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# Enhancing the ocean carbon sink capacity of Shandong province, China, under the “dual carbon” goal

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The ocean is a key component of the global carbon cycle. As climate change becomes increasingly severe, enhancing the ocean's carbon sink capacity is of great significance to achieving the “dual carbon” goal for China. As a major maritime province, Shandong is in an advantageous position to utilize the ocean to respond to climate change and achieve the national goals of carbon peaking and carbon neutrality. Focusing on consolidating and enhancing ocean carbon sink capabilities, Shandong needs to formulate a clear timetable and roadmap to promote blue carbon technology research and development, actively cultivate a blue carbon trading market, and tap the inner potential of ocean carbon sink. Shandong should also strengthen international cooperation to jointly construct a carbon-neutral global community.

## KEYWORDS

ocean carbon sink, “dual carbon” goal, blue carbon market, Shandong province, China

## 1 Introduction

Ocean carbon sink (“blue carbon”) is an important approach for ecosystems to improve their sustainability. It mainly uses marine and coastal ecosystems to bind and store carbon (Wang et al., 2016). In 2009, the United Nations Environment Program, the Food and Agriculture Organization of the United Nations and the Intergovernmental Oceanographic Commission jointly released “Blue carbon: the role of healthy oceans in binding carbon”, confirming the irreplaceable role of the marine ecosystems in global climate change and carbon cycle processes (UN, 2009). The ocean is the largest carbon storage site on Earth, and blue carbon has obvious advantages over green carbon (i.e., using the photosynthesis of terrestrial green plants to absorb carbon dioxide) in carbon capture and storage. The amount of carbon captured by marine organisms per unit sea area is ten times that of forests and 290 times that of grasslands (Wei, 2022). Therefore, ocean carbon sink can provide strong support for the realization of the “dual carbon” goal of China and can be an important driving force for the high-quality development of the marine economy.

Shandong is a major maritime province located in an important geographical area on the eastern coast of China with a relatively developed marine economy. There are a large number of manufacturing enterprises located near the sea, with strong production capacity and strong demand for economic growth. Free trade pilot zones and international seaports in Shandong are well developed as support points for external exchanges. The marine resource abundance index of the province ranks first in the country. All these favorable conditions give Shandong a huge advantage in implementing ocean carbon sink and can thus provide strong support for the province to make full use of its marine resources to achieve ecological protection and economic development simultaneously. Therefore, the development of ocean carbon sink in Shandong will not only help the province accelerate the transformation and upgrading of its traditional marine industries toward a low-carbon and high-quality track, but also open up a new path for creating a novel economic growth engine. This article adopts the method of normative analysis and empirical analysis to study the relevant policies and current development status of ocean carbon sink in Shandong Province, and summarizes its shortcomings and practical problems. On this basis, multiple paths are proposed for how Shandong Province can further develop ocean carbon sink by implementing the sustainable concept of coordinating ecological protection and economic development.

## 2 Development status of ocean carbon sink in Shandong province

“Promoting green and low-carbon development of industries” is one of the four major development goals determined by the State Council of the People’s Republic of China in its “Opinions on Supporting Shandong to Deepen its Transition from Old to New Drivers of Growth and Promote Green, Low-Carbon and High-Quality Development” (The State Council of the People’s Republic of China, 2022). To accomplish this important mission entrusted to Shandong by the central government, the province adheres to the coordinated advancement of carbon reduction, pollution reduction, afforestation, and economic development. By giving full play to its unique maritime advantages, great progress has been made in the construction of ocean carbon sink. However, it should be noted that in order to achieve carbon peaking and carbon neutrality with high quality, Shandong Province still needs to improve relevant policy guidelines and practical applications to guide the further development of ocean carbon sink.

### 2.1 System construction: adequate from a macro perspective, insufficient in details

The 14th Five-Year period (2021–2025) is a critical period of opportunity for China to implement its “dual carbon” goal. With the aim of promoting the construction of a “strong marine province,” Shandong attaches great importance to ocean carbon sink and has

issued a series of policies to provide clear guidance for its development and utilization at the macro level. “Shandong’s Action Plan for Building a Strong Marine Province” clearly states the requirement to actively develop and conduct in-depth research on ocean carbon sink (Shandong Provincial People’s Government, 2022a). The “Implementation Plan for Carbon Peaking in Shandong Province” announced ten major projects for achieving carbon peaking, including consolidating and improving carbon sink capabilities, which clearly requires “vigorously developing marine ecosystem carbon sink” (Shandong Provincial People’s Government, 2022b). The “Three-Year Action Plan for Building a Green, Low-Carbon and High-Quality Development Pioneer Area in Shandong Province (2023–2025)” clearly stipulates that it is necessary to strengthen the investigation and evaluation of natural ecosystem carbon sink, and Shandong should carry out carbon sink background surveys, carbon storage assessments and analyses, and construct the system of “resource survey, storage assessment, potential assessment, and technical standards” for natural ecosystem carbon sink (Shandong Provincial People’s Government, 2023).

