frontiers | Frontiers in Marine Science

TYPE Original Research
PUBLISHED 19 March 2025
DOI 10.3389/fmars.2025.1552567

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OPEN ACCESS

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RECEIVED 28 December 2024
ACCEPTED 03 March 2025
PUBLISHED 19 March 2025

CITATION
Li Y and Huang Y (2025) Research on the impact of green finance on China's ocean economic growth under the "dual carbon" goal.
Front. Mar. Sci. 12:1552567.
doi: 10.3389/fmars.2025.1552567

Research on the impact of green finance on China's ocean economic growth under the "dual carbon" goal

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Introduction: With the introduction of the strategy of a strong marine power and the "dual-carbon" goal, green, low-carbon and sustainable development has become an important requirement for the growth of the Ocean Economy. Green finance is a financial activity that promotes environmental improvement, climate change response and efficient resource utilization. The "dual-carbon" goal is a major national strategy proposed by the Chinese Government in 2020 to achieve carbon peaking and carbon neutrality, which is a two-stage carbon emission reduction strategic goal proposed by the Chinese Government. China is committed to achieving carbon peaking by 2030, i.e., no further growth in carbon dioxide emissions after peaking, and carbon neutrality by 2060, i.e., offsetting its own carbon dioxide emissions through afforestation, energy conservation and emission reduction. This goal is not only an important initiative for China to address climate change, but also has a profound impact on global climate governance. Through the support of green finance, China is promoting the green transformation and sustainable development of its ocean economy while realizing the "dual carbon" goal. As one of the world's largest ocean economies, with more than 18,000 kilometers of coastline and an ocean GDP that accounts for 7.8% of the country's GDP, the development of the ocean economy has a significant impact on the sustainable use of global ocean resources. Therefore, it is of great practical significance for this paper to explore the impact of green finance on China's ocean economy growth under the "dual-carbon" goal based on the data of China's coastal provinces and cities from 2008 to 2022.

Methods: This paper constructs green finance index comprehensive evaluation system, calculates green finance index of Chinese coastal provinces and cities, This paper uses a fixed-effects model to analyze the role of green finance in achieving the 'dual-carbon' goal and fostering the growth of China's ocean economy, and combines with the threshold effect model to further study the nonlinear role of green finance on China's ocean economy. The paper takes green finance as the core explanatory variable. In this paper, green finance is taken as the core explanatory variable, per capita gross domestic product (GDP) as the explanatory variable, income from marine scientific research and the scale of marine industry as the threshold variables, and the number of authorized patents, GDP index, stock market activity, energy consumption structure, the scale of the tertiary industry and the scale of the secondary industry as the other control variables.

Results: It is found that 1) Green finance has a positive effect on China's ocean economic growth, with the strongest positive effect on the Southern Ocean Economic Zone. 2) The scale of the marine industry, the scale of the tertiary industry, and the scale of the secondary industry have a significant positive effect on the ocean economic growth in the Nouthern, Eastern, and Southern Ocean Economic Zones, as well as in China as a whole. In addition, the stock market activity has a positive contribution from a national perspective, but a negative hindering effect in the Northern Ocean Economic Zone. 3) The gross regional product index, stock market activity, and energy consumption structure in the Northern Ocean Economic Zone have a negative hindering effect, and the gross regional product index has the most negative hindering effect. The negative hindering effect of the number of authorized patents, GDP index and stock market activity is not significant in the Eastern Ocean Economic Zone, and the negative hindering effect of the income of marine scientific research institutions, GDP index and stock market activity is not significant in the Southern Ocean Economic Zone. From a national perspective, the number of authorized patents has a negative hindering effect, but it has a significant positive promoting effect in the Southern Ocean Economic Zone. 4) The intensity of the positive promoting effect of green finance on China's ocean economic growth is non-linear, and when the index of the income from the funding of marine-based scientific research institutes reaches 11.249, the promoting effect of green finance on the growth of the ocean economy is slightly weakened. When the marine industry scale index reaches -1.9661, the promotion effect of green finance on ocean economic growth will be significantly weakened.

Discussion: This paper comprehensively evaluates the development of green finance in China's coastal provinces and municipalities by constructing a comprehensive evaluation system of green finance indexes suitable for the ocean economic field, dividing the study area into the Northern Ocean Economic Zone, the Eastern Ocean Economic Zone and the Southern Ocean Economic Zone, and investigating the role of green finance on China's ocean economic growth under the goal of "dual-carbon" and its spatial variability. The study will examine the role of green finance on China's ocean economic growth under the "dual-carbon" goal and the spatial variability, and combine with the threshold effect model to further clarify the nonlinear relationship of green finance on China's Ocean Economy, so as to provide valuable countermeasure suggestions for policy makers.

KEYWORDS

"dual carbon" goals, green finance, ocean economy, growth, threshold effect model

1 Introduction

Globally, many countries have committed to reducing carbon emissions from production systems (Huisingh et al., 2015; Huang et al., 2024; Abbas et al., 2021, 2022).On October 31, 2021, the World Meteorological Organization (WMO) released an interim report on "The State of the Global Climate in 2021" at the 26th United Nations Climate Change Conference According to the report's statistical data, the global average temperature in 2021 has increased by about 1.09°C compared to 1850-1900, while the 2020 global greenhouse gas (GHG) concentration has reached a new peak. Global greenhouse gas concentrations have reached a new peak in 2020. Rapid depletion of natural resources and environmental pollution generated by economic development have brought great pressure on the ecological environment (Razzaq et al., 2021), and extreme events such as high-temperature heat waves, high temperature and high humidity, floods, and severe droughts and composite extreme events have increased significantly (Zhao et al., 2024), against this background, realizing the "win-win situation" between energy conservation and emission reduction and economic growth In this context, realizing a "win-win situation" between energy conservation and emission reduction and economic growth is the key to promoting high-quality economic development (Zhang YC et al., 2023). In 2019, at the United Nations Climate Action Summit, United Nations Secretary General Guterres proposed the concept of "carbon neutrality" for the first time. Carbon neutrality refers to the reduction of greenhouse gas emissions by adopting a series of environmental protection measures, so that carbon dioxide emissions are equal to or lower than the amount absorbed, thus realizing zero emissions. This is considered a turning point in the global response to climate change, and countries have subsequently made emission reduction commitments in response to the carbon neutrality goal (Wang and Gao, 2024).In September 2020, China's President Xi Jinping declared at the 75th United Nations General Assembly that China would increase its nationally-owned contribution, adopt more vigorous policies and measures, and that carbon dioxide emissions would strive to peak by 2030, with an Efforts will be made to achieve carbon neutrality by 2060. Since then, the Chinese government has incorporated the "dual-carbon" goals of carbon peaking and carbon neutrality into its overall national development strategy and formulated a series of policies and measures to promote the realization of the "dual-carbon" goals (Sun and Huang, 2020).

