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Development Mechanism and Trading Mode of Marine Carbon Sink

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Abstract

Marine carbon sink is one of the important methods to solve the problem of carbon emission in China. Under the dual constraints of economic development demand and ecological capacity, more policy means need to be explored to achieve carbon emission peak and carbon neutrality in China. There is great potential for the construction of marine carbon sink in China. Hence it is of great significance to build an integrated carbon sink system by combining marine carbon sink with land carbon sink. In the path to achieve marine carbon sequestration increase based on marine ecological improvement, marine breeding, coastal wetland protection and pollution emission will provide the possibility for the increase of marine carbon sequestration. On the basis of the original carbon trading market, through the design of reasonable carbon trading rules, we can guide more resources into the field of marine carbon sink construction by means of market, and achieve the goal of enhancing China's carbon strength.

Keywords

marine carbon sink, trading mechanism, development mode, ecology

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Development Mechanism and Trading Mode of Marine Carbon Sink

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Abstract: Marine carbon sink is one of the important methods to solve the problem of carbon emission in China. Under the dual constraints of economic development demand and ecological capacity, more policy means need to be explored to achieve carbon emission peak and carbon neutrality in China. There is great potential for the construction of marine carbon sink in China. Hence it is of great significance to build an integrated carbon sink system by combining marine carbon sink with land carbon sink. In the path to achieve marine carbon sequestration increase based on marine ecological improvement, marine breeding, coastal wetland protection, and pollution emission will provide the possibility for the increase of marine carbon sequestration. On the basis of the original carbon trading market, through the design of reasonable carbon trading rules, we can guide more resources into the field of marine carbon sink construction by means of market and achieve the goal of enhancing China's strength in carbon regulation. **DOI:** 10.16418/j.issn.1000-3045.20210217104-en

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Since the 21st century, ecological protection faces great challenges with the continuous development of the economy and the expansion of human activities. Climate change has become a common problem for human, and global warming caused by the emission of greenhouse gases such as carbon dioxide (CO_2) is the primary issue that determines the fate of human development. As a major carbon emitter, China plays an important role in international climate change and governance. The demand of economic development and the great pressure of emission reduction have prompted China to explore special pathways of carbon emissions in the new era with new technologies along with other countries in the world.

The pathways to achieve carbon neutrality can be divided into two directions: (1) reducing carbon emissions through energy substitution, technology upgrades, and production capacity shutdown; and (2) reducing the total amount of greenhouse gases in the atmosphere through biological or artificial capture of CO_2 in the air. In the context of rapid economic growth, compared with direct reduction in carbon emissions, CO_2 sequestration by appropriate approaches is more applicable to maintain sustainable economic development [1]. Compared with artificial/physical approaches of CO_2 sequestration, carbon sink enhancement by ecosystem modification is characterized by high safety, stability, and efficiency [2]. Ecosystem-based carbon sinks include forest carbon sink, wetland carbon sink, and marine carbon sink [3].

In comparison to that of terrestrial ecosystems, the carbon sink of marine ecosystems has prolonged carbon cycle and sequestration. For example, marine phytoplankton accounts for more than 45% of the photosynthetic net primary production on Earth [4]. However, assessing marine carbon sink is more difficult than measuring terrestrial ecological carbon sink. The terrestrial producers with the most active photosynthesis are large plants with long life cycles (10 years on average), while microorganisms with short life cycles (typically 1 week) play a major role in the ocean, and thus marine carbon sink is more dynamic than forest carbon sink [5]. In addition, marine carbon sink mostly occurs in the open ocean. For these reasons, the development of marine carbon sink has long been neglected in environmental policies. The establishment of a policy system to promote and guarantee marine carbon sink and the inclusion of marine carbon sink into the main topics of international climate change will provide new ideas for global carbon emission reduction schemes, which will have a prolonged and positive impact on the atmospheric environment and marine ecosystem.

1 Challenges of carbon emission peak and carbon neutrality for human society

The impact of human activities on global warming was first confirmed in the First Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) in 1990, which directly promoted the conclusion of the United Nations Framework Convention on Climate Change (UNFCCC) and the signing of the Kyoto Protocol in 1997. The Protocol specified the emissions of greenhouse gases such as CO_2 and demonstrated the relationship between carbon emissions and

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climate change. Since then, carbon emissions as a common problem for human have been the focus of international political and economic development. The IPCC Fifth Assessment Report states that climate change has affected human health and safety, and social and economic damage from carbon emissions is no longer a future projection but a current problem [6]. In view of this problem, countries have achieved consensuses on reducing carbon emissions, but it has been difficult to reach an agreement on reducing greenhouse gas emissions worldwide. Carbon emissions not only represent a problem of environmental protection but also involve the game among countries to obtain rights of economic development and international relations [7].

