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Original Research

Construction and Application of an Evaluation System for Ocean Carbon Sink Trading

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Abstract

Oceans are the largest and most active carbon sinks in the ecosystem. The ocean carbon sink trading market is a significant component of the emission-reduction market, playing an important role in achieving carbon peak and carbon neutrality (i.e., “dual-carbon goals”). This study aims to identify the characteristics of ocean carbon sink trading and construct a corresponding evaluation index system. SWOT-AHP fuzzy comprehensive evaluation is used to evaluate the ocean carbon sink trading market in Fujian Province. The results show that, first, the ocean carbon sink trading market is at a generally low level, with indicators showing varying degrees of performance. Opportunity indicators tend to have excellent scores, threat indicators are at a moderate level, and advantage and disadvantage indicators are both at relatively low levels. Second, the main factors related to ocean carbon sink trading development are diverse. Current ocean carbon sink trading has not fully utilized its advantages and opportunities, and it is important to address threats and disadvantages to ocean carbon sink trading market development. This study provides a scientific basis for the development of policies related to ocean carbon sink trading markets.

Keywords: Ocean carbon sink trading, Evaluation index system, SWOT-AHP

Introduction

As the world’s largest energy consumer, China has also established the world’s largest renewable energy market as well as a nationwide carbon market, aiming to reduce greenhouse gas emissions. In response to climate change, China has pledged to achieve carbon neutrality by 2060. Achieving this relies in part on the construction of carbon sink markets. Although China has established a national carbon market, compared with developed countries such as those in the EU and North America, China’s carbon market is still in its infancy. China’s timeline for achieving carbon peak and carbon neutrality (the “dual-carbon” targets) is about half that of developed countries, and achieving these dual-carbon goals is of great importance. Oceans are the largest and most active carbon pools in the ecosystem [1, 2]. It is of great significance to achieve the dual-carbon

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goals. In this regard, China has over 30,000 km of coastline, dense ocean aquaculture activities, and multiple types of ocean ecosystems [3], offering considerable potential for developing an ocean carbon sink market.

Research on the development of ocean carbon sink markets has focused on market design, trading mechanisms, problems, and construction pathways [4, 5]. These studies have produced results relevant to national ocean carbon sink market development and the expansion of international comparison. Regarding the design of ocean carbon sink markets, studies have focused on market elements and trading mechanisms. First, the elements of ocean carbon sink markets mainly include suppliers, demanders, government departments, third-party intermediaries or service agencies, trading and information registration institutions, and stakeholders [6]. Second, regarding trading mechanisms, research has focused on participating entities, market price determination, and transaction guarantee systems. Yang noted that the participating entities in transactions mainly include suppliers, demanders, and third-party regulators. Wen et al., however, proposed that the participating entities in transactions include the government, businesses, trading platforms, nongovernmental organizations, institutions or individuals, and the general public [7, 8]. Sheehy, J. et al. proposed, based on an analysis of comparative research studies, that the participation of private entities, such as finance and insurance organizations, should not be ignored in the ocean carbon sink market [9, 10]. Furthermore, given the diverse nature of participating entities, an "enterprise-level and individual-level carbon market" [11] can be formed through the combination of public chains and sidechains. Regarding research on ocean carbon sink prices, studies have investigated the ecological value accounting of ocean systems [12], pricing models based on industry costs and benefits [13], and carbon tax pricing models [14]. Such studies examine how to determine prices, the principles behind price fluctuations, and future price forecasting. Studies of the guarantee systems for ocean carbon sink transactions have underscored the importance of protecting the ecosystem to harness the functionality of ocean carbon sinks, as well as establishing financial mechanisms compatible with ocean carbon markets [15, 16]. Jiang and others emphasized the need for improved legal safeguards in areas such as ownership rights and transaction disputes related to ocean carbon sinks [17, 18]. Overall, ocean carbon market development requires addressing challenges in resource ownership, value accounting [19], and legal, financial, technological, and risk mechanism safeguards [20]. Thus, the construction of ocean carbon markets has followed a phased approach that assigns roles to both the government and the market. It involves improving supply and demand mechanisms, accounting mechanisms, pricing mechanisms, risk mechanisms, and investment and financing mechanisms. These are the trends in the development of ocean carbon markets.

