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1 Tokenising the voluntary carbon credit market: Harnessing opportunities for sustainable development

Abstract: This research develops and explores the process of tokenising the voluntary carbon credit market and its potential to drive sustainable development. Tokenisation, the process of converting carbon credits into digitally represented tokens on a blockchain, promises to address current issues of transparency, efficiency, and liquidity in the market. Through a concise yet informative exploration of this technology and its role in the voluntary carbon market, we formalise the general process of carbon tokenisation. We present the opportunities for tokenisation through well-supported arguments backed by relevant interdisciplinary research. Furthermore, the study analyses current practices and case studies to underscore the relevance of these opportunities. This assessment aims to demonstrate how tokenisation can contribute to a more robust, accessible, and effective voluntary carbon market, supporting global efforts to mitigate climate change and promoting the broader objective of sustainable development.

Keywords: Blockchain, Carbon Credits, Sustainability, Tokenisation, Voluntary Carbon Market

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1 Background

Climate change has a storied history, a history which is ongoing and will become ever more important in the coming decades. Although we commonly attribute the awareness of climate change to the more recent 21st century, its history and awareness stretch back to the early 19th century to the discovery of the Greenhouse Effect by Joseph Fourier in 1824. Awareness of the impact of fossil fuels on global temperatures was largely disregarded until the 1970s when these issues began to be seriously considered as contributing to climate change by the international community.

The first international discussion on the environment took place in 1972 at the first United Nations (UN) Conference on the Human Environment in Stockholm. This event set the stage for the development of environmental policies at both the national and international levels. Having brought international awareness to the environment, a flood of scientific research during the 1970s and 1980s increasingly linked human activities, including burning fossil fuels and deforestation, to the increase of greenhouse gases in the atmosphere, which was subsequently linked to global warming.[1]

Given the increasing evidence of climate change, along with growing environmental awareness and corresponding actions, such as the creation of environmental organisations like Greenpeace, political and diplomatic efforts began to shift towards supporting climate action. 1988 saw the creation of the Intergovernmental Panel on Climate Change (IPCC) by the UN Environment Programme (UNEP) and the World Meteorological Organization (WMO). The creation of the IPCC marked a significant step towards understanding the drivers of climate change and supporting international policy coordination on climate change.

With this new international focus on the climate, a series of events throughout the 1990s further enhanced global cooperation on combating climate change. Following the first Assessment Report of the IPCC in 1990, the United Nations Framework Convention on Climate Change (UNFCCC) was established in 1992 at the Earth Summit in Rio de Janeiro. The development of the UNFCCC provided a framework aiming to stabilise greenhouse gas concentrations in the atmosphere. Along with the establishment of the UNFCCC, annual Conference of the Parties (COP) meetings were introduced to review and monitor the implementation of the UNFCCC, culminating in the development of the Kyoto Protocol at COP3 in 1997. The Kyoto Protocol was a groundbreaking international agreement that set binding targets for 37 countries to reduce greenhouse gas emissions (GHG). Through this agreement, international emissions trading mechanisms were introduced alongside the Clean Development Mechanism (CDM) and the Joint Implementation (JI). While developments were taking place under the UNFCCC, the UN was also developing the Millennium Development Goals, later converted into the Sustainable Development Goals (SDGs), which were intimately linked to environmental protection and development. These goals framed the challenge of climate change in the broader socio-political landscape, laying out the necessity for tackling not only climate change but its associated precipitators and consequences. The

Kyoto Protocol came into force in 2005 and faced criticism during its tenure regarding environmental integrity, equity and fairness, market functionality, lack of ambition, implementation and compliance, long-term effectiveness, and economic and social impacts. Lessons learned from the Kyoto Protocol played an important role in shaping the aims of the Paris Agreement in 2015, which was adopted at COP21.

The Paris Agreement notably extended participation to achieve global coverage, including countries previously excluded from the Kyoto Protocol, and acknowledged the critical role of developing countries in addressing climate change. Long-term temperature targets were set with the goal of keeping global temperatures well below 2 degrees Celsius above pre-industrial levels, while pursuing efforts to limit the increase to 1.5 degrees Celsius.

Importantly, Art. 6 of the Paris Agreement outlines cooperative approaches that countries may utilise to achieve their nationally determined contributions (NDCs) using market and non-market mechanisms. A key outcome of Art. 6 is the prescription of a market for emission reductions (or credits) between countries aimed at ensuring environmental integrity and preventing double-counting of Internationally Transferred Mitigation Outcomes (ITMOs). Concerns about double-counting were rife under the Kyoto Protocol and a focus on eliminating such issues has driven the establishment of many proposed solutions regarding accounting for carbon offsets and reductions, particularly through blockchain applications. In addition to outlining necessary carbon market mechanisms, the Paris Agreement emphasised unifying global standards and goals for emissions reductions, applicable not only to compliance carbon markets but also voluntary carbon markets (VCMs). Ensuring carbon credits represent real and verifiable reductions has become the focus of many initiatives in VCMs. This chapter will focus on the opportunities in the VCM and how blockchain technology can address them.

More recently, a global stocktake was completed alongside COP28 in Dubai in 2023, providing a comprehensive evaluation of progress towards the goals of the Paris Agreement. The report highlighted continued and urgent need for action to meet the target of 2 degrees Celsius under the Paris Agreement, while noting current global efforts were insufficient to limit global warming to 1.5 degrees Celsius above pre-industrial levels. The conference went on to underscore the growing financial burden of climate change and emphasised the need for a transition away from fossil fuels while increasing the global energy capacity from renewable energy sources.

The historical progression of the climate change discourse has largely focused on laying the foundational framework for international coordination and policy development. Recent efforts have increasingly sought to implement effective carbon pricing mechanisms. This can be seen in the shift from the Kyoto Protocol's foundational market-based approach to the sophisticated, multilayered strategies seen in the Paris Agreement. An examination of trends in carbon-related commitments reveals '[on] the whole, 89 countries, representing 86% of global emissions, had adopted net-zero commitments at the end of 2022, with target dates ranging from 2035 to 2060'.[2]

2 Carbon pricing

Typical means of pricing carbon have been established through the implementation of Emissions Trading Systems (ETS) and carbon taxes. Both carbon taxes and ETS set direct prices on carbon in contrast to indirect carbon prices, such as through energy efficiency standards. A deep exploration into carbon pricing reveals there has been growth in ETS prices in most jurisdictions; however, some countries have postponed price increases. As of 2023, ETS and carbon taxes in operation cover approximately 24% of global GHG emissions, where around 19% and 6% of global GHG emissions are covered by ETS and carbon taxes, respectively.[3] This coverage represents significant growth in the coverage of carbon pricing from only 0.49% of global GHG emissions in 1990.[3] During this same period, from 1990 to 2024, we have seen steady increases in the price level of CO_2 emissions on national levels; despite increasing carbon prices, there still exists vast disparities in the general levels of carbon prices among countries. Carbon prices are typically expressed as the cost per metric tonne of carbon dioxide and its equivalents (1 tCO_2e). As of 1 April 2024, carbon prices ranged from USD 0.61/tCO_2e to USD 167.17/tCO_2e in Indonesia and Uruguay respectively.[3]

In addition to ETS and carbon taxes, we have also seen a more recent proliferation of carbon crediting mechanisms. Carbon credits aim to put a direct price on carbon through issuing tradable credits (representing 1 tCO_2e) that are generated through reductions in emissions. These credits represent reductions through either carbon avoidance or carbon removal activities. As of 2024, there are 35 governmental crediting mechanisms implemented globally with an additional 11 currently under development[3]. In addition to government crediting mechanisms, several independent crediting mechanisms exist, most notably, Gold Standard (GS) and the Verified Carbon Standard (VCS) by Verra. In 2023, a total of 5.7 billion carbon credits were issued: 3.3 billion through international mechanisms such as the CDM, 450 million through governmental mechanisms, and 1.9 billion through independent mechanisms.[3] This highlights the significant role independent mechanisms play in issuing carbon credits. Similar to pricing heterogeneity in the compliance market, voluntary carbon credits (VCCs), verified through independent mechanisms, exhibited a range of carbon prices depending on many factors, including the type of underlying project related to the credit, geography, and crediting mechanism employed, among other factors; on average, buyers paid USD 6.53/tCO_2e on the voluntary market in 2023.[4]

3 Voluntary carbon credits

When discussing carbon credits, it is important to distinguish between VCCs and compliance carbon credits. Compliance carbon credits are issued and regulated by governmental and international bodies, generally as a part of national government emissions targeting schemes. They commonly operate under cap-and-trade systems, whereby a national allowable level of emissions is set, and carbon credits are then either auctioned off or freely allocated. In contrast to compliance carbon markets where participation is mandatory for GHG emitting firms, participation in the VCM is not mandated by law but rather driven by organisations and individuals who wish to proactively offset their emissions; organisations generally participate in this market to fulfil corporate social responsibility (CSR) commitments.

