired*, which means that tokenization is a two-way bridge: tokenized credits can be redeemed for their underlying credits.

Tokens are minted using Flowcarbon's GCO2 class of ERC20 tokens, including in the metadata the relevatnt details to the underlying credits that were tokenized. These are similar to Toucan's TCO2 family of tokens, except that GCO2 tokens don't fractionalize an NFT. Flowcarbon has a fungibility layer similar to Toucan's, where their pooling token is a *bundle token*, each bundle has its own acceptance criteria, and bundle tokens are backed one-for-one by GCO2 tokens. At the time of writing, there is one active bundle, the Goddess Nature Token (GNT), whose acceptance criteria are that a carbon credit have a nature-based methodology and a five year vintage period.

2.3 MOSS

MOSS[21] tokenizes legacy-ledger carbon credits into its fungible MCO2 token on Ethereum. The MCO2 token is backed one-for-one by carbon credits which, in contrast to Toucan and Flowcarbon, are chosen from globally recognized registries at the discretion of the MOSS team. The tokenization process, then, is very simple and done by the MOSS team, where they issue tokens for credits that they have in custody. Furthermore, as the user does not participate in the tokenization process, any criteria or guards on which credits are acceptable for MCO2 are made and enforced by the MOSS team. Similar to Flowcarbon, MCO2 tokens represent ownership of an *unretired* carbon credit, held custodially by MOSS. The MCO2 token is also a fungible ERC20 token, where one MCO2 token represents a carbon credit for one ton of prevented CO2 emissions. Since it is backed by a variety of credits, the MCO2 token is similar in kind to Toucan's BCT and NCT tokens (resp. Flowcarbon's GNT token), rather than the more granular TCO2 tokens or NFTs (resp. the GCO2 tokens).

2.4 Carbovalent

Carbovalent[3], built on Solana, uses a public bridge with a similar tokenization process to Toucan's, allowing users to tokenize legacy-ledger credits. Interestingly, in contrast to the projects we've seen, Carbovalent does not address the liquidity issue through fungibility, but rather it uses an order book model to trade assets, rather than an automated market maker (AMM).

2.5 Regen Network

Regen network is a blockchain built for climate data and carbon credits, built with the Cosmos SDK, whose native token is the REGEN token. They mint NCT tokens (of the same standard as the Toucan NCT tokens) as fungible tokens, and have partnered with Toucan to bridge between the Regen Network and Polygon.

2.6 Nori

Nori[27] substantiates their own carbon credits, issuing carbon credits to projects which can prove that they have captured carbon and have agreed contractually to store it for at least ten years. An independent third party verifies the project, and the credits issued by Nori are called Nori Carbon Removal Tonnes (NRTs). These are somewhat similar in kind to the GCO2 and TCO2 token families, where each NRT represents a verified claim that one ton of CO2 has been removed from the atmosphere, along with a contractual commitment that the removed carbon be sequestered for at least ten years.

NRTs are retired immediately on the point of sale, so they cannot be traded on a secondary market. However, in keeping with the other projects that we've seen, Nori is committed to on-chain carbon trading with high liquidity. They have a fungible token, the NORI token, which acts as a fungibility layer over the NRTs. Each NORI token is redeemable one-for-one for an NRT, where the act of redemption retires the credit immediatly. In contrast to the NRTs, the NORI token can be traded on a secondary market.

The NORI tokens differ from other fungibiliy-layer tokens that we've seen, since the NORI token is not backed by pooled credits, but rather it is a medium of exchange, and a separate cryptocurrency, which is always guaranteed to be redeemable one-for-one to retire carbon credits. This involves complex tokenomics, including a token launch and distribution, a treasury, a supply cap, and an insurance mechanism. In the event of a breach of contract, where sequestered carbon backing an NRT is released before ten years, then NORI tokens are automatically taken from the NORI insurance pool to purchase and retire new credits.