In terms of challenges and pathways, there are issues related to a lack of overall coordination in the trading market system. Shortcomings exist in terms of international and domestic markets, regions, industries, technologies, and standards related to the coordinated development of ocean carbon sink trading systems. Various methods are used to address existing challenges and propose pathways for improving ocean carbon sink trading markets. First, there are shortcomings in the allocation of ocean carbon sink resource ownership, value accounting, risk prevention and control, organizational management, and technical support systems [20]. Second, the ocean carbon trading market has not been unified, and it lacks standards [21]. Investigating the ocean carbon sink trading market of the Guangdong–Hong Kong–Macao-Greater Bay Area, studies have noted that ocean carbon trading has not been included in the national carbon trading market layout and that the ocean carbon sink trading market is still in its infancy [21]. Under the constraint of carbon neutrality, Li analyzed problems such as the lack of an ocean carbon financial cooperation system and market link rules in China–EU ocean carbon sink financial cooperation [22]. There is a need to improve the ocean carbon sink market system, develop methods to account for the value of ocean carbon sink products, launch the China–EU initiative on standards and incentives for ocean carbon sink bonds, and use international cooperation to expand international financing channels for low-risk ocean carbon sink industries. Third, various theories have been applied and solutions proposed. Studies have employed evolutionary game theory, aiming to improve the participation of stakeholders such as the government, ocean carbon sink suppliers, and ocean carbon sink demanders to build effective ocean carbon sink trading markets [23]. Considering overall land and sea planning and sustainable development, one study proposed a top-down model to establish a legal support system for ocean carbon sink trading systems [24]. In light of the existing research, the present study aims to construct an evaluation index system to provide a reference for evaluating the development of China's ocean carbon sink market.

This study's main contributions are as follows: First, unlike existing studies, this study does not evaluate the development of the components of the general market system; instead, it first identifies the characteristics of ocean carbon sink trading. Owing to complex property rights, high capital requirements, and a combination of public interest and economic benefits, trading in marine carbon sinks places extremely high demands on trading systems, third-party service providers, policymakers, and so on. Therefore, the design of an evaluation index should fully consider the unique aspects of ocean carbon sink trading. Second, this study constructs an evaluation system applicable to the ocean carbon sink trading market and conducts quantitative research. Existing studies have focused on the trading mechanisms of ocean carbon markets. However, these studies have primarily offered theoretical evaluations of ocean carbon sink trading market development, and there is a lack of continuous monitoring data on the trading system. This study, therefore, uses an evaluation method based on SWOT (strengths, weaknesses, opportunities, and threats) and AHP (analytic hierarchy process) to quantitatively evaluate the SWOT recognition of market participants in the trading system. This overcomes the deficiency of purely theoretical evaluation. Third, the proposed evaluation system is tested using a case to overcome the lack of practical application. Based on field investigation, Fujian Province is selected as a typical case to measure the actual ocean carbon sink trading market using an evaluation index system. This approach allows for the application of the theoretical analysis of the evaluation index system to the development of specific ocean carbon sink trading platforms, distinguishing it from existing studies.

The rest of the study includes a theoretical analysis of ocean carbon sink trading markets, a presentation of the construction of the ocean carbon sink trading market system, a discussion of data sources and research methods, a presentation of the results and a discussion of them, and lastly, conclusions and policy recommendations.

Theoretical Analysis of Ocean Carbon Sink Trading Markets

The purpose of an evaluation indicator system for the ocean carbon sink trading market is to comprehensively evaluate the basic development of the market. The ocean ecosystem has unique variability in terms of carbon sink patterns [25, 26] and property rights characteristics [1, 13]. Therefore, it is necessary to identify the characteristics of ocean carbon sink trading to distinguish it from the general evaluation of carbon sink trading markets within the existing carbon market framework.

Market Attributes of General Commodities

Products of ocean carbon sink trading have the dual attributes of value and use value. Ocean carbon sinks naturally have the use value of absorbing carbon dioxide and regulating the climate [27]. In addition, activities such as the restoration and management of mangroves, salt marshes, seagrass beds, and fishery resources require the input of labor, giving them the value attribute of commodities. As a special commodity, the development and trading of ocean carbon sink projects has been widely supported. Countries like China, Senegal, Kenya, and Indonesia, among others, have engaged in ocean carbon sink project trading, and there is a broad international consensus regarding the value of these carbon sinks for mitigating climate change [28]. Ocean carbon sinks have the commodity attributes of value and use value, resulting in increased market regulation for ocean ecosystem protection. The ocean carbon sink market is conducive to protecting the legitimate rights and interests of all participants, encouraging ocean ecological protection behaviors, or promoting the improvement of carbon sink technology, and is conducive to establishing a gradually improved trading system while simultaneously disclosing trading information and reducing transaction costs. Based on market elements and functions, this study designed evaluation indicators for ocean carbon sink trading markets. These include safeguarding the rights and interests of trading parties, establishing a comprehensive ocean carbon sink trading system, creating trading platforms that promote information symmetry by revealing the price, and so on.

