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Research on the Blue Carbon Trading Market System under Blockchain Technology

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Abstract: To combat global warming, "carbon neutrality" has gradually become a consensus. Some countries have constructed domestic and regional carbon trading markets, and links to global carbon markets are receiving increasing attention. Blue carbon, an important component of nature-based solutions (NbS), has not received the attention it deserves and is still isolated from the carbon trading market. Based on summarizing the existing achievements of blockchain application in carbon trading, this paper analyzes how to make each participating body provide services in the process of blue carbon production, circulation and trading, and designs the architectural diagram of the blue carbon system under peer-to-peer (P2P) transactions based on the theoretical framework of blockchain 3.0. Utilizing the advantages of decentralization, high transparency and non-tamperability of blockchain, we can realize a highly efficient, low-cost and intelligent blue carbon trading management system. Thus, we can make the world pay more attention to the development and utilization of marine resources and increase investment in blue carbon sink projects; and promote the development of blue carbon market, enrich the carbon trading market, and help achieve "emission reduction without reduction in production".

Keywords: blockchain technology; blue carbon; carbon market; blue carbon trading; carbon neutrality

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1. Introduction

"Carbon neutrality" has become a consensus goal for the global response to the climate change crisis. Governments, multinational companies, non-profit organizations and other organizations have taken many actions around this consensus goal. From the 1997 "Kyoto Protocol" to the 2016 "Paris Agreement", all countries agreed to limit the Earth's temperature rise to less than 2 degrees Celsius. In December 2019, the European Union promulgated the "European Green New Deal", which promised to achieve "Net zero emissions" of greenhouse gases by 2050. In 2020, China's President Xi Jinping pointed out at the 75th United Nations General Assembly that "China will increase its nationally determined contributions, adopt more powerful policies and measures, strive to reach the peak of carbon dioxide emissions by 2030, and strive to achieve carbon neutrality by 2060". The United States, Japan, South Korea and other countries have also made "net zero emissions" commitments. It can be seen that the world's major powers and organizations have made commitments on "carbon neutrality" and reached some agreements and consensus. However, "carbon neutrality" not only involves the governments, but is also related to carbon sink providers, manufacturing companies, individual consumers, and the public. The use of market trading mechanisms to integrate these forces together can truly achieve the goal of "carbon neutrality" in practice.

The production of carbon sinks includes two major mechanisms: green carbon (the terrestrial carbon sink) and blue carbon (the ocean carbon sink) [1,2]. Green carbon has been recognized by governments, scholars and related organizations and has developed rapidly. Some countries have established regional carbon sink trading markets. Due to the late discovery of blue carbon, its carbon sink mechanism and measurement methods are not complete, it has not received due attention, and the blue carbon sink trading market has not been fully established either. However, blue carbon has a comparative advantage. It stores 93% of the CO_2 on the Earth and completes more than 55% of the Earth's carbon sink [3,4]. It is the world's largest carbon pool and should be incorporated into the carbon sink trading market system as soon as possible. The "Blueprint for Sustainable Development of Ocean and Coastal Areas" issued by the five major United Nations agencies in 2011 proposed the "Global Blue Carbon Market" plan. One of the five policy goals established in the "Blue Carbon Policy Outline" issued in 2012 is to incorporate blue carbon activities into voluntary carbon markets and other carbon financial mechanisms dedicated to mitigating climate change. Since then, the establishment of the blue carbon market has received more attention. In 2019, the China Green Carbon Foundation held a side event at the China Corner of the 25th Conference of the Parties to the United Nations Framework Convention on Climate Change to discuss the theme of "from green carbon to blue carbon, from land to ocean". The establishment of a comprehensive trading market for green carbon and blue carbon has attracted the attention of various organizations and institutions.

Blockchain technology has become an emerging digital technology. It has been applied to the energy and carbon trading markets to optimize and change the market structure and reduce transaction costs. At present, there are more and more climate-conscious blockchain projects at different stages of development [5]; the value of blockchain applications in carbon trading has also been affirmed [6]. The integration of the market has laid a foundation for practice and theory. Along with the development of blockchain technology and blue carbon sink technology, this research aims to answer the following questions: (1) how can blockchain technology be applied in the blue carbon trading market? (2) why is it suitable for the application?

This article attempts to conduct a review to analyze the application of blockchain in carbon trading. On the basis of blockchain 3.0, the theoretical framework for applying blockchain technology to the blue carbon international trading market is refined. The proposed framework expects to enhance the information transparency of the carbon market; promote the coordinated development of different carbon markets through international cooperation; prepare for accelerating the establishment of the blue carbon market and linking the global carbon market; and provide a new pathway for the realization of the goal of carbon neutrality.

The remaining sections are arranged as follows: The second part conducts a review to summarize the application research of blockchain technology; the third part refines the internal theoretical logic of blockchain technology and the blue carbon trading system; the fourth part summarizes the theoretical model of the application of blockchain technology in the blue carbon international trading market, and explores the feasibility of practical application; the fifth part is the discussion and the last part is the conclusion of the paper.

2. Literature Review

At present, there are two main types of carbon trading markets in the world: quota-based markets and credit-based markets [7]. These two markets complement each other and work together to promote the smooth progress of greenhouse gas emission reduction. Similar to the general market, the carbon trading market also has transaction subjects and transaction objects. The EU emissions trading system was established in 2005 and is the world's first international carbon emissions trading system [8,9]. Participants in the EU carbon market include emissions control companies, financial institutions, and various investors. The diversification of transaction entities provides the market with

ample liquidity supply. This system has also inspired and promoted the development of carbon emissions trading in other countries and regions.