Although some results have been achieved at the macro-planning level, the institutional design of ocean carbon sink in Shandong Province is still insufficient at the detailed level, and the policy’s potential remains to be deeply explored. For example, existing policies are not highly targeted and lack guidelines on clear implementation and specialized arrangements for ocean carbon sink. Shandong has not yet formed a dedicated action plan for enhancing its ocean carbon sink capacity. Policies on ocean carbon sink are usually included as part of the “marine ecological environment protection” category in Shandong’s official papers. In contrast, Zhejiang, another coastal province in China, has issued “Guiding Opinions on Improving Ocean Carbon Sink Capacity in Zhejiang Province” (Department of Natural Resources of Zhejiang Province, 2023) and has made targeted and specialized arrangements for ocean carbon sink. Furthermore, the management and supervision mechanisms for ocean carbon sink in Shandong are insufficient. There is a clear lack of planning and coordination mechanism between maritime-related industries and government departments, and a regulatory system with clear responsibilities for different sectors has not yet been formed. All these have reduced the efficiency of policy implementation.

### 2.2 Technology research and development: initial breakthroughs have been made, but in-depth research is still needed

Shandong Province adheres to the principle of utilizing the sea scientifically and developing ocean resources through science and technology. The province strongly supports scientific institutions that conduct research in the field of ocean carbon sink, which can provide reliable basis for the scientific utilization and development of the sea. It has successively established ocean carbon sink research platforms, such as the Bohai and Yellow Sea Blue Carbon Monitoring and Assessment Center and the Sanggou Bay Algae Carbon Sink Laboratory. At the same time, it relies on comprehensive scientific

research institutes, such as the Ocean University of China and the First Institute of Oceanography of the Ministry of Natural Resources, to cultivate high-quality marine talents and strengthen the scientific and technological prowess of the marine province. These institutions are committed to carrying out basic and applied scientific research on ocean carbon sink, and has made significant technological progress in some key areas, such as seagrass bed artificial turf technology and large seaweed carbon sink mechanism research. In addition, the “Accounting Methods for Ocean Carbon Sink” (Ministry of Natural Resources of the People’s Republic of China, 2023) formulated by the First Institute of Oceanography of the Ministry of Natural Resources provides a complete set of implementation methods to solve the quantification problem of ocean carbon sink. This scientific system ensures that China’s ocean carbon sink accounting work has standards to follow. (Zhao, 2023).

At present, preliminary breakthroughs have been made in some aspects of Shandong Province’s research and development (R&D) in ocean carbon sink, but to achieve greater success, the region still needs to overcome the challenges of in-depth optimization to achieve comprehensive innovation. First, some ocean carbon sink technologies are still in the “laboratory” stage and have not matured sufficiently for practical application. Second, insufficient investment in funds, talents, and facilities, among other resources, affects the speed of technological innovation and development. Third, a comprehensive solution that coordinates multiple disciplines is lacking. Ocean carbon sink involves not only multiple subject areas, including ecology, geology, marine environmental science, and so on, but also multiple practical links, such as carbon capture, storage, and monitoring. Therefore, the R&D of ocean carbon sink technology requires the participation of interdisciplinary talents and a comprehensive solution that closely integrates with the upstream and downstream of industrial chains.

## 2.3 Practical application: just started, still to be improved

From the “blue carbon pool” to the “blue carbon market,” Shandong Province has actively promoted the practical application of ocean carbon sink, transforming abundant marine resources and carbon sink potential into effective measures to mitigate climate change and to promote the sustainable development of the marine economy and marine ecology. The province has pioneered in blue carbon applications, it has innovated new models for the diversified development of marine pastures and implemented China’s first carbon sink loan for seagrass beds and seaweed fields (Dazhong Daily, 2023). This measure aims to encourage the expansion of ocean carbon sink insurance to enrich the supply of carbon financial products. As an emerging field, the practical application of ocean carbon sink faces uncertainties and challenges in market operations, environmental risk assessment, public participation, and social recognition. Shandong Province is no exception in the practical application of ocean carbon sink, and many aspects still need continuous improvement. As an important area for the application of ocean carbon sink, the blue carbon emissions

trading market is still in its preliminary exploration stage, and the market operation mechanism still needs to be perfected. So far, carbon emissions data are not accurate enough, and there is a long way to go to build a sound monitoring and verification system. A price stabilization system is also lacking, and price fluctuations are large. In addition, market transparency is insufficient, information is asymmetric, and market activity is inadequate. Therefore, in-depth research is still needed to find out how Shandong province can better utilize the blue carbon market to balance economic benefits and environmental protection.