The mechanism underlying the VCM also fundamentally differs from the mechanisms underlying the compliance carbon markets. In compliance markets such as the European Union (EU) Emission Trading System (ETS), national carbon emission targets are set by the EU; then, carbon allowances are issued through auctions or free allocations, which permit a company to emit one tonne of CO_2e per allowance.[5] Rather than requiring emitters to purchase carbon allowances, the VCM issues carbon credits for every tonne of CO_2e reduced, avoided, or removed from the atmosphere. Compliance carbon markets directly incentivise emission reductions through reductions to the emissions cap over time; however, these markets are often criticised for having carbon leakage, where emissions are outsourced to jurisdictions with less stringent, or no, emission regulations. While compliance carbon markets may simply lead to carbon leakage, the VCM provides direct incentives tied to measurable emission reductions. One could argue that VCMs play a growing role in reducing total global GHG emissions, especially as CSR becomes a central concern for companies and individuals alike.[5]

The scope of projects covered by the VCM is generally more varied than those covered under compliance markets. For example, the EU ETS scheme covers primarily CO_2 emissions from electricity and heat generation, energy-intensive industry sectors such as oil refineries and raw materials production, aviation, and maritime transport.[6] Conversely, in VCMs such as under Verra's Voluntary Carbon Standard (VCS), the coverage of projects is broader, including projects related to agriculture, forestry, and other land use projects in addition to energy, industrial, waste, and transport projects.[7] In fact, as of 31 March 2024, 38.3% of all VCCs issued by the four largest issuers were related to forestry and land use and 32.3% were related to renewable energy projects.[8]

The VCM also plays a fundamental role in allocating resources equitably among regions. This role is especially pronounced when examining the geographical distribution of total carbon emissions compared to those covered under a governmental compliance scheme. Figure 1.1 shows the geographical disparity of carbon emissions covered under governmental compliance mechanisms.

The left plot shows the total official cumulative carbon emissions from 1990 through 2022 by geographical region; we see that carbon emissions are relatively distributed among regions. In contrast, the right plot shows that the cumulative carbon emissions during this period actually covered under government compliance mechanisms are disproportionately concentrated primarily in Europe and Central Asia. Broken down by income group,[9] high-income countries represent 25.52% of cumulative

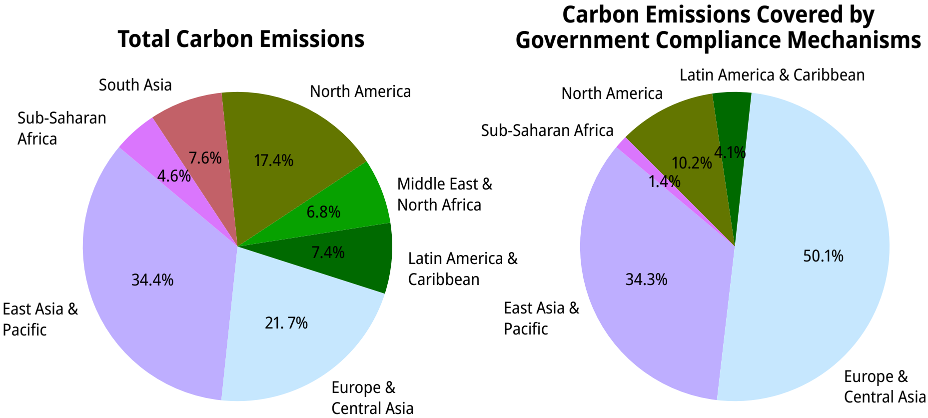

Figure 1.1: Comparison of Total Cumulative Carbon Emissions Versus Carbon Emissions Covered Under a Government Compliance Scheme for 1990–2022.
Source: *Authors' Own, based on data from multiple sources.*[10]

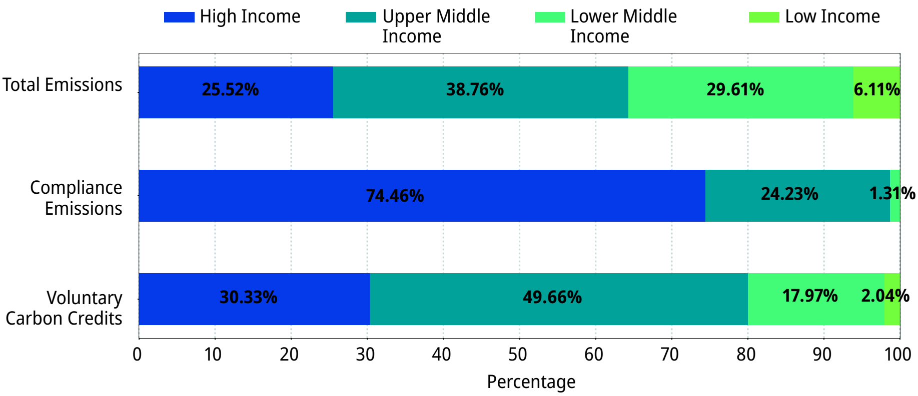

Figure 1.2: Representation of Country Income Groupings by Total Emissions, Emissions Under Government Compliance Mechanisms, and Voluntary Carbon Credits.
Source: *Authors' Own, based on data from multiple sources.*[13]

global carbon emissions from 1990 to 2022,[11] while they represent 74.46% of emissions covered under government compliance schemes during this same period.[12]

This means that lower- and middle-income countries and countries in the global south are underrepresented in compliance carbon markets. This underrepresentation provides a profound opportunity in the VCMs, whereby funds from high-income countries are transferred to projects in low- and middle-income countries. Figure 1.2 shows the relative representation of each country-level income group by its relative total emissions, emissions covered under a government compliance mechanism, and representation in the top four VCM registries. As can be seen, the representation by income level in the VCM is more proportional to the total global emissions by income level, providing significant value to lower- and middle-income countries.

4 Challenges in current voluntary carbon markets

Despite their great potential, VCMs are not without their flaws. Miltenberger, Jospe, and Pittman provide a detailed critique of VCMs.[14] We will highlight a few of the important challenges briefly. The criticism of greenwashing has been longstanding, especially in the early days of VCMs; this is compounded by the fact that many projects lack the necessary transparency to confirm the quality of their carbon credits. This problem may be partially addressed by ensuring sound monitoring, reporting, and verification (MRV); however, the quality of MRV varies greatly among VCC standards bodies.

A central criticism driving new initiatives for carbon accounting under the Paris Agreement is the proliferation of double-counting.[15] Double-counting in the VCM may occur when one project is listed on multiple voluntary carbon registries, allowing for the underlying credits to be claimed more than once. This may also occur due to difficulties establishing ownership of VCCs, allowing multiple entities to claim the offsets.

Greenwashing and double-counting are surface-level problems, largely affected by more fundamental issues in VCMs, especially the fragmentation of the market and standards that have compounding effects. Some independent registries strictly prohibit projects from being cross-listed on multiple registries, for example, Gold Standard[16] and Verra;[17] however, some smaller independent bodies do not explicitly preclude cross-listing. Even with the prohibition of cross-listing, such activity may be difficult to identify due to a lack of standardisation within the industry.