Blockchain is undoubtedly one of the hottest technologies nowadays. It is considered an important driving force of the fourth industrial revolution and an important cornerstone of building the Internet of Value. The characteristics of blockchain technology include "decentralization", "open", "independence", "security" and "anonymity" [10]. Since the world gradually realized the huge potential of blockchain, most research on blockchain has focused on technical challenges and improvements, cryptocurrency and related economic and legal issues, smart contracts, consensus protocol design, and blockchain integration with traditional industries. Application scenarios have been expanded from the initial financial field to [11], for example, blockchain + medical treatment [12,13]; blockchain + energy [14]; blockchain + transportation [15,16]; blockchain + intellectual property [17]; blockchain + supply chain [18] and others. The "blockchain+" model has gradually been explored to promote the deep integration of blockchain and the real economy. Interventionary studies involving animals or humans, and other studies that require ethical approval, must list the authority that provided approval and the corresponding ethical approval code.

Within the research on Blockchain + carbon, part of the research results carried out a feasibility analysis of the blockchain technology on the carbon market mechanism [19]; some scholars also designed a blockchain-based hybrid carbon trading system and related organizational framework [20], and proposed a method for a blockchain-based distributed emissions trading system (BD-ETS) model of reducing carbon emissions [21].

As a new type of implementation of international carbon trading and an important implementation method of the "clean development mechanism", blue carbon is a frontier field of academic research [22,23]. So far, none of the 20 countries or regions that have launched compulsory carbon emissions trading markets have included blue carbon trading [4]. Scholars' research on blue carbon mainly focuses on the current situation analysis [24], pricing research and other aspects [25], and has gradually begun to explore international cooperation from different aspects [26–28]. With the active promotion of international organizations and related countries, the international community has recognized the important role of blue carbon in tackling climate change and has begun to promote the inclusion of blue carbon in the post-2020 international climate governance system [27]. So far, there is limited research on the combination of blockchain technology and blue carbon. Therefore, it is vital to use this technology to develop a blue carbon market with huge potential to actively respond to global climate governance.

The development of the blockchain has roughly gone through three stages, from the digital currency in the 1.0 era, to the smart contract in the 2.0 era, to the imagination of the full application of blockchain technology in the 3.0 era [29]. With the entry into force of the Paris Agreement, carbon emissions rights have become one of the hottest issues. The European Union has a common emissions trading system; Japan has implemented a common offset system with 17 developing countries including Vietnam; South Korea is also considering linking the emissions market with China and Japan [30]. Therefore, the international carbon emissions trading market continues to expand.

As blockchain technology has begun to be used in the fields of carbon emission rights certification and carbon emissions trading, it has provided technical support for the global carbon market. Scholars from various countries have applied blockchain to the research of carbon emissions trading, and some results have been achieved, as shown in Table 1.

By reviewing the application of blockchain technology in different industries and specifically summarizing the application research of blockchain in the carbon trading process, it was found that decision makers around the world have begun to explore the huge potential of this emerging technology to solve policy problems. Among them, the functions and attributes of this technology can enhance the transparency of national climate actions and overcome some of the obstacles encountered in the previous carbon market [38], such as information opacity, high transaction cost, narrow transaction scope,

long transaction cycle and safe data storage, etc. These studies have laid the foundation for the application of blockchain technology in the international blue carbon trading system.

Table 1. Related research on the application of blockchain technology in carbon emissions trading.

Author (Year)	Aim/Main Topic
Al Kawasmi E et al. (2015) [31]	Established a distributed carbon emissions trading platform based on the Bitcoin system to improve user privacy and system security, and to achieve P2P trading of carbon emissions allowances.
Hartmann S and Thomas S. (2020) [32]	Used an established design process to develop the blockchain design of the Australian carbon market to improve the efficiency, fairness and effectiveness of the Australian carbon market, and solve the important research gap of how blockchain technology can be applied to the existing carbon market.
Jiang T et al. (2022) [33]	Data from eight carbon trading pilots in China were collected to demonstrate the factors that influence the adoption of blockchain technology by carbon trading companies. Among them, the willingness to use blockchain technology is inversely proportional to the time it takes for companies to learn to master it. Moreover, the higher the number of companies involved in carbon trading, the earlier the companies use the technology.
Khaqqi KN et al. (2018) [34]	Proposed a carbon trading management mechanism based on blockchain technology, combined with a reputation system, and introduced a market segmentation mechanism and a priority value order mechanism to solve carbon trading management and fraud problems.
Kim SK and Huh JH. (2019) [35]	A reliable blockchain algorithm was designed to verify the carbon emission rights in the 17 tasks of the United Nations Sustainable Development Goals (UN-SDGs'), which provides a reference for the design of smart contracts in the decentralized carbon trading system.
Schletz M et al. (2020) [36]	Evaluated the applicability of blockchain technology to Article 6.2 of the Paris Agreement's carbon market mechanism. The results showed that the technology can improve the transparency and automation of the transaction process and blockchain applications are promising.
Zhao F and Chan WK. (2020) [20]	Used the advantages of blockchain technology and integrated the institutional risk control framework to propose a new hybrid blockchain system architecture that provides for the adoption of blockchain in carbon trading and other industries through integrated analysis.
Zhang N et al. (2016) [37]	It is believed that blockchain technology can realize the automatic measurement and certification of carbon emission rights through smart contracts, and use a distributed structure to ensure the traceability and non-tampering of all transaction information, and to solve the problems of large workload of carbon certification in traditional carbon markets and the traceability of transaction records.

3. Design of Blue Carbon Cycle and Transaction Circulation System

Blue carbon trading has the dual value goal of slowing down global warming and increasing the economic benefits of carbon sinks [22,39]. Some scholars have also proposed that incorporating the benefits of blue carbon storage into local climate policies can be used as a model for the future formulation of negative emissions technology policies and methods, and will have a positive impact on the success of the Paris Agreement and scientific decarbonization in the middle of this century [40]. This section scientifically designs the blue carbon cycle and transaction circulation system by combing and summarizing the relevant literature on blue carbon trading and management.