## 3 Suggestions for developing ocean carbon sink in Shandong province

Ocean carbon sink has great potential in achieving carbon neutrality and promoting high-quality economic development in Shandong Province. The region needs to implement new development concepts, innovate and explore key areas where the ocean can unleash its potential, achieve sustainable utilization of ocean resources, and balance the relationship between ocean economic development and ecological protection.

### 3.1 Coordinate the land and sea

#### 3.1.1 Implement new development concepts

With the goal of achieving carbon peaking and carbon neutrality, Shandong should implement new development concepts in a more resolute, comprehensive and accurate fashion. It should set short-, medium-, and long-term goals and tasks for developing ocean carbon sink based on the current situation and development requirements of the province. The ultimate aim is to guide Shandong’s marine-related industries to undergo green and low-carbon transformation to ensure the steady realization of the national “dual carbon” goal. To implement green, low-carbon development, Shandong should strengthen policy support and reform exploration to coordinate environmental conservation and sustainable socio-economic development. The Shandong Provincial Government should effectively implement its macro-control role, improve the overall coordination mechanism among various government departments, strengthen collaboration, clarify the division of responsibilities, and strengthen supervision.

#### 3.1.2 Innovate and explore key areas

Shandong should make full use of multiple innovation platforms in the field of ocean carbon sink in the region and strengthen research on blue carbon technology. China’s first Accounting Methods for Ocean Carbon Sink, formulated by the First Institute of Oceanography of the Ministry of Natural Resources in Qingdao, Shandong, has been officially implemented on January 1, 2023. At present, there is an urgent need to use science to clarify carbon storage, and then make decisions on a scientific basis. Coastal ecosystems, such as salt marsh wetlands, seagrass beds, and mangroves, are recognized as blue carbon resources with

extremely high carbon sinking and storing efficiency. These blue carbon ecosystems besides mangroves are widely distributed in the coastal areas of Shandong Province, and they have broad application prospects. However, compared with green carbon, a dedicated observation and evaluation system for blue carbon has not yet been established, making blue carbon resources difficult to be “measurable, reportable, and verifiable” (Yang et al., 2023). Therefore, it is necessary to further strengthen the scientific research and monitoring of ocean carbon sink, establish and perfect its accounting system, and form a systematic set of verification, monitoring and evaluation methods.

### 3.1.3 Achieve sustainable utilization of ocean resources

Shandong may establish a healthy marine ranch model and expand blue carbon enrichment areas and marine life habitats. Marine ranches use natural bait in the ocean to cultivate seafood through technical means such as placing artificial fish reefs, building algae reefs and algae fields, and releasing fish fry into the sea. This model can achieve the conservation and replenishment of biological resources and effectively reduces the negative impact on the marine environment (Yang et al., 2016). Specifically, it helps to solve problems such as resource depletion caused by seawater pollution and overfishing, and diseases caused by offshore aquaculture (Wang, 2011). It has the function of conserving ecological resources and restoring the ecological environment in waters (Shen and Liang, 2018). The Special Report on the Ocean and Cryosphere in a Changing Climate issued by the Intergovernmental Panel on Climate Change proposed that green development concepts and scientific breeding can turn marine aquaculture from a “pollution source” into a “sink-increasing site.” (IPCC, 2019). Study showed that artificially cultivated seaweed alone in China can remove approximately 330,000 tons of carbon from seawater every year (Tang and Liu, 2016), and since Shandong Province has relatively large areas for shellfish, algae, and fishery cultivation, its carbon sink capacity and scale are considerable. Shandong has a developed coastal breeding industry, it can make full use of the gathering of marine scientific and technological talents and strong platform advantages to establish a new model of healthy and modern marine ranching to promote negative ocean emissions and sustainable development (Jiao et al., 2021). Specifically, Shandong should focus on major technical bottlenecks such as the clean production and utilization of original species of economic animals and plants in marine ranches, digital management of fishery resources, automated environmental safety assurance, and efficient quality control of fishery products (Yang, 2016).

## 3.2 Actively explore application scenarios for ocean carbon sink

### 3.2.1 Cultivate the blue carbon trading market

Blue carbon trading is an important measure to transform marine resources into carbon trading assets. It can be developed

into a standard financial instrument to combine financial capital and the real economy, and guide the real economy to follow the path of low-carbon development through the power of financial capital (Gao, 2022). It is necessary to actively and steadily implement the two action plans of “Innovative Development of Green Financial Products” and “Implementation of Carbon Finance Development” in Shandong Province’s “Three-Year Action Plan.” In addition, determining the value of blue carbon trading is an important prerequisite for cultivating a carbon trading market. Under the current world rules for carbon sink measurement and standardization, only carbon trading that meets Verified Carbon Standard can gain international recognition and offset emissions (Liu et al., 2019). And Shandong Province should formulate a price stabilization mechanism for blue carbon trading, maintain the contributions of the market to carbon emissions (Sun and Zhang, 2023).