2.7 Likvidity

Likvidity[18] tokenizes carbon credits onto Ethereum, using its LCO2 family of tokens similar in kind to what we've seen in TCO2 and GCO2 tokens. Credits are currently tokenized from legacy ledgers, including Verra, but Likvidity is looking, through industry partnerhsips, to tokenize their own credits by using satellite data and artificial intelligence to quantify carbon capture for new projects. Likvidity uses a pool token, LCO2x, as its fungibility layer, where the acceptance criteria are determined by the Likvidity team. LCO2x tokens are backed one-for-one by LCO2 tokens. Likvidity also has a utility token, LIKK, which can be staked in return for LCO2 tokens as a reward.

2.8 Others

There are simply too many carbon-related projects to cover here, but we will finish by mentioning a few that deal with carbon capture in some adjacent ways to what we've seen above. Cascadia Carbon[4] allows users to tokenize trees into a so-called *NFTree*, and gives rewards in their native token, CODEX, which is meant to be a carbon-backed stablecoin. Other groups have the concept of an NFTree, including NFTreeHaus[24], and some groups simply called NFTrees[25, 26]. Further groups, like Rewilder[29], raise money with NFTs to purchase and conserve land, effectively tokenizing the land similar to the concept of an NFTree. Finally, Save Planet Earth[30] has various projects combatting climate change, which are facilitated by their cryptocurrency SPE, which is traded on BNB. As they grow, they will sell carbon offsets which can be bought with SPE, advocating their cryptocurrency as a medium of exchange more broadly.

3 Trading Carbon Credits

Most of the projects we just looked at were concerned with trading on-chain with deep liquidity, and each had their own solution to deal with the fact that their tokenized carbon credits were non-fungibile, many of them opting for a pooling mechanism of some sort. Toucan argues that pooling allows "for some level of commoditization by pooling similar carbon tokens," and claims that "this is necessary to produce a transparent price signal to the market for different categories of carbon credits."[31] When introducing their pool token LCO2x, Likvidity argues that to "scale the market's size, the credits need to look more like commodities."[18] Flowcarbon argues that "liquidity is at the heart of any efficient market," and that it "reduces market volatility and overall risk for the market participants."[13] Finally, Open Forest Protocol, whom we will see in §5, argues that carbon markets as-is are "fragmented, illiquid, and prone to problems of ... price volatility."[28] The simple advantage of the pool token as a solution for market liquidity is that it is fungible and higher in total quantity than its individual constituents. Perhaps unsurprisingly, the tokenized carbon credits which can be pooled tend to be traded on automated market makers (AMMs) rather than orderbook-style exchanges. Toucan's BCT can be traded on QuickSwap and SushiSwap (Polygon), and NCT can be traded on Osmosis via the Regen Network. MCO2 can be traded on Uniswap and QuickSwap. Flowcarbon's GNT can be traded on SushiSwap as well.

While most trade on AMMs, there are some deviations from this model. Likvidity has a somewhat unique approach, using their so-called *Carbon DEX*, which they describe as a "non-custodial semi-decentralized carbon token exchange for trading ERC-20 compatible voluntary market carbon credits," which "combines a centralized order book and order matching engine with a trustless ledger kept in an Ethereum smart contract to achieve fast performance and smooth user experience."[18] Carbovalent has an orderbook-style decentralized exchange, also called Carbon DEX, which is a central limit order book.

Despite this, we make the note here that one of the primary goals of most of these projects is to have as much liquidity on-chain as possible for trading carbon credits, and that this is mostly accomplished through fungibility layers. Indeed, each argues for high liquidity as a central piece of their value proposition to the market. However, because existing token pools value all the constituent tokens equally, there is a tradeoff between liquidity via a fungible token and preserving the key characteristics of each carbon credit. Any time tokenized carbon credits are pooled together, their individual differences are essentially discarded for the sake of fungibility. This means that there is a tension and tradeoff between liquidity and how granular our valuation mechanism is on carbon credits.

4 Programmable Carbon

Let us zoom out a bit and look at the question of interoperability from a wider lens: that of the kinds of applications that are built on top of carbon credits. Because interoperability manifests itself in part in how easy or difficult it is to build applications on top of these credits, the kinds of applications which build on tokenized carbon credits are a key component that could inform token interoperability standards. There are already a variety of applications that build directly on tokenized carbon credits or the data which backs credits. Let us review a number of them, and then discuss some key takeaways at the end of this section.