3.1. Selection of Method

This study adopts a conceptual model research approach from a qualitative perspective to construct a framework for blue carbon trading under blockchain. The field of conceptual modeling continues to evolve and is used in many areas [41]. The conceptual model is mainly used for modeling the information world, and is the first level of abstraction

from the real world to the information world [42]. It bridges the gap between problem and solution domains and acts as a bridge between domain experts and developers [43]. Current conceptual model validation focuses on qualitative and subjective investigations conducted by domain experts on the basis of conceptual model descriptions [42]. Therefore, the conceptual model should have strong semantic expression capability on the one hand, which can easily and directly express various semantic knowledge in the application, and on the other hand it should be simple, clear and easy to understand by users [44]. Since the research on the combination of blockchain and blue carbon trading is in the initial exploration stage, this paper adopts the conceptual modeling approach with the experience of experts in the field to build a conceptual framework for the combination between the two, which will facilitate the readers' understanding and provide thoughts for other researchers in the field.

3.2. Introduction to Participants

First of all, the clarification of the participants is the prerequisite and basis for a sound blue carbon trading system. Multiple stakeholders are involved in the management and application system of blue carbon, which can be divided into core stakeholders, important stakeholders and general stakeholders. Core stakeholders include: relevant government departments, blue carbon buyers (carbon allowances + carbon sinks < carbon emissions), and sellers (carbon allowances + carbon sinks > carbon emissions), to realize the market operation and carbon reduction of blue carbon trading. Key stakeholders include: R & D institutions and financial institutions that provide necessary financial support and guarantees for various risks that may be encountered in the initial stage of blue carbon projects. General stakeholders play a supporting role in carbon sequestration, such as non-profit organizations. The specific participant behavior is reflected in the blue carbon circulation diagram, as shown in Figure 1.

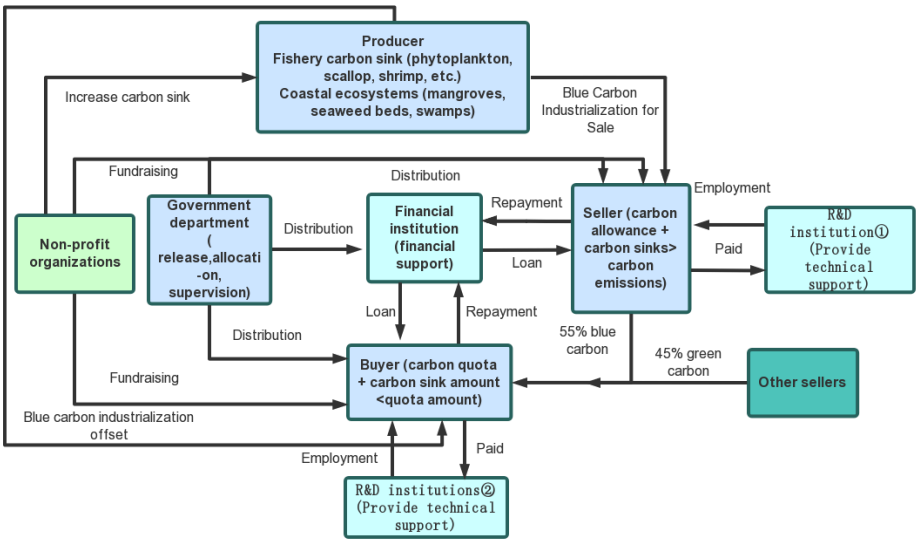

Figure 1. Blue carbon circulation diagram. (Source: Designed by the authors).

3.3. Analysis of the Specific Behavior of the Participants

The main difference between the traditional carbon market and the carbon market based on blockchain technology is that the former includes the allocation of carbon allowances in the primary market, carbon trading in the secondary market (carbon rights trading and carbon sink trading), the financing services market, and the support services market [45]. The latter can integrate these four types of markets in the same system to realize information sharing, save costs, and improve transaction efficiency. Therefore, after understanding the main differences between the two, a detailed analysis of the blue carbon transaction flow process with blockchain as the underlying technology can be carried out.

(1) Producers: The blue carbon sinks that can be considered for inclusion in the carbon market are divided into two main parts: fishery carbon sinks and coastal ecosystem carbon sinks [46]. The former mainly revolves around the processes and mechanisms that promote the absorption of carbon dioxide by marine organisms through fishery production activities, and remove stored carbon through marine product capture. Specific activities can include algae farming, shellfish farming, filter-feeding fish farming, etc. [47]. The carbon sinks of the latter coastal ecosystems have very similar mechanisms to forest carbon sinks. The coastal ecosystems include mangroves, seaweed beds, salt marshes, seaweed beds, coral reefs, etc., which have significant carbon sinks [48]. Protecting these ecosystems or expanding their scope can increase carbon sinks. These two carbon fixation methods reflect the ecological and economic value of blue carbon, making it one of the objects of carbon sink trading in the carbon market.

(2) Sellers and buyers: The definition of buyers and sellers in the blue carbon transaction flow mainly depends on the difference between the total carbon emissions of the controlling company and the total carbon ownership (the sum of the initial allowances and carbon sinks). When carbon emissions > initial allowance + carbon sinks, the company acts as a buyer; otherwise, it is a seller. Among them, the choices of emissions control companies are concentrated in industries such as electricity, cement, steel, petrochemical, papermaking, and civil aviation with high carbon emissions. The flow of transactions between the two parties is shown in Figure 2. The buyer's insufficient part can be offset by the carbon sinks of its own emission reduction certification, or purchasing the seller's wealthy part, which comes from the seller's remaining allowances and the carbon sinks obtained from the development of blue carbon projects.

