Blockchain-based Carbon Footprint Traceability System for Home Appliances

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Abstract. Carbon footprint management is becoming an important issue for governments and enterprises worldwide. This paper proposes a blockchain-based carbon footprint traceability system for home appliances. The system integrates Internet of Things (IoT), IPFS distributed storage, and smart contract technology to achieve automated data collection, on-chain storage, and sharing of carbon footprint information throughout the entire product lifecycle. Through a modular design, the carbon footprint is divided into five main modules: raw material acquisition, production and manufacturing, logistics and transportation, product usage, and recycling and disposal. Leveraging the immutability and transparency of blockchain technology, the system ensures the reliability and traceability of carbon footprint data. Finally, the evaluation indicates that the proposed system can effectively trace the carbon footprint of home appliances, achieving innovations in data accuracy, consistency, and traceability efficiency.

Keywords: Home appliances; Carbon footprint traceability; Modular design; Blockchain

1 Introduction

With the intensification of global climate warming, greenhouse gas emissions have become a focus for governments and international organizations [1]. Some developed countries have begun to enforce carbon tariffs and carbon reduction certification policies in international trade, and carbon barriers are gradually emerging as new obstacles in global commerce [2]. Chinese home appliance enterprises are now facing stricter carbon footprint management requirements to meet international market demands for the traceability and compliance of carbon footprints.

Current research on carbon footprint management covers a range of topics—from low-carbon upgrade strategies to specific software development, and how information technology can enhance carbon management efficiency. For instance, Yonggao Fu [3] and colleagues developed a practical carbon footprint analysis and evaluation software

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for home appliances; Jia yi Zhang [4] and others designed a work mechanism and system architecture for the traceability and accounting of carbon footprints in textile and apparel products based on blockchain technology; Alia Sadavi [5] et al. proposed a comprehensive blockchain-based carbon emission trading framework.

Research focusing specifically on the carbon footprint traceability of home appliances is still limited. The lifecycle of home appliances comprises multiple stages, with carbon footprint data coming from dispersed sources. Traditional carbon footprint traceability methods, which rely on centralized management, encounter difficulties such as data sharing challenges and susceptibility to tampering [6]. Blockchain technology, with its distributed ledger, transparency, immutability, encryption, and smart contract features [7], has already been applied in various fields such as data management [8], supply chains [9], cybersecurity [10], and the energy industry [11]. It can record carbon footprint data from each stage of the home appliance supply chain on a distributed ledger, enabling complete process traceability and automated management of carbon footprint accounting and data sharing through smart contracts.

Therefore, this paper proposes a blockchain-based carbon footprint traceability system for home appliances, which combines IoT technology, IPFS distributed storage, and smart contracts to achieve data collection, on-chain storage, automated accounting, and cross-entity sharing, thereby ensuring the authenticity and integrity of carbon footprint data.

2 System Architecture

The proposed blockchain-based carbon footprint traceability system for home appliances is structured as shown in Figure 1.

(1) Data Collection Layer: Connects and manages IoT devices to collect and transmit real-time carbon footprint data throughout the lifecycle of home appliances.

(2) System Data Layer: Protects and stores inter-block data information using hash function encryption algorithms together with IPFS distributed storage technology.

(3) System Network Layer: Implements communication and data transmission among internal system components and provides interfaces with external systems.

(4) Smart Contract Layer: Implements the business logic and data processing of the system, including the traceability, verification, and querying of carbon footprint data.

(5) System Application Layer: Allows users to query, manage, and operate home appliance carbon footprint information. This layer translates user requests into the execution of smart contracts.

