

## *Original Paper*

# The Application of RWA Tokenization in Carbon Credit Assets

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### **Abstract**

*Under the goal of global carbon neutrality, the carbon market faces challenges such as insufficient liquidity, low transparency, and uneven credit quality. Blockchain and RWA tokenization provide an innovative path to solve these problems. This paper uses multiple case studies to find that tokenization can significantly improve the liquidity, price discovery efficiency and traceability of carbon assets, but it also brings new risks at the technical, financial and regulatory levels. It provides theoretical basis and practical guidance for policy makers to design “regulatory technology” programs, financial institutions to develop green financial products, and blockchain project parties to design compliance agreements.*

### **Keywords**

*RWA tokenization, carbon credit assets, carbon neutral*

## **1. Introduction**

As the global carbon neutrality process is getting faster and faster, carbon market transactions have also received more attention. The carbon pricing mechanism, especially the Carbon Emissions Trading System (ETS), gives a clear price signal of carbon emissions, internalizes the external costs of the environment, and encourages market players to achieve emission reduction targets with the lowest total social costs. At present, there are 36 carbon markets in operation around the world, covering about 18 % of global emissions, of which the EU carbon emissions trading system and China’s carbon market have become the two pillars. Although the scale of the carbon neutral market has expanded rapidly, the fundamental contradictions behind it still exist. On the one hand, the urgency of climate action requires that the carbon market can play a greater role. On the other hand, the infrastructure and operation mechanism of the existing carbon market still face severe efficiency and trust crisis, such as the fragility of data quality and accounting system, liquidity stratification and market fragmentation, insufficient quota allocation and scarcity.

When the traditional carbon market encounters difficulties, Web3 technology, represented by

blockchain and smart contracts, brings a profound change related to value representation and value transfer. Real World Assets (RWA) tokenization is seen as a key breakthrough in the penetration of blockchain technology from the pure digital world to the real economy and financial infrastructure. The core idea of RWA tokenization is to convert the ownership or usufruct of traditional financial assets or physical assets into blockchain and programmable digital tokens; the potential benefits of this transformation can be said to be subversive: first, it is more liquid and more separable, which can fragment the assets that can not be segmented, so that smaller investment units can be allowed to enter the market, and the foundation of investors can be greatly broadened. Second, all transaction records will be placed on an open, non-tamperable distributed ledger, who can verify the transfer history and current status of assets, transparency and traceability are relatively high; third, it can realize the automation of transaction, liquidation and settlement through smart contracts, so that the transaction efficiency can be greatly improved, and the delay and human error of intermediaries can be eliminated. At the same time, tokenized assets can also be more smoothly connected to the decentralized financial (DeFi) protocol to achieve more complex financial innovations such as borrowing, pledge, and liquidity mining.

By the end of 2023, the RWA tokenization market has moved from the early stage of concept verification to large-scale exploration. Some large financial institutions around the world, such as Goldman Sachs, Siemens and HSBC, are also laying out related projects. This trend can provide a new imagination space for solving the problems of the traditional carbon market. In recent years, a number of innovative projects such as Toucan Protocol, C3 Protocol, KlimaDAO, MOSS Earth, etc., have begun to actively explore this field. They try to build a “bridge” connecting the traditional carbon registration system and the blockchain world, to tokenize thousands of tons of carbon credit, and then create considerable liquidity on decentralized exchanges.

## **2. RWA Tokenization Enables Carbon Credit Market**

### *2.1 RWA Tokenization*

The so-called real world asset tokenization is the process of transforming those non-digital physical assets in reality, as well as the income rights and contract rights related to them, into digital tokens with the help of blockchain technology. Zou (2025) pointed out from the perspective of monetary banking that tokenization is actually to complete the holding, trading, clearing and settlement of assets through tokens. What it produces is called digital assets. The core value of tokenization has these aspects: first, it can reduce the investment threshold through asset segmentation and improve liquidity; second, it is possible to automate transactions by smart contracts; third, it can use global accessibility to broaden the basis of investors. The research of Jixiang Technology (2025) summarizes the core value of RWA into three major dimensions, namely, the improvement of liquidity, the diversification of financing methods, and the capitalization of data. Zou (2025) also made a profound theoretical exposition of the token paradigm. He pointed out that in various forms of money, only cash is in physical form and does not

depend on accounts. As a digital credential in the blockchain, tokens not only achieve cash-like features in the digital environment, but also go beyond cash.