4.1 Ofsetting Services

A primary purpose of tokenized carbon credits is that they can be retired to offset emissions. Aside from the retirement functionality that all tokenized carbon credits given here offer, there are already some services built around ofsetting emissions. For example, from the projects we've seen, Flowcarbon also offers automated offsetting for Web3 users and Nori offers automated offsetting for businesses.

4.2 Carbon-Backed Digital Assets

There is an emerging landscape of tokenized digital assets which are backed by carbon credits or related climate data. KlimaDAO[16], who works with Toucan, issues a carbon-backed currency called KLIMA. KLIMA tokens are backed by at least one retired carbon credit from various sources, including BCT and MCO2 tokens. KLIMA can also be minted by the rules governing the treasury, which themselves are governed by the DAO. The goal of this project is to drive up demand for carbon credits, creating what they call a *carbon economy* in which the currency is carbon-backed, and the true cost of carbon is internalized into every transaction. Similarly, KumoDAO[17] is a small project which attempts to back a stablecoin with carbon offsets. And, as previously mentioned, other examples include CODEX and the NORI token. Finally, Arbol[1] sells agriculture and energy derivatives based on climate data collected and monetized on dClimate.

4.3 Climate Insurance

Arbol also offers parametric insurance to guard against issues related to climate, *e.g.* unexpected weather. The payout is based on a predetermined trigger event, governed by a smart contract, which can be verified using data on dClimate (see §5).

4.4 Art and Gaming

Finally, there is a thriving art and gaming ecosystem built around tokenized carbon credits, ranging from NFTs to metaverse projects. Celostrials[5] is an algorithmically-generated collection of NFTs on the Celo blockchain which have partnered with Toucan, and will allow holders of Celostrials to "carbonize" their NFT with NCT tokens. Celostrials holders will also be able to earn so-called climate activity rewards. Flowcarbon is also launching a collection of NFTs, named Flow3rs[12], which were auctioned off to support various climate-positive projects, including projects which tropical forest conservation, biodiversity, and carbon sequestration. Flowcarbon also calculates and offsets on-chain emissions of NFT projects. Moving on, Likvidity has the Origins Collection[19], which is a collection of one thousand twenty carbon-backed NFTs. Holders of Origins NFTs can stake their NFTs and earn carbon credits, and have other benefits as part of the originators club. And finally, Ecosapiens[10] is an NFT project where minted NFTs are backed by fifteen tons of captured carbon, and which are meant to be used as profile pictures (PFPs).

Taking a slightly different direction, Nori has an API that allows any artist who mints NFTs to offset their minting, and then choose a percentage of their sales that are automatically diverted to purchase and retire carbon offsets. KlimaDAO also interacts with the offsetting process with an initiative called "love letters," where someone retiring carbon can include a message, or a "love letter to the planet," which accompanies the act of retirement. These love letters are encoded on the blockchain, and KlimaDAO has a dashboard where they can be seen.

Finally, in the metaverse space, Metamazonia[23] is building a 3D, photorealistic metaverse to make a digital twin of certain parts of the Amazon rainforest. The metaverse can be explored with an avatar. They use NFTs as a funding mechanism to prevent deforestation, promote R&D in the Amazon, and to fund other projects. NFTs correspond to pieces of land in the metaverse, which themselves correspond to coordinates in the physical reserve in the Amazon rainforest.

4.5 Key Takeaways

There is already a vibrant ecosystem of applications that build on tokenized carbon credits which align with the general goals of climate action, from art and NFTs to services and derivatives. As carbon credits grow on the blockchain, this is likely to continue developing. From the lens of token interoperability, note that there is really little to no technical hurdle to interoperating between various carbon credits, so long as they are on the same blockchain. Because these tokens conform to established token standards, swapping out, *e.g.* which carbon credits are retired, or which carbon credits back an NFT of some kind, would likely be little more than changing a contract address or a line of code.

The real hurdle, however, to interoperating between tokenized carbon credits in the above examples comes in the semantic meaning of each of the applications: retiring one carbon credit instead of another is not necessarily the same thing semantically, even though technically it is likely a nearly identical process; likewise, the carbon credits that back a particular NFT have to match the ethos and goals of the NFT project itself, so it's unclear *a priori* if one carbon credit can be substituted for another in these instances.

