

Blockchain Management Empowering Green and Climate Finance: Mechanisms, Real-World Dilemmas and Optimization Paths

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Abstract. Against the background of China's dual-carbon strategic goals, green and climate finance have achieved rapid scale expansion as critical instruments for low-carbon economic transition. Nevertheless, the whole market is still plagued by prominent governance risks, including intentional environmental data manipulation, and repeated double-counting of carbon assets, as well as poor traceability of green project capital flows. As an innovative trust-rebuilding management paradigm rather than simple technical tools, blockchain management leverages distributed ledgers, data immutability and smart-contract functions to deliver credible technical support for green-climate finance. This paper adopts qualitative analytical research, including literature review and dual-case comparison, to investigate how blockchain management functions within green credit, carbon trading and green bond scenarios. It identifies major practical obstacles and puts forward coordinated institutional-technical optimization proposals. The study reveals that blockchain can effectively mitigate information asymmetry in green-financial practice. Nevertheless, its large-scale commercial deployment is hindered by on-chain-off-chain data fragmentation, insufficient unified regulatory standards and relatively high technical operation costs. Therefore, collaborative governance mechanisms, unified industry-wide standards and lower access thresholds for small- and medium-sized enterprises are urgently required for future development.

Keywords: Blockchain Management, Green Finance, Climate Finance, Carbon Assets, Smart Contracts

1. Introduction

Global climate change urges capital resources to shift toward low-carbon and climate-resistant projects, making green and climate finance critical instruments for advancing sustainable development [1]. Governments across the globe have released policy documents to encourage financial institutions to allocate capital toward emission-reduction and climate-adaptation initiatives. In China, the scale of green credit and green bonds keeps growing, and the national carbon market has established basic operational frameworks. Nevertheless, widespread greenwashing, unreliable

Monitoring, Reporting and Verification (MRV) outputs and untraceable fund usage severely restrain market performance [1]. Misleading environmental disclosure distorts asset pricing and discourages investors from participating in genuine green projects. Existing literature mostly treats blockchain as pure information-technology hardware, while insufficient attention is paid to its management value for green-climate financial governance [2]. Many published works focus merely on technical features rather than the systemic governance capacity brought by multi-party consensus and distributed record-keeping. This study explores the mechanisms through which blockchain management addresses prevailing market pain points, alongside practical barriers and feasible solutions for real-world implementation. Qualitative analysis including literature review, mechanism deduction and dual-case comparison is applied. The research fills gaps regarding blockchain-oriented governance in sustainable finance and provides practical references for regulators and market participants [2].

2. Theoretical framework and core concepts

2.1. Green finance and climate finance

Green finance covers investment, financing and risk-management services for environmental improvement, energy conservation and resource efficient utilization [1]. It supports diversified activities ranging from industrial pollution treatment, waste recycling to large-scale renewable-energy deployment. Multiple financial instruments such as green credit, green bonds, green insurance and carbon trading fall within its scope. Climate finance constitutes a core subset of green finance, focusing specifically on climate-mitigation and climate-adaptation initiatives [1]. Mitigation projects aim to cut greenhouse-gas emissions, while adaptation projects enhance social and economic resilience against extreme weather. Although the two concepts overlap, green finance provides a broader institutional framework, and climate finance targets climate-related risks directly. Jointly, they guide capital toward low-carbon transition and climate-resilient economic construction. Clear conceptual distinction helps identify suitable application scenarios for blockchain-enabled governance tools.

2.2. The connotation of blockchain management

Blockchain management represents a reconstructed trust-building mode rather than isolated technical components [3]. Built upon distributed ledger, asymmetric encryption and consensus algorithms, it delivers four core properties: data immutability, full-life-cycle traceability, automatically-executed smart contracts and multi-party co-governance [4]. Instead of relying on single central institutions, multiple network nodes jointly maintain records. Modification of historical data requires consensus from most participating nodes, which raises the threshold for deliberate tampering. Smart contracts translate business rules into executable codes that respond automatically when preset conditions are satisfied. Such features enable credible data storage, automated workflow execution and distributed collaborative supervision, which match the governance demands of green-climate finance [5]. It is necessary to distinguish blockchain management from simple blockchain technology deployment. The management perspective emphasizes organizational coordination and trust reconstruction, instead of merely discussing cryptographic algorithms.