Due to the special stage of economic development and international division of labor, China has now become a major carbon emitter with the per capita carbon emission close to that of the European Union (Figure 1). Therefore, carbon emission reduction has become an important embodiment of China's responsibility as a great country. To this end, on September 22, 2020, President Xi Jinping announced at the 75th Session of United Nations General Assembly that China would make efforts to achieve peak CO_2 emissions before 2030 and carbon neutrality before 2060. However, China is in a period of rapid economic growth, during which the direct constraint of carbon emissions will significantly affect the industrial transformation and economic development. The relationship between carbon emissions and economic growth has become the key to the sustainable and stable economic growth in China. Scholars have shown that it is difficult to achieve peak CO_2 emissions before 2030 only by reducing carbon emissions in the benchmark mode [8]. In the context of COVID-19 pandemic, China achieved a gross domestic product (GDP) of CNY 101.5 trillion and an increase of 2.3% in 2020. The increase in the secondary industry accounted for 37.8%, which was higher than that in 2019, and industrial growth played an important role in stabilizing economic growth. Meanwhile, the Global CO_2 Emissions in 2019 released by the International Energy Agency (IEA) shows that China's carbon emissions increased moderately to approximately 9.8 billion tons. In view of the current economic development and national conditions, China has successively formulated the "Twelfth Five-Year Plan" for Controlling Greenhouse Gas Emissions and the "Thirteenth Five-Year Plan" for Controlling Greenhouse Gas Emissions, which included increasing ecosystem carbon sink as an important part of low-carbon industrial system and forest carbon sink as the main pathway while encouraging the pilot study on exploring carbon sink in marine ecosystems.

China has huge potential in marine carbon sink. In offshore ecosystems, mangroves, seagrass, and salt marshes cover less than 0.5% of seabed area but account for 50% or more of the carbon storage in marine sediments. Globally, the carbon exchange between the marine system and the atmospheric system can reach 74 billion tons per year [9]. Marine carbon sequestration is mainly achieved by biological pump, solubility pump, and carbonate pump. Biological pump refers to the process by which ocean surface carbon is carried to the deep seafloor through sedimentation and decomposed for storage by marine organisms such as phytoplankton [10]. China has 18 000 km of coastline and vast sea area with abundant ecological resources. Therefore, making full use of marine carbon sink can provide sufficient ecospace for China's economic development and industrial production.

2 Development patterns of marine carbon sink

Healthy marine ecosystems serve as the basis of marine carbon sequestration. Compared with terrestrial ecosystems,