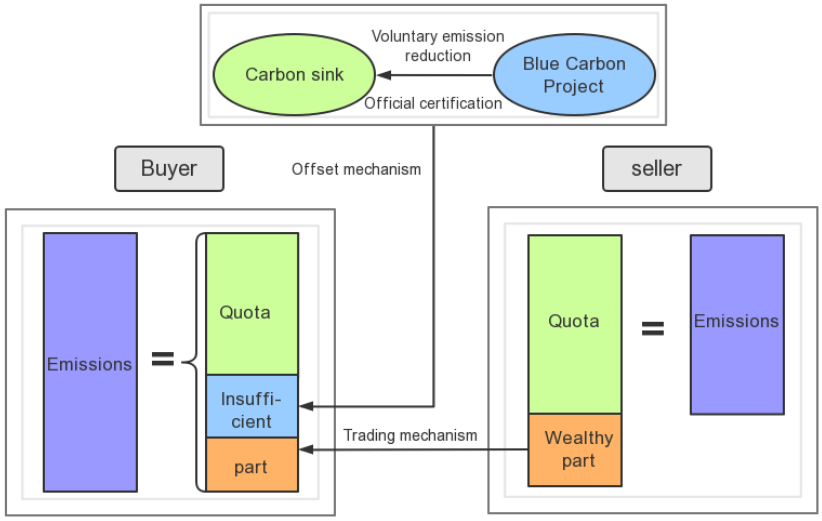

Figure 2. The transaction flow process of buyers and sellers. (Source: Collated from [49]).

In the development of blue carbon projects, both parties can emulate the two project-based emission reduction mechanisms of CDM (Clean Development Mechanism) and JI (Joint Implementation Mechanism) formulated in the Kyoto Protocol. Under certain market trading rules, the blue carbon sink project is carried out to obtain or increase the corresponding amount of carbon sinks that can be used for trading. The buyer pays the consideration to purchase the amount of carbon sinks it needs to offset its own carbon dioxide emissions. Therefore, the development of blue carbon sink projects makes full use of the advantages of marine resources and reduces greenhouse gas emissions. In essence, it uses the marketization and payment of blue carbon sinks to achieve the balance between the environmental, social and economic benefits of the entire ecosystem.

(3) Relevant government departments: Blockchain technology has huge potential in realizing smart government services [50]. It is an important means to optimize government management, improve decision-making capabilities, and promote public services [51]. Therefore, the application of blockchain in the field of government affairs is becoming more and more extensive. In terms of environmental management, relevant government departments that can be chained can be designed as the Ministry of Environment or Climate Bureau of the country where the chain enterprise is located. In the traditional carbon trading market, government departments mainly provide the issuance, distribution and registration of carbon emission allowances for domestic enterprises. Based on the underlying technology of the blockchain, the carbon emission allowance for the year can be calculated based on the company's emissions over the years by designing smart contract algorithms; then, the data are broadcast on the whole network so that all users on the chain can make inquiries, and it also plays a supervising role for the enterprises. This greatly reduces costs and improves efficiency. If the company defaults, the relevant government departments can allocate part of the company's carbon allowance rights for the next year to international financial institutions, and then auction it.

(4) Financial institutions: In the practice and prospects of the application of blockchain, the banking industry has become the most popular application field of blockchain [52]. For example, Indian commercial banks introduced blockchain technology to overcome high debt and capital risks; the Brazilian Development Bank used blockchain technology to lend and monitor development projects [53]; Italian banks used blockchain to solve practical business problems, in order to provide greater data transparency and visibility, faster execution, and the possibility of transferring checks and money directly within the application [54]. Among them, the most influential R3 blockchain alliance brings together more than 40 world-leading financial institutions, including Bank of America, Citigroup, Morgan Stanley, Deutsche Bank, and Barclays Bank [55]. Therefore, the financial institutions that apply for chaining in this article can provide loans or financing for blue carbon suppliers, and only need to register an electronic account on the financial institution chain platform to provide financial support for their projects' development. Financial institutions can also provide loan services for high-energy-consuming buyers, so that they have sufficient capital circulation capacity, balance their own emission reduction tasks, and improve corporate emission reduction technologies.

(5) Non-profit organizations: First of all, non-profit organizations themselves are an important force in environmental governance, and they are dedicated to the public. Secondly, non-profit organizations can use blockchain to build trust between donors, thereby improving the transparency of donation management, and meeting demand with lower costs and higher efficiency [56]. A blue carbon trading application system under blockchain technology can be built and designed for non-profit organizations to register on the chain; donors can choose the goal of donations; all details of donations can be recorded on the blockchain; once the donation reaches the beneficiary's account, relevant information about transfers and withdrawals will also be recorded. Non-profit organizations can raise funds for high emitting companies to improve production technology and replace energy-saving equipment. Education and publicity can also be carried out in maintaining the ecosystem, and more environmental maintenance volunteers can be provided. The design of this node on the chain can refer to the international non-governmental organizations in the international blue carbon partners, such as the World Conservation Union (IUCN), the Pacific Regional Environmental Program Secretariat, and the Nature Conservancy (TNC) [27]. These kinds of public welfare participants have made their own contribution to global climate governance, and can also enhance the image of the organizations and attract more volunteers to strengthen the organizations.

(6) Research and development institutions: These mainly provide technical support for emission control companies, such as mangrove area estimation, restoration technology, project carbon sink accounting and reasonable pricing for the development of blue carbon projects.

4. Blockchain-Based Blue Carbon Governance Cooperation System

Through the analysis and summary of blockchain applications in the above different fields, it is reasonable to design the blue carbon production, supply, circulation, trading, supervision and other processes on a unified platform to build a carbon sink trading application system. Since the carbon sequestration amount of blue carbon sinks is a "commodity" that cannot be directly perceived, blue carbon sinks trading refers to how, on an equal and voluntary basis, one party to the transaction receives the corresponding blue carbon sink generated and calculated by carrying out the carbon sink project and paying the consideration. It is a virtual type of transaction used to offset the CO_2 emissions generated by one's own production activities.