In 2020, the Outline of the Fourteenth Five-Year Plan for the National Economic and Social Development of the People's Republic of China and the Visionary Goals for 2035 proposes to "actively expand the space for the development of the Ocean Economy" (Shi, 2022). The ocean economy has become the blue engine of China's economic development. In 2023, China's gross marine product was 9909.7 billion yuan, an increase of 6.0% over the previous year, a growth rate of 0.8% higher than that of GDP, and accounted for 7.9% of GDP, an increase of 0.1% over the previous year (Liu, 2024). The development of the ocean economy is an important support for the implementation of China's sustainable development strategy. The sustainable utilization of marine resources and the protection of the marine environment are the keys to achieving sustainable development of the ocean economy (Li et al., 2024). However, with the rapid development of the ocean economy and the increasing frequency and expansion of human activities, the marine environment has suffered a certain degree of pollution and damage, and environmental problems have become more and more prominent, and the concept of green development of the ocean economy has been put forward (Gai et al., 2021). Scholars believe that green finance is of great significance to the green development of ocean economy (Xu and Gao, 2022; Zheng et al., 2022). The "dual-carbon" goal creates new opportunities for marine environmental protection and sustainable resource use. Green finance serves as a key tool in achieving these objectives (Baştürk, 2024).

Green finance, also known as environmental financing, is a financial concept that optimizes financial business and achieves sustainable development from the perspective of environmental protection (Southwestern University of Finance and Economics et al., 2015). Green finance seeks economic development in environmental protection and realizes the balance between the economy and the environment (Salazar, 1998), and mainly studies the problem of green economic capital financing, which is an organic combination of sustainable economic development and financial issues (Cowan, 1998). By the end of June 2023, the balance of local and foreign currency green loans in China was RMB 27.05 trillion, an increase of 38.4% over the previous year, higher than the growth rate of all loans by 27.8%, and an increase of RMB 5.45 trillion over the beginning of 2023. China has formed a green financial product system with green credit as the main body and comprehensive green bonds, green insurance, green funds, green trusts, green leasing, carbon finance and other co-development (Zhou SJ. et al., 2024). While green finance significantly reduces the credit line of high-pollution industries, it diverts more funds to green industries, realizes the optimal allocation of resources, and thus effectively reduces carbon emissions (Zhang and Wu, 2024). Under the guidance of green financial policies, enterprises will independently carry out green technological innovation to improve the degree of enterprise specialization, socialization and energy-saving and emission reduction efficiency, thus promoting the process of enterprise decarbonization (Zhang and Jia, 2024).

Green finance can not only effectively promote the development of the ocean economy and boost the optimization and upgrading of the marine industrial structure, but also provide financial support and risk management services to help the ocean economy achieve low-carbon development (Liu and Yang, 2019). Through financing and investment support, the marine industry is able to expand the scale of development, issue blue bonds, provide financial support for the layout of the whole industry chain of clean energy, and respond to the national goals of carbon peaking and carbon neutrality (Hou et al., 2020; Ji et al., 2020). In addition, the financial support brought by green finance has provided assistance to the marine industry to carry out technological development and assume environmental social responsibility (Bian and Yang, 2023). However, some scholars question whether green finance can reduce carbon emissions and promote the sustainable development of the Ocean Economy. Some scholars argue that financial agglomeration has not served to promote the efficiency of marine technology to reduce carbon emissions (Sun et al., 2017), and that there is an inhibitory effect on the growth of the ocean economy (Zhao and Peng, 2017; Yu, 2013). This is due to the high risk nature of the ocean economy that makes it more difficult for commercial banks to lend money, making it difficult to produce a positive promotion effect (Zhuang, 2020).

In 2020, Chinese President Xi Jinping clearly put forward the "dual carbon" targets. Prior to that, the concept of "dual carbon," along with the sustainable development and green finance ideas behind it, had already been deeply practiced in China. In 2008, China Industrial Bank announced its adoption of the "Equator Principles," becoming the first "Equator Bank" in China, marking a milestone in the development of green finance in the country. In 2016, the People's Bank of China, the Ministry of Finance, and seven other ministries and commissions jointly issued the "Guiding Opinions on Building a Green Financial System," proposing to promote green finance to support environmental protection and sustainable development. In 2021, the Central People's Government of the People's Republic of China released the "14th Five-Year Plan for Marine Economic Development," advocating for the green and low-carbon transformation of the ocean economy and facilitating the integration of green finance with the ocean economy. In recent years, China's practices in green finance and the pursuit of the "dual carbon" targets have provided valuable experience for the global community. This paper selects China as the scope of study and sets the research time frame from 2008 to 2022. This period covers the entire journey of green finance, from its nascent stages to rapid development, and also witnesses the historical process of the "dual carbon" targets, from their proposal to their comprehensive implementation. It not only facilitates a deeper understanding of the impact of green finance on China's marine economic growth but also offers useful insights for other countries and regions.

This paper constructs a comprehensive evaluation system of green finance index, adopts a fixed-effects model, to study the role of green finance on China's ocean economic growth and spatial heterogeneity under the "dual-carbon" goal, and combines with the threshold effect model to further clarify the nonlinear role of green finance on China's Ocean Economy. The purpose of this paper is to explore the role of green finance in promoting the transition of China's ocean economy to a green and sustainable direction and realizing the "dual-carbon" goal in the marine sector, as well as the specific impacts of this transition on economic growth, so as to provide feasible countermeasures for the marine industry, financial institutions and other stakeholders, as well as for policy makers, which is of strong practical significance. It is of great practical significance.