Policy-Driven Nature

The international control of greenhouse gas (GHG) emissions under the Kyoto Protocol resulted in widespread attention being paid to carbon sinks [29, 30]. This is because the stricter the emission regulations are, the greater the need to reduce carbon emissions. The UN Framework Convention on Climate Change and the Paris Agreement have further increased market opportunities for ocean carbon sinks [30]. China has continued to incorporate the construction of ocean carbon sinks into its national policy system. In 2020, China proposed the "30.60" dual-carbon target, which increased the domestic demand for ocean carbon sink trading. In sum, ocean carbon trading is significantly driven by policy.

This policy-driven nature provides market opportunities for ocean carbon sink trading. In particular, the concept of global environmental governance has changed from "isolated" protection to livelihood development and environmental governance at the same time [27], providing opportunities for the development of the ocean carbon sink market potential. Thus, this study selects three indicators: China's "dual carbon" goal provides market opportunities, the construction of an international carbon trading market provides national policy opportunities, and carbon market price fluctuations lead to trading demand. However, while the policy-driven nature of ocean carbon sink trading creates opportunities, it also imposes certain constraints on market competition. At present, the carbon sink trading price is still dominated by government pricing, and there is no market transmission mechanism. Therefore, the non-marketization of carbon prices reduces the enthusiasm of enterprises, which is one of the potential threats listed in this study.

Complexity and Risk

First, ocean carbon sink trading encompasses both economic and public benefits. The economic benefits depend on the visualization of public benefits. However, given the dynamic nature of ocean environments with unique ecological characteristics, accounting for public benefits often requires a wide range of technologies, disciplines, and methods. The tracking of carbon budgets has revealed persistently low consistency in carbon flux results obtained from different measurements taken on land and sea over several decades [30]. Thus, despite advancements in monitoring and accounting practices for carbon sinks, a standardized global system for ocean carbon sinks has yet to be established. Moreover, incorporating the ecological value of ocean carbon sinks into mitigation and adaptation strategies remains an ongoing topic of discussion, thus posing potential obstacles to seamless trading.

Second, ocean carbon sink trading involves diverse targets encompassing ecosystem restoration efforts (e.g., mangroves, seagrass beds, and salt marshes) alongside economic activities that generate supplementary carbon sinks, such as fishery aquaculture. Realizing ecological value through market mechanisms requires highly skilled professionals. However, training programs for specialized talent in China still lag behind. Academic institutions have yet to introduce majors focused on carbon trading in environmental studies. China's ocean carbon sink trading thus faces a scarcity of specialized personnel, which is one of its main disadvantages.

Third, the problem of unclear property rights in ocean carbon sink trading is becoming more prominent. Different from ordinary commodities, ocean carbon sinks are ecological products with significant externalities. According to Coase's theory, certain institutional arrangements need to be established before main market players can enter the trading market [31, 32]. However, there is currently no unified property rights system for ocean carbon sink carriers. In China, only "quasi-property rights" are assigned to ocean carbon sinks. Given the complexity of ocean ecosystems and variations in ecological functions across different regions and species, it is challenging to determine the scope of rights confirmation and payment [27], thus increasing the risks associated with ocean carbon sink trading and threatening its smooth operation.

Fourth, the ocean carbon sink trading market is still in the early stages of development. Although such trading projects exist in countries such as the US, Australia, Indonesia, and China, the international market for ocean carbon sinks remains nascent. Among nearly 10,000 carbon sink trading projects, ocean carbon sink initiatives account for a very small proportion. China's market for carbon sinks is also in the preliminary exploration stage. Thus, there is a lack of mature experience to guide ocean carbon sink trading efforts, resulting in drawbacks such as the limited effect of pilot programs.

Fifth, ocean carbon sink trading often has long cycles, high operating costs, and large price fluctuations [31]. The uncertainty of the future and the difficulty of harmonizing the discount standards aggravate the complexity and risk of ocean carbon sink trading. As a result, blue carbon trading often requires substantial capital to meet operational and risk prevention needs. Many of the international ocean carbon sink projects need support from governments, enterprises, and other development funds [30]. Currently, China's financial support for ocean carbon sink trading lags behind that offered for forestry carbon sink trading [33], which is one disadvantage of ocean carbon sink trading in China.