By analyzing the application cases of blockchain technology in different fields, it can be concluded that the design of each project will be based on the underlying blockchain technology, selecting the appropriate consensus mechanism, and using smart contracts to achieve P2P peering between nodes and information transmission, and to finally realize the docking with the application layer. Three technologies currently widely used are Bitcoin, Ethereum, and advanced ledgers, all of which belong to the application of blockchain 1.0 technology (including the data layer, the network layer, the consensus layer, the incentive layer, and the application layer). The application of the blockchain in the relevant cases freed the operation process from the traditional shackles that must be encountered by relying on the minded organization, and greatly promoted the convenience and wideness of social activities. Therefore, the application of blockchain technology to build a distributed, decentralized and traceable blue carbon trading network can be applied to international blue carbon trading. It is also one of the contents of the carbon trading system under blockchain technology.

4.1. Construction of the System Architecture

The system can adopt the basic architecture model of blockchain 3.0: the data layer, the network layer, the consensus layer, the incentive layer, the contract layer and the application layer [57]; it is divided into three modules: basic, core and interaction.

The data layer provides the data structure processing foundation for the entire architecture. The data information includes the basic information of each participating subject, which must be filled out when registering as a user, such as the creation of a trading enterprise, the type of business engaged in, and the relevant reputation and other basic information. This information includes the application materials of the enterprise in the identity authentication process (shown in Figure 3). After passing the authentication, the specific data types involving each participant are shown in Figure 4. These data will be processed based on blockchain technology, and all data information in the system will ultimately be transmitted, stored and processed using the basic structure of data blocks, which involves data blocks, chain structures, hash algorithms, and Merkle Technical, timestamps, asymmetric encryption and other technical elements.

The network layer is based on actual application requirements. By designing a specific propagation protocol and data verification mechanism, each node in the blockchain system can participate in the verification and accounting process of block data. Data can only be recorded in the blockchain after they have been verified by most nodes in the entire network.

The consensus layer encapsulates the consensus mechanism to ensure that each node efficiently reaches a consensus on the validity of the block data. In other words, the consensus mechanism manages a series of coherent implementation rules among participating nodes. The earliest consensus mechanism is POW (Proof of Work). With the

development of blockchain technology, consensus mechanisms such as POS and DPOS have emerged subsequently.

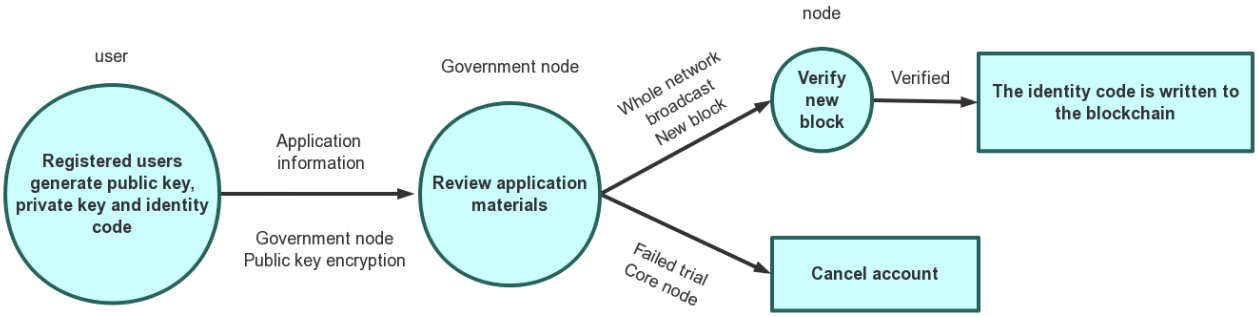

Figure 3. Identity authentication flow chart. (Source: Designed by the authors).