### 3.2.2 Accelerate the construction of “smart ocean”

The smart ocean, which is deeply integrated with “informatization + industrialization,” represents the future direction of ocean development. The construction of a smart ocean will largely reform the upstream and downstream chain of industry-academia-research on ocean carbon sink. First, establishing a comprehensive database and using big data to dynamically calculate and accurately measure ocean carbon sink. Second, developing a pilot blue carbon trading market and further stimulating the realization of the financial value of ocean carbon sink; exploring and developing futures, credit, and other financial products based on ocean carbon sink. Third, creating a blue carbon compensation mechanism, promoting blue carbon equity financing, and providing a basic support platform for carbon financial products. In short, the province should give full play to the fundraising role of the carbon financial market, achieve the dual reduction goals of total carbon emissions and energy consumption, and use market-based means to promote energy structure adjustment (Ma, 2022).

## 3.3 Embrace the advantages of the opening-up policy and jointly build a carbon-neutral community

### 3.3.1 Leverage open “special zones” to explore and implement green and low-carbon innovation

First, Shandong should leverage the policy advantages of open “special zones”, such as the China (Shandong) Pilot Free Trade Zone and the China-SCO Local Economic and Trade Cooperation Demonstration Area in Qingdao, to explore and implement the cultivation of green and low-carbon innovation. It is worth noting that, from a nationwide perspective, although China has made breakthroughs in the R&D of ocean carbon sink technology, its relatively late start and lack of technical reserves in the field make it lags behind countries such as those in Europe and the United States. Therefore, Shandong should set high standards that match

international economic and trade rules, and promote the innovative development of the entire green and low-carbon industrial chain. Particular attention should be paid to extending the ocean carbon sink industry chain and increasing its added value (Cheng and Chen, 2021). At the same time, Shandong should promulgate laws and regulations related to carbon tax in a timely manner, improve relevant fiscal and taxation mechanisms, utilize trade remedy rules wisely, and actively respond to green trade barriers (Lin, 2023).

### 3.3.2 Promote international cooperation and jointly build a carbon-neutral community

Blue carbon is a convergence point in global governance hotspots such as climate change, biodiversity protection and sustainable development. It can be classified as an environmental issue related to climate change, and is relatively insensitive in international politics (Zhao and Hu, 2019). There are broad prospects for international cooperation in this area. Promoting international cooperation in the field of blue carbon is in the common interests of all parties, and will greatly enhance the international influence of Shandong and even China in related fields. The UN Ocean Decade Collaborative Center on Ocean-Climate Nexus has been officially established in Qingdao and it provides an important platform for international cooperation on climate change. Also, one of the three sub-forums of the 2023 East Asia Marine Cooperation Platform Qingdao Forum held in June 2023 is the International Blue Carbon Forum. The forum focused on the theme “Blue Carbon Empowers Response to Global Climate Change and Supports High-Quality Development of the Marine Economy”. It discussed the current status and development trends of ocean carbon sink, relevant policies and technologies, and the path to realize the value of ocean carbon sink products. Shandong should make full use of the international influence of relevant forums and actively participate in international ocean science exchange programs. Under the United Nations framework, Shandong could develop itself into an international platform for promoting consensus and cooperation in the field of ocean carbon sink, and jointly establish a carbon-neutral community.

## 4 Conclusions

This study selected Shandong, an important coastal province in China, as the research object and systematically analyzed the feasibility and necessity of developing ocean carbon sink in the region. The authors summarized the achievements and problems in the development of ocean carbon sink in Shandong from three levels: system construction, technology R&D, and practical application. The study asserts that improving Shandong’s ocean carbon sink capacity is a key measure for building a strong maritime

province. By formulating a clear timetable and roadmap to promote blue carbon technology R&D and cultivate a blue carbon trading market, Shandong is expected to become a pioneer and leader in China in the field of ocean carbon sink. Through sharing experience and technology exchange, Shandong will drive more provinces to cooperate to achieve common development in this field, thereby successfully accomplishing China’s “dual carbon” goal. In addition, by leveraging its geographical and policy advantages, Shandong Province may also serve as a vanguard for China to further promote international cooperation and contribute to building a carbon-neutral community.

## Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

## Author contributions

ZM: Conceptualization, Writing – original draft. HL: Writing – review & editing. ZZ: Supervision, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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