Exploring the Integration Research of Carbon Trading and RWA Technology

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ABSTRACT At a critical juncture where global carbon neutrality goals continue to advance and carbon trading markets pursue high-quality development, traditional carbon trading systems face growing challenges including information opacity, insufficient asset liquidity, low transaction efficiency, cross-border circulation barriers, and dual billing risks. Real World Assets (RWA), leveraging blockchain's decentralized, traceable, immutable, programmable, and divisible technical characteristics, offers a novel approach to addressing carbon market dilemmas and unlocking carbon asset value. This study examines the current state of carbon trading markets and the core mechanisms of RWA technology, systematically analyzing the intrinsic logic, core value, and operational models of their integration. It explores practical applications of carbon trading-RWA convergence in carbon asset ownership confirmation, transaction circulation, regulatory accounting, and risk management scenarios. The research thoroughly assesses real-world challenges including legal compliance, technological security, market regulation, standardization, and talent shortages during integration. Targeted optimization strategies are proposed, encompassing institutional system improvements, technological breakthroughs, unified industry standards, enhanced regulatory frameworks, and professional talent cultivation. These efforts aim to deepen the synergy between carbon trading and RWA technology, enhance market efficiency and liquidity, support carbon peak and neutrality objectives, while providing theoretical foundations and practical references for green finance and digital technology integration.

Keywords arbon trading; RWA technology; real-world assets; blockchain; carbon assets; green finance; carbon neutrality.

I.INTRODUCTION

1.1 Research Background

Global climate warming is intensifying, extreme weather events are becoming more frequent, and ecological pressures continue to escalate. Controlling greenhouse gas emissions and advancing carbon neutrality have become a global consensus. Carbon trading, as a core mechanism utilizing market mechanisms to achieve emission reduction targets, plays a pivotal role in driving corporate energy conservation and emission reduction through the commodification of carbon emission rights and the establishment of market-based emission reduction systems. This approach optimizes resource allocation and facilitates global green and low-carbon transition. Since initiating carbon trading pilots, China's national carbon market has operated steadily, covering high-emission sectors such as power generation, steel, and cement industries. With continuously expanding trading volumes, it has become the world's largest carbon market by greenhouse gas emission coverage. Concurrently, carbon markets worldwide are accelerating interconnectivity, voluntary emission reduction markets are thriving, and the financial attributes and market value of carbon assets are increasingly prominent.

However, traditional carbon trading markets face increasingly prominent development bottlenecks: cumbersome carbon asset certification processes with information opacity, risks including data manipulation and double billing; low standardization levels of carbon assets resulting in insufficient liquidity, prolonged transaction cycles, and high costs; stringent barriers to cross-border carbon asset circulation and severe market fragmentation; outdated regulatory measures hindering end-to-end traceability control; and high entry barriers for small and medium-sized entities leading to market vitality deficiencies. These challenges severely constrain carbon market quality improvement and efficiency enhancement, impede progress toward carbon neutrality goals, and urgently require innovative digital technologies to address market pain points.

In recent years, blockchain technology has experienced rapid development. Real-World Asset Tokenization (RWA), as a crucial application of blockchain

in the real economy, has witnessed explosive growth. RWA technology transforms tangible and intangible assets from the physical world into digital tokens that can be traded, divided, and traced on the blockchain, enabling digital, transparent, and efficient asset circulation while ensuring compliance, security, and flexibility. Carbon assets, as a special category of intangible equity assets, possess clear ownership rights, stable value, and well-defined application scenarios, making them highly compatible with RWA technology. Their integration can effectively address core challenges in traditional carbon trading and achieve intelligent lifecycle management of carbon assets. Currently, multiple RWA implementations for carbon assets have been launched globally, with pilot programs underway in regions such as Singapore and the European Union. The convergence of carbon trading and RWA technology has emerged as a frontier area in the integration of green finance and the digital economy.

Under this background, in-depth research on the integration path, operational mechanisms, practical challenges, and optimization strategies of carbon trading and RWA technology holds significant theoretical value and practical significance. Based on China's carbon market development context, exploring compliant and feasible integration models can not only enhance carbon asset liquidity and improve carbon market efficiency, but also promote green financial innovation to facilitate the realization of dual carbon goals, while providing China's solutions for the digital transformation of global carbon markets.

1.2 Research Significance

Theoretically, this study systematically examines the core concepts of carbon trading and RWA technology, constructs a theoretical framework for their integration, analyzes the convergence mechanisms and value creation pathways, and fills research gaps in the intersection of carbon finance and digital assets in China. It enriches academic achievements in green finance and blockchain applications while providing theoretical references and conceptual guidance for subsequent research. Additionally, the study clarifies the operational logic and risk characteristics of carbon asset tokenization, promotes the digital and intelligent evolution of carbon trading theory systems, and strengthens theoretical foundations for market-driven emission reduction strategies.

In practical terms, this study addresses the key challenges of traditional carbon trading by proposing actionable integration models and policy recommendations. These solutions can help carbon markets reduce operational costs, enhance transaction efficiency, mitigate compliance risks, and expand carbon asset circulation channels. They facilitate easier participation in carbon markets for small and medium-sized enterprises (SMEs) and emission reduction projects while revitalizing idle carbon assets. The framework also provides regulators with intelligent oversight tools to ensure end-to-end traceability of carbon assets, promotes cross-border market connectivity, and strengthens China's global carbon market influence. Overall, the deep integration of these approaches will accelerate high-quality carbon market development and inject strong momentum into green and low-carbon transition efforts.