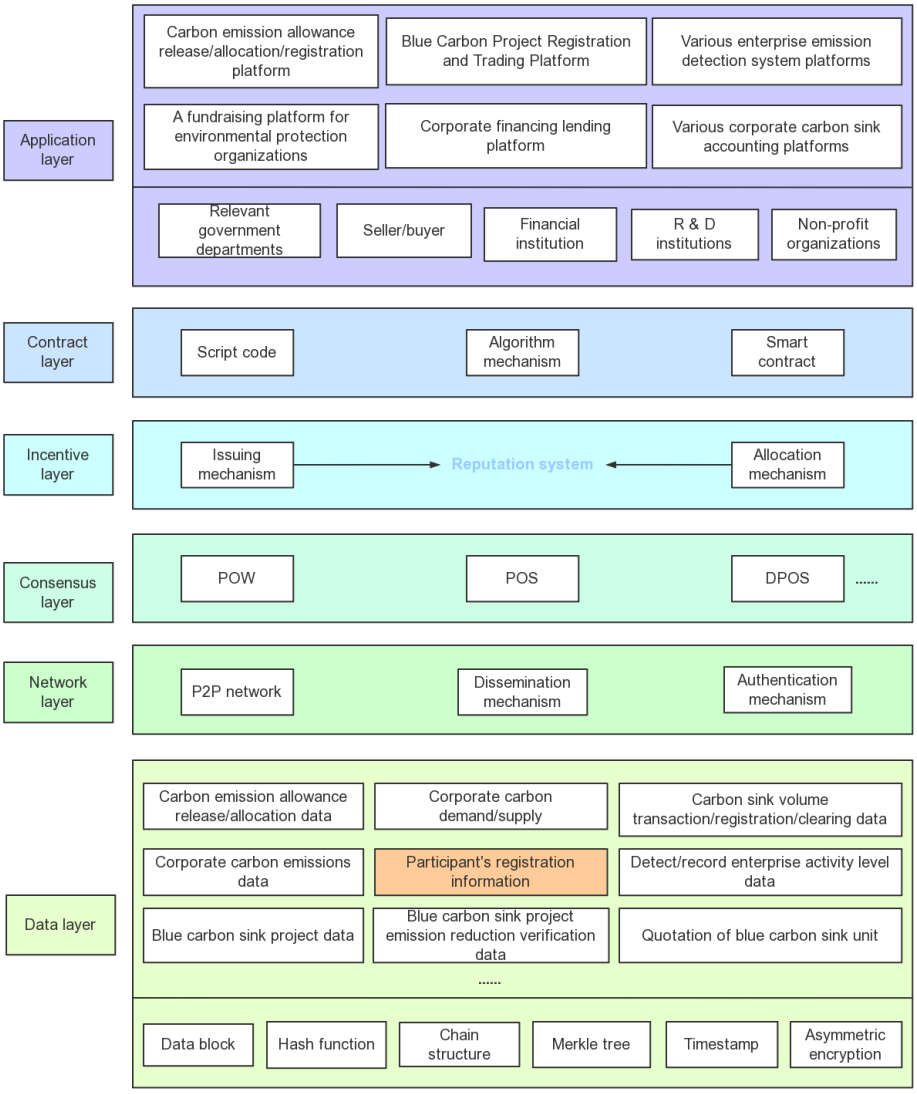

Figure 4. Blue carbon management application system architecture diagram. (Source: Designed by the authors).

The incentive layer mainly includes the issuance system and distribution system of economic incentives. Its function is to provide certain incentives to encourage nodes to participate in the security verification work in the blockchain, incorporate economic factors into the blockchain technology system, and encourage compliance with rules to

participate in the record and punish the nodes that do not follow the rules. Earlier studies have found that the reputation system is an effective way to ensure the good behavior of participants and improve the quality of the market [58]. Under the incentive mechanism, Khaqqi proposed a blockchain-based emissions trading system based on the reputation of buyers and sellers to incentivize industry participants [59].

The contract layer encapsulates the various script codes and algorithms of the blockchain system and the more complex smart contracts generated therefrom, which are the basis for realizing the flexible programming and operating data of the blockchain system. In the application of carbon sink trading, companies dynamically adjust output and carbon trading volumes in accordance with carbon emission rights and carbon emission production benefits to develop smart contracts from the perspective of maximum value. For example, according to standard methodology, the activity level data of emissions control companies are converted into emissions data; the emission reductions of blue carbon sink projects developed according to the rules are converted to offset emission allowances.

The application layer integrates information collection of blue carbon production, industrialization, circulation, trading and other application scenarios, and provides responses to information inquiries from buyers and sellers, financial institutions, R & D institutions, non-profit organizations, and government regulatory agencies participating in blue carbon transactions, business liquidation, financial lending, corporate carbon emission supervision and other services.

Based on the analysis of the behaviors of the entities participating in the blue carbon circulation and a summary of the key technologies of blockchain in different application scenarios (shown in Table 2), this article constructs a blue carbon trading application system architecture diagram (shown in Figure 4).

Table 2. On-chain blue carbon trading process and key technologies.

Process	Elaboration	Key Technologies
Information release and matching	High-energy-consuming enterprise users with transaction qualifications and carbon sink project development companies register through websites or applications and submit requests for purchase and sale of carbon sinks. Users and suppliers reach transaction intentions, that is, the matching of buyers and sellers has been completed at this stage.	Consensus mechanism, P2P network transmission technology
Transaction information on the chain	The blockchain client developed based on the application framework and blockchain standards writes the data information obtained in the previous stage to the blockchain, including initial information such as quotations and matching information.	Consensus mechanism, smart contract, cryptography
Transaction settlement	After the block link receives the matching information from the buyer and the seller, it settles the transaction and realizes the automatic transfer of funds from the buyer to the seller. Records the transaction content and provides a reference for the next round of transactions.	Consensus mechanism, smart contract, cryptography
Transaction storage	When storing transaction information, it is necessary to ensure that the information is true and checkable, but also to ensure that the information will not be tampered with. Finally, the transaction results will be announced on the entire network.	Consensus mechanism, cryptography, distributed storage technology, P2P

4.2. Advantages of Blockchain as a Blue Carbon Trading System

Traceability and non-tamperability: After frequent transactions, all transaction records can still be traced. Under the conditions of blockchain technology, the carbon emissions trading behavior of enterprises can be recorded in real time, and each transaction can be time stamped. As a proof of the existence of block data, it helps to form an immutable and unforgeable blockchain database. It is helpful to calculate the distribution of the company's carbon emission credits and determine whether the company participates in the purchase of additional carbon credits. The specific process design is shown in Figure 5, where n represents the number of defaults by the enterprise in the node.