3. Empowerment mechanisms of blockchain management

3.1. Credible data traceability to mitigate greenwashing risks

Some researchers hold optimistic expectations that blockchain technology can fundamentally eliminate greenwashing behaviors within green-financial markets [5]. Greenwashing originates from information asymmetry and loopholes within traditional MRV systems [1]. Enterprises may exaggerate emission-reduction performance to obtain preferential green financing. Third-party verification brings high costs yet cannot completely eliminate human-induced data falsification. Verification reports depend heavily on materials submitted by project operators. Blockchain management enables multi-party nodes including governments, investors and verification agencies to record project construction, operation and emission-reduction data on distributed ledgers [5]. Once recorded, data cannot be altered arbitrarily. Full-process traceability raises the cost of deliberate misreporting of environmental benefits. External stakeholders can review historical records without repeated on-site investigation. Even so, such optimistic expectations are still questionable. Blockchain only guarantees post-upload data integrity, authenticity of raw off-chain data still depends on pre-chain supervision [6]. Blockchain cannot correct false information generated in physical project sites.

3.2. Optimizing whole-life-cycle carbon asset management

Carbon allowances and CCER (Chinese Certified Emission Reductions) form the foundation of domestic carbon markets [7]. Traditional administration faces risks of duplicate accounting and repeated trading of identical emission-reduction volumes. Manual filing systems create possibilities for administrative errors and deliberate fraud. Under blockchain management, every carbon asset obtains a unique digital identifier [5]. Registration, transfer and cancellation records are permanently stored on ledgers. Every transfer action leaves immutable traces. Smart contracts realise automatic matching, clearing and settlement of transactions, lowering manual intervention risks. Regulators can access real-time records to supervise carbon-market operations. Transparent asset lifecycle information helps market participants judge asset value and reduces information search costs for carbon-market investors.

3.3. Reinforcing supervision over green investment and financing

Misappropriation of green-project funds is a long-standing hidden danger for green credit and green bonds [8]. Conventional supervision mainly depends on post-event auditing, lacking real-time control. Financial institutions can hardly track capital flow continuously after releasing loans. Relevant performance indicators can be coded into smart contracts. Subsequent funds are released automatically only after preset green-project milestones are fulfilled [4]. Capital-flow records remain traceable throughout fundraising, disbursement and redemption. The supervision mode transforms from post-hoc inspection toward in-process dynamic control, improving investor confidence and reducing credit risks for financial institutions [2]. Nevertheless, smart contract execution still relies on externally-input project-performance data, which sets inherent limits for this supervision mechanism.

4. Real-world dilemmas of implementation

4.1. Separation between on-chain and off-chain data

The most prominent limitation comes from the disconnection between real-world raw data and ledger records [6]. Blockchain cannot detect falsified off-chain source data. If manually collected monitoring data contain distortions, on-chain storage merely solidifies incorrect information. Reliable automatic data acquisition channels, such as Internet-of-Things devices are not universally popularized across green projects. Many small-scale green projects still depend on manual statistical reports. Human-operated data collection creates bottlenecks for uploading trusted data. Even with multi-node verification on the chain, the quality of original field data determines the practical value of all subsequent on-chain analysis.

4.2. Shortages of regulatory frameworks and unified standards

Present financial regulatory systems are designed for traditional financial businesses [7]. Clear industry specifications for blockchain-based green-financial products remain insufficient. Different institutions build independent blockchain platforms with inconsistent data formats and interface protocols, generating new data silos. Information generated by one platform cannot be identified or read by other systems. Additionally, the legal validity of smart contracts and admissibility of on-chain evidence in judicial practice have not been fully clarified [8]. Uncertain legal status discourages financial institutions from large-scale adoption. Ambiguous rules increase compliance costs for market participants and hinder large-scale commercial adoption.

4.3. Constraints from cost, performance and privacy

Deployment and continuous operation of blockchain nodes impose relatively high financial burdens, especially for small- and medium-sized enterprises [3]. Hardware investment, system maintenance and technical personnel bring sustained expenditure. Public blockchains suffer from throughput limitations, which restrict large-volume transaction processing. Consortium blockchains achieve better performance yet sacrifice partial decentralization. Conflicts emerge between blockchain's openness requirement and commercial-confidential-information protection. Enterprises are unwilling to expose sensitive operational data to all network participants. Balancing transparency and data privacy remains a practical challenge that existing technical solutions cannot fully resolve.

5. Case analysis

5.1. Blockchain-based carbon trading platforms in Chinese carbon pilots

Several regional carbon-trading pilots in China have constructed blockchain-supported trading infrastructures [7]. Local exchanges cooperate with technology enterprises to realize on-chain confirmation of carbon-allowance and CCER ownership. Smart contracts support automatic transaction settlement, and supervisory authorities gain real-time access to transaction logs. Pilot platforms shorten trading cycles and strengthen market transparency. Transaction disputes caused by duplicate-asset trading decrease within pilot scope. Nevertheless, inter-platform interoperability is insufficient, and reliable off-chain MRV-data docking still constitutes a major barrier. Most environmental monitoring data are imported manually. These pilots provide valuable practical

experience for the national unified carbon market, while large-scale nationwide promotion has not been realized.