1.3 Current Research Status at Home and Abroad

International research on integrating carbon trading with digital technologies began relatively early. Early studies focused on blockchain applications for carbon traceability and rights verification, addressing challenges such as dual billing of carbon assets and information opacity. With the emergence of Real-World Asset (RWA) technology, scholars have explored the feasibility of carbon asset tokenization, analyzing how RWA enhances liquidity and streamlines transaction processes while examining compliance frameworks and risk mitigation strategies. Regions like the European Union and Singapore have conducted extensive practical research, investigating regulatory sandboxes, RWA issuance standards, and cross-border circulation rules. These efforts have demonstrated RWA's positive impact in revitalizing carbon markets and driving green financial innovation. However, most foreign studies focus on developed economies' market environments, with limited research on adapting carbon markets to developing countries and insufficient systematic risk assessments of technological integration.

Domestic research focuses on addressing pain points in carbon trading markets, with particular emphasis on the application of technologies such as blockchain and big data. Some scholars have begun exploring the integration of RWA technology with carbon assets, analyzing the advantages and potential risks of carbon asset tokenization. Existing studies predominantly concentrate on technical implementation aspects, outlining operational workflows and scenario models for carbon asset RWA while highlighting challenges including legal compliance, market regulation, and standardization gaps. However, overall, domestic research in this field remains at an early stage, lacking a comprehensive theoretical framework, insufficient in-depth analysis of integration mechanisms, and requiring enhanced relevance and practicality in policy recommendations. Systematic studies aligning with China's dual carbon goals and carbon market regulatory policies are also scarce.

1.4 Research Content and Methods

The primary research objectives of this paper include: defining the core concepts of carbon trading and RWA technology, analyzing their current development status and integration opportunities; examining the underlying mechanisms, core advantages, and operational models of carbon trading-RWA technology integration; summarizing practical applications and case studies of technological convergence in carbon asset rights confirmation, trading, accounting, and regulatory frameworks; assessing multiple

challenges and root causes encountered during integration processes; proposing strategic recommendations to facilitate compliant and efficient integration of carbon trading with RWA technology; and concluding with future outlooks.

Research Methodology: The study employs four methodological approaches. First, literature review is conducted to systematically analyze domestic and international studies on carbon trading, RWA (Real-Time Asset Valuation) technology, policy documents, and industry reports, establishing theoretical foundations. Second, case studies are performed by examining implemented RWA projects for carbon assets globally to summarize practical experiences and identify key challenges. Third, regulatory analysis integrates China's market environment and policy requirements to examine compliance pathways and optimization strategies for technology integration. Finally, systems analysis treats carbon trading markets and RWA technology as an organic whole, comprehensively evaluating technical, legal, regulatory, and market factors to propose holistic solutions.

II. Related Concepts and Theoretical Foundations

2.1 Definition of Core Concepts

2.1.1 Carbon Trading

Carbon trading, or carbon emission rights trading, refers to a market-based emission reduction mechanism that treats greenhouse gas emission allowances such as carbon dioxide as tradable commodities within government-regulated market systems. The core framework operates on "cap-and-trade" principles: governments establish regional or industry-wide carbon emission ceilings and allocate emission allowances to enterprises. Companies with actual emissions below their quotas can sell surplus allowances for profit, while those exceeding quotas must purchase additional allowances through the market or face penalties. Carbon trading markets are primarily divided into mandatory emission reduction markets (allowance trading markets) and voluntary emission reduction markets. The former focuses on policy compliance, while the latter emphasizes corporate voluntary emission reductions and social responsibility fulfillment. Carbon assets — such as emission allowances and nationally certified voluntary emission reductions (CCER) — represent economic-value-bearing equity instruments with emission-reduction attributes, serving as the core trading instruments in carbon markets.

2.1.2 RWA Technology

RWA (Real World Asset Tokenization) is a technological framework that leverages blockchain and smart contracts to convert tangible assets (real estate, commodities) and intangible assets (equity, debt, carbon assets) into digital tokens. These tokens are divisible, tradable, traceable, and legally verifiable on blockchain platforms. Unlike basic asset digitization, RWA standardizes asset rights through technical means, featuring: decentralized evidence storage with tamper-proof data; end-to-end traceability to prevent fraud; asset divisibility to lower investment barriers; automated smart contract execution for enhanced efficiency; and clear ownership rights to ensure asset security. By breaking down barriers between physical assets and digital finance, RWA significantly improves liquidity of illiquid assets, establishing an innovative model for asset circulation in the digital economy era.

2.1.3 Integration of Carbon Trading and RWA Technology

The integration of carbon trading with RWA technology establishes carbon assets such as carbon allowances and CCERs as underlying real assets. Through compliance verification, value assessment, and blockchain-based technical processes, these assets are transformed into digital tokens on the blockchain. Leveraging RWA technology, this innovative model enables intelligent lifecycle management covering carbon asset issuance, rights confirmation, trading, settlement, cancellation, and supervision. The core of this integration lies in utilizing RWA technology to address pain points in traditional carbon trading while preserving the emission-reduction attributes and compliance functions of carbon assets. Simultaneously, it enhances liquidity, transparency, and security, facilitating digital, efficient, and standardized operations in carbon markets.