Fragmented standards are especially rife, contributing to issues of greenwashing. Recent work has examined the impact of the role MRV plays in crediting issues. Problems with methodologies have led to the gross overissuance of carbon credits, especially in relation to REDD+ projects.[18] Generally, many of the issues underlying VCCs are attributable to the lack of standardisation in the industry.

5 Introduction to tokenisation

When we discuss carbon tokenisation, it is first important to understand what the technology behind it is so we have a framework for understanding the mechanisms of tokenisation. Tokenisation in terms of blockchain is the act of converting ownership or rights into a digitally represented form recorded on a blockchain. To understand what exactly this means, it is useful to understand the origins of this technology. Distributed Ledger Technology (DLT) is a concept dating back to the 1970s and 1980s when work on distributed databases[19] and efficient and secure verification of data began.[20] This technology aimed to create a decentralised environment, creating trust among network participants. This trust arose out of the ability of this technology to provide transparency and immutability of the data stored in the distributed databases, later DLT.

Since its inception, DLT has grown vastly in its implementations and utilisation. Largely popularised by the application of the technology to the Bitcoin network in 2008,[21] its use in the emergence of other cryptocurrencies has led to a market size of USD 2.47 trillion as of June 2024.[22] The prospect to record transactions on a public, immutable ledger has led to additional applications of the technology to convert real-world rights and assets to a digitally represented form, recorded on blockchains through the process of tokenisation.

6 Process of carbon tokenisation

To understand the role of blockchain technology in carbon tokenisation, it is valuable to first review the lifecycle of a typical VCC project. Figure 1.3 highlights the high-level lifecycle of a VCC project in accordance with using a traditional voluntary carbon registry such as Verra. First, a project idea is initiated, the project design is detailed, and the project leaders apply for validation and registry through a voluntary carbon registry. The carbon registry then confirms the project adheres to its standards and verifies or rejects the project; once verified, the project is then registered on the corresponding registry. Next, the project is implemented and monitored, receiving periodic verification assessed by third-party monitoring services. Upon successful completion of key milestones, carbon credits are then issued; these credits are recorded in the registry database and transferred into the project developer's registry account.

Having been deposited into the developer's account, these credits can then be traded in the VCM. Alternatively, these credits may be tokenised and subsequently traded on a blockchain, if authorised by the registry[23] using varying methodologies depending on the carbon bridge used. The credits may be traded by interested parties in their respective markets; then, once a party wishes to retire the credit and claim a carbon offset, a retirement request is sent to the registry. The credit is subsequently retired, and the registry records the retirement, updating the registry.

While the lifecycle of a carbon credit in traditional markets is relatively well established and straightforward, the tokenisation of carbon credits is fraught with criticisms and challenges, which will be briefly addressed later. Here, we will briefly outline the main ideas underlying the tokenisation process previously employed by major carbon bridges. Figure 1.4 shows the general process of carbon tokenisation used by major carbon bridges such as Toucan, C3, and Moss.

To bridge a carbon credit from traditional registries, the carbon credit in the traditional registry is first transferred into a custodial account in the name of the bridging

Figure 1.3: Lifecycle of a Typical Voluntary Carbon Credit.
Source: *Authors' Own*.

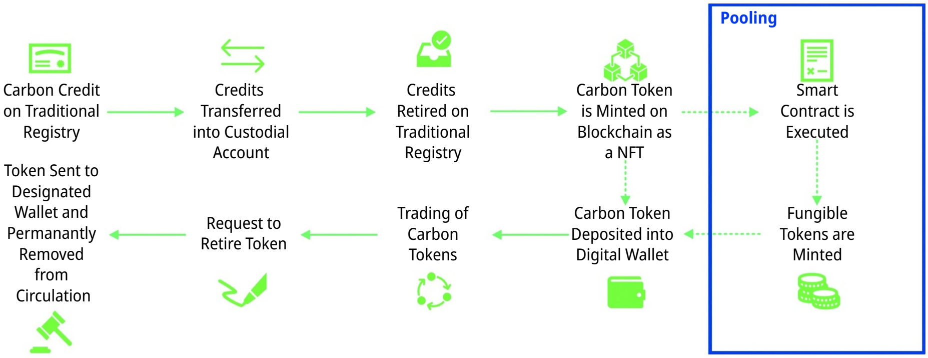

Figure 1.4: Process of Carbon Credit Tokenisation.
Source: *Authors' Own.*

service; this credit is then retired on the traditional registry when the corresponding carbon token is minted on a blockchain as a Non-Fungible Token (NFT) and the underlying project metadata is stored.[24] Commonly, bridging services engage in pooling activities, where a smart contract is executed, locking the NFT into the smart contract and simultaneously minting a fungible token.[25] Once the carbon token is created, as an NFT or fungible token, it is then deposited into the user's digital wallet and tokens are then traded either in peer-to-peer transactions or in the relevant digital marketplaces. When a token holder wishes to claim the underlying carbon offset, the holder requests the bridging service to retire the token, whereby it is sent to a designated wallet and permanently removed from circulation.[26] This process describes a one-way carbon bridge, where once on the blockchain, the carbon token cannot be converted back into a traditional registry credit. Conversely, the development of two-way carbon bridges has been established, allowing the underlying registry credit to remain active and have its retirement triggered by the corresponding token retirement.[27]

7 Current state of carbon tokenisation in practice

The full and current state of carbon tokenisation of the VCC is incredibly difficult to understand and quantify due to the fragmentation of this market. While there are some well-known and large players in the space, there are many more small players and new emerging initiatives. For example, large carbon token projects such as KlimaDAO and Flowcarbon have been reported on by large news platforms such as the *Wall Street Journal*,[28] *Bloomberg*,[29] and the *Financial Times*,[30] raising public awareness about carbon tokenisation. However, there are many smaller carbon token initiatives that go relatively unnoticed by those not intimately familiar with the carbon token space.

Generally, the major carbon token initiatives appear to be concentrated on improving market efficiency and access. This typically takes the form of two distinct activities; first, there are the initiatives that focus primarily in managing the tokenisation process itself. These players deal with the details and methods for getting VCCs on the blockchain in preparation for trading in marketplaces. Second, there are initiatives primarily dedicated to serving as marketplaces for those looking to buy and sell tokenised credits. However, not all initiatives are confined to fulfilling a single activity in the value chain. In fact, many initiatives engage in more than one of these roles with some initiatives even venturing into fulfilling other roles in the voluntary carbon lifecycle. Some focus on native tokenisation whereby they develop their own project standards, monitoring, and verification requirements and no carbon bridging takes place, but rather the project issues a native digital token, for example, Coorest.[31]

To understand the role carbon tokenisation projects play in markets, we can look at trading and marketplace platforms such as KlimaDAO, Air Carbon Exchange, Regen, Senken, and many others. In most of these marketplaces, there is an option to purchase credits directly linked to a specific project, such as in Regen Market. Or, another common approach is to market a fungible token representing carbon offsets in an underlying pool, as in the case of KlimaDAO. Some markets rely on carbon bridging services to provide the supply of tokens; for example, KlimaDAO partners with Toucan, C3, and Moss to bridge all its credits. Since KlimaDAO is the most well-known carbon token project, we can expect that Toucan, C3, and Moss are likely the three largest carbon bridges. Currently, Toucan, which is the largest source of credits for

KlimaDAO, has not tokenised any additional credits from Verra or Gold Standard since May 2022 after both Verra and Gold Standard banned unauthorised tokenisation of their credits, which is still in effect in 2024.[32] As a result of this ban, we have seen a shift towards using credits from other carbon registries for tokenisation, for example, Toucan's tokenisation of Puro.earth credits.[33]

To understand more about the carbon credits being bridged, we will look at activity related to KlimaDAO. As of July 2024, KlimaDAO has made 20,393,479 tokenised carbon credits available in its marketplace, with 88.58% of its credits having been bridged by Toucan, 10.83% by Moss Earth, and 0.59% by C3. KlimaDAO has essentially pooled credits from Toucan, Moss, and C3 and issued a new fungible token representing a claim on the pool. This means Toucan tokens make up the majority of the pool and represent a significant number of credits bridged. We will examine the extent of tokenisation by Toucan as an indication of the tokenisation of Verra credits.