Data Sources and Research Methods

Data Sources

First, considering the complexity of evaluating ocean carbon sink trading, the data used in the evaluation and analysis come from expert questionnaires. Experts in the field of ocean carbon sink research were invited to perform scoring. The expert questionnaire involved scoring and evaluating the importance of 18 evaluation indicators (e.g., advantages, disadvantages, opportunities, and threats related to the national ocean carbon sink trading market). Based on existing research on evaluating the property rights trading market, one-on-one interviews were conducted with 12 experts in Fujian Province and online interviews were conducted with 11 experts in Beijing, Guangdong, Shanghai, and Hainan from January to August 2023. The experts mainly fell into two categories: the staff of institutions engaged in the formulation of trading policies and market management (10 experts) and experts or experienced managers from universities or forestry and ocean fishery research institutes who were familiar with and had a long-term interest in carbon sink market research (13 experts).

Second, questionnaires were distributed based on market research on ocean carbon sink trading market evaluation indicators. Fujian's ocean carbon sink trading market was selected as a case to apply the evaluation index system. Fujian Province has built an ocean carbon sink trading mechanism, developed ocean carbon sink investment and financing products, implemented ocean carbon sink trading projects, and has gradually built a relatively complete ocean carbon sink. Farmers were investigated using stratified questionnaires, measured using Likert scales divided into five measurement levels: excellent, good, medium, poor, and poorer, with scores of 100, 80, 60, 40, and 20, respectively. A total of 104 questionnaires were sent out, and 104 were recovered, 103 of which were valid. The membership of each evaluation index was calculated to obtain the fuzzy matrix index value of the ocean carbon sink trading market evaluation.

Construction of the Ocean Carbon Sink Trading Market System

Based on the characteristics of the ocean carbon sink trading market and the principles of scientificity, completeness, and feasibility required for building evaluation index systems, a SWOT analysis of the ocean carbon sink trading market is carried out to obtain indicators. Then, based on AHP, the ocean carbon sink trading market is taken as the target layer, SWOT as the criterion layer, and 18 indicators corresponding to SWOT are taken as the indicator layer to build a multilevel, multifaceted ocean carbon sink trading market evaluation index system (Table 1).

Method Selection

SWOT-AHP

SWOT-AHP is a quantitative analysis method that determines the weight of each indicator in a logical sequence of decomposition, comparison, judgment, and synthesis. It decomposes complex decision problems into several relatively simple influencing factors to obtain the weights of these factors on the problem. It overcomes the limitation that SWOT analysis can only perform qualitative analysis. The operational process involves four aspects:

Table 1. Ocean carbon sink trading market evaluation system

Target layer (A)	Criterion layer (B)	Index level(C)	Literature
Ocean carbon sink trading market	Strengths (S)	It is beneficial for protecting the rights and interests of all parties involved in the transaction.	Shen & Liang, 2018 [13]
		It has formed a relatively complete ocean carbon sink trading system.	Yang et al., 2021; Xie et al., 2021 [1, 20]
		Building a trading platform facilitates information symmetry and price discovery.	Jiang, 2022; Ji, 2021 [17, 19]
		Market bidding mechanisms are beneficial for increasing user profitability.	Wang & Li, 2021 [33]
		A sound organizational trading structure helps provide professional services to traders.	Chen et al., 2022 [26]
		Market-based trading incentivizes ocean ecological protection behavior/improvement of carbon sink technologies.	Contreras & Thomas, 2019 [34]
	Weaknesses (W)	Ocean carbon sink trading is in the exploratory stage.	Xie et al., 2021; Duan et al., 2021; Wang & Li, 2021 [20, 21, 33]
		The influence of pilot projects on ocean carbon sink trading is not high.	Contreras & Thomas, 2019 [34]
		The degree of financialization of ocean carbon sinks is relatively low.	Li et al., 2022; Pan, 2018 [2, 28]
		Professional talent in ocean carbon sinks is relatively scarce.	Li et al., 2022 [2]
		The market trading of ocean carbon sinks lacks compulsory safeguards.	Xie et al., 2021; Pan, 2018 [20, 28]
	Opportunities (O)	The dual-carbon target promotes the development of ocean carbon sink trading, providing a broad market space.	Xie et al., 2021; Chen et al., 2022 [20, 26]
		Carbon market construction provides national policy opportunities for promoting ocean carbon sink trading.	Chen et al., 2022; Contreras & Thomas, 2019 [26, 34]
		Price fluctuations in the carbon market create demand for the market trading of ocean carbon sinks.	Ji, 2021; Xie et al., 2021 [19, 20]
	Threats (T)	The ownership of ocean carbon sink rights has not been clarified.	Bai & Hu, 2021; Sun et al., 2023 [24, 35]
		Measurement standards and methods for ocean carbon sinks are relatively weak.	Li et al., 2022; Liu et al., 2022 [2, 36]
		Non-market-based carbon prices reduce corporate enthusiasm; there is	Ji, 2021; Xie et al., 2021 [19, 20]
		Competition from other trading methods.	Wang et al., 2014; Xie & Wei, 2010 [37, 38]