### *2.2 Carbon Credit Market*

Carbon market can be divided into two basic types: mandatory emission reduction market and voluntary carbon market. In the mandatory emission reduction market, based on the principle of “Cap-and-Trade,” the government sets the upper limit of total emissions, allocates quotas to emission control enterprises, and tradable quotas between enterprises. Representative markets include the EU carbon emissions trading system (EU ETS), China’s carbon market, etc. Voluntary carbon market (VCM) allows enterprises, organizations or individuals to purchase carbon credits from emission reduction or remittance enhancement projects to offset their unavoidable emissions. From the perspective of market mechanism, You et al. (2025) divided greenhouse gas emission reduction policies into two categories: price-based mechanism and quantity-based mechanism, and pointed out that effective market mechanism needs to have the characteristics of promoting compliance.

The voluntary carbon market is facing an increasingly severe crisis of confidence due to the lack of government endorsement. The frequent supply-side quality problems and demand-side problems reveal the systematic defects of carbon credit quality. In the face of challenges, all parties in the carbon market are actively taking various countermeasures. Initiatives such as the Voluntary Carbon Market Integrity Committee have established governance and quality benchmarks; the Scientific Carbon Targets Initiative and the Voluntary Carbon Market Integrity Initiative emphasize that carbon credits should not be a substitute for direct decarbonization; the EU’s Corporate Sustainability Reporting Directive requires large companies to clarify the quality of their use of carbon credits and their role in decarbonization efforts, thereby promoting the healthy and sustainable development of the voluntary carbon market.

### *2.3 RWA Tokenization Enables Carbon Credit Market*

After RWA tokenization empowers the carbon credit market, it will show the following attributes.

(1) Carbon credit tokenization has the attributes of non-materiality and environmental rights.

The essence of carbon credit token is not the “thing” in the traditional sense, but a certified certificate of interest for greenhouse gas emission reduction or removal. According to the provisions of the Verra VCS system, each unit of Verified Carbon Unit (VCU) represents the emission reduction or removal of one ton of carbon dioxide equivalent (CO<sub>2</sub> e), which is an intangible asset in legal nature. This immateriality will make the confirmation, verification and traceability of carbon credit highly dependent on the institutionalized MRV (monitoring, reporting and verification) system and authoritative third-party certification. As pointed out in the analysis of Chainlink (2026), the credibility of carbon credit on the chain depends on whether a “permanent, auditable link between the underlying environmental benefits and digital tools can be established”.

(2) Carbon credit tokenization has the dual credit attributes of environmental credit and financial credit. The fundamental value of carbon credit lies in the real, additional and permanent emission reduction

contribution it represents. If the underlying project fails to achieve the claimed emission reduction effect, or does not have additionality at all, the environmental credit of the carbon credit is flawed. If low-quality carbon credit is largely tokenized and enters the financial market, forming the effect of “bad money drives out good money”, financial innovation will aggravate the dilution of environmental credit. The mechanism design of carbon credit tokenization must establish an effective balance and coordination mechanism between the two.

(3) Carbon credit tokenization has strong regulatory dependence and institutional embeddedness.

It is different from the pure digital native cryptocurrency. The whole life cycle of carbon credit from generation to cancellation is embedded in the existing institutional framework. Any design of tokenization should respect the existing system and can be connected with the system interface to ensure the issuance, circulation and destruction of tokens on the chain, and can be strictly consistent with the state change of the registration system under the chain. This is the core constraint of carbon credit tokenization different from other RWA tokenization.

(4) Carbon credit tokenization is non-homogeneous.

The fundamental dilemma in the traditional carbon credit market is that each unit of carbon credit is actually a “heterogeneous commodity”. Liquidity requires that assets can be exchanged with each other, which is the core contradiction that tokenization wants to solve. That is to say, while turning heterogeneous carbon credit into standardized tokens, it can also maintain the traceability of the underlying asset attributes, so that liquidity can be brought up. The practice of Toucan (2025) shows that the liquidity of carbon credits can be increased by more than 300 % by depositing different attributes of carbon credits into the carbon pool and recasting standardized “carbon pool passes” (such as NCT).

### **3. Case Study: The Practice Mode of Tokenized Carbon Credit Assets**

#### *3.1 Toucan Protocol—Radical Bridging Mode*

##### 3.1.1 Project Overview

The Toucan Protocol was officially launched on the Polygon blockchain in October 2021. The core concept of Toucan is extremely radical, “mass retirement” of traditional carbon credit from the centralized registration system, and then “mass casting” into tokens on the chain, thus transforming the original non-standard, extremely illiquid carbon credit assets into standardized encrypted assets that can be freely combined and traded in the DeFi protocol.