However, if there is a meaningful way to compare tokenized carbon credits, we may be able to effectively interoperate between them: if we know that one tokenized carbon credit is double the quality of another, perhaps we can retire two of the latter in place of one of the former. Similar logic applies to the other application use cases. As one might expect, this comparison may need to have different semantic meaning depending on the context.

5 Climate Data Availability

In the following two sections, we will treat topics that are slightly tangiential to tokenized carbon creidts, but still highly relevant. Firstly, essential to the process of tokenizing carbon credits is that there be data available on which to apply the methodology backing the credit. For tokens backed by a legacy ledger, this data is collected and analyzed by the certifying organization, *e.g.* Verra. However, there are good reasons for the data to be publicly stored, and for the methodology to be transparently applied to the data. These include verifiability, reproducibility, and reducing the need to trust intermediaries, and are generally in line with the advantages blockchain offers to voluntary carbon markets. Furthermore, if the process can be largely automated, and climate data can be collected and made available *en masse*, then the process of verification may become more scalable. Finally, if blockchain-based carbon credit projects rely only on legacy ledgers, then the project may be dependent on decisions made by verification agencies out of their control (see Verra's recent statement on tokenized carbon credits[34]). We will take a brief look into three organzations which are looking to collect and store climate data in a decentralized fashion.

5.1 Filecoin Green

Filecoin is a decentralized ledger for storing data using the IPFS protocol. With Filecoin, a user can pay for storage to be hosted on the Filecoin network over a specified period of time. Filecoin Green[11] is an initiative on Filecoin to store climate data and make it broadly available. Their stated goal is to build infrastructure so that anyone can make transparent and substantive environmental claims. Their first initiative on climate data is to measuring the electricity consumption of their validators to be transparent about the emissions of the blockchain itself. Their goals are to host more extensive climate data and make it available to various applications, which could include tokenized carbon credits.

5.2 dClimate

dClimate[9] is a decentralized network for climate data, consisting of four layers: the governance layer, through which dClimate operates like a DAO via its native WTHR token; the oracle layer, which makes climate data available to applications, operating like Chainlink; the blockchain and data storage layer, where data is stored via IPFS; and the marketplace layer, where users can access (and pay for) data. Climate data is published confidentially until accessed and paid for by a user, though contributors can choose to make their data free. As we mentioned previously, Arbol offers parametric insurance against climate-related events, using dClimate as its data source. More broadly, dClimate is attempting to lower the barrier to entry for climate data capture and monetization, and could host data which is relevant to carbon credits and the corresponding ecosystem of applications.

5.3 OFP

The Open Forest Protocol (OFP)[28]is a protocol built to manage forest data, with the goal of improving forests. While the protocol hopes to eventually mint carbon credits backed by data managed by the protocol, it is also meant to be a more general forest data management tool. The protocol itself has a native token, the OPN token, which grants access to the OFP, allows a holder to verify or challenge the accuracy of a specific MRV data upload, and govern the protocol's parameters as a DAO. When the time comes, the process of creating carbon credits with OFP is meant to be open and transparent. Users will be able to create a new project and upload data, which will generate an NFT contract for them. To mint tokens, on-the-ground forest data must be collected by the OFP field mobile app, after which validators check the legimitacy of the ground data. Acceptable methodologies to mint carbon credits, as well as any guards on what types of credits or methodologies are acceptable, will be governed by the DAO.

5.4 Key Takeaways

Making climate data readily available to blockchain-based applications, and incentivizing people and entities to collect and publish that data, will no doubt play an important role in how tokenized carbon credits are minted and in other financial derivatives built on-chain using the data. If the data is high quality, this could support a wide range of methodologies which compute over the data to substantiate tokenized carbon credits on the blockchain. If done in a transparent and verifiable way, this could be a highly effective marketplace of ideas that works to mitigate climate change and monetize carbon capture from the atmosphere, among other things.

6 Outlook

In our final section, we mention a few groups that are interested in decarbonizing blockchains, using blockchains for climate action, and who are interested in making standards for tokenized carbon credits. From the work of these groups, we are most interested in the work of standards for tokenized carbon credits, though each contributes more to the ecosystem.