2 Literature review

2.1 Green finance and the ocean economy

In the 1990s, the concept of green finance was formally proposed (White, 1996), and the early theoretical research focusing on the role of financial institutions in environmental protection and sustainable economic development (Jeucken and Bouma, 1999), since then, it has gradually shifted to quantitative research. At present, research mainly focuses on the economic and environmental effects of green financial development, and scholars generally believe that green finance can optimize resource allocation, promote ecological and resource protection (Eremia and Stancu, 2006), and promote economic structural change (Chen et al., 2019). However, scholars have not yet agreed on the nature of the impact of green financial development on economic growth. Some scholars believe that green financial development can significantly promote economic growth (Markandya et al., 2015; Ruiz et al., 2016; Zhou et al., 2020), and generate new kinetic energy by suppressing outdated production capacity and promoting industrial transformation to help economic development (Chu and Zong, 2018; Fang and Lin, 2019a); however, there are scholars who believe that green financial development will inhibit economic growth (Ning and She, 2014), the correlation between green finance and economic growth in five provinces in northwest China was tested, and it was found that the overall impact coefficient was positive, but the performance of each province was different (Liu and Liu, 2020), which indicates that green finance and economic development cannot be simply understood as a linear relationship.

Technological innovation, informationization level, green finance and environmental regulation are considered to have important impacts on the green development of the ocean economy (Xu and Gao, 2022; Li et al., 2020; Zheng et al., 2022), and scholars have also explored the impacts of the marine environment on the marine economies of different countries (Kildow and McIlgorm, 2010; Wang et al., 2021), using variable fuzzy identification model, set-pair analysis method and other methods to measure the level of green development of the Ocean Economy, as well as spatio-temporal evolution analysis, regional differences and dynamic change trend analysis (Liang, 2019). The expansion of the total scale of green financial funds has a significant role in promoting the green transformation of the ocean economy (Xu et al., 2019), and further research has found that environmental regulation plays a positive regulating role between the development of green finance and the upgrading of industrial structure, strengthens the role of upgrading of industrial structure in promoting the high-quality development of the Ocean Economy, and also shows a positive regulating effect in the direct effect of green finance on the high-quality development of the ocean economy effect (Xu and Dong, 2024), a view that has received more support (Liu et al., 2015; Wang and Yao, 2016; Hu and Zhao, 2018). In addition, some studies have shown that the coupling and coordination between green finance and high-quality development of the ocean economy is generally on a steady upward trend, but there are significant differences between provinces and cities, such as the coupling and coordination degree of Tianjin, China, which is significantly higher than that of other provinces (Wang et al., 2023). However, green finance faces challenges such as mismatch between the supply and demand of funds, difficulties in meeting the needs of financial service institutions, and the lack of financial instruments and products in supporting the development of the Ocean Economy, and its role in promoting the growth of the ocean economy is limited by the differences in the level of construction of relevant supporting facilities in different regions (Zhao et al., 2020).

2.2 "Dual carbon" and the ocean economy

China's ocean economy has undergone a rapid transition from a "crude" model that relies on high inputs of labor, capital, energy and excessive CO2 emissions to a more "frugal and intensive" development model (Ding and Dong, 2024).In this transition process towards a "dual-carbon" goal, China's shipping industry has taken measures such as accelerating the green transformation of the shipbuilding industry, which has significantly reduced carbon emissions and maintained a dominant position in the field of reducing carbon emissions in global shipping Hu and Dong, 2024). In the future, the decarbonization of the shipping industry will rely more on intelligent technologies (Xiao et al., 2025). In addition, there are significant differences in the carbon emission efficiency of ocean fisheries among regions in China. Except for Hebei and Guangxi, the carbon emission efficiency of marine fisheries in most regions is maintained at a high level, and these high-efficiency regions show a certain spatial dependence, especially the "high-high" clustering characteristics (Zhang, 2021). Scholars have deeply analyzed the factors affecting the efficiency of marine carbon emissions, and the level of science and technology is considered to be the most important factor, while the scale of marine fisheries, the scale of the Ocean Economy, the degree of opening up to the outside world, and the structure of the marine industry also play an important role (Di et al., 2024). Innovation is the core driving force to promote the high quality of the ocean economy and achieve the "dual carbon" goal (Pan et al., 2024). In addition, carbon trading policies, ownership structure, industrial structure, environmental regulations, and technological level all contribute significantly to the synergistic development of China's marine industry agglomeration and carbon emission reduction. However, the facilitating effects of these factors are significantly heterogeneous across regions (Cheng et al., 2022; Xu et al., 2023). ocean economic activities to satisfy domestic demand are the main source of carbon emissions, while in terms of carbon transfer, the ocean economy is characterized by a two-way co-existence, which is generally manifested in the fact that carbon outflow is greater than carbon inflow. In the carbon transfer network, Tianjin, Shandong and Guangdong become the central nodes in the network by virtue of their strong centrality (Zhang Y. et al., 2023). The level of marine science and technology and innovation are the key factors driving the realization of the "dual-carbon" goal, and there is spatial heterogeneity in the contribution of these factors to carbon emission reduction in different regions (Lin and Teng, 2024).

2.3 "Dual carbon" and green finance

A high level of green finance plays a key role in promoting the realization of the "dual-carbon" goal, and this contribution is largely dependent on the effective guidance of the government (Wang JY et al., 2024). A number of studies have revealed that there are regional differences in the impact of green finance on carbon emissions. Green bonds can significantly reduce the intensity of urban carbon emissions, and this effect is more pronounced in regions with a higher degree of financial marketization and weaker environmental regulations (Zhang K. et al., 2023). Green finance is most effective in promoting carbon emission reduction in central China, followed by western and Eastern regions (Yan et al., 2024). The carbon emission reduction effect of green finance is more prominent in cities of large scale and above, as well as in cities with stronger innovation capacity. Green technology progress and industrial structure optimization is an important way for green finance to promote the realization of the "dual-carbon" goal, and there are obvious differences in the role of green finance development in carbon emission reduction in different regions (Tan, 2020; Chen et al., 2024). Green technology innovation plays an intermediary role in the carbon emission reduction effect of green finance, while environmental regulation and financial marketization further enhance the carbon emission reduction effect of green finance (Zhou WH. et al., 2024). Technological innovation is an important mechanism for green finance to exert emission reduction effects (Wen et al., 2022). Expanding the scale of the green finance market, providing enterprises with the financial support needed for low-carbon transformation, and guiding substantive technological innovation to optimize the domestic industrial structure are key ways to achieve the "dual-carbon" goal (Wang YL. et al., 2024). However, some studies have also pointed out that environmental investment and the increase in the level of economic development may have a negative moderating effect on the carbon emission reduction effect of green finance (Xu et al., 2024). In addition, the coupling and coordination degree of green finance and low carbon economy in China shows a fluctuating upward trend, but it has not yet reached the state of high-quality coupling and coordination, and the green financial system is relatively lagging behind (Liu and Xu, 2024). The impact of green finance on carbon emission efficiency also shows some lag and backward effects, indicating that green finance needs to be continuously focused and optimized in the process of achieving the goal of "double carbon" (Wu and Xu, 2023).