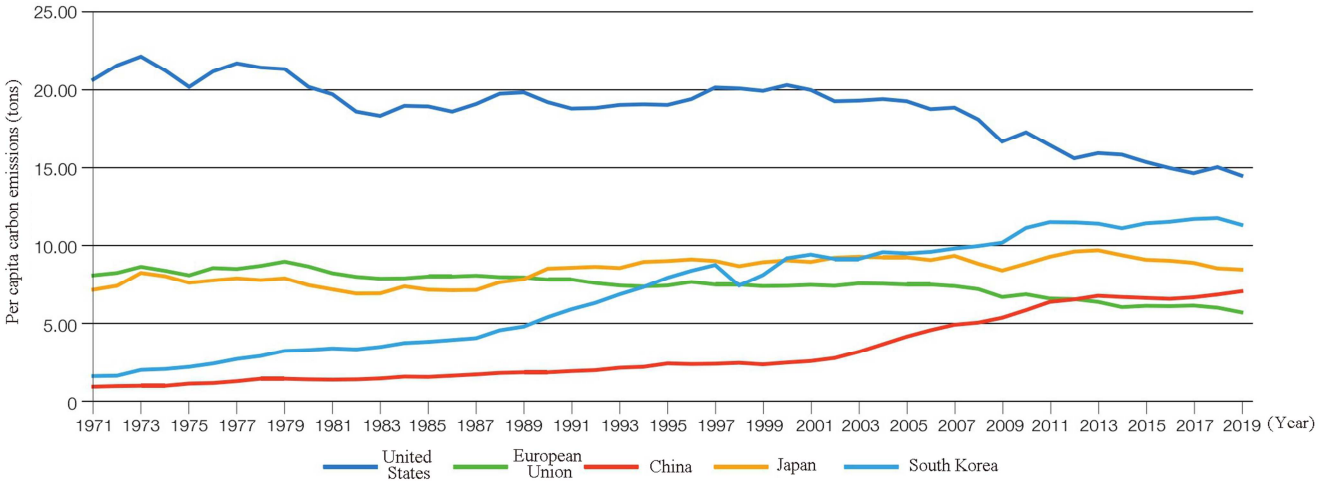

Figure 1 Trend of per capita carbon emissions in major economies

According to IEA data

marine ecosystems feature difficult-to-evaluate health, concealed patterns, and high susceptibility to damage. Marine ecosystems in many regions are rapidly shrinking or even disappearing, followed by a decrease in marine carbon sink at an average rate of 2%–7% each year, and the pace of decline has significantly accelerated. The development patterns of marine carbon sink should be based on marine ecological restoration and target sustainable development. An integrated marine environmental governance system should be established based on the current situation of marine science/technology and industry.

2.1 Mechanism of land–sea coordination in reducing carbon emissions and enhancing carbon sink

The reduction and substitution of fossil energy consumption represent the traditional pathways to reduce carbon emissions, whereas it is difficult to achieve sustainable development by reducing emissions alone. Alternatively, restoration of eco-environment can actively enhance the carbon sequestration of natural ecosystems to achieve a balanced and sustainable state between human activities and global carbon cycle. The carbon sinks based on ecological restoration are from terrestrial and marine ecosystems. Forest carbon sink as a form of terrestrial ecological carbon sink has long received attention, and the role of forest carbon sink was clearly recognized by the 15th Conference of the Parties to the UNFCCC in December 2009. The carbon sinks of forest and grassland can be estimated based on the net ecosystem production (NEP) of terrestrial ecosystems. The assessment of carbon sink from marine ecological restoration relies on the data of overall ocean conditions. The estimation of marine carbon sink puts more emphasis on entirety than that of terrestrial carbon sink, and forest and marine carbon sinks have significantly different approaches of construction, evaluation, and support.

Although marine and terrestrial carbon sinks can be enhanced in different ways, they are both indispensable for global carbon emission reduction. Forest carbon sink is generally enhanced by REDD [①], afforestation, and "REDD+"[②][11], all of which involve active construction targeting forest coverage and vegetation and depend on land space and regional ecology. Since human activities share the land space with forest carbon sink, the enhancement of forest carbon sink is significantly limited by space with the expansion of human activities. There is no conflict between human space and the construction of marine carbon sink, and therefore the potential for active restoration and construction of marine ecosystems is huge. An in-depth understanding of marine ecosystem functioning patterns allows us to make full use of the spatial and integrated advantages of marine ecosystems, and the restoration of only specific links of marine ecology and carbon cycle can significantly enhance the carbon sink of the whole system. Therefore, it is necessary to coordinate and enhance forest and marine carbon sinks to maximize the marginal utility of efforts to reduce carbon emissions.

The main human activities that reduce marine carbon sink include coastal eutrophication, land reclamation, coastal engineering, and coastal urbanization. Enhancing marine carbon sink first requires the restoration of marine ecosystems, which can be integrated with the development of marine fisheries to achieve the dual purpose of species diversity conservation and carbon emission reduction [12]. From the perspective of action strategy, enhancing marine carbon sink requires restoration and reconstruction of marine ecosystems by eliminating eutrophication, expanding coastal wetlands, improving marine fishery structure, and protecting seabed ecosystem, which are measures to increase carbon sequestration capacity.

2.2 Mechanism of multi-stage marine carbon sink development based on ecological compensation

The society-wide active marine carbon sink management involves marine pollution treatment, marine ecosystem restoration, and marine culture, which are related to different productive and living sectors such as industry, tourism, and agriculture. Regions with different levels of social and economic development should implement marine carbon sink measures in different ways and with different intensities based on local conditions. Considering the complex marine carbon sink system, China should deploy multi-stage management to gradually realize the stable and orderly development of marine carbon sink and obtain greater speech right and international influence in carbon emissions.