We can quantify the extent of tokenisation of Verra's carbon credits by examining the underlying credits attributed to Toucan in the Verra registry. Toucan has tokenised a total of 22,119,807 credits issued by Verra; this includes credits issued between 2009 and 2022. During this same period, Verra issued a total of 1,093,576,461 carbon credits. This means that Toucan bridged approximately 2% of the carbon credits Verra issued in this period. Previously, we looked at the representation by region and income group for compliance carbon programmes and VCMs. Using the registry data from Verra, we can look at what tokenisation means in terms of the projects that underlie tokenised credits and what types of projects are tokenised.

In Figure 1.5, we show two interesting observations. First, the regional representation in the Verra registry for issuances between 2009 and 2022 tends to represent regions with a higher number of developing economies, a result that contrasts with the representation of total emissions and compliance emissions in Figure 1.1. Second, we

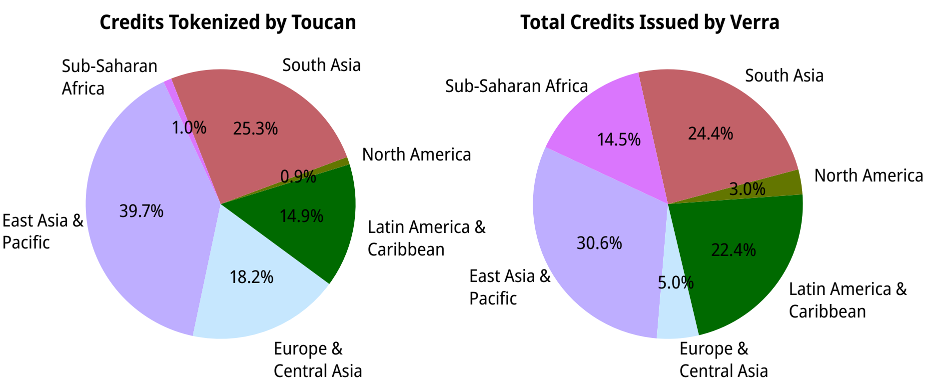

Figure 1.5: Verra Voluntary Carbon Credits Tokenised.
Source: *Authors' Own*.[34]

see that in comparison to the projects in the Verra registry, the credits tokenised by Toucan tend to be more concentrated in Europe and Central Asia and less concentrated in sub-Saharan Africa, suggesting a difference in the underlying carbon credit portfolio of carbon tokens in comparison with the overall market. These differences suggest that the demand and supply for tokenised credits might differ fundamentally from traditional markets.

We can also see in Figure 1.6 that credits in high-income countries represent less of the total tokenised credits when compared with the total credits issued by Verra between 2009 and 2022. While this supports the expectation that tokenisation may improve accessibility to credits from developing countries in general, we see credits from low-income countries are minimally represented in the Toucan portfolio.

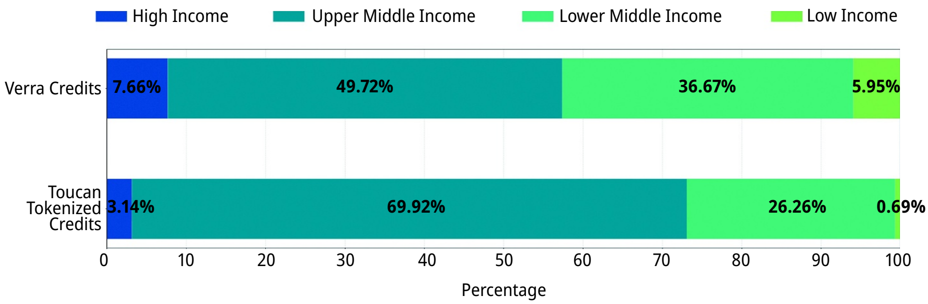

Figure 1.6: Comparison of Verra Credit Portfolio Between Toucan Tokenised Credits and All Verra Issued Credits Between 2009 and 2022.
Source: *Authors' Own*.[35]

8 Opportunities for carbon tokenisation

Blockchain's ability to provide immutable transaction records enhances trust and transparency. The technology has also proven to be efficient and scalable, especially with recent developments over the past few years. Considering these benefits, general market accessibility is improved when applying blockchain technology to the VCM. Blockchain has the potential to disrupt current carbon markets. There are several new innovations the technology presents as solutions for the existing VCM, especially smart contracts, that can allow for the full integration of an end-to-end solution, which is of great interest to the international community. On top of these opportunities, the discussion inevitably expands into what new markets can be reached with blockchain. Previously, we saw that tokenised carbon credits appear to represent different carbon projects in comparison to the traditional VCM (Figures 1.5 and 1.6). Although more research into this area is needed to determine if this is a wider trend or limited to the case study of Toucan. From here on, we discuss the especially relevant cases which would extend the market reach beyond simply corporate demand but also include consumer demand and the potential role of tokenised credits in the compliance market. Finally, we briefly discuss the potential for a tokenised carbon asset class to provide diversification benefits to the broader market of investors, improving overall market liquidity.

8.1 Market accessibility

Since its creation, blockchain has been heralded as a means to improve market accessibility, especially in developing countries.[36] The technology is easy to access since all that is required is a digital device, an Internet connection, and a digital wallet. Part of the allure of the technology is the ability to improve transparency and trust, which results in greater market participation and, as a result, higher market liquidity. Additionally, the efficiency gains and automation from the technology reduce transaction costs as intermediaries are no longer needed. The possibility for fractional ownership of crypto assets also lowers investment thresholds for potential buyers. Overall, these benefits should translate to increased inclusivity by allowing participation from individuals and smaller entities in the network[37] while also providing the same benefits to large participants.

Problems with market structure in the VCM are pervasive and have far-reaching ramifications for all participants. In fact, in a recent survey by NASDAQ, 25% of VCM participants noted that the current market issues prevent them entirely from entering the market with an additional 16% and 40% noting severe and moderate restrictions inflows, respectively.[38] An assortment of foundational issues underlies this core problem, including poor pricing efficiency, poor trading liquidity, fragmented standards and markets, and general inefficiencies. Current VCCs are typically traded in over-the-counter markets and often incur high transaction fees, poor informational transparency, and high search costs. The current leading market is the Carbon TradeXchange.[39] In this market, participation is limited to large enterprises and corporations; credits are sold in large, costly lots; auction mechanisms utilised have lengthy trading and settlement times; and participants face high overall transaction costs, including search and sourcing costs. In addition to markets for VCCs, projects themselves often have difficulties registering for several reasons, mainly due to problems with efficiency.

Blockchain presents a few opportunities to improve market accessibility for both buyers and sellers of VCCs. First, it would lower entry barriers for individuals and small businesses, especially through the ability to purchase individual credits and through fractionalisation. Individuals could better offset their personal emissions, expanding the market. Centralised market platforms that pull data directly from the blockchain allow users to more easily compare carbon credits before purchasing. The fact that many token markets are publicly accessible rather than behind a wall only accessible to corporate buyers not only helps participation rates but also improves general market efficiency and price discoverability. The greatest benefit is how improved market accessibility will enhance liquidity in carbon token markets. Faster, more efficient trading mechanisms foster greater participation. Liquidity would also be enhanced through pooling protocols, which provide the ability to trade fractional ownership of pooled carbon credits. This can allow buyers to reduce investment risk when purchasing credits, negating the need for extensive research into individual carbon credit projects. The ability to purchase pooled credits alone significantly reduces barriers to entry for smaller entities and individuals.

Like buyers, sellers receive much the same benefits. Lower costs and accessible marketplaces can reduce the amount of time it takes sellers to sell their credits. Tokenisation projects with their own standards can also streamline the process for sellers, reducing barriers and facilitating participation. Generally, small projects are more susceptible to the challenges in existing markets, whereas blockchain can allow for their participation in carbon token markets. Small projects facing high costs to entry, which is a common issue,[40] are more likely to become funded in carbon token markets, where funding is more accessible. Additionally, the ability to pool credits means that projects that may otherwise be considered too risky become funded; however, careful market design and possible regulation will be required to ensure pools operate transparently and maintain market integrity.