In summary, it is widely recognized in the current academic community that green finance has a driving effect on the growth of the Ocean Economy, but this relationship is not a simple linear link, but shows significant regional heterogeneity. China's ocean economy is undergoing a transition from a "crude" mode to a "conservation and intensification" mode, during which the carbon emission efficiency of the marine industry is characterized by spatial aggregation (Tian et al., 2023). In terms of the impact of green finance on China's carbon emissions, different regions show obvious differences, with the central region showing the most prominent role of green finance in carbon emission reduction, followed by the western and Eastern regions (Li and Lin, 2023).

However, although existing literature has extensively explored the relationship between green finance and China's ocean economy and its regional variability, there are still many shortcomings. Most studies use qualitative analysis or simple statistical analysis methods, and lack in-depth and systematic quantitative research and modeling, which limits the in-depth understanding and accurate prediction of the relationship between green finance and China's Ocean Economy. In addition, although the literature has noted the differences between green finance and ocean economy in different regions, there is still a lack of in-depth exploration of the deep-seated reasons and mechanisms behind these differences. Therefore, the purpose of this paper is to further explore the deep relationship between green finance and China's ocean economy under the "dual-carbon" goal, and to explain the reasons for the differences between green finance and China's ocean economy in different regions, with a view to providing a more accurate and scientific basis for the formulation and implementation of relevant policies.

3 Study area and evaluation system

3.1 Study area

The ocean economy has become an important engine of global economic growth. As the world's second largest economy, China's rapid growth in the ocean economy not only promotes domestic economic development, but also enhances China's influence in the global economy. Coastal areas are an important part of the development of the Ocean Economy, and play an important role in China's national strategy. There are 14 coastal provinces and cities in China, and considering the availability and completeness of the data, this paper excludes Hong Kong, Macao, and Taiwan, and the study area covers a total of 11 provinces and cities, including Liaoning, Hebei, Tianjin, Shandong, Jiangsu, Shanghai, Zhejiang, Fujian, Guangdong, Guangxi, and Hainan. According to China's "13th Five-Year Plan for the Development of the National Ocean Economy" (The 13th Five-Year Plan for the Development of the National Ocean Economy: the Northern Ocean Economic Zone consists of the Liaodong Peninsula, Bohai Bay and Shandong Peninsula coasts and sea areas; the Eastern Ocean Economic Zone consists of the Jiangsu, Shanghai and Zhejiang coasts and sea areas; and the Southern Ocean Economic Zone consists of the Fujian Province, the mouth of the Pearl River and its two flanks, the Beibu Gulf, and the coasts and sea areas of Hainan Island), the 11 provinces and cities in the study area are categorized into the Northern Ocean Economic Zone, the Eastern Ocean Economic Zone and the Southern Ocean Economic Zone, of which the Northern Ocean Economic Zone includes Liaoning, Hebei, Tianjin, Shandong and Hainan; the Eastern Ocean Economic Zone includes Jiangsu, Shanghai and Zhejiang; and the Southern Ocean Economic Zone includes Fujian, Guangdong, Guangxi and Hainan (Table 1).

Different regions have different natural resource endowment and ecological environment capacity due to their geographic location, climatic conditions, geological structure and other factors. The Northern Ocean Economic Zone is located in the north of China, covering Liaodong Peninsula, Bohai Bay and Shandong Peninsula, with rich marine fishery resources and port resources; the Eastern Ocean Economic Zone is located in the Yangtze River Delta region, with unique marine transportation conditions and rich marine mineral resources; the Southern Ocean Economic Zone involves Fujian, the Pearl River Estuary and its two flanks, the Beibu Gulf, and Hainan Island, whose tropical and subtropical climate conditions are suitable for the development and utilization of marine biological resources. China's coastal provinces and cities have their own characteristics and advantages in the development of the Ocean Economy, and a categorized discussion is more conducive to clarifying the actual role of green finance on ocean economic growth in each region.

TABLE 1 Scope of the study area.

Study area	Name of region, province and city	Number of provinces and cities
Northern Ocean Economic Zone	Liaoning, Hebei, Tianjin, Shandong	4
Eastern Ocean Economic Zone	Jiangsu, Shanghai, Zhejiang	3
Southern Ocean Economic Zone	Fujian, Guangdong, Guangxi, Hainan	4

This paper uses Arcgis software to draw the distribution map of China's Ocean Economic Zone, as shown in Figure 1 below, the Ocean Economic Zone presents the characteristics of the development of marine industry clusters, and the marine industries with similar industrial characteristics, technological level and market demand will form industrial clusters, so as to reduce the cost, improve the efficiency, and enhance the competitiveness.

3.2 Comprehensive evaluation system of green finance index

During the G20 Hangzhou Summit, China and the United Kingdom jointly released the G20 Green Finance Synthesis Report, which provides an authoritative definition of green finance, which refers to investment and financing activities that generate environmental benefits in support of sustainable development (Hou and Guo, 2024). Most of the existing studies use green credit to characterize the level of green finance development, which is difficult to fully reflect the connotation of green finance. Green credit, green securities, green funds, green financial bonds, green insurance, eco-banking, etc. have become the "new normal" of the financial industry, and the main products of green finance include green credit, green securities, green insurance and carbon finance. Green credit is the largest component of green finance, directly reflecting the support of financial institutions for green projects; green investment, including equity investment, project investment and other forms of investment, can reflect the market's long-term support for the green industry; green insurance for green projects to provide risk protection to reduce the impact of environmental risks on the project; green bonds are one of the most mature tools in the development of the global green finance market; green support includes government subsidies, tax incentives, special funds and other policy tools, which is an important force to promote the development of green finance; green rights and interests include carbon emission rights, sewage rights and other market-based environmental rights and interests trading tools; green fund focuses on green industry investment, which can effectively guide the flow of funds to green projects Li and Xia, 2014; Ma, 2016; He and Cheng, 2022).Most of the existing studies use green credit to characterize the level of green financial development, which is difficult to comprehensively reflect the connotation of green finance. On the basis of existing studies, this paper constructs a comprehensive evaluation system of green