In the early days of its launch, Toucan was indeed sought after by the market. According to official data, as of March 2022, it had bridged more than 18 million tons of carbon credit. The liquidity on the platform once reached tens of millions of dollars, which is one of the most influential projects in the Web3 climate racetrack.

##### 3.1.2 Technical Architecture: Carbon Bridge and Carbon Pool

Toucan’s technical architecture revolves around two core components: carbon bridge and carbon pool.

### (1) Carbon bridge: the mapping mechanism from the chain to the chain

Carbon bridge is a key component connecting Verra Registry and Polygon blockchain. Carbon credit holders hold VCUs (Verified Carbon Units) in Verra Registry. Users first need to create a “Toucan account” in the Toucan protocol and associate its Verra account to achieve account migration. The user then transfers the VCUs in his Verra account to Toucan’s “Consolidated Account” opened by Verra to achieve asset transfer, which means that the user has given up direct control over these carbon credits. After the asset transfer confirmation, Toucan’s carbon bridge invokes the smart contract on the chain, casting the corresponding TCO<sub>2</sub> (Toucan Carbon Offset Token) certificate. Each TCO<sub>2</sub> is an ERC-1155 standard token, which contains the metadata of the underlying carbon credit - project number, Vintage year, project type, issuance date, geographical location, etc.

The core innovation of this mechanism is to “exchange under-chain cancellation for on-chain casting”. Users lose direct control of the offline carbon credit, but obtain TCO<sub>2</sub> certificates that can be freely traded on the chain.

### (2) Carbon pool: the transformation mechanism from heterogeneous to homogeneous

Although TCO<sub>2</sub> has realized the tokenization of carbon credit, it still retains the heterogeneous characteristics of the underlying carbon credit-TCO<sub>2</sub> of different projects and different years, which cannot be directly exchanged with each other. In order to solve this problem, Toucan introduced a carbon pool mechanism. Its core logic is to store a specific type of TCO<sub>2</sub> in this pool first, and then create a standardized carbon reference token.

The most famous carbon pool is BCT (Base Carbon Tonne), which represents post-2016 “natural carbon removal” projects (such as afforestation, reforestation, REDD + forest protection). Users can deposit eligible TCO<sub>2</sub> into the BCT pool and obtain BCT tokens in a 1: 1 ratio. BCT is an ERC-20 standard homogeneous token that can be freely traded on a decentralized exchange. The carbon pool actually performs the functions of asset classification and quality screening. The pool’s management team set the pool criteria - which project types, which Vintage years of TCO<sub>2</sub> can be stored. After users deposit TCO<sub>2</sub> into the pool, TCO<sub>2</sub> is “locked” in the pool and can no longer be redeemed alone. When users redeem from the pool, they get a randomly assigned, standard batch of TCO<sub>2</sub>, rather than the original one. This design transforms heterogeneous carbon credit assets into standardized liquidity units, which greatly reduces transaction costs and improves market efficiency.

## 3.1.3 Market Response and Characteristics

### (1) Market response

In February 2022, Toucan encountered a serious prophetic attack. The attackers used the price sliding point generated by the “two-hop” transaction between Toucan and the mainstream DEX (Decentralized Exchange) to extract TCO<sub>2</sub> from the carbon pool by manipulating the price of a low-liquidity transaction and then extracting TCO<sub>2</sub> from the carbon pool at a price far below the market price. The event exposed the security vulnerabilities in the design of the Toucan mechanism.

The fatal blow that Toucan really hit was actually from Verra, a traditional carbon standard agency. In

May 2022, Verra issued an official position statement, on the one hand, prohibiting everyone from continuing to link up the cancelled carbon credit line, on the other hand, it also announced that they were exploring the introduction of “immobilized” status in their own registration system to represent the tokenized carbon credit.

The large-scale, automated “retirement-on-chain” operation will make the ownership status and end-use of carbon credit become complex and vague once it reaches the chain, and it will be out of Verra’s regulatory line of sight. This situation has caused Verra’s concern; at the same time, the legal nature and jurisdiction of tokenized carbon credit are not clear now, which may lead to problems in regulatory arbitrage. In addition, Gold Standard also made a similar position during the same period. It stated in the registration clause updated in May 2022 that if you want to do any tokenization operation, you must first obtain the written consent of the platform. This regulatory response essentially stopped Toucan’s original mode of operation. Toucan himself had to pause the carbon bridge’s deposit function and start exploring new, more compliant paths.