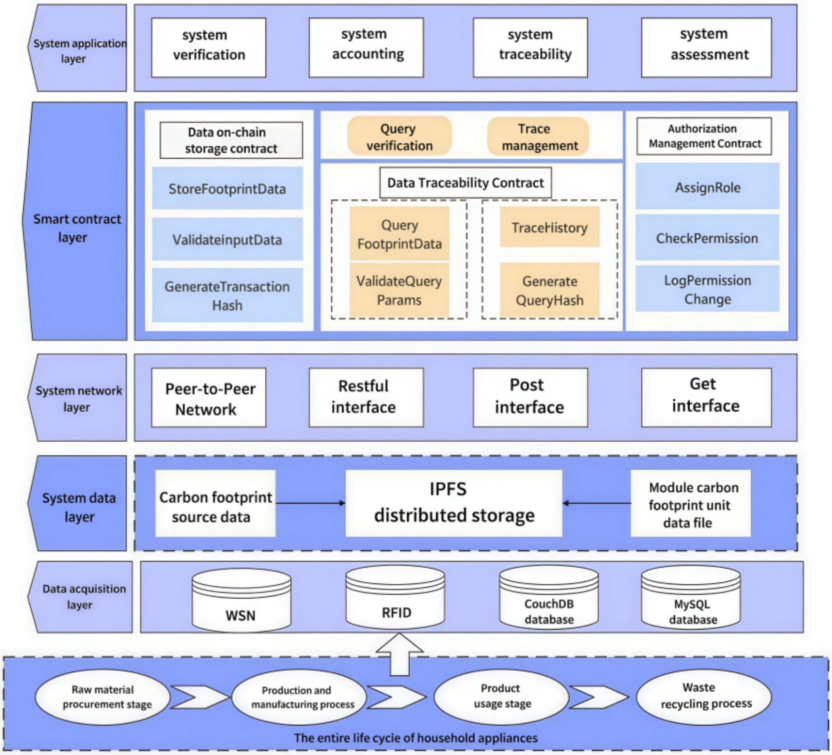

Fig. 1. Architecture of the Blockchain-based Carbon Footprint Traceability System for Home Appliances

3 Establishment of Modular Carbon Footprint Units and Data On-Chain Mechanism

3.1 Establishment of Modular Carbon Footprint Units and Coding

To address the issue of dispersed data sources across different stages, the system adopts a modular design approach, dividing the product lifecycle into five major modules: raw material acquisition, production and manufacturing, logistics and transportation, product usage, and recycling and disposal. Each module establishes a corresponding accounting unit based on the responsible entity and process flow, as shown in Figure 2.

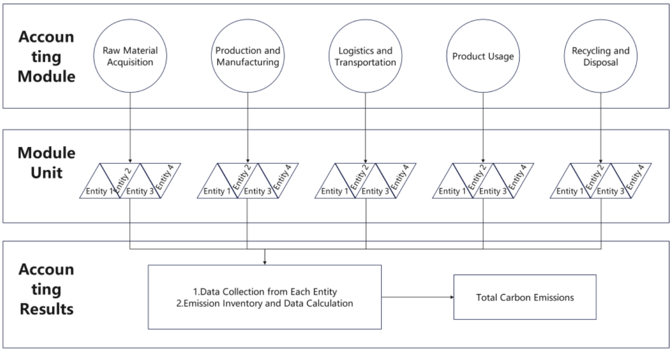

Fig. 2. Carbon Footprint Accounting Modules in the Home Appliance Supply Chain

A unified coding scheme is applied to match the carbon footprint units of the product with modular codes, enabling retrieval, comparison, and traceability across different modules. As shown in Table 1, different levels of modules correspond to different code depths and boundary scopes:

(1) Primary Module: Represents only the geographical location and product category, using a two-digit code.

(2) Secondary Module: Includes geographical location, product category, and lifecycle stage information, using a three-digit code. For example, "US-AC-PM" indicates the manufacturing stage of air conditioner components produced in the United States.

(3) Tertiary Module: Contains geographical location, product category, lifecycle stage, and process attribute information, using a four-digit code to enable the smallest granularity of traceability. For example, "CN-RF-PM-E01" denotes the compressor production process for refrigerators manufactured in China.

Table 1. Carbon Footprint Module Attribute Coding Rules

Module Attribute	Geographic Location	Product Category	Lifecycle Stage	Process Type
Examples	CN-China	RF-Refrigerator	RM-Raw Material Acquisition	E01-Compressor Production
	US-USA	WM-Washing Machine	PM-Component Manufacturing	P03-Injection Molding
	DE-Germany	AC-Air Conditioner	LG-Logistics	A07-Final Product Assembly

During the accounting process, the combination and invocation among different module codes need to be flexibly adjusted according to the accounting objectives, ensuring that each module provides transparent and reliable data support for the final carbon footprint analysis. This coding system not only improves the efficiency of carbon footprint accounting but also provides valuable data references for process optimization and supply chain design in home appliances, thereby achieving low-carbon production goals.