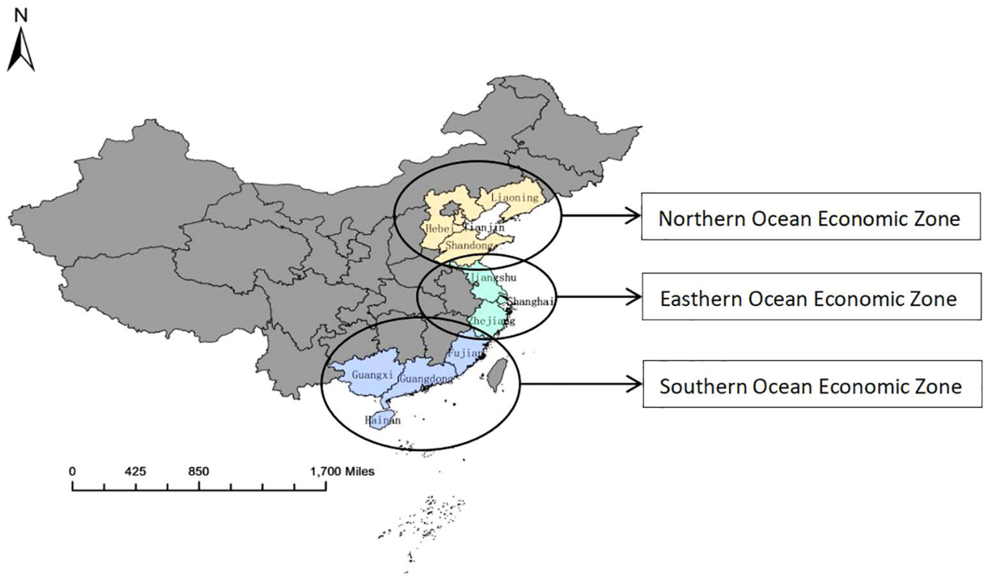

FIGURE 1
Distribution of China's Ocean Economic Zones.

financial index applicable to the ocean economic field (Fang and Lin, 2019b; Yu and Fan, 2022), which consists of seven level 1 indicators, namely, green credit, green investment, green insurance, green bond, green support, green fund and green rights and interests, and the contribution of each indicator is positive. Among them, green credit is represented by the proportion of total credit for environmental protection projects to total credit; green investment is represented by the proportion of investment in environmental pollution control to GDP; green insurance is represented by the proportion of revenue from environmental pollution liability insurance to total premium income; green bonds are represented by the proportion of total green bond issuance to total issuance of all bonds; green support is represented by the proportion of fiscal environmental protection expenditure to fiscal general budgetary expenditure; green fund is represented by the proportion of total market value of green funds to total market value of all funds; and the contribution of each indicator is positive. Green funds are represented by the total market value of green funds as a percentage of the total market value of all funds; green equity is represented by the total amount of equity market transactions in carbon trading, energy use rights trading, and sewage rights trading (Table 2).

3.3 Green finance index for China's coastal provinces and municipalities

The green finance index is an important indicator for measuring the performance of financial institutions in environmental, social and governance aspects. According to the comprehensive evaluation system of the green finance index constructed above, the green finance index can reflect the proportion of credits for environmental protection projects, investment in environmental pollution control, the degree of promotion of environmental pollution liability insurance, the issuance of green bonds and other aspects. Calculating the green finance index of China's coastal provinces and cities will help to understand the development status of coastal provinces and cities in the field of green finance, as well as the spatial characteristics of the level of green finance development, so as to formulate a more scientific and reasonable strategy of sustainable development and promote the realization of the "dual-carbon" goal for the marines.

The entropy method, which is used as the main method for determining the weights of criteria/structures, can assess data completeness more objectively, enhance the interpretability of the results, and mitigate the influence of subjective factors (Wang et al., 2013). In this paper, the entropy method is used to measure the green finance index of China's coastal provinces and cities. There are six measurement steps, including data standardization, calculation of sample value weight, calculation of information entropy, calculation of redundancy, calculation of information weight and calculation of comprehensive score, as follows:

The first step is to standardize the data (Equation 1):

$$x_{ij}^{'} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \tag{1}$$

In the second step, the weight of each sample value in the total sample, $P_{(ij)}$, is calculated from the normalization matrix (Equation 2):

$$p_{ij} = \frac{x_{ij}^{'}}{\sum_{i=1}^{n} x_{ij}^{'}} \tag{2}$$

In the third step, the information entropy e_j for each indicator is calculated based on the weight (Equation 3):

TABLE 2 Green finance index comprehensive evaluation system.

First-level index	Secondary indicators	Methodology for measuring secondary indicators	Attributes	Weights
Green Credit	Percentage of credits for environmental projects	Total credit/total credit for environmental projects	+	13.903%
Green Investment	Investment in environmental pollution control as a share of GDP	Investment in environmental pollution control/GDP	+	12.36%
Green Insurance	Extent of promotion of environmental pollution liability insurance	Environmental pollution liability insurance income/total premium income	+	18.474%
Green Bond	Extent of green bond development	Total green bond issuance/total all bond issuance	+	13.202%
Green Support	Percentage of fiscal expenditure on environmental protection	Financial environmental protection expenditures/financial general budget expenditures	+	16.72%
Green Fund	Percentage of green funds	Total market capitalization of green funds/total market capitalization of all funds	+	14.317%
Green Benefits	Green equity development depth	Carbon trading, energy rights trading, emissions trading/total equity market transactions	+	11.025%

$$e_j = \frac{1}{\ln n}\sum_{i=1}^{n} p_{ij}\ln p_{ij} \tag{3}$$

In the fourth step, the redundancy d_j of each metric is calculated based on the information entropy (Equation 4):

$$d_j = 1 - e_j \tag{4}$$

In the fifth step, the weight w_j of each indicator is calculated based on the redundancy (Equation 5):

$$w_j = \frac{d_j}{\sum_{j=1}^{m} d_j} \tag{5}$$

In the sixth step, the green finance index GFI_i is calculated based on the weights and normalized indicator values (Equation 6):

$$GFI_i = \sum_{j=1}^{m} w_j x_{ij}^{'} \tag{6}$$

This paper calculates the green finance index of China's coastal provinces and cities based on the above methodology, and the related data are from the Statistical Yearbook and Environmental Status Bulletin of China and provinces and cities, as well as the China Science and Technology Statistical Yearbook, the China Energy Statistical Yearbook, the China Financial Yearbook, the China Agricultural Statistical Yearbook, the China Industrial Statistical Yearbook, and the China Tertiary Industry Statistical Yearbook.