(1) The initiation stage based on ecological compensation. While focusing on different pathways of marine carbon sink enhancement, we should strengthen top-level design and reasonable allocation of resources and investment. At the early stage of marine carbon sink development, due to the poor understanding of marine carbon sink by the participants, consensus-building becomes the key for the initiation of marine carbon sink enhancement. When marine carbon sink has become a consensus in international research on ecological protection [13], ecological compensation should be implemented in the main factors (scientific research, ecological protection, and construction of ecological information monitoring system) that affect the changes in marine carbon sink enhancement [14]. On the one hand, leading by scientific research, we should gradually decipher the mechanism of marine carbon sink generation and the relationship between sea-related activities and marine carbon sink, understand marine environment and marine carbon cycle, lead global

[①] REDD refers to reducing emissions from deforestation and forest degradation.

[②] "REDD+" refers to forest conservation, sustainable forest management, and forest carbon sink enhancement.

marine carbon sink research, and thus lay a theoretical foundation for the development of marine carbon sink. On the other hand, focusing on the existing marine ecological protection system, we should include marine carbon sink as an ecological protection indicator. Ecological protection resources should be reasonably allocated to actively engage research institutions, industrial enterprises, farmers, service organizations, and other subjects of the whole society related to marine carbon sink.

(2) The growth stage based on ecological compensation and supplemented by carbon sink trading. Economic means should be employed to regulate the interests of participants, and a marine carbon sink development system with the coordination between directional compensation and emission rights trading should be gradually established. On the basis of ecological compensation for the directly related subjects of marine carbon sink, mechanisms of trading marine carbon sink and emission rights should be established to attract more subjects to recognize and participate in the enhancement of marine carbon sink, and various carbon emission subjects should be introduced to the marine carbon sink market. We should increase the social resources allocated to marine carbon sink, and promote the synchronous development of methods and technologies for marine carbon sink monitoring, assessment, ecological restoration, energy conservation, and emission reduction.

(3) The maturity stage of global governance. International development of marine carbon sink and introduction of China's maturing measures and construction plans for marine carbon sink governance can enhance China's speech rights and international influence of carbon emissions. On the basis of the international consensus in research, it is recommended to gradually open the marine carbon trading market to the world and expand the marine carbon trading system to create an international market system. With more international participants involved and their interests respected, a global marine carbon sink governance plan should be formulated to gradually build a sustainable carbon emission framework worldwide.

2.3 Ecological restoration to eliminate marine pollution, reduce carbon emission, and increase carbon sink

The pollutants discharged into the marine ecosystem have severely destroyed the original marine ecological environment, resulting in destructive changes in marine ecosystems such as eutrophication that frequently occurs on the coast. Reducing marine pollution can be a measure to restore marine environment and increase marine carbon sink. Marine carbon sink projects can be decomposed into several marine environmental protection projects that reduce pollutant emissions. Compared with the detection of marine pollutants, the recovery of marine carbon sink may take a long time, while the implementation of marine carbon sink projects has considerable prospect in carbon sink enhancement.

2.4 Coastal wetland conservation and carbon sink calculation

Because coastal wetlands are close to human habitations and easily affected by human activities, the ecofunctions of coastal wetlands are rapidly disappearing. Special policies should be established to protect the eco-environment of existing coastal wetlands such as seagrass pastures, salt marshes, and mangroves to fulfill their role as carbon sink. The overall carbon sequestration capacity of coastal wetlands can be up to 1 500 $g \cdot C \cdot m^{-2} \cdot a^{-1}$, and the carbon sink of coastal wetlands in China can exceed 400 000 tons [15]. Accurate estimation of the carbon sink of coastal wetlands requires the tracking of carbon sink capacity for a certain period of time based on the actual ecosystem composition and characteristics and will fully display the dynamics and capacity of the carbon sink.