3.2 Modular Carbon Footprint Data Collection, On-Chain Processing, and Storage

The system employs IoT devices to collect carbon footprint data at each stage of the product lifecycle. The data is transmitted via readers to consensus nodes, and then time-stamped data blocks are generated by ordering nodes. After confirmation by the consensus mechanism, the new block is added to the blockchain and broadcast to all nodes. Subsequently, through asymmetric encryption and smart contracts, the collected data is encrypted before uploading. The data files are then segmented and stored using IPFS, forming a unique address to enable rapid query and secure access to the data files. The overall process is illustrated in Figure 3.

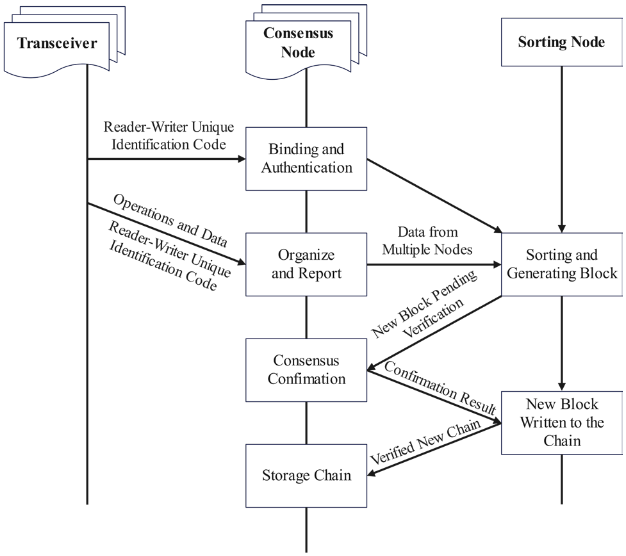

Fig. 3. On-Chain Data Upload and Storage Process for Carbon Footprint Data

4 System Functional Design and Evaluation

4.1 Carbon Footprint Traceability and Management Functions

The system consists of four parts: the home page, user management, product management, and traceability management. The following focuses on the core function—traceability management.

Basic Search for All Users: Users log into the system and retrieve carbon footprint evaluation results using the product identification number, as shown in Figure 4.

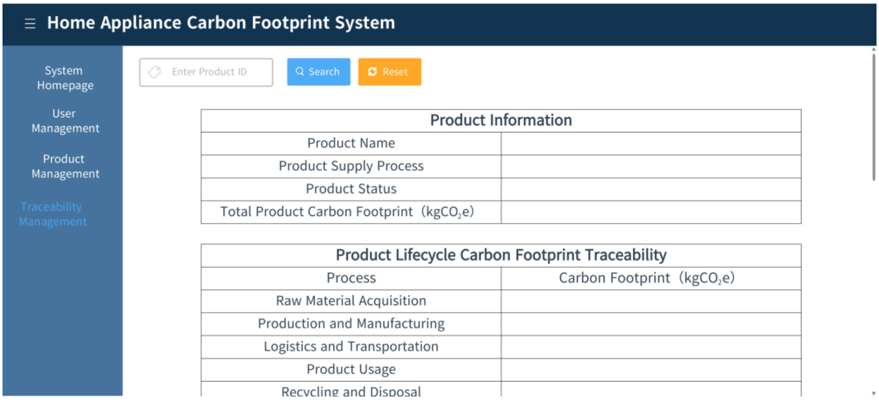

Fig. 4. Display Page for Product Carbon Footprint Data in the Blockchain-based Home Appliance Carbon Footprint Traceability System

Advanced Search for Suppliers, Accountants, and Supervisors: In addition to basic search that retrieves product carbon footprint data files, supplier enterprises, accounting parties, and supervisory entities can perform an advanced search directly using the carbon footprint module code to trace module-specific carbon footprint data files, as shown in Figure 5.