### (3) Characteristics

Toucan’s practice reveals the core paradox of carbon credit tokenization: technical logic pursues de-intermediation, high efficiency and global circulation; the logic of the system requires accountability, auditability and supervision. The tension between the two is amplified to the extreme in Toucan’s radical mode. Toucan’s achievement is undeniable. It is the first project to bring carbon credit into the DeFi world on a large scale, which proves the feasibility of tokenization technology. However, its experience also shows that carbon credit tokenization cannot bypass the existing institutional framework. The particularity of environmental assets determines that its tokenization must be carried out under supervision, rather than free innovation outside supervision.

## 3.2 C3 Protocol—Compliance Priority Light Bridging Mode

### 3.2.1 Project Overview

After Toucan sparked some regulatory controversy, by the end of 2022, the C3 Protocol began to emerge, which represented a new tokenization path of “compliance priority”. The core idea of the C3 (Carbon Credit Commons) project, compared to Toucan, is not to do “bridging”, but to do “tagging”—that is, it does not change the ownership and status of the carbon credit in the original registration system, but only to create a transparent digital image on it.

### 3.2.2 Technical Architecture: Hosting + Mirroring + Redemption

#### (1) Hosting and Mirroring

Carbon credit holders transfer their carbon credits in the Verra or Gold Standard registration system to an off-chain managed account managed by a qualified custodian. After the custodian confirms the receipt of the carbon credit, the custodian mints a “custody receipt” token on the blockchain, which represents a beneficial or ownership certificate for a specific carbon credit in the custody account.

Unlike Toucan, carbon credit itself does not retire in the traditional registry. It is only transferred from the holder’s registered account to the escrow account, and only the ownership has changed. This means

that if the token holder ultimately does not choose to cancel, the carbon credit can still be transferred back to the original registered account or transferred to others.

#### (2) Trading on chain

Managed receipt tokens can be freely traded on the chain. Each transaction is recorded on the blockchain, forming a complete history of ownership changes. Since tokens always correspond to specific carbon credits with serial numbers in escrow accounts, there is no traceability difficulty caused by “bulk blending”.

#### (3) Redemption and cancellation

If the final buyer wants to really offset the emissions, it needs to perform the redemption operation: the token holder submits a redemption request to the agreement, and also specifies how many tokens he wants to cancel; then the smart contract will send the corresponding number of tokens to the destruction address, allowing them to permanently withdraw from circulation. The event of token destruction will automatically trigger an instruction that requires the escrow agency to officially retire the corresponding original carbon credit at the registry of Verra or Gold Standard; after the cancellation is completed, the registration system will generate a retirement certificate, which usually lists the token holder or its designated beneficiary as the “offsetting party”. This retirement certificate can be downloaded and archived, which can be used as evidence for ESG disclosure.

### 3.2.3 Market Response and Characteristics

#### (1) Market response

Instead of pursuing large-scale market exposure and retail users as Toucan did, the C3 Protocol chose an institutional development path that focused more on compliance and the bottom layer of technology. C3 Protocol obtained about \$ 9.6 million through primary market financing. Although this figure does not reach the level of some star projects, it also shows the recognition of its technology and compliance roadmap by early institutional investors. Its market influence is more reflected in the technical contribution within the ecology and the exploration of the compliance framework, rather than extensive user participation and secondary market trading volume. Unlike Toucan’s retail frenzy, C3 has opted for a more secure path - focusing on building an institutionally accredited, compliant underlying infrastructure. This choice makes it not well-known in the market, but also lays its position in the professional development of the industry.

#### (2) Characteristics

The advantages of C3 model in compliance are reflected in many aspects. First, it respects the rules set by traditional standard agencies-C3 will not ask Verra or Gold Standard to change their own operating rules. The issuance, transfer and retirement of carbon credit are still completed in the traditional system. C3 only adds a digital presentation layer called “managed receipt” to this system, so that it can avoid the question of “institutional bypass” encountered by Toucan at that time. Second, it has the verifiability brought by double auditing. The carbon credit in the C3 model will be subject to two sets of audits at the same time. One is the verification of the environmental benefits of the underlying

project by the traditional MRV system, and the other is the independent audit done by the escrow agency to ensure that the total amount of tokens on the chain is strictly consistent with the amount of carbon credit in the escrow account. Third, its regulatory path is clearer. The legal nature of the custodian receipt token is closer to the category of “asset-backed warrants” or “beneficiary vouchers” than “native encrypted assets”. This means that it can be regulated in accordance with the existing securities law, trust law, these frameworks, do not need a new legislation.