First, construct the SWOT-AHP analysis model. Based on the results of the SWOT analysis, determine the sequence of the overall goals, subgoals, and evaluation indicators. Through field surveys and expert interviews, the advantages, disadvantages, external opportunities, and threats of Fujian's carbon trading platform are used as criteria, and the specific indicators corresponding to SWOT are used as indicator layers.

Second, construct pairwise comparison matrices. Invite multiple experts to participate in the evaluation. Based on the 1–9 evaluation scale shown in Table 2, experts compare and assign values to the elements of the criteria layer in pairs. Similarly, they compare and assign values to the indicators of SWOT corresponding to the indicator layer in pairs, thus forming five matrices.

Third, calculate the characteristic vectors of the matrices and perform consistency checks. For judgment matrix A, calculate the eigenvalues and eigenvectors that satisfy $AW = \lambda_{\max} \times \omega$. Normalize the eigenvectors, where element A_i is the corresponding element's weight without scaling.

Table 2. AHP evaluation scale

Scale	Definition
1	Equally important
3	Slightly important
5	Moderately important
7	Strongly important
9	Extremely important
2, 4, 6, 8	Intermediate value between two adjacent judgments.

Fourth, perform consistency checks. The consistency check uses $CR = CI / RI$, where if $CR < 0.1$, it is valid and if $CR > 0.1$, it is invalid. Value adjustments are made until the result is valid.

The Fuzzy Comprehensive Evaluation Method

The fuzzy comprehensive evaluation quantifies the importance of various factors through fuzzy transformation. This method is not only applicable to the evaluation of indicators at different levels but can also comprehensively and accurately reflect the actual situation. To enhance the accuracy and reliability of the evaluation, this study uses a weighted average fuzzy evaluation method and establishes evaluation criteria scoring functions by introducing an arithmetic progression. This improvement helps reduce the loss of valuable information and evaluate the construction of the ocean carbon sink trading market more effectively. The specific steps are as follows:

(1) Establish a factor set and an evaluation set.

First, divide the factor set of fuzzy comprehensive evaluation into subfactor sets to obtain the factor set of the construction effect of the ocean carbon sink trading market, $U = \{U_1, U_2, ..., U_n\}$. Then, determine the evaluation set. Given the different levels of the construction of ocean carbon sink trading markets, all possible evaluation results are composed into an evaluation set according to the equal division principle, defined as V = {excellent, good, average, poor, poorer}.

(2) Determine the membership matrix. Represent the fuzzy relationship between the factor set U of the construction effect of the ocean carbon sink trading market and the evaluation set V. Here, the matrix elements represent the membership vector R_n of U_n evaluating among the m evaluation comments, giving the membership matrix R.

(3) Determine the fuzzy comprehensive evaluation. Calculate the membership matrix R of the evaluation comment set. Then, perform the composition operation with the relative weight W_i of the secondary indicators to obtain the first-level fuzzy comprehensive evaluation matrix, $B = W_i \times R_i$ Using the first-level fuzzy comprehensive evaluation matrix B and the importance weight W of the first-level indicators, we can obtain the second-level fuzzy comprehensive evaluation vector, $D = W \times B$. After normalizing D, we can obtain a comprehensive evaluation result. Using the formula $Z = D \times V$, we can calculate the comprehensive evaluation value.