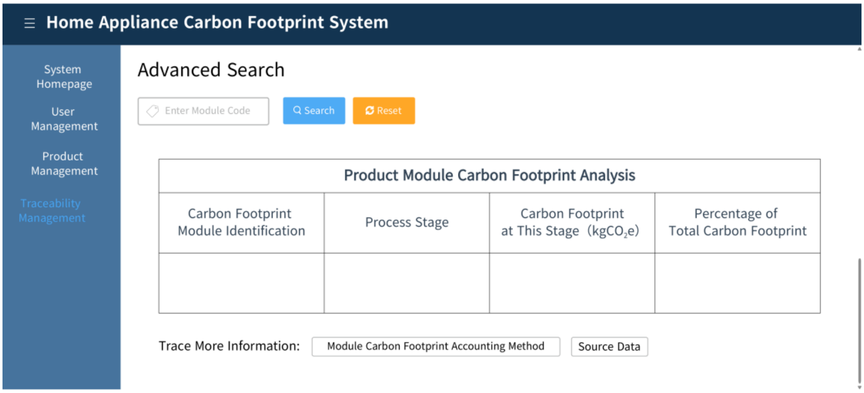

Fig. 5. Display Page for Module Carbon Footprint Data in the Blockchain-based Home Appliance Carbon Footprint Traceability System

4.2 System Evaluation and Innovations

The system implements hierarchical access control whereby different users can query carbon footprint information progressively, ensuring data security while maintaining transparency. It achieves tamper proof, traceable, and transparently shared carbon footprint data across the entire lifecycle of home appliances. The automatic execution of data submission, review, accounting, and report generation through smart contracts enhances efficiency and reduces the risks associated with human error and operational risks.

In terms of innovation, the system adopts a modular coding and accounting method, which enhances the precision and flexibility of accounting. By integrating blockchain and IoT technology, it ensures automated and secure data collection, eliminating the reliance on manual input. The use of distributed storage further improves data consistency, and any issues can be quickly traced back to the responsible entity.

5 Conclusions

This paper presents a blockchain-based carbon footprint traceability system for home appliances, offering a feasible solution for the low-carbon transformation of the home appliance industry. By utilizing a modular design of the blockchain system and the application of smart contracts, the system not only realizes transparent traceability and automated accounting of carbon footprint data but also enhances the credibility and compliance of the data. It is expected that this system will provide theoretical support for promoting the sustainable development of a green and low-carbon economy.

References

1. Liu,J.D. Research on the Impact of China's Carbon Trading Market on Enterprises' Low-Carbon Development [D]. Jilin: Jilin University, 2024. https://doi.org/10.27162/d.cnki.gjlin.2024.000141.
2. Zhu,R.X., Huang,N. (2024) Research on the Impact of International Carbon Barriers on Carbon Management of Chinese Export Enterprises. J. China Certified Public Accountant., 12: 50-57. https://doi.org/10.16292/j.cnki.issn1009-6345.2024.12.020.
3. Fu,Y.G., Wan,C., Zhao,X., et al. (2024) Research on Carbon Footprint Calculation Method of Household Appliances Based on Life Cycle Assessment. J. Household Appliances., 11: 50-54. https://doi.org/10.3969/j.issn.1673-6079.2014.11.016.
4. Zhang,J.Y., Zhou,L.Y., Wu,X.Y., et al. (2023) Application of Blockchain Technology in Carbon Footprint Traceability and Accounting of Textile and Apparel Products. J. Silk., 60(02): 14-23.
5. Al Sadawi,A., Madani,B., Saboor,S., et al. (2021) A comprehensive hierarchical blockchain system for carbon emission trading utilizing blockchain of things and smart contract. J. Technological Forecasting and Social Change., 173: 121-124.
6. Muzumdar,A., Modi,C., Vyjayanthi,C. (2022) A Permissioned Blockchain-Supported Trusted and Incentivized Emission Trading System. J. Journal of Cleaner Production., 349: 131-274.
7. Zhang,Q., Miao,Y.H. (2025) Blockchain Technology Empowering the Construction of a New Ecosystem for Trusted Data Space. J. China Security & Protection., (Z1): 110-114.
8. Dai,W., Dai,C., Choo,K.K.R., et al. (2019) SDTE: A secure blockchain-based data trading ecosystem. J. IEEE Transactions on Information Forensics and Security., 15: 725-737.
9. Tian,F. (2016) An agri-food supply chain traceability system for China based on RFID & blockchain technology. In: 2016 13th international conference on service systems and service management (ICSSSM). Kum Ming. pp. 1-6.

10. Singh, A., Click, K., Parizi, R.M., et al. (2020) Sidechain technologies in blockchain networks: An examination and state-of-the-art review. J. Journal of Network and Computer Applications., 149: 102-471.
11. Chaudhary, R., Jindal, A., Aujla, G.S., et al. (2019) BEST: Blockchain-based secure energy trading in SDN-enabled intelligent transportation system. J. Computers & Security., 85: 288-299.