We have seen that market accessibility is a major problem for existing VCMs, where markets are opaque and mostly exclusive to large institutional investors. With blockchain technology, the market opens to smaller participants, both buyers and sellers looking to engage in the VCM, will be enabled with blockchain technology. Demand for carbon offsets by individuals and small entities is already evident;[41] blockchain will simply provide the means to open this market more to such participants.

8.2 Transparency and trust

The ability to timestamp and trace ownership is of great importance in the digital world, where it can often be difficult to ascribe ownership to digital assets.[42] By nature, blockchain technology lends itself to improved transparency in its related markets through the utilisation of DLT technology. The immutable record, which stores all transactions, is easily audited and publicly available, if it is a public blockchain. Private blockchains may still be audited by permissioned members, still allowing for monitoring. Nonetheless, participants can easily review previous history and confirm the legitimacy of activity on the blockchain. This means that every token or coin on a blockchain can have its full history traced from address to address, which means there is a clear audit trail. Since the ledger is publicly accessible, the data on a blockchain can be verified by any participant, reducing the risk of fraud.

When understanding the role of blockchain in trust and transparency, one must first understand how the relationship between trust and transparency arises. Transparency is the absence of asymmetric information; it occurs in markets where individuals have information on the quality of goods and services. Asymmetric information is linked to inefficient markets, exemplified by the infamous Lemon's Problem.[43] In terms of VCMs, this manifests as buyers not knowing the quality of the carbon offsets they are purchasing. Essentially, there is a risk for buyers of purchasing a poor-quality VCC; transparency is a way to resolve risk and create trust. This ability to resolve risk has been well studied in two relevant strands of literature: governance and supply chain.

First, the relationship between trust and transparency has been well-studied in corporate governance, where organisations that are more transparent in their governance tend to have higher levels of stakeholder trust;[44] this result is also paralleled in the public policy literature. The participation of corporations in the VCM is often used as a tool for CSR. In participating in CSR, especially regarding the corporations' environmental impact, it is important that stakeholders are able to transparently evaluate the corporation's actions. The overuse of environmental claims, especially in regard to actions that are in fact not environmentally friendly, is known as greenwashing. Greenwashing has been directly linked to lower levels of green trust in corporations,[45] a result that can be mitigated by improving traceability of carbon offset purchases using blockchain. Second, there are similar findings linking transparency to trust in product markets, where supply chain transparency leads to increased consumer trust and willingness to purchase products. Yavaprabhas et al. provide a comprehensive literature review on trust, transparency, and the role of blockchain in developing this in supply chains.[46]

Transparency and trust play multiple roles when we consider the lifecycle of carbon credits. In Figure 1.3, we are reminded of the roles in the VCC value chain. Having trust and transparency improves all processes in the value chain and provides significant benefits in role 6, the trading and utilisation of carbon credits. More specifically, they have implications in CSR, VCC quality and traceability, and market participation. We will briefly discuss VCCs as a product that buyers obtain with the goal of using the credits to offset their carbon emissions. Traditional registries have put in good effort to maintain transparency and trust. For instance, the utilisation of public, searchable registries by Verra and Gold Standard ensures transparency and allows credits to be attributed to both their sources and end-users, where the end-user is the user that claims the credit upon retirement. Despite these efforts, issues such as greenwashing and over-issuance have been reported, raising questions about the quality of carbon credits, ultimately putting into question the ability to trust carbon credit impact claims. The existence of fragmented standards does not help matters; the risk of double-counting carbon credits is difficult to estimate, given the extent of fragmentation and lack of full transparency.[47]

The ability for participants to directly participate in maintaining and governing blockchains also increases trust. Increased participation in a blockchain network enhances trust by decentralising the network, making it safer and more secure. Commonly used Proof-of-Stake protocols have embedded mechanisms that incentivise honest behaviour in the nodes, since participant nodes must put up collateral to support their validations. Although there are still challenges with this approach, with a sufficiently decentralised network, this mechanism enhances trust and improves the reliability of the data. Similarly, many blockchains are governed through Decentralised Autonomous Organisations (DAOs), allowing the community to directly participate in decision-making, increasing the probability of resulting in a transparent and fair system.

Although blockchain appears to improve trust in the system, not all proponents agree that blockchain is a trust-enhancing technology but rather a technology used to navigate trustless markets. In the absence of trust, users can rely on the application of smart contracts, using blockchain technology, to facilitate transactions. Smart contracts can automate and enforce agreements in situations where participants do not trust each other; this technology provides additional security and reduces the need for trust. Primarily, smart contracts are used for financial and legal transactions in the digital space.[48] Even the willingness to use a smart contract itself can serve as a signal to a user's authenticity, reducing information asymmetry in transactions.[49]

Blockchain technology's ability to enhance transparency and trust has direct and tangible benefits for tokenised VCCs. First, tokenised carbon credits can be easily traced back to their original projects, but many protocols directly link project metadata to carbon tokens, negating the need to audit the original registry but rather allowing important information to be easily referenced. It is also common for carbon token marketplaces to provide full project information, increasing verifiability, especially for projects that can be electronically monitored. Even in the event of project information being difficult to access, the availability of a public ledger to all participants means that the full history of the credit can be traced back to its origination point. A publicly available ledger also allows regulators to verify data and reduces the risk of double-counting.[50] Double-counting, under the tokenisation method we discussed earlier, is typically prevented by retiring the underlying credits in a custodial account on the underlying registry upon tokenisation and later retiring the tokenised credits in a digital custodial account when the offset is requested by the user. There is also the potential for native tokenisation with their own standards, which has the added benefit of ensuring that carbon credits are exclusively represented by a specific carbon token, avoiding coordination issues with physical registries.

The ease of auditing the public ledger has a few important benefits. First, the balances of carbon credits held by organisations are publicly available on the organisation's related wallet addresses, which stakeholders can easily audit. This is especially true when an organisation has a single wallet where all its carbon credits are held and has publicly verified its wallet address. This is far more efficient to audit in comparison to existing systems, where multiple registries would need to be checked. The ability to view all blocks on a public ledger can also improve price discovery, especially if carbon tokens are purchased with another cryptocurrency. In some types of markets, this transparency can have negative effects due to not being able to hide transactions,[51] however, the general VCM would benefit from this transparency.

How does this all translate to an opportunity for carbon tokenisation? It is well documented in the financial literature that trust increases market participation.[52] We could reasonably expect this observation to apply to carbon token markets, especially as more data becomes available. Increased participation in VCMs would mean increased access to funding for carbon mitigation and sequestration projects. This would materialise in lower interest rates on funding with more projects being funded, ultimately leading to positive environmental and social benefits.

Case study: Toucan protocol

Earlier, we discussed in brief the Toucan Protocol and how it has affected carbon tokenisation. In this section, we expand on how it exemplifies trust and transparency by implementing a blockchain solution in the VCM. This case study will detail the mechanisms of transparency and provide an example of how carbon credits can be traced to their origin.

The Toucan Protocol was founded in 2021 with the aim of providing improved transparency in the VCM. It focuses on partnerships with traditional VCC registries, currently with Puro Registry, to bridge traditional VCCs onto the blockchain, where the credits can then be traded with instant settlements, providing full data transparency on the source of credits and verifying any retirements. Since its inception, it has facilitated the trade of over USD 4 billion of carbon credits, retired nearly 300,000 tonnes of credits, and bridged over 20 million credits.[53] As part of its core business values, Toucan aims to embody the 10 core carbon principles.[54] As of 2024, Toucan has announced collaborations with major organisations such as the World Economic Forum, Gold Standard, and the World Bank, solidifying its importance in the international drive to enhance VCMs. Having previously engaged in tokenising Verra's VCUs, Toucan has shifted to its current focus and partnership with the Puro Registry, tokenising biochar carbon, due to a ban on tokenisation by Verra and Gold Standard for their credits.