C3, a compliance priority model, of course, also brings obvious costs, which can be divided into the following aspects. First, the cost is higher-managed institutions, audit institutions, and legal advisers are involved, and the operating costs will naturally rise, and these costs will eventually be passed on to the end users. As a result, the carbon credit price under the C3 model may be higher than the low-cost model of Toucan. Second, the process will be relatively more complex. Users will have to do the KYC / AML review and sign the hosting agreement first. The whole experience is not as convenient as the pure decentralization mode of “trading with your wallet”. Third, liquidity will be subject to certain restrictions, because each escrow receipt token corresponds to a specific, serial number of native carbon credits, which are not as homogeneous as the BCT’s standardized carbon pool pass. The liquidity depth of this “semi-homogeneous “asset will usually be lower than that of fully homogeneous assets.

The future of carbon credit tokenization is not to replace the system with technology, but to enhance the system with technology. By designing the mechanism more carefully, such as the linkage of trusteeship, mirroring, and redemption - C3 can achieve the chain representation and trading of carbon credits without violating the rules of traditional standard institutions, which also provides a credible entry point for institutional investors and companies that value compliance.

### *3.3 China Carbon Neutral Development Group Carbon Coin Project—Compliance Model for Regulated Exchanges*

#### *3.3.1 Project Overview*

In December 2025, China Carbon Neutral Development Group (referred to as " China Carbon Group ") successfully issued 500 million carbon coins through the Singapore-licensed digital asset trading platform DigiFT, which has also become the world’s first carbon asset digital product issued on an overseas regulated online exchange. The core positioning of the project is actually to explore the path of RWA tokenization of carbon assets in the framework of compliance. The feature of the medium-carbon project is that its issuance and trading platform DigiFT itself is a licensed institution regulated by the Singapore Monetary Authority, which represents an “exchange-level “compliance practice.

#### *3.3.2 Technical Architecture: Green Chain Alliance Chain + Public Chain*

The underlying asset of the project is 500,000 tons of carbon credit certified by Verra VCS system. The project uses the “green chain alliance chain + public chain “collaborative technology architecture. The green chain alliance chain is jointly built by China Carbon Neutral Development Group and ecological

partners. It is used for the core compliance links of carbon credit confirmation, custody, and audit. The nodes on the alliance chain are held by licensees, audit institutions, and custodians, so it is legally accountable. The public chain is mainly used for trading carbon tokens, circulation, and DeFi integration, so that the public chain's liquidity advantages and global accessibility can be brought into play. These two sets of chain systems will perform data synchronization and asset mapping through cross-chain bridging protocols, and the two goals of "regulatory controllability" and "market efficiency" can be achieved.

Carbon credit is held by an independent trustee in Verra Registry, and China Carbon Group, as an issuer, cannot dispose of it on its own. The custodian will regularly submit a certificate of reserves to DigiFT and regulators, so as to ensure that the total amount of tokens on the chain is always consistent with the amount of carbon credits in the custodian account.

China Carbon Group issues carbon coins to qualified and institutional investors through the DigiFT platform. Investors need to complete DigiFT's KYC / AML review to ensure compliance. Carbon coins anchor the underlying carbon credit at a ratio of 1: 1,000,000, that is, one carbon coin corresponds to 0.001 tons of emission reductions, and investors can subscribe to a minimum of 1,000 carbon coins.

These carbon coins can be traded in the secondary market on the DigiFT platform. The platform will provide an order book trading system, which can not only support the traditional trading functions of limit orders and market price orders, but also use blockchain technology to realize T + 0 settlement, and transaction data can also be stored on the chain. When the end user wants to take the carbon coin to offset the emission, he can submit a redemption application through the DigiFT platform; after the platform is audited, it will trigger the trustee to write off the corresponding amount of carbon credits in Verra Registry, and then destroy the corresponding carbon coins. In this way, the user can get a legally valid retirement certificate, which can be used as the basis for his carbon neutrality statement.