2.5 Mariculture patterns for negative carbon emissions and carbon sink enhancement

As an important part of marine industry, mariculture is the main pathway for human activities to affect marine ecosystems. Compared with other sectors of marine industry, mariculture relies more on marine resources. In general, it is difficult to improve marine ecosystems through the development of marine chemistry and transportation. Because of its natural properties, mariculture can achieve a balance with marine ecological optimization by identifying a point that benefits both marine ecological evolution and mariculture. The culture of shellfish, seaweeds, and other aquatic products, which capture carbon in seawater and are harvested from marine carbon cycle by harvesting can realize carbon sink. Alternatively, seaweeds and seagrasses can be cultivated as energy plants to achieve environmental optimization and sustainable marine energy supply. Therefore, mariculture may become an important way to increase marine carbon sink and serve as the basis of achieving the dual purpose of industrial development and carbon sequestration.

3 Marine carbon sink trading systems

3.1 Marine carbon sink assessment

The development of marine carbon sink is an important way to enhance China's carbon regulation strength and a technical lever to achieve global cooperation in carbon emissions. From the perspective of global collaboration, all parties of emission reduction should reach an agreement on emission rights and development rights to achieve the overall reduction of carbon emissions. As a prerequisite, carbon emission arrangement should meet national carbon regulation strength, and the potential of emission reduction is a key of national carbon regulation strength. The enhancement of marine carbon sink will undoubtedly impact the potential of emission reduction in China. The evaluation of the current

situation and potential of marine carbon sink in China is a prerequisite for promoting the sustainable and orderly development of marine carbon sink.

3.2 A broad foundation has been established for market-oriented carbon emission policies

The practice of carbon trading serves a basis for the implementation of market-oriented governance of marine carbon sink. The carbon emission trading system (ETS) is a market-oriented policy tool for energy conservation and emission reduction that follows the principle of total emission control and trading to regulate the total carbon emissions from various industrial sectors by government. In recent years, several countries have implemented carbon trading policies, and market-oriented policies have become a key component of greenhouse gas emission reduction policies. The international carbon market has been expanding since the launch of the world's first carbon trading market in the European Union in 2005. According to the report of the International Carbon Action Partnership (ICAP), there are a total of 20 ETSs of various sizes in operation worldwide, covering 1 supranational system (European Union), 4 national systems, 15 province/state systems, and 7 urban systems, totaling 27 jurisdictions.

Since 2011, China has carried out pilot carbon emission rights trading in Beijing, Shanghai, and Shenzhen. On February 1, 2021, the Guidelines for Management of Carbon Emission Rights Trading (Trial Version) issued by the Ministry of Ecology and Environment was officially implemented. The Guidelines regulates the trading and related activities of national carbon emission rights, defines the mechanisms of confirmation, registration, trading, and management involved in carbon emission trading, and identifies 2 225 electric power enterprises as key emission units. The practice of carbon trading provides a framework that can be used as a reference for the marketing of carbon sink, which makes it possible to build a market system for marine carbon sink.

3.3 Marine carbon sink trading modes

Carbon sink trading is a market-oriented way of exchanging ecological products that can sequestrate carbon with greenhouse gas emission rights through carbon credit for ecological compensation. Carbon trading offers monetary incentive for ecological conservation and ensures that emission reduction always provides the greatest marginal benefit. Compared with marine carbon sink, forest carbon sink is the primary choice to replace CO_2 emission reduction in the Kyoto Protocol because of its simplicity in measurement and evaluation [16]. According to the Protocol, developed countries can establish forest carbon sink projects in developing countries through technical and financial support.

China has received a total of 1 557 projects from the Clean Development Mechanism (CDM) issued by the United Nations Clean Development Mechanism Executive Board, accounting for the largest proportion of the total CDM projects worldwide [17]. Since China is still a developing country and has no obligation of providing assistance in carbon sink, the emission reduction trading practice in China is mainly based on carbon quota.