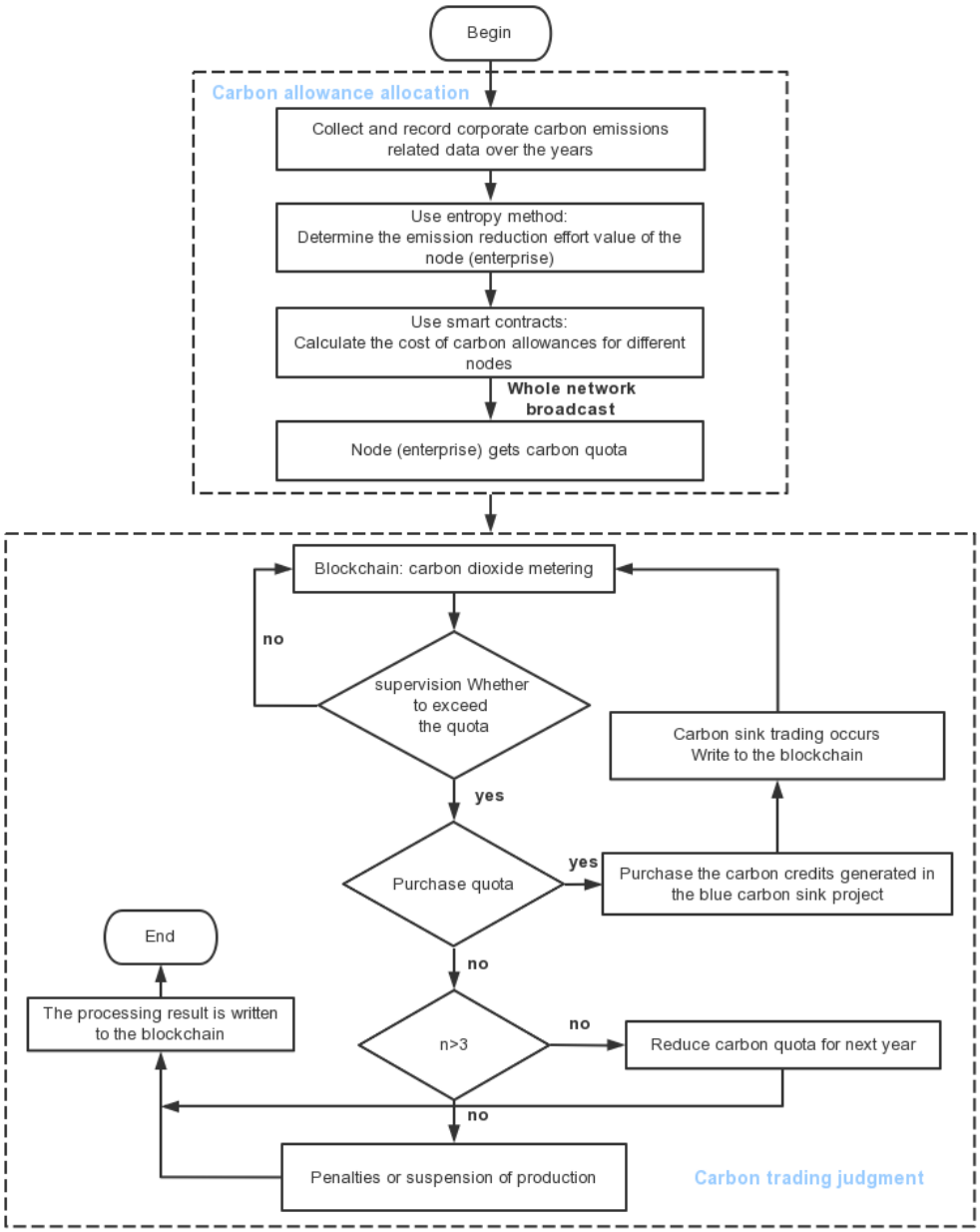

Figure 5. Flow chart of carbon sink transaction source traceability under blockchain. (Source: Collated from [60,61]).

Transparency and safety: The transaction data of each company are all contained in the block, including carbon allowances, carbon emissions, historical transaction prices, and quantities; current transaction quotations, quantities, etc., are recorded in a distributed, open, and transparent manner at each node; and the information is completely symmetrical.

Nodes can be queried at any time. All users maintain the ledger together, and the data cannot be tampered with, ensuring the security of transaction records. The core feature of blockchain technology is decentralization, adopting a peer-to-peer network architecture (P2P); everyone is a shared server, and each node is highly autonomous and has the function of data ledger recording. It can prevent the risk of the database crashing and being unable to obtain data under the traditional mode, and at the same time can ensure the authenticity and validity of the data. Safety is a technical guarantee for the traceability and traceability of products (blue carbon can be regarded as an ecological product). This technology also makes the market trading environment more credible.

High efficiency and low cost: The transaction platform constructed under the blockchain technology can improve the transaction efficiency of various entities and reduce transaction costs. It compiles the development, carbon sink auctions, transactions and other links involved in blue carbon trading into smart contracts, so that digitization runs through the trading chain to simplify the current carbon trading process. Based on the P2P network, participating companies can directly trade without third parties. Institutions do not need to pay commissions, which reduces the transaction costs of enterprises. It also greatly simplifies the supervision of government and inspection agencies, thereby reducing supervision and management costs and improving transaction efficiency.

Contributing to "carbon neutrality": The ocean is the largest carbon sink on the planet, and coastal blue carbon is a carbon sink resource with huge potential. Under the three advantages of blue carbon's original "long storage time", "high capture efficiency", and "huge ecological and environmental benefits" [62], the introduction of blockchain technology can actively promote the linking of the global carbon market and provide a mature carbon market. The market (carbon rights and carbon sinks) provides a smart trading platform. Therefore, under the rigid constraint of the carbon neutral goal, we should give full play to the role of blue carbon, use the advantages of blockchain technology to attract all participants to cooperate in tackling climate problems, and fully tap the "decarbonization space".

5. Discussion

In 2020, the scale of global corporate blockchain spending reached four billion U.S. dollars, nearly doubling compared to the previous 19 years [63]. The digital currency of central banks around the world is advancing rapidly, the underlying technology of the blockchain has achieved key breakthroughs, global blockchain supervision has also achieved good progress, and the industrial blockchain is also developing steadily [63] ("Global Blockchain Panorama and Trends" report, 2021). As the blockchain technology gradually emerges from the trough period, more and more countries pay attention to it. Scholars have gradually explored the application of blockchain in the energy industry, but few have used blockchain in the application to ecological product (carbon sink) transactions in environmental governance. This article is different from current research in the three following aspects:

(1) Providing research ideas for the integration of blockchain and the virtual economy industry in environmental governance: At present, government governance projects based on blockchain are also concentrated in applications such as digital identity authentication, electronic medical care, and electronic election voting. Moreover, the current blockchain is mainly used in the field of industrial finance for commodity transactions to provide financing for small and medium-sized enterprises. This article combines the two in ecological product (carbon sink) trading and expands its application range to blue carbon.