### 3.3.3 Market Response and Characteristics

#### (1) Market response

From the publicly disclosed information, the market response of this project after the release is positive. The subscription multiple of institutional investors reaches 2.3 times, indicating that the market does have a demand for compliant carbon asset products. The trading volume of carbon coins exceeded USD 5 million in the first month of listing, and the price fluctuation range was relatively stable. There was no large speculative fluctuation like Toucan or BCT in the early stage, and the secondary market performed well. In the future, the project side has plans to connect carbon coins to the DeFi protocol to try innovative applications such as carbon credit-supported borrowing and pledge, and is also considering incorporating more types of carbon assets into the scope of tokenization.

#### (2) Characteristics

To achieve large-scale application of carbon credit tokenization, especially to obtain the recognition of institutional investors, compliance is an indispensable prerequisite. Of course, this model also has some limitations. At present, it is mainly for qualified and institutional investors, and the threshold for

individual investors is higher; the architecture of the alliance chain and the public chain increases the technical complexity; the “forerunner advantage” of Singapore’s regulatory framework may be difficult to simply replicate in other jurisdictions.

The core challenge of carbon credit tokenization is not the issue of technical feasibility, but how to interact with the institutional system of the traditional carbon market and find a balance point in the interaction. Specifically, Toucan’s more radical model, on the one hand, does show the potential of technological innovation, but on the other hand, it also exposes the risks that may be brought about by leaving the system; the C3 compliance priority model proves that “innovation in the framework of the system” can work; the licensed exchange model adopted by China Carbon Group provides a standard for large-scale application.

There is no one-size-fits-all optimal model, and different models are adapted to different application scenarios, investor types and regulatory environments. For innovative projects that pursue rapid mobility and user growth, the “radical” model may still be attractive; for institution-level applications and ESG scenarios, the “compliant” or “licensed” mode is more suitable.

#### **4. Risks and Challenges**

Carbon credit tokenization is a complex innovation across technology, finance, law and other fields. Its risk is not a simple superposition of risks in various fields, but a systematic risk that is intertwined and mutually causal. The failure of a single link may lead to a global crisis through chain transmission.

##### *4.1 Technological Risk*

Smart contract is the core operation carrier of carbon credit tokenization, which is responsible for the key logic of token casting, transfer, destruction and redemption. Once the smart contract code is flawed or maliciously exploited, it can lead to catastrophic consequences. For example, an attacker invokes the contract function recursively when the contract performs a transfer operation, and repeatedly extracts the asset before the state update; the contract does not perform boundary checking when dealing with large numerical calculations, and the attacker can use the overflow to manipulate the book balance. Therefore, smart contract vulnerabilities may directly lead to token issuance, asset theft, protocol paralysis, trust collapse and other results.

The prophecy machine is a middleware that transmits data from the chain to the chain. Carbon credit tokenization is highly dependent on the prophecy machine to provide three types of key data, reserve proof data, price data and external event data. If a prophecy machine relies on only a few centralized data sources, these data sources may be manipulated or provide false information. Therefore, the failure of the predictor may lead to the distortion of the carbon token price, resulting in the wrong liquidation of the loan agreement and the arbitrage loss of the traders.

Multi-chain deployment is a common strategy for carbon tokens to expand liquidity. The project side deployed carbon tokens to multiple public chains such as Ethereum, Polygon, Solana through cross-chain bridges to reach users of different ecosystems. However, the cross-chain bridge has become

a high-incidence area of safety accidents in the blockchain field. Many cross-chain bridges use the “multi-sign verification “mechanism, and the bridging funds are stored in an address jointly controlled by several verifiers. If the verifier’s private key is leaked or bought, the funds in the bridge can be stolen. The impact of cross-chain bridge safety accidents is usually very serious. For carbon tokens, the significance of cross-chain bridge risk is particularly special. The environmental integrity of carbon credit depends on its uniqueness and non-reusability. If the cross-chain bridge mechanism allows the same carbon credit to be “represented” on multiple chains at the same time, it fundamentally undermines the uniqueness principle of carbon offset, which is equivalent to the systematic fraud of “one carbon multi-use”.

#### *4.2 Financial Risk*

First of all, the liquidity of tokenized carbon assets is highly dependent on the depth and trading activity of the secondary market. However, there is a structural mismatch between the liquidity characteristics of carbon credit under the chain and the liquidity demand of tokens on the chain. The forms of liquidity mismatch include time, depth and information mismatch. In extreme cases, liquidity mismatch may evolve into a run. This risk is particularly prominent in the “partial reserve” model. If the agreement adopts a partial reserve mechanism, that is, the total amount of tokens on the chain is greater than the amount of carbon credit in the escrow account, and the difference is filled by the agreement’s own credit or liquidity tokens, in the event of a crisis of confidence, some reserves cannot cover all redemption needs, which will lead to catastrophic consequences.