Toucan's bridging process is closely aligned with that outlined earlier in Figure 1.4. To begin the bridging process, a user must hold the Puro Earth CORCs (CO_2 Removal Credits) they wish to bridge and hold them in their registered Puro Earth account. The user then requests the initiation of bridging directly from Toucan; at this point, the user provides the serial numbers and project name of the credits from Puro they would like to tokenise. They then specify the wallet address to which they wish to send the tokenised credits. Once the request is received, Toucan locks the corresponding CORCs on the Puro registry through an integrated API, preventing double tokenisation. Next, an NFT is minted, attaching the project's metadata to the token using a smart contract. Then, the NFT is sent to Toucan's Biochar pool, and subsequently, fungible CHAR tokens are minted on the Celo blockchain using ERC-20 standards. These fungible tokens are then deposited into the user's account with one CHAR token for every one CORC bridged. Given its integration with the Puro registry via an API, Toucan has also developed the means for a two-way bridge so the user can convert their digital CHAR tokens back into active Puro CORCs. This API integration also allows for better handling of retirements; for example, when a user wishes to retire a CHAR token, claiming the carbon offset, the carbon token is retired on-chain while a retirement request is simultaneously sent to the Puro registry. The Puro CORC is then retired, and the digital CHAR token is destroyed. Since these processes are digitally integrated, they occur within minutes.[55]

To exemplify the transparency of this process, we examine the traceability of the CORCs underlying Toucan's Biochar pool. On Toucan's website, there is a dashboard dedicated to displaying data on its carbon pools and the underlying projects.[56] In this application, the user can clearly see the current composition of the carbon pool, broken down by blockchain. This shows the total amount of bridged carbon along with retirements and prices. In its explorer section, the user can directly view projects that have been bridged from Puro and deposited into the carbon pool; every project contains the unique project ID from the Puro Registry as well as the full project data, including all metadata and related documents. To confirm the status of the CORCs on the Puro registry, the user can simply look up the project ID and find the full details of CORC issuances related to the project. To distinguish credits bridged by Toucan from other retirements, Toucan makes sure to list 'TOUCAN' followed by the corresponding address into which the tokenised credits were deposited to ensure the user of the Puro registry can identify the credits attributed to Toucan's bridge. One can even audit all bridged credits directly on the Puro registry by searching 'Toucan' in the retirement purpose field; here, the full portfolio of pooled CORCs would be displayed to the user.[57]

The Toucan Protocol is a great example of how blockchain can enhance trust and transparency in VCMs. Although Toucan is providing an innovative and integrated solution with Puro Earth, there are still more opportunities to enhance transparency and trust, such as providing digital project audits directly to token holders from the underlying projects, providing additional evidence of the actual environmental impact underlying the tokenised credits. Going forward, collaboration and integration with Verra and Gold Standard would enhance trust in Toucan's pooled tokens as these organisations have strong reputations built on existing public trust.

8.3 Efficiency and scalability

The decentralised nature of blockchain eliminates the need for intermediaries by automating transactions, thereby reducing transaction time and costs. Often, blockchain transactions are settled through smart contracts, which ensure instant and error-free settlement. In the carbon lifecycle, smart contracts can be employed to automate steps throughout the lifecycle of a carbon credit. In the early days of blockchain technology, there were concerns about long transaction times and scalability. However, these concerns have been almost entirely resolved with the current state of the technology.

Blockchain is especially suited to handle large transaction volumes efficiently, especially with recent innovations. Ethereum, the largest blockchain currently, is frequently used by blockchain initiatives and is often employed in carbon tokenisation solutions. Previously, the Solana blockchain had the highest transaction-per-second capacity, being able to handle up to 65,000 transactions per second.[58] After the recent Dencun update[59] to the Ethereum blockchain, on 13 March 2024, Ethereum's Layer 1 capacity expanded to be able to handle up to 100,000 transactions per second.[60] For perspective, Ethereum is widely used by many tokens and coins. Its highest number of daily transactions to date has been 1.96 million,[61] which corresponds to an average of 22 transactions per second. Even more frequently used blockchains, such as Solana,[62] report average transactions well below the upper bound for both Ethereum and Solana. This means scalability, at least in the current market, should not be an issue with blockchain solutions.

Another concern noted with using blockchain technology is the need for nodes to store the data of the blockchain. Since blockchains record every transaction to have occurred on-chain, the data storage requirements can be quite extensive. For instance, the current size of the Ethereum blockchain is approximately 1.12TB,[63] although recent developments with Dencun have enabled transaction data to be compressed, reducing data storage requirements. A better solution to this problem is the implementation of Layer 2 solutions, which function as secondary chains off the main blockchain (Layer 1) and then periodically align the transaction record back with the main chain.[64] Layer 2 solutions increase transaction speeds, lower transaction costs, support greater scalability, and enhance user experience. The Polygon blockchain is a well-known application of a Layer 2 solution.

The current VCM has experienced significant inefficiencies where existing infrastructure leads to long processing times in every part of the carbon credit lifecycle, largely due to the proliferation of manually managed processes. The average project registration process alone can take several months to years to complete. In fact, the 2023 survey conducted by NASDAQ to survey participants of all parts of the carbon credit lifecycle showed that 25% of respondents rated traditional VCM as inefficient or highly inefficient.[65] These difficulties translate to realised impacts on project developers and carbon credit buyers. Projects face funding challenges, especially cash flow problems when faced with long registration and processing times. Additionally, projects may lack the resources to navigate the administrative burden and engage in MRV processes, especially problematic for smaller projects, often excluding them from the VCM entirely. Secondly, poor market accessibility and transparency lead to higher costs. The MRV burden and high intermediation costs contribute to higher carbon credit prices and transaction costs. Additionally, the difficulty navigating existing carbon marketplaces can be complex, leading to even more participation barriers for buyers. While there are some existing carbon exchanges, such as the Carbon TradeXchange, that purport to offer scalability and efficiency, the reality is that they lack the efficiency and transparency that can be realised by employing blockchain solutions.

Blockchain can be implemented in the current carbon credit lifecycle either fully, providing end-to-end coverage or covering partial roles. Currently, most projects play partial roles in the lifecycle, primarily covering the trading and marketplace process. However, using Web3 technology, an end-to-end solution is possible, where all tasks are automated and built on infrastructure that integrates fully and seamlessly. For example, the utilisation of the Internet of Things (IoT) can provide real-time data collection and monitoring for many projects, such as measuring renewable energy generated by solar power projects. This enhances the accuracy and reliability of carbon credit verification while simultaneously making monitoring cheaper and more efficient. Carbon trading and marketplaces have already been vastly improved by blockchain technology. Blockchain has been shown to minimise transaction costs, allow for 24/7 trading, improve information transparency, and provide automatic execution of trades. In comparison, the largest traditional exchange can settle transactions instantly; however, it largely relies on auction mechanisms to sell large batches of carbon credits, significantly extending the amount of time required to find a suitable buyer.[66]

Here, we have outlined exactly how blockchain technology itself is efficient and scalable. There are many inefficiencies in the existing VCM, inefficiencies that can be fixed through the implementation of blockchain and Web3 solutions. Improvements in efficiency would directly translate into improved accessibility for both project owners and buyers, propelling forward many smaller carbon initiatives and participants. While it is difficult to estimate the future requirements of a blockchain-based carbon credit solution, given the current capabilities of the technology and its rate of improvement, the technology itself is doubtful to restrict the ability of the network to meet demand.

Case study: Coorest

We briefly discussed the implementation of an end-to-end solution as a potential application of blockchain in the carbon space to effectively reduce all existing inefficiencies with the current VCM. Here, we look at a case study that works on doing exactly that. Coorest was founded in 2021 with the aim of improving transparency and efficiency in the existing VCM. They implemented an end-to-end solution utilising several Web3 integrations to achieve a fully digital and decentralised carbon tokenisation solution.[67] They focused exclusively on forestry projects. Here, we detail the implementation of this solution and the realised efficiency gains.