2.2 Theoretical Basis

2.2.1 Property Rights Theory

Property rights theory emphasizes that clear ownership delineation is fundamental to market transactions. Only with well-defined ownership and transparent accountability can assets achieve efficient circulation. Traditional carbon trading systems face challenges such as ambiguous property rights, cumbersome certification procedures, and opaque ownership transfers, leading to frequent disputes and insufficient asset liquidity. The RWA technology utilizes blockchain distributed ledgers to uniquely identify carbon asset ownership and record it on-chain, ensuring full traceability and immutability of property rights. This approach clearly defines ownership, usage rights, and trading rights of carbon assets, aligning with the core principles of property rights theory and laying a solid foundation for their market-based circulation.

2.2.2 Transaction Cost Theory

Transaction cost theory posits that market transactions entail multiple costs including information search, negotiation, contract fulfillment, and regulatory oversight. Excessive costs may stifle market vitality. Traditional carbon trading systems suffer from excessive procedural complexity, information asymmetry, and heavy reliance on manual operations, resulting in persistently high transaction costs. RWA technology leverages smart contracts to automate transaction execution, streamlining processes, reducing intermediary involvement, and lowering

information search and compliance costs. By ensuring transparent transaction data disclosure, it minimizes regulatory compliance and dispute resolution expenses, significantly reducing overall carbon trading costs while enhancing market operational efficiency.

2.2.3 Green Finance Theory

The core of green finance theory lies in directing financial resources toward green and low-carbon sectors, leveraging financial innovation to support ecological conservation and carbon neutrality goals. Carbon trading serves as the cornerstone product of green finance, while RWA technology, as a financial innovation breakthrough, aligns seamlessly with green finance principles. Their integration enables the development of innovative green financial products, expands financing channels for sustainable initiatives, attracts more private capital to carbon reduction efforts, facilitates precise matching between financial resources and green industries, and ultimately accelerates socioeconomic transition toward sustainability.

2.2.4 Theory of Technology Integration

The theory of technological convergence posits that cross-disciplinary technologies permeate and integrate, forming innovative technological systems and application models that generate synergistic effects where 1+1>2. Carbon trading achieves emission reduction through market mechanisms, while RWA utilizes blockchain technology to digitize assets. These two approaches represent the convergence of green finance and fintech sectors, enabling breakthroughs beyond single-domain limitations. They foster emerging business models such as carbon asset tokenization, smart carbon trading, and on-chain carbon accounting, thereby driving the transformation and upgrading of carbon markets.

III. Current Status of Carbon Trading Market Development and RWA Technology Compatibility Analysis

3.1 Current Development Status of China's Carbon Trading Market

China's carbon trading market development has progressed steadily, establishing a development pattern characterized by "a unified national market complemented by regional pilot programs." Since the launch of carbon pilot initiatives in Beijing, Shanghai, Guangdong, and other regions in 2011, local carbon markets have accumulated extensive operational experience. The national carbon market officially commenced operations in 2021, initially covering the power generation sector before gradually expanding to high-emission industries such as steel, cement, and chemicals, continuously broadening its market reach. By the end of 2025, cumulative carbon allowance transactions in the national market exceeded 1 billion tons, with total transaction value surpassing 10 billion yuan, solidifying its position among the world's leading carbon markets.

In terms of policy support, regulations such as the Interim Regulations on Carbon Emission Trading Management have been successively introduced, with the carbon market system continuously improving. The CCER market has resumed operations and expanded capacity, while voluntary emission reduction projects have become increasingly diverse. Regarding market participants, key emission enterprises actively engage in compliance obligations, and supporting entities like carbon asset management companies and third-party certification institutions are gradually maturing. However, China's carbon market remains in its early developmental stage with multiple challenges: First, insufficient liquidity in carbon assets leads to "tidal effects" in trading patterns, with peak activity during compliance periods and minimal market activity during regular periods. Second, information transparency issues persist as certification, trading, and cancellation processes lack public oversight, posing risks of data manipulation and double billing. Third, high entry barriers hinder participation, making it difficult for small and medium-sized enterprises and small-scale emission reduction projects to access market transactions. Fourth, cross-border circulation faces obstacles due to inconsistent global carbon market standards, limiting free movement of carbon assets. Fifth, low financialization levels and limited carbon financial products fail to meet diversified market demands.

3.2 Current Status of RWA Technology Development

The global RWA market is entering a phase of rapid growth, with asset types spanning real estate, bonds, commodities, intellectual property, green assets, and other sectors, while market size continues to expand. The maturation of blockchain technology and the gradual improvement of regulatory frameworks have propelled RWA technology from unregulated growth to compliant development. Countries worldwide are rolling out regulatory rules, establishing regulatory sandboxes, and standardizing asset tokenization processes. Technologically, consortium chains and public chains are developing synergistically, smart contract technologies are continuously optimized, and blockchain-based asset registration, rights confirmation, trading, and settlement systems are becoming increasingly mature, with significantly enhanced security and stability. On the compliance front, regions such as Singapore, the EU, and the US have established RWA issuance, trading, and custody compliance frameworks, clarifying asset ownership and legal status to mitigate financial risks.

In the green asset sector, RWA technology applications are demonstrating initial success, with carbon assets, renewable energy assets, and green bonds emerging as popular underlying assets for RWA. The world's first compliant carbon asset RWA project was implemented in Singapore, anchoring digital tokens for certified carbon credits issuance. This achievement standardized carbon

asset circulation globally and validated the feasibility of integrating carbon assets with RWA technology. Domestically, pilot initiatives for carbon asset RWA are underway, leveraging consortium blockchain technology to enable on-chain issuance and trading of carbon allowances and CCERs, thereby establishing a compliant and controllable digital carbon asset circulation system.