The Crypto Climate Accord (CCA)[8], an initiative to decarbonize blockchains and cryptocurrencies supported by various companies and nonprofits, has as its goal to "develop standards, tools, and technologies with CCA Supporters to accelarate the adoption of and verify progress toward renewably-powered blockchains by the 2025 UNFCCC COP30 conference." It puts forward various solutions, including guidance for accounting and reporting electricity use and carbon emissions from cryptocurrencies.

The Climate Collective[6] is a coalition of entrepeneurs, investors, non-profit organizations, and scientists, whose aim is to promote blockchains and cryptocurrencies (Web3 infrastructure) as a tool for climate action at scale.

Finally, Gold Standard[15] has launched some working groups with the aim to develop "an open, global collaboration on digital solutions for carbon market standards and monitoring, reporting, and verification (MRV)."[45] They consist of a digital assets working group, which "looks at the role of blockchain to track carbon credits in decentralised environments"; an open APIs and digital infrastructure working group, which "looks into how new digital methodologies can increase the robustness of carbon credit calculations"; and a digital MRV working group, which looks into the "details of how to turn earth observations into meaningful carbon metrics."

While we expect the token contracts of these carbon credits to all conform to established token standards, we don't yet have a standardization framework for methodologies substantiating carbon credits. Because methodologies can vary widely as we saw in §2, we do not expect standards to be strictly prescriptive in the way that token standards are. However, standards on token metadata, data collection, or measurement practices could be useful as key guidelines ensuring that tokenized carbon credits are rigorously substantiated and can be effectively compared along various metrics.

7 Conclusion

Tokenized carbon credits vary in the wild in their implementation details and in what substantiates them (§2). As the goal of this research is to help maximize interoperability between tokens, we face the technical hurdle that carbon credits exist on various chains and with various token standards. Luckily, in practice most (non-fungible) tokenized carbon credits are pooled into a fungible token, conforming to established token standards. Thus by using inter-chain bridges, the technical hurdle itself for token interoperability is not particularly high.

Instead, as we saw, interoperability can be hampered by variations in what substantiates a token. In contrast to token standards, where it is productive to have all tokens conform to established standards, it is likely unproductive to fully standardize the data and methodologies that substantiate carbon tokens. Instead, we can drive innovation with an open and transparent marketplace for methodologies of data capture and processing that rewards accuracy and efficacy. In time, such an open marketplace could be supported by the various decentralized carbon data collection and availability schemes (§5), and reproducible or verifiable computation over them. Even so, organizations seeking to form some consensus around standardization could prove productive in providing a common framework for these methodologies (§6), which could include standard ways of structuring token metadata.

In some sense, however, this desire for a rich variability in the methodologies substantiating tokenized carbon credits stands in conflict with the nearly ubiquitous goal of having as much liquidity as possible on-chain by pooling carbon credits together (§3). This is because, as they exist, fungibility layers pool tokens by valuing them one-for-one, and so tokens can be pooled together insofar as they are valued equally to each other. This achieves fungibility by *discarding* differences between the constituent tokens in methodology, project type, vintage, *etc.* Because we *want* carbon credits to be able to vary in price depending on their characteristics, ideally where higher quality credits are valued more highly, we are inherently restricted in our ability to pool tokens and achieve higher levels of liquidity on-chain.

Ideally, we would be able to pool tokens in such a way that: values distinct tokens differently according to some market price, *e.g.* a carbon credit worth twice as much as another would trade for twice as many pool tokens as the other; and allows for dynamic price discovery between the constituent tokens over time.

This would achieve the goals stated above of high liquidity and fungibility, while still valuing carbon credits individually with their granular data, encouraging a rich landscape of tokenized carbon credits. It could also prove useful for interoperability as it relates to applications building on tokenized carbon credits (§4), achieving our goals of interoperability more broadly. Such a pooling mechanism has not yet, to our knowledge, been invented or implemented, but in our estimation could be the next step in unifying the fractured body of tokenized carbon credits on the blockchain.

8 Conflict of Interest

I am a member of the Cambridge Centre for Carbon Credts (4C), which is implementing a marketplace and tokenizing carbon credits on the Tezos blockchain.

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