(2) Enriching the carbon market and promote "emission reduction without reducing production": The current mainstream framework believes that to solve the huge and hyper-spatial externality of "carbon emissions", it is necessary to realize the internalization of this negative externality through carbon pricing (carbon tax and carbon trading). However, some scholars have gradually questioned carbon pricing as the

main policy tool to deal with climate change [64] and reviewed the post-mortem quantitative assessment of global carbon pricing policies since 1990, showing that carbon pricing has a limited impact on emissions and only maintains between 0−2% [65]. Carbon rights and forest carbon sinks are often mainly discussed in carbon trading, and ocean carbon sinks are not included. Moreover, the ocean is the world's largest carbon reservoir, and its high carbon sequestration efficiency is conducive to achieving "emission reduction without reducing production". Therefore, this research discusses carbon sink trading under the blockchain, enriches the carbon trading market, and increases the contribution of carbon trading in the path to carbon neutrality.

(3) Making the world pay more attention to the development and utilization of marine resources: The establishment of the blue carbon market has been blocked due to various factors such as the lack of blue carbon measurement standards and monitoring mechanisms. With the maturity of blue carbon sink quantitative research methods [66], and the establishment of a well-functioning blue carbon trading mechanism, a fair market environment and effective regulatory framework can be established [67]. From a forward-looking perspective, this article assumes that under the conditions of mature blue carbon sink data collection and accounting methods, the programming language of smart contracts under blockchain technology can be used to measure blue carbon sinks and improve transaction efficiency.

6. Conclusions

The research on the application of blockchain in carbon trading is gradually increasing, focusing more on forest carbon sinks rather than ocean carbon sinks. This paper is an ahead of its time study combining blockchain technology with blue carbon trading in the process of gradual assetization of blue carbon. After analyzing the research on blockchain applications in various fields, the theoretical logic of this technology was refined. The possibility of practical application of blockchain in transactions involving ecological products (e.g., carbon sinks) was investigated. A conceptual model approach was used to construct a theoretical model of blockchain technology in the blue carbon international trade market, and the advantages of combining the two were demonstrated. It is conducive to reducing transaction costs and improving efficiency, and has the effect of universal supervision, enabling enterprises to fulfill their social and environmental responsibilities and helping to achieve carbon neutrality. Therefore, this paper differs from previous studies in that: (1) from a qualitative perspective, it constructs a conceptual framework for applying blockchain to blue carbon trading; (2) it combines financial institutions and relevant government departments to participate in the virtual economy industry in environmental governance; (3) it uses the marketization and reimbursement of blue carbon sinks to achieve a balance between environmental and socio-economic interests of the whole ecosystem, and helps to achieve "emission reduction without production reduction".

Limitations and Future Research Directions

We combined blockchain technology and blue carbon trading to build a theoretical framework for blue carbon trading under the blockchain technology. We analyzed the operation process in the production, industrialization, trading and circulation of blue carbon, and demonstrated the advantages of this application in the operation process. However, there were still some shortcomings in this study, especially some limitations in the following two aspects:

(1) In this study, a framework for blockchain application in blue carbon trading was assumed to be established in an ideal state. Among them, the coordination of interests among various subjects, the selection of carbon quota indicators and the setting of benchmarks for emission reduction rewards and penalties have not yet been specified and are at a preliminary stage. Therefore, the literature needs to gradually refine and improve the setting of relevant indicators and benchmarks as the blue carbon market develops.

(2) This paper adopted a qualitative research approach to summarize the conceptual framework for the participation of emissions control enterprises in blue carbon trading under blockchain in the context of the trend of research related to the application of blockchain in carbon trading. There was a certain lack of rigidity in the data. In the future, based on the independent quantification of blue carbon-related emission factors, the gradual maturity of blue carbon measurement methods and the increase of practical application cases, modeling and simulation methods can be used to further study what factors affect blue carbon trading under blockchain.

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Nomenclature

Nomenclature	Definition
Nature-based solutions (NbS)	It emphasizes respecting the laws of nature, and through afforestation, strengthening farmland management, protecting wetlands, oceans and other ecological protection and ecological restoration, improving ecological management and other implementation paths, controlling greenhouse gas emissions, improving the ability to deal with climate risks, and at the same time increase carbon sinks. It is a comprehensive means of mitigating and adapting to climate change and improving climate resilience.
peer-to-peer (P2P)	A P2P network is the networking method of blockchain. Each node in the P2P network has the characteristics of equality, autonomy and distribution, and so on. All nodes are connected to each other in a flat topology, without any centralized authority node and hierarchical structure.
Clean Development Mechanism (CDM)	One of the mechanisms for flexible compliance introduced in the Kyoto Protocol. It allows Parties to undertake joint projects with non-Parties to reduce emissions of greenhouse gases such as carbon dioxide. The amount of emission reductions generated by these projects can be used by Parties to meet the emission limits or reductions to which they are committed.
Joint Implementation (JI)	It is one of the flexible compliance mechanisms introduced in the Kyoto Protocol. It is the certification and transfer or acquisition of emission reduction units (ERUs) between Annex I countries under the supervision of a "supervisory committee", using ERUs. As tradable commodities, ERUs can help Annex I countries meet their Kyoto Protocol emission reduction commitments.
Proof of Work (POW)	A consensus mechanism, which is simply understood as "work-based distribution", that is, how much one gets paid for the work one puts in, and labor in blockchain refers to the computing services provided to the network.
Proof of Stake (POS)	A consensus mechanism, simply understood as "assignment by capital", where interest is paid based on the amount and duration of money held by users.
Delegated Proof of Stake (DPOS)	It is a consensus mechanism in which a trusted account elected by the community, i.e., the one with the highest number of votes, creates the block. Similar to a shareholding company, ordinary shareholders do not have access to the board of directors and need to elect representatives to make decisions in their place.

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