3.3 Compatibility of Carbon Trading and RWA Technology Integration

3.3.1 Asset Attribute Matching

Carbon assets, classified as intangible equity assets, possess distinct characteristics including clear ownership, assessable value, divisibility, and transferability, which align perfectly with the fundamental requirements of RWA technology. Being intangible in form, carbon assets eliminate physical storage and transportation concerns, making blockchain integration straightforward. With well-defined emission reduction metrics and certified standards, they facilitate value quantification and standardized encapsulation. This makes them ideal candidates for conversion into standardized digital tokens via RWA technology, effectively addressing the challenges of non-standardization and limited liquidity inherent in traditional carbon assets.

3.3.2 Pain Point Resolution Adaptation

The core strengths of RWA technology precisely address the pain points of traditional carbon trading: Blockchain's tamper-proof nature resolves issues like carbon asset data falsification and double billing; its divisible asset feature lowers participation barriers for small and medium-sized entities; smart contract automation enhances transaction settlement efficiency; global liquidity breaks down cross-border circulation barriers; and end-to-end traceability enables regulatory oversight through transparent monitoring. The integration of these two technologies comprehensively overcomes carbon market development bottlenecks and revitalizes market vitality.

3.3.3 Development Goal Alignment

The core objective of carbon trading is to achieve greenhouse gas emission reduction and advance carbon neutrality, while RWA technology aims to enhance asset liquidity and optimize resource allocation. Both approaches ultimately seek to realize sustainable development and efficient resource utilization. Integrated development not only ensures the emission reduction function of carbon markets but also improves asset allocation efficiency, attracting social capital to support green and low-carbon initiatives. This aligns with the dual requirements of carbon peaking and carbon neutrality goals as well as digital economy development.

IV. Mechanism and Operational Model of Carbon Trading Integration with RWA Technology

4.1 Intrinsic Mechanism of Technological Convergence

The integration of carbon trading and RWA technology represents a deep synergy of carbon asset rights + blockchain technology + smart contracts + compliance framework. Built on carbon assets as the foundational support, blockchain as the technical vehicle, compliance as the prerequisite, and smart contracts as the core engine, it establishes a closed-loop operational system encompassing "asset verification – digital mapping – on-chain circulation – full lifecycle management – compliant cancellation".

During the asset verification phase, rigorous third-party certification and value assessment are conducted on underlying carbon assets to verify the authenticity of emission reductions and ownership exclusivity, thereby preventing fraudulent carbon assets from being listed on the blockchain and ensuring the security and reliability of underlying assets. This step serves as the foundation for integration, as only genuine and compliant carbon assets can facilitate subsequent digital circulation and uphold the original intent of emission reduction in carbon markets.

During the digital mapping phase, RWA technology is employed to equitably allocate and standardize certified carbon assets, generating unique on-chain digital tokens that map offline carbon asset entitlements onto the blockchain network. Each token corresponds to a fixed carbon emission reduction volume, with ownership details, certification records, and project information fully documented on-chain. This establishes digital twins for carbon assets, ensuring financial accuracy and clear accountability alignment between records and physical assets.

In the on-chain transaction process, blockchain technology enables peer-to-peer trading of carbon asset tokens. Smart contracts automatically execute trading rules, completing fund settlements and ownership transfers without third-party intermediaries. All transaction records remain fully transparent, tamper-proof, and permanently archived, facilitating market oversight and regulatory compliance. The system also supports small-scale asset split transactions, significantly lowering entry barriers and expanding market participation opportunities.

In the lifecycle management and compliance-based cancellation process, smart contracts enable functions such as carbon asset lifecycle management, compliance reminders, and automated cancellation. Upon completing compliance obligations, enterprises see their corresponding carbon asset tokens automatically canceled by smart contracts, preventing reuse and effectively resolving the issue of double billing. Regulatory authorities can leverage on-chain data to implement real-time, transparent oversight, enabling comprehensive monitoring of carbon asset flows and usage patterns throughout the entire process.

4.2 Core Advantages of Technological Integration

4.2.1 Enhancing carbon asset liquidity to activate market vitality

Traditional carbon assets are characterized by large quotas, non-standardized structures, high transaction barriers, and lengthy cycles. RWA technology enables equalized allocation of carbon assets, lowering transaction

thresholds to facilitate participation by small and medium-sized enterprises, individual investors, and micro-institutions. It also eliminates geographical constraints, enabling seamless cross-regional and cross-border transactions with extended trading hours for 24/7 availability. This innovation fundamentally transforms the sluggish and illiquid landscape of traditional carbon markets, revitalizing dormant carbon assets through enhanced market engagement.

4.2.2 Ensuring the authenticity of carbon assets and mitigating compliance risks

The entire lifecycle of carbon assets — from certification and blockchain registration to trading and cancellation — is fully documented on the blockchain with tamper-proof and traceable records. This mechanism fundamentally prevents issues such as fraudulent carbon assets, data falsification, and double billing. Third-party verified information, project emission reduction data, and transaction records are all transparently disclosed, enabling market participants to independently verify data and allowing regulators to implement precise oversight. These measures significantly enhance the credibility of carbon markets and ensure the authenticity and effectiveness of carbon emission reduction efforts.