Figures 2a, 3a, 4a show the green financial development status of China's coastal provinces and cities in 2008, 2015 and 2022, respectively. To enhance the credibility of the study, this paper uses factor analysis to cross-validate the green financial development status of China's coastal provinces and cities. Factor Analysis (FA) is a multivariate statistical method used to study the underlying structure between observed variables. It explains the correlation between variables by attributing multiple observed variables to a few potential factors. Its formula is expressed as Equation 7:

$$X = AF + \varepsilon \tag{7}$$

X denotes the matrix of observed variables. f denotes the matrix of factor scores, which are unobservable latent variables. a denotes the matrix of factor loadings, which reflect the correlation between the variables and the factors. ε denotes the error terms, which are a part of the information unique to each variable and are usually ignored in the actual analyses.

The factors were first extracted using principal component analysis and the number of factors was determined. Then the factor loading matrix was rotated to make the factor interpretation clearer. Finally, the performance of each sample on the public factors was obtained by calculating the scores of each public factor, and the factor scores were weighted and averaged according to the variance contribution ratio of each factor to finally obtain the composite score. It is found that the obtained comprehensive scores of green finance in China's coastal provinces and cities in 2008, 2015 and 2022 (Figures 2b, 3b, 4b) are highly similar to the results of the previous study (Figures 2a, 3a, 4a), and the distribution of the level of green finance development in each coastal province and city is basically the same. The entropy value method and factor analysis method are objective assignment methods, and the two methods yield similar results, proving the reliability of the study.

From the viewpoint of the spatial characteristics of development, the green finance index of the Northern Ocean Economic Zone is always higher than that of the Eastern and Southern Ocean Economic Zones, but the gap is gradually narrowing, and there is an obvious difference in the development speed of green finance in different Ocean Economic Zones. The development speed of green finance in the Eastern Ocean Economic Zone is relatively fast, while Hainan in the Southern Ocean Economic Zone has a rapid development momentum, and the development of green finance in the Northern Ocean Economic Zone is relatively smooth.

From the perspective of development potential characteristics, the development of green finance in China's Ocean Economic Zones still has a large potential, especially Hainan in the Southern

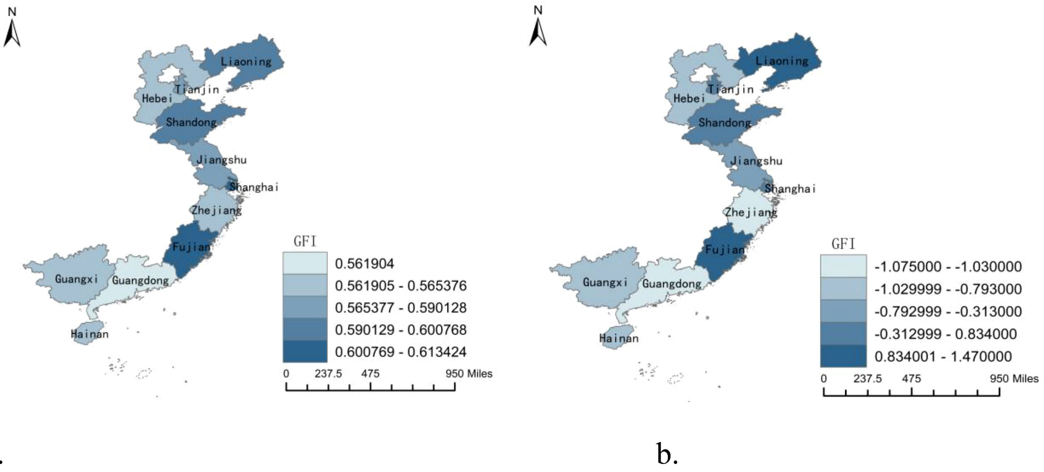

FIGURE 2
(a) Green finance developments in 2008 **(b)** Green finance developments in 2008.

Ocean Economic Zone and Liaoning in the Northern Ocean Economic Zone. Although Hainan started late, it is growing faster and is expected to become a new engine of green finance development in the future. Hainan's green financial index was low in 2008, in order to accelerate the development of Hainan eight relevant departments jointly issued the "Hainan Provincial Green Financial Reform and Development Implementation Program", the issuance of green bonds and green credit balance of the annual incremental rankings of the top five of the province's enterprises and banks to give incentives to guide the financial resources tilted to the field of green, emission reduction, innovation of green financial products, support for the issuance of green and blue bonds, the establishment of green low-carbon investment funds, and enriching green insurance products, Hainan's green financial index has improved significantly, and the speed of green financial development is the fastest among coastal provinces and cities. Liaoning's green financial index in 2008, 2015 and 2022 has been at the leading level. Liaoning has established an advanced green financial service platform "Liao Green Pass", continuously improved the green financial support project database, set up a carbon emission right pledge service center, and incorporated the green financial evaluation results into the rating system of financial institutions of the central bank. In addition, Liaoning has formulated evaluation standards for the identification of green enterprises and green finance, and standardized the development of green finance business.

As can be seen from the development of green finance in China's coastal provinces and municipalities in 2008, 2015 and 2022, despite the overall increase in the index, there are still differences in the green finance index between different regions, reflecting the unevenness of green finance development. Second, the growth rate of the green finance index is not consistent across

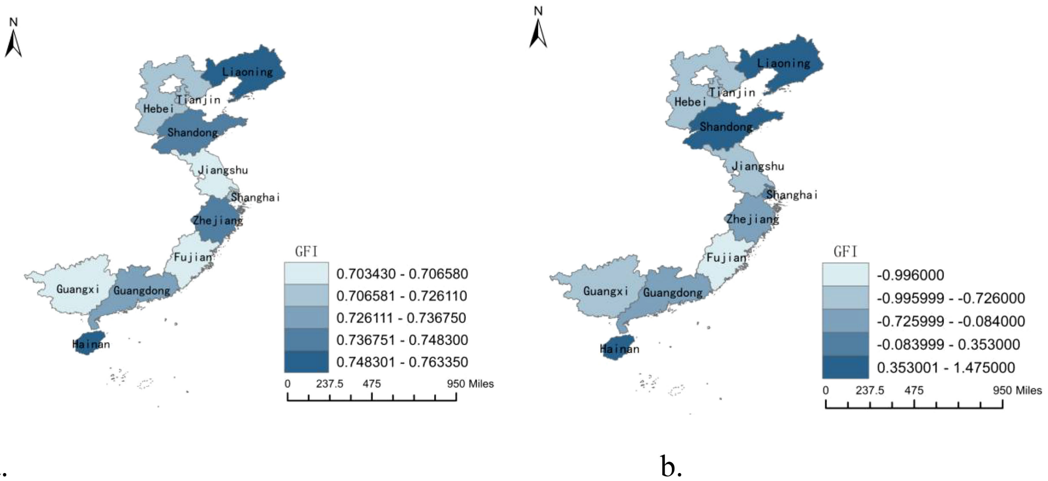

FIGURE 3
(a) Green finance developments in 2015 **(b)** Green finance developments in 2015.