Results and Discussion

Evaluation Index Weight Determination

Based on AHP, the weighting coefficients of each indicator are calculated. A judgment matrix is constructed based on experts' scores on the importance of different indicators. Consistency is tested to determine the weight vector values of the indicators. Through expert ratings, the consistency of the judgment matrix scores is tested using the consistency ratio, which measures the reasonability of the ratings. The consistency ratio of 0.0055 is less than 0.1, indicating that it meets the basic requirements of the configuration, as shown in Table 3. The level of construction of the ocean carbon sink trading market is shown to be in its early stages.

Tables 4–7 show the weight results of the second-level indicator judgment matrix. Similarly, the consistency ratios are 0.0678 and 0.0375, both of which are less than 0.1; that is, they meet the requirements of the basic settings.

We can see from the above that the maximum eigenvalue of matrix S, $\lambda_{\max} = 4.18$, and the normalized eigenvector corresponding to the maximum eigenvalue is (0.3823, 0.2918, 0.2236, 0.1023) T, $CR = 0.0678 < 0.1$.

We can see from the above that the maximum eigenvalue of matrix W, $\lambda_{\max} = 4.0996$, and the normalized eigenvector corresponding to the maximum eigenvalue is (0.4211, 0.2455, 0.1545, 0.1789) T, $CR = 0.0375 < 0.1$.

We can see from the above that the maximum eigenvalue of matrix O, $\lambda_{\max} = 3.0061$, and the normalized eigenvector corresponding to the maximum eigenvalue is (0.5244, 0.2349, 0.2406) T, $CR = 0.0059 < 0.1$.

Table 3. Weights and tests of the evaluation index judgment matrix

B	S	W	O	T	ω
S	1	2.7391	2.2174	2.6522	0.45
W	0.3651	1	1.0333	1.3460	0.1916
O	0.4510	0.9678	1	1.5217	0.2046
T	0.3770	0.7429	0.6572	1	0.1487
$\lambda_{max} = 4.0157$, $CI = 0.0052$, $RI = 0.8862$, $CR = 0.0059$					

Table 4. Weights and tests of the second-level index S judgment matrix

C	S_1	S_2	S_3	S_4	S_5	S_6	ω
S_1	1	2.1304	2.1304	2.4783	2.2609	2.5652	0.3065
S_2	0.4694	1	1.9239	1.6196	1.4600	1.5217	0.1899
S_3	0.4694	0.5198	1	1.3696	1.6665	1.9348	0.1560
S_4	0.4035	0.6174	0.7301	1	1.7317	1.8478	0.1404
S_5	0.4423	0.6849	0.6001	0.5775	1	1.8043	0.1169
S_6	0.3898	0.6572	0.5168	0.5412	0.5542	1	0.0903
$\lambda_{max} = 6.1578$, $CI = 0.0316$, $RI = 1.2482$, $CR = 0.0253$							

Table 5. Weights and tests of the inferiority W judgment matrix of secondary indexes

C	W_1	W_2	W_3	W_4	W_5	ω
W_1	1	3	2.8696	3.1739	2.9130	0.4217
W_2	0.3333	1	1.4746	1.6993	1.6812	0.1874
W_3	0.3485	0.6782	1	1.6594	1.4591	0.1566
W_4	0.3151	0.5885	0.6026	1	1.7355	0.1276
W_5	0.3433	0.5948	0.6854	0.5762	1	0.1067
$\lambda_{max} = 5.0964$, $CI = 0.0241$, $RI = 1.1089$, $CR = 0.0217$						

Table 6. Weights and tests of the second-level index chance O judgment matrix

C	O_1	O_2	O_3	ω
O_1	1	2.4134	2.0158	0.6089
O_2	0.4144	1	1.0556	0.2302
O_3	0.4961	0.9474	1	0.1609
$\lambda_{max} = 3.0093$, $CI = 0.0047$, $RI = 0.5180$, $CR = 0.0090$				

Table 7. Weight and test of the second-level index threat T judgment matrix

C	T_1	T_2	T_2	T_3	W
T_1	1	2.8696	3.5217	3.2609	0.5130
T_2	0.3485	1	1.5652	1.5000	0.2035
T_3	0.2840	0.6389	1	1.1793	0.1455
T_4	0.3067	0.6667	0.8480	1	0.1381
$\lambda_{max} = 4.0149$, $CI = 0.0050$, $RI = 0.8862$, $CR = 0.0056$					

Table 8. Summary of the membership degree of ocean carbon sink trading market indicators