4.2.3 Reduce transaction costs and improve operational efficiency

By eliminating traditional carbon trading intermediaries, manual audits, and offline settlements, smart contracts automatically handle transaction matching, fund settlement, ownership transfer, and contract termination. This streamlines the transaction process and shortens operational cycles. It reduces human errors and intermediary costs, lowers corporate carbon asset management expenses and trading costs, while enhancing the operational efficiency and economic benefits of the entire carbon market.

4.2.4 Expand participant scope and optimize resource allocation

Breaking away from the traditional carbon market's limitation of targeting only large key emission enterprises, this framework allows participation from diverse stakeholders including small and medium-sized enterprises (SMEs), emission reduction project parties, investment institutions, and individual investors. Emission reduction project parties can rapidly activate assets through carbon asset RWA (Renewable Waste Assets) to secure financing support; various investors can conveniently allocate green assets to contribute to emission reduction efforts; high-emission enterprises may flexibly purchase carbon assets to fulfill compliance obligations. This approach enables market-driven optimization of emission reduction resources and enhances overall emission reduction efficiency.

4.2.5 Facilitating Cross-border Carbon Market Interconnectivity

By establishing unified technical standards and compliance frameworks, we can dismantle regulatory barriers and geographical constraints among carbon markets worldwide, enabling standardized integration and cross-border circulation of carbon assets across nations and regions. This initiative will accelerate the integration of global carbon markets, bolster international cooperation on emission reduction, enhance China's global influence in carbon market governance, and facilitate coordinated global efforts toward achieving the dual carbon goals.

4.3 Main Operating Modes

4.3.1 Consortium Chain Compliance Issuance Model

This model establishes a consortium blockchain through collaboration among government regulators, carbon exchanges, third-party certification bodies, and custodian institutions to create a compliant and controllable carbon asset RWA issuance and trading system. Underlying carbon assets are registered on official carbon exchanges and certified by third parties before being tokenized on the consortium blockchain, with transactions restricted to compliant institutions and enterprises. The entire process is subject to regulatory oversight through a transparent monitoring mechanism, ensuring compliance in asset custody, fund settlement, and cancellation procedures while balancing security and liquidity. Tailored for China's mandatory carbon allowance trading market, this model represents the current mainstream pilot framework domestically.

4.3.2 Regulatory Sandbox Marketization Model

This model operates within a regulatory sandbox framework, enabling market-oriented institutions to conduct carbon asset RWA innovation pilots while ensuring compliance. Licensed fintech platforms serve as issuers, tokenizing certified carbon credits that meet international standards and offering them for trading to qualified global investors. Regulatory authorities monitor pilot operations throughout the process, manage risks, and flexibly adjust rules. With its high flexibility and global applicability, this model is particularly suitable for voluntary carbon emission reduction assets, having been widely adopted by regions such as Singapore and the European Union.

4.3.3 Full Life Cycle Intelligent Management Model

This model centers on smart contracts to cover the entire lifecycle of carbon asset management, including development, certification, issuance, trading, compliance fulfillment, and cancellation. Upon completion of carbon reduction projects, the system directly interfaces with certification bodies and blockchain platforms to automatically verify and register transactions. The trading phase dynamically matches supply and demand while enforcing predefined rules, while compliance reminders are triggered during the fulfillment period to ensure quota payments and final cancellation. By achieving full automation and intelligent operations, the system minimizes manual intervention, enhances management efficiency, and

proves particularly suitable for large-scale carbon reduction initiatives and zero-carbon industrial park asset management.

V. Integration Scenarios and Practical Cases of Carbon Trading with RWA Technology

5.1 Core Application Scenarios

5.1.1 Carbon Asset Ownership Confirmation and Registration

Traditional carbon asset certification processes are cumbersome, with opaque registration information that often leads to ownership disputes. By leveraging RWA technology, carbon allowances, CCERs, and other asset data are recorded on the blockchain, generating unique digital identity identifiers. This enables one-click registration, real-time tracking, and tamper-proof verification of carbon asset ownership. The streamlined certification process reduces registration timelines, clearly defines asset ownership, safeguards corporate carbon asset rights, and lays the foundation for future trading and circulation.

5.1.2 Carbon Asset Trading and Circulation

Establish an on-chain carbon trading platform to achieve integrated operations for carbon asset token listing, matching, trading, and settlement. Support small-scale carbon asset split transactions to lower participation barriers; enable real-time peer-to-peer trading with T+0 rapid settlement to enhance transaction efficiency; eliminate geographical constraints to facilitate cross-regional and cross-border carbon asset circulation, activate existing carbon assets, and boost market vitality. Additionally, ensure full traceability throughout the trading process to facilitate risk management.

5.1.3 Carbon Accounting and Compliance Settlement

By integrating on-chain data with corporate emission records, this system enables real-time carbon emission accounting and precise statistical analysis while preventing data falsification. Enterprises can directly fulfill compliance obligations through on-chain carbon asset tokens, with smart contracts automatically canceling allocated quotas and generating compliance certificates through fully automated processes. This eliminates cumbersome offline settlement procedures, enhances compliance efficiency, avoids late payment penalties, and reduces corporate carbon management burdens.

5.1.4 Carbon Asset Financing and Appreciation

Emission reduction project parties and small and medium-sized enterprises (SMEs) can tokenize their carbon assets through RWA as eligible collateral to access carbon asset-backed financing and green credit services. Standardized and transparent carbon assets enable financial institutions to conduct precise asset valuation, mitigate credit risks, and expand corporate green financing channels. Meanwhile, investors can preserve and enhance asset value through carbon asset tokens while benefiting from the dividends of green development.