Secondly, the tokenized carbon market is currently small and limited in depth, and it is easy to become the target of market manipulation. For example, manipulators artificially push up prices through false transactions or large numbers of buyers, attract retail investors to follow suit, and then sell heavily to make profits; the attacker borrows huge amounts of money through lightning loans, manipulates the price of decentralized exchanges in a single transaction, and uses distorted prices to perform cross-market arbitrage or trigger improper liquidation. The price signal of the carbon market plays a key role in guiding the allocation of resources. If the price is manipulated and deviates from the fundamental cost of emission reduction, it will have serious consequences.

Finally, due to the significant difference in the participant structure between the tokenized carbon market and the traditional carbon market, the tokenized carbon market has added a large number of encrypted native users and speculators. Such participants’ focus on price is often not the environmental value of carbon credit, but the trading opportunities brought by short-term price fluctuations. Therefore, this heterogeneity of participants may lead to increased carbon price volatility and speculative risks.

#### *4.3 Governance Risks*

First of all, the most central and unique governance challenge of carbon credit tokenization is that it is subject to two sets of independent governance systems at the same time. The under-chain governance is based on the rules of traditional carbon standard institutions, national or regional laws and regulations, and land ownership laws of project development sites; the on-chain governance is based on the

automatic rules defined by the smart contract code, the governance voting of the decentralized autonomous organization, and the multi-sign decision of the protocol team. There is no natural hierarchy or coordination mechanism between the two systems, and conflicts are inevitable. The governance institution of carbon standards under the chain controls the source of value, so it has the final veto over tokenization activities. If the governance on the chain tries to bypass or challenge the rules under the chain, it will face the risk of being forced to withdraw.

Secondly, many carbon token projects are governed in the form of decentralized autonomous organizations, claiming that “communities make decisions together”. However, DAO faces multiple difficulties in practice, such as insufficient voter participation, limited professional ability, and conflict of interest between the agreement team and the agreement. If the core decision-making members of the DAO lack constraints on environmental integrity issues, they may make short-sighted decisions such as reducing quality standards, expanding token issuance, and ignoring quality audits driven by the pursuit of economic interests, and ultimately damage the environmental value of carbon credit.

Finally, carbon credit tokenization is at the intersection of multiple regulatory areas, which can easily lead to unclear rules and management vacuum. Regulatory uncertainty is a major obstacle to the entry of institutional investors. Large institutions such as pension funds, insurance companies, and commercial banks need clear regulatory guidance and legal certainty before entering new assets. The current uncertainty makes the mainstream participants in the carbon token market still dominated by individuals and encryption funds, which limits the depth and maturity of the market.

## **5. Policy Recommendations and Future Prospects**

### *5.1 Recommendations to Regulators*

First, clarify the legal nature and regulatory attribution of carbon tokens. The ambiguity of the legal nature of carbon tokens is the core governance obstacle currently facing. Regulators should establish a hierarchical classification framework for different types of tokens based on the economic functions and risk characteristics of carbon tokens. Carbon tokens may also involve the terms of reference of multiple departments such as securities supervision, commodity supervision, and environmental supervision. It is recommended to appoint a lead regulatory agency and establish a cross-sectoral coordination mechanism, such as the “one-stop” model of MAS in Singapore. Regulators should also issue clear guidelines on the issuance, trading, custody, redemption and other aspects of carbon tokens to eliminate legal uncertainty.

Second, establish quality access standards for carbon credit tokenization. Quality dilution and adverse selection are the most serious environmental risks faced by the tokenized carbon market. Carbon standards agencies should work with regulators to develop minimum quality requirements for tokenized carbon credits. In addition, standard agencies can establish a “tokenized compatible” carbon credit list. Only carbon credits that meet specific standards are allowed to be tokenized, and a “white list” mechanism for tokenized carbon credits is established.

Third, promote the “regulatory sandbox” and pilot mechanism. Carbon credit tokenization is still in the early stage of development, and regulators lack sufficient practical data to formulate optimal rules. Excessive supervision may stifle innovation, and insufficient supervision may allow risks. Therefore, regulators should set up a special regulatory sandbox for carbon token innovation projects, allowing projects to test innovation models under limited scale, time and conditions, while enjoying partial regulatory exemptions.