Having developed its own certified standard, the Coorest Carbon Standard allows for the native tokenisation of carbon credits rather than bridging credits from other registries.[68] As administrators of its own standard, Coorest has reduced registration fees for project owners and simplified the registration process. Project owners can register their projects directly with Coorest, although there is still extensive work required to provide appropriate documentation to ensure project eligibility and quality as in traditional registries. However, once the project is registered, the process becomes streamlined. For every tree digitally documented, Coorest issues an NFTree, which represents the real-world asset. Once the NFTree is issued, digital monitoring, reporting, and verification (dMRV) are carried out by Coorest by using a Web3 integration with Chainlink, where API data is requested from Floodlight's biomass satellite data.[69] This allows off-chain data gathered by Floodlight to come on-chain and verify a project's carbon credits. All project data is maintained in the CCS Registry and is regularly updated with yearly monitoring reports generated by the satellite data feed. Having digitally verified the project, each NFTree then mints a CCO2 token for every kilogram of CO_2 absorbed by the tree. NFTrees can be bought and sold in the Venly Marketplace, another Web3 integration. The CCO2 token also currently trades on the Polygon blockchain but has no dedicated marketplace as of 2024. Having obtained CCO2 tokens, the user can decide to retire them and claim the offsets directly through Coorest's decentralised application.[70] The retirements are recorded, and token holders are issued a Proof of Carbon Compensation (PoCC) Certificate, which is an NFT recorded on the Polygon blockchain.

The solution offered by Coorest presents a good example of how Web3 applications can be leveraged in the carbon credit lifecycle to automate processes such as MRV that are otherwise difficult and costly. Issuing blockchain-native credits also removes many inefficiencies and issues in the lifecycle of a carbon token when compared to carbon bridging; both minting tokens and retiring tokens are streamlined and automated.

8.4 Innovation and new markets

8.4.1 Technological innovations

Blockchain technology is constantly changing and evolving, which means that this technology can increasingly support new applications. What started out as a relatively simple cryptocurrency in 2008, has evolved into several more advanced applications. Improvements in technology will inevitably lead to more widespread adoption and applications. In the carbon credit market, tokenisation would not have been possible without the advent of these technologies, so they serve as drivers for sustainability and change.

One of the major innovations in this market that has allowed for the creation of tokenisation has been the development of smart contracts. While a relatively established idea,[71] the technological implementation and widespread use did not occur until the rise of smart contracts alongside the creation of Ethereum in 2015.[72] Smart contracts allow for advanced contract programming that automatically executes based on preprogrammed conditions. These contracts provide opportunities for integration within the VCC verification process, especially with their ability to integrate with other data sources into the blockchain. Additionally, the contracts can be programmed with dynamic pricing mechanisms that can adjust based on underlying conditions. As an example, a possible implementation could be to adjust the carbon credit price on the first sale based on underlying measures of carbon credit quality collected from prespecified data sources. Where this technology really presents an opportunity for market advancement is through its integration with emerging technologies such as the IoT and other digital monitoring technologies, including geographic information systems (GIS) and remote sensing. For example, initial satellite imagery can be used to assess the project zone of a reforestation project. Once trees are planted, soil monitoring sensors can be deployed in the soil to collect real-time data on soil conditions. Meanwhile, growth monitoring can be conducted by regular analysis of satellite imagery. Once appropriate milestones are met based on data from monitoring, smart contracts can ensure the automatic issuance of carbon credits. Together, these technologies can provide real-time project reports and allow for continuous time monitoring, in comparison to the discrete monitoring used in the current VCM, where reports are conducted at certain intervals, commonly only yearly. This technology plays a strong role in enhancing transparency, trust, efficiency, and scalability, which we discussed earlier.

Not only do smart contracts provide opportunities for continuous monitoring, but they are the foundations for Web3 technology[73] that can be implemented to decentralise the entire VCM. The adoption of Web3 represents the shift from centralised to decentralised systems; this hinges on employing smart contracts to automate delivery. A full Web3 solution could cover automated verification and issuance of credits, facilitate trade, automate retirement processes, provide decentralised governance to the network, and integrate into existing systems. With Web3 comes the emergence of DAOs where governance is carried out among participants of the network by leveraging smart contracts;[74] this again has benefits to the earlier discussed topics, especially for transparency and trust. Overall, the innovation of smart contracts is adaptable and can be implemented in creative ways. We have only outlined some of the applications in the basic VCM, but other applications, such as creating new financial instruments can be carried out using this technology.

Smart contracts can allow for the construction of complicated financial instruments without the need for intermediaries. Utilising the technology, advanced contracts can be programmed to execute automatically. When looking at the traditional carbon credit activity, only 61% of activity is carried out in spot markets. Carbon forward markets make up the other 39% of all carbon credit activity.[75] Currently, tokenised credit transactions are almost entirely concentrated in spot markets. The utilisation of smart contracts in developing carbon forward tokens represents a significant opportunity that would likely enhance the flow of funds to projects in developing countries. Allowing projects to obtain funding in advance to support their projects rather than waiting until project maturity to cash in on gains.

8.4.2 New markets

CSR has become an increasing concern for stakeholders and has been a well-documented phenomenon that will continue to grow; 67% of corporate demand for VCCs is driven by stakeholder demand and 33% by demand to meet net-zero commitments.[73] We also see an increasing amount of disclosure of sustainability information by companies, driven by changes in stakeholder expectations as well as developments in regulation and reporting requirements.[76] Carbon tokens can be used to meet these goals of both CSR and net zero commitments by companies while providing traceable impacts for stakeholders to view. The adoption of carbon tokens in supply chains also has the ability to be implemented in supply chain monitoring, which presents an interesting opportunity for companies to further improve the traceability of their net-zero actions.

While the primary demand for VCCs comes from corporations, we are also seeing trends in consumer markets for VCCs. There is increasing demand and interest in carbon credits from consumers; many consumers note issues with the existing VCM as barriers to participation.[77] Most of these barriers, such as transparency and pricing inefficiencies would be at least partially resolved by adopting carbon tokenisation; however, additional efforts to inform consumers about the technology may be required to precipitate adoption. In this market, there are solutions increasingly targeted towards consumers, such as personal carbon footprint calculators and the ability to integrate carbon offsets while making online purchases, but there is still more potential to launch blockchain solutions in this market.

Currently, there are no issued tokenised compliance carbon credits, but this may also present a significant market opportunity. There is an increasing level of interest in implementing a blockchain solution at the international level to serve the requirements of the Paris Agreement and improve country-level carbon accounting.[78] There have been a few initiatives that have aimed to explore this market, such as the World Bank Climate Warehouse, which tested the ability of the technology to fully integrate and fulfil the needs of markets and the UNFCCC.[79] This proposed solution aims to integrate the entire carbon credit ecosystem into an end-to-end solution for carbon markets, and it integrates independent, national, UNFCCC, and D4C registries. Even without tokenisation of the compliance market, there are some country-level compliance schemes that in fact accept VCCs as offsets against carbon taxes; for instance, South Africa accepts some Verra VCUs as offsets.[80] Given these possible integrations, the question of tokenisation in the compliance market becomes more nuanced with a possible goal of fully integrating all carbon markets into a unified system.

While these three markets represent most of the demand for VCCs themselves, there is also the matter of having a ready supply of projects to fill this demand. As we saw in Figure 1.2, developing countries are profoundly underrepresented by compliance schemes; as a result, the VCM plays an important role in providing representation of these countries in carbon markets. The fact is that as a world we aim to meet net-zero commitments, and this requires participation and representation in all countries. We have already developed the idea that blockchain would lower barriers to smaller projects, which more commonly operate in developing countries, allowing for their representation in the VCM. This outcome is critical for sustainable development, especially when we consider the spillover effects of investment in economies, and can be secured by improving VCM solutions, ensuring increased accessibility. Carbon forward tokens could play a significant role in reaching this market as we have so far seen that even though projects in developing countries are more likely to be tokenised, see Figure 1.6, least developed countries are still underrepresented in carbon markets. More research would need to be conducted as to why this is the case, but it is quite likely attributable to the lack of project viability absent additional funding opportunities. Overall, the global supply and demand of VCCs is sure to become increasingly important as the world races to mitigate climate change.