5.2. Project genesis: blockchain green bond in Hong Kong

As an international financial hub, Hong Kong Monetary Authority launched the Project Genesis blockchain green-bond pilot [9]. Issuance information, environmental-benefit disclosure and bond redemption procedures are recorded on distributed ledgers. Smart contracts automate principal and interest payment. Transparent on-chain records reduce third-party-verification expenses and enhance trust among international investors. Cross-border investors can review environmental performance records conveniently. This project delivers replicable experience for Asian green-bond digital transformation. However, it remains an experimental pilot with limited transaction scale. Widespread replication requires coordination among multiple regulatory authorities across jurisdictions.

Despite differences in market background, these two cases reflect similar core constraints. Both projects verify blockchain's capacity to optimize procedural efficiency, yet neither can thoroughly resolve defects originating from offline data collection and incomplete institutional rules. The mainland carbon pilots face barriers of fragmented local standards, while Project Genesis is restrained by limited market scale. Neither case achieves full large-scale commercial roll-out, confirming that technical advantages cannot offset institutional deficiencies [10].

6. Optimization paths for large-scale application

First, construct collaborative on-chain-off-chain MRV governance systems. Promote automatic data collection via Internet-of-Things sensors and cross-validation mechanisms among multiple parties to improve the quality of raw data before uploading [6]. Relevant departments may set baseline requirements for data collection equipment for key green projects. Supervisory inspection toward off-site monitoring activities needs to be strengthened, because high-quality off-chain data constitute the precondition for blockchain governance.

Second, formulate unified technical-data standards and adaptive regulatory frameworks. Authorities need to unify interface specifications for blockchain green-financial platforms to break isolated data systems. Regulatory sandbox mechanisms can encourage innovation while controlling potential financial risks [7]. Regulators may permit controlled pilot operations before formal industry rules are finalized. Legal departments should clarify legal status of smart contracts and evidential effectiveness of on-chain records [8]. Clear legal expectations reduce market participants' worries about compliance risks.

Third, popularize consortium-chain and Blockchain-as-a-Service (BaaS) modes to reduce technical-operation costs for small-and medium-sized enterprise [3]. Shared technical services avoid repeated hardware investment for individual firms. Industry-oriented consortium chains can balance operational efficiency and multi-party supervision. Meanwhile, developers should adopt encrypted data-sharing technology to balance information transparency and commercial-privacy protection [4]. Sensitive corporate information can be encrypted, while core environmental-performance indicators remain open for supervision.

7. Conclusion

Blockchain management delivers powerful instruments to tackle inherent governance defects within green-climate finance by improving transparency, traceability and automation level [3]. It helps restrain widespread greenwashing behaviors, prevent repeated carbon-asset fraud, and strengthen whole-process supervision over green investment and financing activities. Nevertheless, blockchain functions merely as a technical auxiliary tool. Its practical values cannot be realized independently without matching institutional arrangements, complete regulatory frameworks and sound offline data-collection infrastructure. Practical large-scale adoption is restrained by multiple intertwined barriers including on-chain-off-chain data disconnection, absence of unified industry technical standards, and relatively high implementation and maintenance costs for most market participants. Simple technical deployment cannot eliminate institutional defects, so coordinated joint efforts from both technical optimization and institutional construction are essential for unlocking its real-world application potential. Effective practical measures should include building collaborative MRV governance systems, completing supporting regulatory systems, clarifying the legal status of smart contracts, and lowering market-participation thresholds for small- and medium-sized enterprises.

This study adopts qualitative analysis and dual-case comparative research, lacking quantitative empirical evidence to measure concrete economic and environmental effects brought by blockchain applications. Limited by insufficient publicly-available project-level data resources, quantitative assessment on actual cost-reduction efficiency or practical green-performance improvement cannot be conducted within this research scope. Future research can collect more real-world operational data from domestic and overseas pilot projects for further quantitative evaluation. Further exploration on innovative regulatory modes such as on-chain supervision is also meaningful for advancing the digital transformation of green-climate finance [10]. Market practitioners and policymakers should maintain rational expectations and avoid over-optimistic assumptions about blockchain's standalone problem-solving capacity. In the long-term development of green and climate finance, technological innovation should always advance synchronously with institutional improvement, so as to give full play to the trust-building value of blockchain management.

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