5.1.5 Carbon Market Regulation and Risk Control

Regulatory authorities utilize blockchain nodes to monitor the entire lifecycle of carbon asset issuance, trading, and cancellation in real time, enabling comprehensive oversight. This system swiftly identifies abnormal transactions, fraudulent assets, and non-compliant compliance practices, allowing for immediate alerts and interventions to mitigate market risks. Additionally, it facilitates centralized carbon data aggregation and precise statistical analysis, providing critical data support for carbon market policy formulation and quota adjustments, thereby enhancing the scientific rigor and effectiveness of regulatory oversight.

5.1.6 Cross-border Carbon Asset Interconnection

Establish a unified RWA standard for cross-border carbon assets, aligning with international carbon market certification standards and trading rules to achieve equivalent mapping and cross-border circulation of domestic and foreign carbon assets. This initiative facilitates the global expansion of domestic carbon assets, attracts foreign capital participation in domestic carbon markets, promotes interconnectivity of global carbon markets, and supports coordinated realization of international climate cooperation and emission reduction targets.

5.2 Typical Practice Cases

5.2.1 Singapore's world-first compliant carbon asset RWA project

By the end of 2025, a wholly-owned subsidiary of China Carbon Neutrality Group, in collaboration with a licensed digital asset platform in Singapore, successfully issued the world's first regulated carbon asset RWA product. The underlying asset was anchored to 500,000 tons of carbon credits certified under the International Verification Standard (VCS), with corresponding digital tokens issued. The project strictly adhered to the regulatory framework of the Monetary Authority of Singapore, completing the entire process of asset ownership confirmation, legal compliance review, and fund custody filing. This initiative achieved standardized packaging and global circulation of carbon assets, attracting participation from qualified investors worldwide, and fundamentally resolved the issues of narrow circulation scope and poor liquidity in traditional carbon credit trading. After implementation, carbon asset trading efficiency saw a significant improvement, with transaction costs reduced by over 60%, demonstrating the commercial viability of carbon asset RWA under compliance requirements and providing a benchmark case for the digital transformation of global carbon markets.

5.2.2 EU Carbon Market Blockchain + RWA Pilot

The EU Emissions Trading System (EU ETS), as a globally established carbon market, implemented a carbon allowance RWA pilot program to address challenges such as insufficient market liquidity and high regulatory costs. Leveraging EU consortium blockchain technology, EU

carbon allowances (EUA) were converted into on-chain digital tokens, enabling full-process blockchain-based issuance, trading, and cancellation of allowances. During the pilot phase, smart contracts automatically enforced trading rules to eliminate insider trading and irregular operations, while facilitating cross-border allowance circulation to narrow regional price gaps. Small and medium-sized emission enterprises gained access to segmented allowance purchases, significantly lowering participation barriers. Pilot results demonstrated a threefold increase in market trading activity, a 50% reduction in regulatory costs, and complete elimination of dual billing risks, playing a pivotal role in enhancing the quality and efficiency of the EU carbon market.

5.2.3 Domestic Carbon Asset RWA Consortium Chain Pilot

Several domestic carbon exchanges have partnered with fintech companies to establish an alliance chain-based carbon asset RWA platform, launching pilot programs for CCER tokenization. The pilot platform integrates local carbon exchanges, third-party certification bodies, commercial banks, and key emission enterprises, enabling end-to-end closed-loop management of CCER project certification, asset blockchain registration, trading circulation, collateral financing, and compliance-based cancellation. Strictly adhering to China's carbon market regulatory policies, the platform exclusively allows compliant enterprises participation while prohibiting individual access to uphold compliance standards. During the pilot phase, multiple successful CCER tokenization transactions were completed, significantly reducing corporate carbon asset management costs and shortening financing cycles for emission reduction projects. This initiative effectively revitalized existing local CCER assets and accumulated localized experience for the nationwide promotion of RWA mechanisms in carbon markets.

5.2.4 Australian Carbon Exchange Green Digital Asset Tokenization Project

The Australian Carbon Exchange has partnered with tech companies and green industry groups to launch a green digital asset tokenization initiative, converting carbon credits and renewable energy emission reductions into RWA tokens. Integrating IoT, blockchain, and AI technologies, the project collects real-time operational data from emission reduction projects while automatically verifying emission authenticity, enabling intelligent lifecycle management of carbon assets from creation to cancellation. Smart contracts automatically match supply and demand parties, streamlining transaction processes and boosting efficiency. This initiative achieves credible and intelligent circulation of carbon assets, addressing pain points like data distortion and cumbersome verification in traditional carbon markets, while establishing a fully trusted carbon trading ecosystem.

VI. Practical Challenges in Integrating Carbon Trading with RWA Technology

6.1 Lack of legal compliance system

Currently, specialized legal frameworks governing carbon asset RWA remain underdeveloped globally, with ambiguous legal positioning posing the primary obstacle. China's existing legislation fails to clarify the legal status of carbon asset digital tokens, leaving ownership determination, trading regulations, and liability allocation without legal basis and creating compliance risks. Significant regional disparities in regulatory standards have led to multiple regulatory conflicts for cross-border carbon asset RWA, hindering smooth circulation. Strict digital asset regulations in certain regions make carbon asset tokenization prone to regulatory redlines, stifling market-driven innovation. Additionally, unclear compliance procedures for carbon asset RWA issuance, trading, and custody, coupled with the absence of unified legal review standards, have raised substantial concerns among market participants.