International consensus regarding the role of marine carbon sink has been attained in many aspects such as marine microbial sedimentation and coastal wetlands [18]. Trading marine and forest carbon sinks is an important supplement to the trading of carbon quota. By incorporating marine carbon sink trading into the carbon emission trading system, we can improve the carbon emission trading market and prompt the building of marine carbon sink capacity in China, thereby improving China's carbon regulation strength. Furthermore, marine carbon sink trading should be extended to the world with the changing pattern of international carbon emission negotiations. Unlike carbon quota trading, marine carbon sink trading should be based on a state fund from the government. The subjects of carbon quota trading are carbon-emitting manufacturers. Quota can be determined in advance and manufacturers can choose the price and traders based on their carbon emissions in production. However, the trading of marine carbon sink requires long-term tracking of the actual performance of specific projects. As the development of marine carbon sink can be achieved in three modes, the trading subjects should be divided into three categories. The first category comprises manufacturers, whose emissions to the ocean affect marine carbon sink, and they can improve marine ecosystem and increase marine carbon sink by reducing emissions. Quota-based approaches can be employed by such subjects, with the rules similar to carbon quota trading. The second category concerns subjects of marine environment management, who are supervisors for the protection of coastal wetlands and seabed, and their roles are reflected by restoration of the protected eco-environment. The total carbon sink of ecological conservation actions is measured by the increase in carbon sink capacity of the protected ecosystem, and the trading should be conducted in a way similar to the CDM projects. The third category includes subjects of marine aquaculture, which increase the total marine carbon sink through the biological characteristics of aquaculture products, and the trading should be carried out by credit transfer. The exchange of carbon quota between the three categories of subjects and the enterprises in the current carbon emission market should be designed for the building of the basic framework of marine carbon sink trading. However, the exchange between carbon sink market and carbon quota market requires a subject with credit and a state fund that initiates seed subsidies to the three categories of subjects, which can thus maintain the contribution of the two markets to carbon emissions and the price at a reasonable level.

3.4 Construction of trading platforms

Trading platforms for information publication and price

negotiation of marine carbon sink should be established on the basis of the original evaluation platform, which can be supported by the state fund of marine carbon sink for collecting and disclosing market information. The platform should focus on evaluation before trading, thus establishing credibility in the early stage of platform operation. The evaluation function needs to be retained during platform operation. As the evaluator of the effect and potential of marine carbon sink, the platform needs a subject to conduct information collection and statistical analysis in the measurement of marine carbon sink regarding the connectivity of oceans.

4 Implications and recommendations

China is a developing country with rapid economic growth and a large number of infrastructure and industrial projects to be completed, facing great pressure on carbon emissions. Meanwhile, China is a big country and should take the responsibility of addressing environmental issues in front of the human population. Reducing carbon emissions and increasing carbon sink are the two main pathways to achieve the goals of carbon emission peak and carbon neutrality in China. The research on marine carbon sink is developing rapidly in recent years. The great potential of marine carbon sink and the geographical structure of China suggest that the development of marine carbon sink can significantly increase the potential of carbon emission reduction in China. From the perspective of dynamic technological and industrial development, marine carbon sink market should be combined with the existing carbon quota market for the enhancing the China's marine carbon sink. The subjects of marine carbon sink in China should be encouraged by market-oriented policies to actively seek new technological and productive approaches to increase marine carbon sink and achieve both environmental and economic benefits.

(1) Establishing and improving systematic monitoring and evaluation systems for marine carbon sink. We should increase the national investment in the basic research on marine carbon sink, and design mechanisms to stimulate the enthusiasm of local departments in marine carbon sink monitoring. A national marine carbon sink information platform should be established and marine carbon sink monitoring equipment should be integrated into the framework of new marine infrastructure construction. Multi-source data should be linked to support the research on marine carbon sink, and multiple subjects from China and the world should be attracted to participate in the analysis and evaluation of marine carbon sink. China is a big country and has special advantages in leading the frontier of international marine carbon sink technologies and building the international consensus on marine carbon sink.

(2) Implementing policies in stages to gradually promote marine carbon sink as a key link in carbon emission management. At the three stages of marine carbon sink development, environmental protection departments should promote the trading of marine carbon sink in a staged approach. We should pay close attention to scientific frontiers at the initiation stage with emphasis on ecological compensation, focus on the construction of market system at the growth stage based on ecological compensation and supplemented by carbon sink trading, and take the advantages of system achievements at the stage of global governance. In this way, China can gain the speech rights in international carbon emission and incorporate marine carbon sink as an important link of international carbon emission governance.

(3) Exploring the pathways of market-oriented governance of marine carbon sink based on the trading of carbon emission rights. The development of marine carbon sink requires the participation of subjects from various social groups, and the market-oriented marine carbon sink trading mechanisms will allow better economic benefits for all parties. A monitoring system can be established on the basis of the existing trading systems of carbon emission rights, and the standardized and quantified marine carbon sink should be certified and included in the carbon emission trading system. While improving carbon emission trading, the whole society should fully understand marine carbon sink and participate in the enhancement of carbon sink to accelerate the achievement of carbon emission peak and carbon neutrality in China.

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