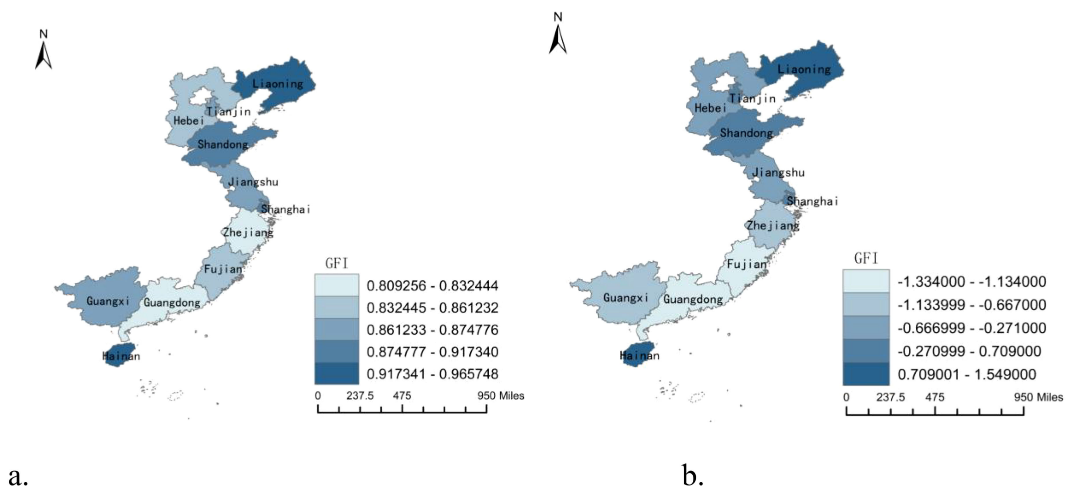

FIGURE 4
(a) Green finance developments in 2022 **(b)** Green finance developments in 2022.

regions. The indexes of some regions grow faster, while the growth of other regions is relatively slow. Therefore, this paper investigates the heterogeneity of the development of green finance indexes in various regions, with a view to finding corresponding programs to promote the development of green finance in various regions and to promote the overall high-quality growth of China's Ocean Economy.

4 Methodology and data

This paper firstly adopts a fixed-effect model to explore the relationship between green finance and China's ocean economy under the "dual-carbon" goal. Fixed Effects Model (FEM) is able to control for individual characteristics (e.g., geographic location, ocean resource endowment, etc.) that do not vary over time, thus estimating more accurately the impact of green finance on ocean economy growth. In addition, the Fixed Effects Model is suitable for dealing with panel data and can alleviate the endogeneity problem. In order to verify the applicability of the fixed-effects model, this paper conducts a Hausman test, which shows that the fixed-effects model is superior to the random-effects model (see Table 3). Considering the differences in the level of economic development, resource endowment and policy environment of China's coastal regions, this paper further conducts a heterogeneity test by dividing the sample into the Northern, Eastern and Southern Ocean Economic Zone and conducting fixed effects regressions separately. This sub-regional analysis can reveal the spatial heterogeneity of green finance on ocean economy growth and provide a scientific basis for the formulation of differentiated policies. Finally, through the threshold effect model, the non-linear relationship between green finance and ocean economic growth is further studied, the threshold value is identified, and countermeasures are proposed to promote the development of China's ocean economy through green finance under the "dual-carbon" goal.

TABLE 3 Results of Hausman test.

Hausman test	Value
chi2(9)	34.67
Prob>chi2	0.0001

4.1 Fixed effects model

The development of the ocean economy is influenced by various factors, including geographic location, resource endowment, and the policy environment, and there are significant differences in ocean economic growth between different regions.

The fixed-effects model can capture this individual variability and more accurately analyze the impact of green finance on ocean economy growth. At the same time, the fixed-effects model can alleviate the endogeneity problem to a certain extent. Certain individual characteristics that do not change over time may affect green finance development and ocean economy growth at the same time. Through the Fixed Effects Model, the interference of these time-varying factors can be eliminated and the reliability of the conclusions can be improved. In this paper, we use the panel data of China's coastal provinces and cities from 2008-2022, and the fixed-effects model is very suitable for analyzing this kind of data structure with both time and individual dimensions. It can take full advantage of the panel data to analyze the dynamic impact of green finance on ocean economy growth. Its formula can be expressed as Equation 8:

$$y_{it} = \alpha_i + \beta X_{it} + \varepsilon_{it} \tag{8}$$

Where i denotes provinces and municipalities and t denotes time; Y_{it} denotes the per capita gross marine product of province and municipality i at time t; α_i denotes an individual fixed effect, which represents an individual-specific characteristic that does not change over time; β denotes the coefficient of the independent variable; X_{it} denotes the value taken by province and municipality i at time t; and ε_{it} is the error term.

Substituting the explanatory variables, core explanatory variables and other control variables selected in this paper to get Equation 9:

$$GMP_{it} = \alpha_i + \beta_1 GFI_{it} + \beta_2 FMR_{it} + \beta_3 NPG_{it} + \beta_4 GRI_{it} + \beta_5 SMA_{it} + \beta_6 SMI_{it} + \beta_7 ECS_{it} + \beta_8 STI_{it} + \beta_9 SSI_{it} + \varepsilon_{it} \quad (9)$$

Where GMP denotes the per capita gross marine product of each province and city; GFI denotes the green finance index of each province and city; FMR denotes the funding income of marine scientific research institutions; NPG denotes the number of authorized patents of each province and city; GRI denotes the index of the gross regional product of each province and city; SMA denotes the stock market activeness of each province and city; SMI denotes the scale of the marine industry of each province and city; ECS denotes the energy consumption structure; STI denotes the scale of tertiary industry in each province and city; SSI indicates the scale of secondary industry in each province and city.