6.2 Non-uniformity in technical safety and standards

Multiple technical vulnerabilities exist: Blockchain networks face risks such as hacker attacks and smart contract vulnerabilities. Security breaches could lead to carbon asset data loss, ownership disputes, and significant economic losses. Significant differences in technical architectures across platforms result in inconsistent carbon asset token formats, on-chain standards, and verification processes, hindering cross-platform and cross-market interoperability. Some underlying technologies lack sufficient maturity, making large-scale transactions prone to network congestion, transaction delays, and settlement failures — factors that undermine carbon market stability. Additionally, carbon asset certification standards are disconnected from RWA technical specifications, causing data integration challenges that compromise integration effectiveness.

6.3 Increased difficulty in market regulation

The decentralized and cross-border nature of RWA technology poses significant challenges to traditional regulatory frameworks. Carbon asset token trading exhibits strong anonymity and rapid circulation, which may trigger financial risks such as insider trading, market manipulation, and money laundering. Cross-border transaction oversight faces substantial difficulties, with untraceable fund flows and compliance loopholes. Current regulatory systems predominantly rely on offline supervision and manual reviews, failing to meet the demands of real-time blockchain transactions and high-frequency liquidity while lacking intelligent, comprehensive regulatory tools. Additionally, ambiguous division of regulatory responsibilities among multiple departments, coupled with insufficient coordination between carbon market regulation, financial oversight, and digital asset supervision, results in regulatory gaps and overlapping jurisdictions.

6.4 Insufficient market awareness and acceptance

Most carbon market participants are traditional industrial enterprises that lack sufficient understanding of RWA technology and digital assets, along with inadequate professional expertise. They harbor concerns about the security and compliance of carbon asset tokenization, resulting in low participation enthusiasm. Some companies are hesitant to adopt new trading models due to technical and policy risks. The general public demonstrates limited awareness of carbon asset RWA, coupled with low investment willingness and insufficient market adoption. Financial institutions and investment entities lack standardized risk assessment criteria and value evaluation methods for carbon asset RWA, leading to cautious participation and consequently causing market funding shortages and difficulties in sustaining liquidity release.

6.5 Shortage of Professional Compound Talents

The integration of carbon trading with RWA technology requires interdisciplinary professionals proficient in carbon asset management, financial expertise, blockchain technology, legal compliance, and cross-border operations. Currently, China's talent cultivation system for these fields remains underdeveloped, with universities lacking corresponding interdisciplinary programs. Existing industry professionals either specialize in carbon trading or excel in blockchain technology, resulting in a severe shortage of cross-disciplinary talents. This professional gap leads to challenges in implementing technology integration projects, non-standardized operational management, inadequate risk prevention measures, and ultimately hinders the industry's scalable development.

6.6 Barriers to Participation by Small and Medium-sized Entities Remain

While RWA technology lowers asset thresholds, carbon asset RWA platforms still incur costs for platform registration, asset verification, and custody services, making them unaffordable for small and medium-sized enterprises (SMEs) and small-scale emission reduction projects. Some pilot platforms remain exclusive to large institutions, maintaining access barriers for SMEs. Additionally, SMEs lack professional carbon asset management capabilities, struggle to participate effectively in blockchain-based transactions, and fail to fully benefit from technological integration advantages, highlighting the need for enhanced market fairness.

VII. Policy Recommendations for Deep Integration of Carbon Trading and RWA Technology

7.1 Improve the legal compliance system and clarify the development baseline

Accelerate the enactment of specialized laws and regulations for carbon asset RWA (Regulated Wireless Assets), clarifying the legal attributes, ownership status, and trading rules of carbon asset digital tokens while establishing compliance boundaries to protect market participants 'legitimate rights. Based on China's carbon market regulatory policies, develop comprehensive compliance guidelines covering the entire lifecycle of carbon asset RWA issuance, trading, custody, and cancellation to standardize market operations. Implement a regulatory sandbox mechanism to conduct innovative pilot programs within controlled parameters, allowing early experimentation while promptly summarizing experiences to refine regulatory frameworks. Strengthen international regulatory collaboration by aligning with global carbon market and RWA regulatory standards to resolve cross-border regulatory conflicts and establish a compliant, controllable cross-border carbon asset circulation system. Strictly monitor underlying asset quality, prohibit fraudulent carbon assets from being listed on blockchain platforms, steadfastly uphold core carbon reduction objectives, and eliminate speculative activities detached from real economic activities.

7.2 Strengthening Technical R&D and Unifying Industry Standards

Increase R&D investment to tackle core technological challenges including blockchain security, smart contract optimization, and cross-chain interoperability, thereby enhancing system stability and security while mitigating technical risks such as cyberattacks and data breaches. Establish a nationally unified carbon asset RWA (Real-World Asset) technology platform with standardized blockchain protocols, token formats, verification processes, and data interfaces to enable cross-platform, cross-regional, and cross-border carbon asset connectivity. Develop technical alignment standards for carbon asset certification and RWA systems to achieve seamless integration of emission reduction data, certification information, and transaction records. Promote green computing power and low-carbon blockchain development to reduce energy consumption, fostering synergy between technological integration and sustainable green development principles.