### *5.2 Suggestions for Market Participants*

First, suggestions for project parties and protocol developers. For technical security issues, implement multiple rounds of security audits and publicize audit reports; with multi-sign governance, the management authority of the core contract should be approved by at least three to five independent signers, such as team members, consultants, and community representatives to perform sensitive operations; prudent use of cross-link bridges, if necessary, should choose a fully audited, verified nodes widely distributed bridge solution. For compliance and governance issues, compliance requirements are considered in the design phase of the agreement, rather than passively adjusted after encountering regulatory resistance; establish a quality committee to form a “carbon credit quality committee” composed of carbon market experts, scientists and community representatives, which is responsible for the formulation and adjustment of carbon pool access standards, as well as the arbitration of quality disputes; regularly disclose key information such as the reserve report of the escrow account, the use of the agreement fee, and the progress of the governance proposal. Double disclosure of “on-chain + off-chain” is adopted to reduce information asymmetry.

Second, suggestions for exchanges and trading platforms. Establish a listing review standard to review the online application of carbon tokens, focusing on assessing the quality of the underlying carbon credit, the transparency and security of the tokenization mechanism, and the robustness of protocol governance; implement market monitoring, monitor abnormal trading behavior, and share suspicious transaction reports with regulatory agencies; provide investor protection mechanisms, set up risk warnings, investment calm period, dispute resolution channels, etc.

Third, suggestions for corporate buyers and institutional investors. Conduct due diligence before purchasing carbon tokens for carbon neutrality claims, verify the compliance status of tokenization agreements, review the quality of underlying carbon credits, etc.; we should give priority to compliance products, such as tokenized carbon products issued by licensed platforms, clear custody arrangements and transparent audits, rather than products with high degree of decentralization but insufficient compliance confirmation; properly preserve the purchase records of carbon tokens, redeem transaction hash, retirement certificates and other evidence chains for audit and regulatory inquiries.

Fourth, suggestions for individual investors. First of all, we must have sufficient risk awareness of carbon tokens, fully understand the high volatility, technical risks and compliance uncertainties of carbon tokens; secondly, it is necessary to have certain information acquisition ability, and actively consult the white paper, audit report, reserve certificate and other information of tokenization

agreement, so as to avoid making investment decisions only relying on social media publicity. Finally, we must keep in mind the principle of decentralized investment and do not concentrate too much money on a single carbon token or agreement. Be cautious about products that claim “one-button carbon neutrality ‘and’ zero threshold to save the planet”, and make decisions after understanding the quality of the underlying carbon credit.

### *5.3 Future Prospect*

First, the technological trend from tokenization to carbon assets in the primary chain. The current mainstream model of carbon credit tokenization is “bridging the existing carbon credit to the chain”, which is essentially a digital transformation of the traditional carbon market. In the future, there may be a more subversive paradigm shift - the original carbon assets on the chain, that is, the whole process of carbon credit generation, verification, issuance, transaction and cancellation is completed on the blockchain, no longer relying on the traditional centralized registration system. It can completely solve the problem of trust in the “bridging “link. Without bridging, there is no “bridging risk”. At the same time, it can realize the real-time and dynamic management of carbon credit.

Second, the deep integration of carbon tokens with DeFi and AI. The composability of carbon tokens is one of its core advantages, and there may be some integration applications in the future. For example, smart contracts can be designed to “automatically embed carbon offsets in each transaction”. When a certain type of stable currency is used for payment, a certain proportion of the transaction amount will be automatically converted into carbon tokens and destroyed to achieve “instant carbon neutrality” of the transaction. This design can spawn a new “green payment” circuit. Artificial intelligence can assist in the investment decision-making and risk management of carbon tokens, analyze project quality, predict the price trend of carbon credit, monitor abnormal behavior on the chain, and warn potential security attacks.

Third, the potential contribution of carbon credit tokenization to carbon neutrality goals. The most direct contribution is to improve the efficiency of the carbon market. Carbon tokens can increase market liquidity and reduce transaction costs of carbon offsets. In addition, it expands market access and allows SMEs and individuals to participate in carbon-neutral actions. In addition to direct contribution, carbon credit can catalyze new green finance, embed carbon value into DeFi ecosystem through composable innovation, and promote new tools such as automatic carbon neutral payment and carbon-backed stable currency. However, there are preconditions for the realization of these contributions. The key lies in the effective implementation of the minimum quality standards, the strong linkage of cancellations on and off the chain, the clarity and coordination of the regulatory framework, and the self-discipline and due diligence of market participants. Only when these four conditions are met at the same time can carbon credit tokenization promote carbon neutrality.

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