Target layer	Criterion layer (*B*)	Index level (*C*)	Very poor	Poor	Average	Good	Excellent
Ocean carbon sink trading market	*S*	S_1	0.4078	0.3010	0.0777	0.0971	0.1165
		S_2	0.3107	0.3883	0.1165	0.0874	0.971
		S_3	0.2913	0.2913	0.0971	0.1553	0.1650
		S_4	0.2913	0.2913	0.1553	0.1359	0.1553
		S_5	0.2913	0.2913	0.0971	0.0097	0.0097
		S_6	0.2718	0.2816	0.1553	0.1359	0.1553
	W	W_1	0.4466	0.4272	0.1068	0.0097	0.0097
		W_2	0.2427	0.3786	0.2718	0.1068	0.0097
		W_3	0.2427	0.4369	0.2621	0.0388	0.0194
		W_4	0.4078	0.3981	0.1553	0.0194	0.0194
		W_5	0.3204	0.3495	0.2330	0.0485	0.0194
	O	O_1	0.1650	0.1456	0.1262	0.3107	0.3495
		O_2	0.2039	0.2718	0.3204	0.1942	0.2039
		O_3	0.2816	0.5146	0.1262	0.1262	0.1456
	T	T_1	0.1456	0.4854	0.2330	0.2233	0.1068
		T_2	0.2233	0.2913	0.2427	0.1942	0.2427
		T_3	0.2816	0.3010	0.2427	0.1748	0.1942
		T_4	0.2427	0.3010	0.2330	0.2233	0.1942

We can see from the above that the maximum eigenvalue of matrix T, $\lambda_{max} = 4.2454$, and the normalized eigenvector corresponding to the maximum eigenvalue is (0.2933, 0.2217, 0.3050, 0.1801) T, $CR = 0.0923 < 0.1$.

According to the consistency test results of the above judgment matrix, the *CR* values of all levels of evaluation indicators are less than 0.1. Thus, the condition requirements for matrix consistency are met.

The Fuzzy Comprehensive Evaluation and Analysis

Based on the evaluation results of experts for each indicator, this study obtains the membership degree of each indicator from the rating, as shown in Table 8.

On this basis, a single-factor fuzzy comprehensive evaluation matrix is established. Through the analysis and calculation of AHP and fuzzy comprehensive evaluation, the comprehensive evaluation value of the ocean carbon sink trading market is obtained:

$$Z = D \times V = 100 \times 0.1444 + 80 \times 0.1414 + 60 \times 0.1542 + 40 \times 0.3261 + 20 \times 0.2867 = 53.7861$$

Results and Analysis

The ocean carbon sink trading market is in its early development stage.

The comprehensive evaluation score of the ocean carbon sink trading market is 53.7861, indicating that its market construction level is relatively low. The evaluation scores and levels of each indicator align with the actual situation. Although coastal cities such as Xiamen, Shenzhen, and Weihai have taken the lead in conducting pilot projects related to ocean carbon sink

Table 9. Statistical tables of various grades

Type	Score
S	48.2472
W	39.0567
O	72.1242
T	64.4524
Total points	53.7861

Table 10. Fuzzy comprehensive evaluation results for the evaluation indicators at the index level

Index level	Maximum membership	Evaluation result	Index layer	Maximum membership	Evaluation result
S_1	0.4078	Very poor	W_4	0.4078	Very poor
S_2	0.3883	Poor	W_5	0.3495	Poor
S_3	0.2913	Poor	O_1	0.3495	Excellent
S_4	0.2913	Poor	O_2	0.3204	Average
S_5	0.2913	Poor	O_3	0.5146	Poor
S_6	0.2816	Poor	T_1	0.4854	Poor
W_1	0.4466	Very poor	T_2	0.2913	Poor
W_2	0.3786	Poor	T_3	0.3010	Poor
W_3	0.4369	Poor	T_4	0.3010	Poor

trading, the lack of practical experience results in very few projects related to ocean carbon sinks in the market. The regulations, technology, and standards related to ocean carbon sink trading are not well established. In terms of the main indicators, the evaluation results for the opportunity and threat aspects of the ocean carbon sink trading market are between average and excellent. These are important indicators that positively influence the overall level of the trading market. The advantages and disadvantages of the market are at a relatively low level, significantly lowering the comprehensive score of the market.