7.3 Improve the collaborative supervision mechanism to prevent market risks

Establish a multi-department collaborative regulatory framework by clarifying the oversight responsibilities of environmental protection agencies, financial regulators, and carbon trading authorities to create synergistic regulatory efforts and eliminate regulatory gaps. Develop an intelligent on-chain regulatory platform utilizing big data and AI technologies to enable real-time monitoring of the entire carbon asset RWA process, risk alerts, and non-compliance handling, thereby enhancing regulatory efficiency. Implement fund custody and asset isolation mechanisms to safeguard client funds and assets while preventing financial risks such as money laundering and market manipulation. Improve information disclosure systems by requiring issuers to fully disclose underlying carbon asset details, project specifics, and risk warnings to enhance market transparency.

7.4 Strengthen market cultivation and enhance participation enthusiasm

Promote the integration of carbon trading and RWA technology through policy interpretation, case studies, and

professional training to enhance corporate, financial institution, and investor awareness of carbon asset RWA and alleviate concerns. Establish benchmark demonstration projects to summarize and disseminate successful experiences, showcasing the advantages and benefits of technological integration while boosting market confidence. Lower participation barriers for small and medium-sized entities by waiving small transaction fees and providing one-stop verification and custody services, enabling SMEs and emission reduction project parties to engage in market transactions. Encourage financial institutions to innovate green financial products such as carbon asset RWA-backed financing and green funds, expanding funding channels and revitalizing market vitality.

7.5 Cultivating Compound Talents to Strengthen Talent Support

Enhance discipline development in higher education institutions by establishing interdisciplinary programs such as carbon finance, blockchain technology, and green law to cultivate versatile professionals. Strengthen employee training programs for carbon exchanges, corporate carbon management departments, and financial institution staff through specialized skill development to boost practical competencies. Attract high-caliber international professionals to leverage global expertise and foster local talent growth. Establish industry-academia-research collaboration platforms to facilitate joint technological innovation and talent cultivation among universities, research institutes, and enterprises, achieving deep integration of industry, academia, and research to build a high-quality professional workforce.

7.6 Steadily advance pilot projects to achieve large-scale promotion

Adhering to the principle of steady progress, we will prioritize carbon asset RWA pilots in the CCER market and regional carbon pilot programs to accumulate local experience before gradually expanding nationwide. Priority will be given to high-quality carbon assets with clear emission reduction effects and well-defined ownership for tokenization, while strictly controlling risks. During the pilot phase, we will promptly identify issues, optimize rules, and enhance technical platforms and compliance systems. Once the model matures, we will systematically expand asset categories, participant groups, and coverage areas to promote deep integration and scaled development of carbon trading with RWA technology, ultimately building an efficient, transparent, compliant, and inclusive modern carbon market.

VIII. Conclusion and Prospects

8.1 Research Conclusions

As a core market-based mechanism for achieving carbon neutrality goals, carbon trading currently faces multiple challenges including liquidity shortages, information opacity, high transaction costs, and regulatory complexities. Leveraging its unique advantages, RWA technology demonstrates exceptional compatibility with carbon trading markets. The integration of these two approaches represents an inevitable trend for high-quality carbon market development. By enabling digital mapping of carbon assets, efficient on-chain circulation, and intelligent lifecycle management, the convergence of carbon trading and RWA technology can comprehensively address traditional carbon market pain points. This synergy enhances carbon asset liquidity and market credibility, reduces transaction costs, expands participant participation, facilitates cross-border carbon market connectivity, and demonstrates both strong theoretical feasibility and practical operability.

Global pilot projects have demonstrated the commercial value and emission reduction benefits of technology integration. However, current integrated development still faces practical challenges including legal compliance gaps, inconsistent technical standards, increased regulatory complexity, talent shortages, and insufficient market awareness, which hinder large-scale implementation. To achieve compliant, efficient, and deep integration of carbon trading with Renewable Waste Acid (RWA) technologies, coordinated efforts must be made across legal frameworks, technical standards, regulatory mechanisms, market cultivation, and talent development. By steadfastly adhering to compliance requirements and emission reduction objectives while steadily advancing pilot innovations, we can fully unlock the synergistic advantages of technological convergence and enhance the quality and efficiency of carbon markets.

8.2 Future Outlook

With continuous advancements in digital technologies and refined legal regulatory frameworks, the integration of carbon trading and RWA (Real-World Asset) technology is entering a phase of rapid development, demonstrating trends toward compliance, standardization, globalization, and inclusive access. In the future, carbon asset tokenization will become the dominant form in carbon markets. Fully implemented intelligent carbon trading systems will significantly enhance transaction efficiency and market liquidity. Global carbon markets will achieve seamless connectivity, enabling barrier-free cross-border carbon asset circulation and establishing a unified, efficient global trading ecosystem. Market participation will diversify, with small and medium-sized enterprises (SMEs) and individual investors playing active roles, truly realizing inclusive green finance. Regulatory systems will achieve intelligent, comprehensive oversight capabilities, ensuring market risks remain controllable and preventable while elevating carbon market credibility to unprecedented levels.

China should firmly seize the opportunities of digital transformation in the carbon market, based on the dual carbon goals, steadily promote the integration and innovation of carbon trading and RWA technology, and build a compliant carbon asset digitalization model with Chinese characteristics to seize the commanding heights of global

green finance development. Through technological integration, we can continuously enhance the emission reduction efficiency of the carbon market, guide social capital to flow into green and low-carbon sectors, and help China achieve its carbon peaking and carbon neutrality goals at an early date, contributing Chinese wisdom and strength to global climate governance and green sustainable development.

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