8.4.3 Case study: Senken and Vlinder in the world's first carbon forward token

Here, we look at a specific project and the impact of blockchain technology and financial innovation on funding sustainable development. We established the potential for tokenisation of carbon forward contracts; this solution was realised in 2023, when Vlinder and Senken launched the first carbon forward token.[81] The underlying project is a mangrove restoration project that aims to reforest 1500 ha of degraded mangrove along the Kwale, Kilifi, and Tana River counties in Kenya and remove 727,418 t of CO_2e. The project will not only result in carbon removals but also wider community benefits outlined in the project documents on Verra. For this project to take place, it required an initial investment of USD 537,500. It was expected that after 2–3 years of implementation, the project would issue enough carbon credits to be self-sustaining, by selling the issued credits on the market. However, the initial investment was critical to implement the project, as in many projects in developing countries, where funds are scarce. To serve this need, Vlinder provided the initial investment required while simultaneously issuing carbon forward tokens to cover these project costs.

The carbon forward tokens were initially sold on the Senken marketplace for the 2024–2025 carbon credit vintage. The mechanics of this project saw the issuance of a

FCO2 (a carbon forward token), initially issued and available for purchase on Senken. The idea is that subsequently, after the carbon credits are verified, this FCO2 can be swapped for a spot carbon token, a TCO2, and can then be retired as the holder claims the offset. This first vintage appears to serve as more of a pilot project for issuing carbon forward tokens, details are publicly available on the actual mechanics and details of the forward contract.[82] However, for the vintages from 2026 onwards, Vlinder has partnered with Solid World to sell the FCO2 tokens.[83] Here, there are more details on the mechanics and processes underlying the contracts.[84] Vlinder has guaranteed the delivery of the VCCs against the forward tokens to be delivered no later than 60 days after the credits have been issued by Verra. Solid World retains Forward Clips against every Forward Contract issued and from this creates a Collateralized Basket Token (CBT), which is the pool of Forward Clips. Buyers can then purchase Forward Clips from the pool. At any point, the Forward Clip holder can redeem the contract for the underlying Forward Delivery Commitment (as long as certain conditions are met).[85] This implementation of forward tokens remains to be fully explored and represents a significant opportunity, given that 39% of the traditional VCM is concentrated in forward markets.[86] Although there are some working implementations of forward tokens,[87] many of the contract details and legality are currently unknown.

8.5 Diversification benefits

Carbon credits also offer the potential for investors to invest in a new asset class, translating to portfolio diversification benefits. Some medium-term studies empirically show increased Sharpe ratios from investing in carbon forwards Swinkels and Yang show diversification benefits on the risk-return of portfolios when holding compliance carbon futures; however, this type of portfolio increases liquidity risk due to frictions in current carbon markets.[88] Additionally, they find that there is a poor correlation in prices across regions, suggesting the presence of global diversification benefits. More recently, Behr, Mueller, and Orgen[89] showed diversification benefits from investing in VCC futures in addition to compliance futures, yet there are still market efficiency and liquidity issues. It tends to be more difficult for individual investors to invest in these derivative markets, given the relatively large number of underlying credits and the cost relative to individual investor portfolios. Here, blockchain solutions, by permitting fractional ownership, especially in pooled tokens, can allow individual investors to enter this market and obtain additional diversification benefits for their portfolios.

Another consideration is the diversification benefits of the carbon asset class in managing long-term risks, particularly climate risks, such as physical and transition risks. The literature looking at short-term and cross-sectional effects of ESG diversification tends to find benefits of diversification into carbon-related assets.[90] However, several papers suggest climate risks should be distinctly evaluated in portfolios as distinct risk factors to hedge against. Chepni et al. show that the diversification benefits from investing in ESG assets in general depend on the type of climate risk being hedged against, where there are stronger effects of hedging against physical climate risk in comparison to transition risk.[91] This means that during periods of high physical climate risk, it is beneficial to invest in ESG assets, while this relationship is not so apparent for managing transition risks of portfolios. Both transition risk and physical risk are difficult to quantify, leading to difficulties in portfolio optimisation. However, across many studies, there appears to be evidence that ESG-related investments, and especially direct investments in carbon credits, can help reduce portfolio risk. As transition and physical risk increase, carbon credits as an asset class are increasingly important for investors looking to hedge against these risks.

9 Regulatory considerations

Implementations of carbon tokens must take into consideration the applicable regulatory frameworks that apply to them, which are steadily increasing in number as efforts to regulate crypto assets become more important. In the European Union, the Markets in Crypto-Assets Regulation[92] intends to provide a comprehensive framework for regulating crypto assets. Comparatively, in the United States, there is debate on whether carbon tokens are classified as securities falling under the purview of the Securities and Exchange Commission or the Commodity Futures Trading Commission. The purview depends on whether carbon tokens meet the Howey Test criteria.[93] Regulating the VCM itself is another important consideration since regulation in this market would likely improve trust and transparency, which we have established as being critical to having well-functioning markets. Here, we have questions, such as how to reconcile the fragmentation in the market and ensure the issuance of high-quality carbon credits. This becomes especially important as we consider the increasing number of integrations of VCCs into national compliance mechanisms, as in Colombia[94] and South Africa.[95] Additionally, since 2022, Verra[96] and Gold Standard banned the unauthorised tokenisation of their carbon credits, so not only do national laws need to be considered but the terms and conditions of voluntary carbon registries must be followed. Overall, the existing and emerging regulations applicable to tokenising carbon credits are complex and multi-fold; other chapters in this volume discuss the nuances with existing regulations and how they may apply to tokenised carbon credits.

10 Outlook and potential

Overall, blockchain's ability to support DAOs will likely be instrumental not only for overhauling the current VCM but possibly other financial markets as well. Given the concerns regarding transparency, quality, efficiency, and general market issues in the current VCM, it would seem that blockchain solutions can entirely address the current shortcomings. However, it should be noted that decentralised networks are secure and safe only when they have a high number of independent, distributed participants. As a result, when structuring new blockchain solutions, it is paramount to consider the potential vulnerabilities of the technology to ensure successful implementation.

Carbon forward tokens also provide a significant opportunity in the carbon tokenisation market, especially considering the prevalence of forward tokens in traditional markets. There is a clear demand for forward tokens, which would prove instrumental in directly providing project funding to small projects.

Carbon tokens not only enable individual investors to meet their carbon reduction goals but also increase the flow of funds to developing countries through the VCM, supporting low-carbon and carbon-removal projects. This is vital to the global goal of achieving net-zero emissions since currently developing countries are poorly represented by compliance emissions schemes. Investment in carbon tokens would thus lead to direct effects of reducing CO_2e in the atmosphere and transferring funds to least developed countries, where they are most needed. Overall, using blockchain in the VCM presents an opportunity that is still relatively underdeveloped and has the potential for high impact.

11 Conclusion

We have examined advancements in the climate change discourse and regulations that have led to concerted global efforts in addressing climate change. Although the percentage of carbon emissions covered by compliance schemes has risen over the past decades, there is still low emission coverage by such schemes in developing countries. Tokenisation of carbon credits presents a solution to many of the issues that inhibit the potential of the VCM to have a strong impact on climate change. We established that blockchain technology would greatly improve market efficiency, which would ensure that funds go to projects that can best use them to reduce and capture atmospheric carbon emissions. The VCM plays an important role in remedying the lack of representation of compliance emissions schemes. We have also explored how tokenisation can further remedy this, especially through issuing carbon forward tokens that could provide pre-funding to small projects that would otherwise not be able to take place.

Carbon tokenisation is not one unified process but rather encompasses several different processes implemented by organisations that find unique ways to use blockchain across the carbon credit lifecycle. The development of two-way carbon bridges and end-to-end solutions appears to be the most promising and comprehensive solutions, but the optimal solution is difficult to predict currently. We have focused on outlining the opportunities for carbon tokenisation, drawing upon several sources to support our conclusions, including technical whitepapers, industry reports and surveys, and related academic research. It is clear that solutions in this market will rely on diverse stakeholders coming together to reach an optimal solution, especially considering the complexity of the market. Good solutions require expertise from climate experts, lawyers, governments, economists, corporations, and individuals. By considering blockchain technology as a solution for the VCM, and potentially the overall carbon market, policymakers could optimise the market for higher impact, contributing better to the global goal of mitigating climate change.

Notes

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