Factors Affecting the Construction of the Ocean Carbon Sink Trading Market

Based on the maximum membership degree principle and according to Table 10, the advantage indicators of the evaluation system for the ocean carbon sink trading market are at a relatively low level. Although ocean carbon sinks are receiving increasing attention, the trading market system is still incomplete. The lack of institutional rules and technical specifications for ocean carbon sink trading hinders leveraging the advantages of ocean carbon sink trading. Regarding the disadvantage indicators, the levels are generally low. This is because ocean carbon sink trading is still in the exploration stage, and the market has low participation, a shortage of professionals, and limited financing channels. Therefore, while simplifying carbon trading procedures, it is necessary to focus on the cultivation of professional talent in carbon trading. This is consistent with the findings of on-site investigations. In terms of opportunities, the carbon market price fluctuation index is at a relatively low level. Owing to uncertain price trends in the ocean carbon sink trading market, market participants' willingness to invest in ocean carbon sinks and related products is not significant. Regarding threats, the secondary indicators are all at a relatively low level. This indicates that market participants regard the ownership, measurement methods, and trading methods of ocean carbon sinks as important criteria when choosing ocean carbon sink trading. Advantages and opportunity conditions are the core of the efficient operation of the ocean carbon sink trading market. Regarding criteria levels, the weight of the advantage conditions is higher than that of other development conditions (Table 3). This is the most significant focus area and the most direct reflection of market construction. At the specific level of tertiary indicators, in terms of advantage conditions, the weight value of protecting the rights and interests of all parties (S_1) exceeds 0.3, which is the highest weight value among the six indicators. This indicates that protecting the rights and interests of all parties is key to the sustainable development of ocean carbon sink trading markets. Opportunity conditions are the basis for promoting the development of ocean carbon sink trading markets. At the level of tertiary indicators, the weight value of the dual-carbon target (O_1) is the highest, indicating that it is an important factor in evaluating market opportunity development conditions. Additionally, the effects of disadvantages and threats should not be overlooked in the ocean carbon sink trading market.

Conclusions and Policy Recommendations

In this study, an evaluation system is constructed for the ocean carbon sink trading market. Using a SWOT-AHP fuzzy comprehensive evaluation model, the ocean carbon sink trading market is comprehensively evaluated, providing insights for policy-making in China. The main conclusions and recommendations are as follows:

(1) Current ocean carbon sink trading has not fully utilized its advantages in protecting the rights and interests of all parties, and it is not effective in reducing the disadvantages. Previous studies have revealed similar results [20]. It is important to leverage the advantages of regional ocean carbon sink markets and enhance the enthusiasm of market participants. Governments should

take the lead in establishing institutional frameworks and incentive policies for ocean carbon sink trading markets (e.g. green financial policies and incentives for carbon trading platforms) to increase the scale of the ocean carbon sink market and leverage market advantages.

(2) The evaluation results for opportunity indicators tend to be at an excellent level. The overall construction of the carbon trading market provides a broad market space for ocean carbon sink trading. Opportunities should be seized in the promotion of dual-carbon targets. Depending solely on government initiatives can be costly and challenging; therefore, promoting ocean carbon sink trading is necessary. In the initial stages of market development, diverse pilot projects and supporting systems should be conducted to activate the ocean carbon sink trading market.

(3) The evaluation results for the threat indicators are at a general level. This finding is consistent with previous research [6, 39]. We should pay attention to the threats to the trading market by building cooperation platforms and sharing technology. It is important to align the technical standards of China's ocean carbon sink trading market with international standards to reduce threats.

(4) The evaluation results for the disadvantage indicators are the lowest among all indicators. More than 80% of experts believe the ocean carbon sink trading market is still in the exploration stage and lacks professionals. Therefore, international platforms for learning should be actively provided. Similarly, simplifying transaction procedures and reducing transaction costs will encourage the entry of more market participants. Furthermore, we should study relevant valuation standards and improve the existing legal and institutional framework to address the unclear ownership of ocean carbon sink rights.

Currently, the evaluation of China's ocean carbon sink trading market is still in the exploration stage. The evaluation standards are not yet unified, and a comprehensive, systematic evaluation database is still not established. Therefore, it is important to continue improving the systematic analysis of the effectiveness of the ocean carbon sink market, with a focus on an accurate understanding of indicators and data collection methods. However, other studies have paid less attention to this, and this is also the direction of future research.

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Data Availability Statement

The data generated and analyzed in this manuscript are available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Author Contributions

All authors have read and approved the final manuscript. Ziyan Wang is the first author of this paper. Qun Zhang and Junjie Lin are the corresponding authors of this paper.

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