

# Verifiable State Transitions in Supply-Chain Carbon Accounting: A Smart Contract Architecture for Double-Counting Resilience

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内 容 梗 概

This dissertation addresses reliability in supply-chain carbon accounting by treating the problem as lifecycle consistency over carbon-related claims shared across organizational boundaries. Rather than viewing carbon-accounting failures as isolated reporting mistakes within individual firms, this dissertation models them as failures in lifecycle operations such as issuance, splitting, transfer, and integration. From this perspective, representative double-counting situations can be understood as invalid states and transitions that should be excluded by design.

To address this problem, the dissertation proposes a smart-contract architecture based on a three-tier NFT structure consisting of P-NFTs, C-NFTs, and I-NFTs. Building on the author's prior publications, the architecture enforces three execution-time conditions: quantity conservation, immediate parent retirement after split, and complete-set same-transaction consumption during integration. Together, these conditions prevent representative forms of parent-child coexistence and fragment reuse while preserving compact on-chain headers and references to off-chain evidence.

Beyond the prior conference and journal work, the principal doctoral contribution is an explicit dissertation-level systematization of both the problem and the solution. First, the dissertation organizes representative double-counting failures as generalized state-transition patterns rather than as isolated examples. Second, it restructures the contract-side protections as an invariant-oriented lifecycle discipline for split and integration. Third, it develops bounded routine verification into an operational audit procedure centered on the issuance context of an I-NFT, with deterministic escalation when anomalies are detected. Fourth, it integrates implementation and evaluation evidence into a unified dissertation framework. In this way, earlier publications are extended into a coherent doctoral study of lifecycle-safe digital claim management in supply-chain carbon accounting.

Finally, the proposed architecture is implemented in both local and Ethereum-compatible public test environments and evaluated in terms of transaction cost, inclusion latency, and scalability under the evaluated workloads. These evaluations demonstrate feasibility and clarify practical trade-offs among traceability granularity, execution cost, and auditability. Overall, the dissertation presents an engineering framework for preventing representative double-counting states during execution while supporting routine downstream verification.