4.2 Fixed effects model test

In order to verify the reasonableness of the selected model, this paper used the Hausmann test for model testing. The results show that the statistic of the chi-square test reaches 34.67, and the significance level of this statistic is much lower than 0.01, which strongly rejects the original hypothesis, thus proving that the selection of the Fixed Effects Model to analyze in this paper is reasonable (Table 3).

4.3 Threshold model

Under the “dual-carbon goal”, the impact of the development of green finance on the growth of the ocean economy shows a complex non-linear relationship. With the continuous development of green finance, its role in promoting the ocean economy gradually increases, while it may also be limited by certain thresholds. Threshold Model is a kind of nonlinear regression model, which assumes that the relationship between the dependent variable and the independent variable has different manifestations in different intervals, and is able to capture the nonlinear relationship of the dependent variable when the independent variable reaches a certain threshold, which is suitable for studying the potential threshold effect of green finance on ocean economy growth. Traditional segmented regression models and high order term models, etc. can also simulate the nonlinear relationship, but segmented regression models often need to determine the segmentation point in advance, and there may be the case of multiple cut-off points, which is complicated to deal with and easy to interfere with the objectivity of the empirical results. Higher term models can also simulate nonlinear relationships by introducing higher terms for the independent variables, but they may be overfitted, especially when the true relationship is segmented and linear, the higher terms may not be accurate enough, and the coefficients are difficult to interpret. In contrast to traditional segmented regression models, high order terms, and other models that explore nonlinear relationships, Threshold Effect Models are able to automatically determine cut-off points based on the characteristics of the data itself, and deal with single or multiple thresholds while maintaining linearity within the segments, which makes it more straightforward to interpret the effects in each interval. In addition, the Threshold Model fits the data more accurately, especially when there is an obvious structural change in the relationship between the variables, rather than a smooth nonlinear change, and the use of the Threshold Model is more effective in exploring the nonlinear relationship between green finance and ocean economy growth. Therefore, this paper adopts the Threshold Model for analysis. The formula is as follows:

When the threshold variable qit is less than or equal to the threshold value γ, the model is Equation 10:

$$Y_{it} = \mu_i + \beta_1 X_{it} + \varepsilon_{it}(q_{it} \le \gamma) \quad (10)$$

When the threshold variable q_{it} is greater than the threshold value γ, the model is Equation 11:

$$Y_{it} = \mu_i + \beta_2 X_{it} + \varepsilon_{it}(q_{it} > \gamma) \quad (11)$$

Equations 10, 11 are combined to obtain Equation 12:

$$Y_{it} = \mu_i + \beta_1 X_{it} I(q_{it} \le \gamma) + \beta_2 X_{it} I(q_{it} > \gamma) + \varepsilon_{it} \quad (12)$$

Where i denotes provinces and cities, and t denotes time; Y_{it} denotes gross marine product per capita; X_{it} denotes green finance index; q_{it} denotes threshold variable; γ denotes a specific threshold value; I(·) is an indicator function that takes the value of 1 when the condition is established, and 0 otherwise; μ_i denotes the individual effect; and ε_{it} denotes a random disturbance term.

4.4 Variable selection and data sources

4.4.1 Selection of variables

4.4.1.1 Explained variables

Gross Maritime Product per capita (GMP). In this paper, the Gross Maritime Product per capita (GMP) of China’s coastal provinces and cities is selected as an explanatory variable, representing the development of the ocean economy of coastal provinces and cities in the current year, which is obtained by dividing the sum of the value added of the marine industry and marine-related industries by the resident population of each province and city (Xia et al., 2019).

4.4.1.2 Core explanatory variables

Green Finance Index (GFI). The GFI represents the level of green finance development in China's coastal provinces and cities, and consists of seven level 1 indicators: green credit, green investment, green insurance, green bond, green support, green fund and green equity, and is calculated by the entropy method. Green finance supports low-carbon, environmentally friendly and sustainable economic activities through financial instruments, promotes environmental protection and actively responds to climate change, and the development of green finance is an important tool for realizing the goal of "double carbon" (An, 2021).

4.4.1.3 Threshold variables

Marine research funding revenue (FMR). FMR is obtained from the current year's revenue of marine scientific research institutions plus the government's input in capital construction funds. By providing financial support and preferential policies, green finance guides the flow of social capital to marine scientific research institutions, thus increasing the revenue from marine scientific research funding. This injection of funds helps to promote research and development and innovation in marine science and technology, improve the utilization efficiency of marine resources and reduce environmental pollution, in line with the "dual-carbon" goal of reducing carbon emissions and promoting green development (Lu and Yao, 2024).

Scale of Marine Industry (SMI). It is expressed by the proportion of regional gross marine product to GDP. Green finance support for the marine industry can promote the rapid development of the industry and thus expand the scale of the marine industry. As the scale of the marine industry expands, its contribution to the ocean economy will also increase, which will help optimize the industrial structure and reduce the dependence on traditional high-pollution industries, in line with the orientation of the "dual-carbon" goal (Cao et al., 2015).

4.4.1.4 Other control variables

Number of Granted Patents (NPG). It is expressed by the number of patents authorized in the current year. The number of authorized patents reflects the results of technological innovation and R&D activities. For the ocean economy, technological innovation is an important driving force to promote the development of ocean resources, the upgrading of ocean equipment, and the protection of the ocean environment, among other key aspects. Technological innovation is a key factor in enhancing the competitiveness of the ocean economy, and green finance, by supporting ocean science and technology R&D, can promote the authorization of more ocean-related patents, thus promoting the development of the ocean economy (Wu et al., 2020).

Gross Regional Index (GRI). Taking 2000 Gross Regional Product as the base period (Gross Regional Product Index 100), it is calculated based on the growth ratio of Gross Regional Product in that year. The Gross Regional Index is an important indicator for measuring the development of the regional economy, and for the ocean economy, the overall development of the regional economy will lead to the prosperity of the ocean industry. By supporting green industries and projects, green finance helps to improve the overall quality and efficiency of the regional economy, thus indirectly promoting the development of the ocean economy (Li et al., 2014).

Stock Market Activity (SMA). The total value of outstanding shares derived from the number of tradable shares outstanding in the year multiplied by the share price at that time indicates the stock market activity reflects the financing ability of the capital market and investor confidence, for the ocean economy, an active stock market can provide more financial support for the ocean industry. Green finance financing through the capital market can guide the flow of funds to the field of ocean environmental protection, ocean science and technology, and promote the sustainable development of the ocean industry (Ju et al., 2015).

Energy Consumption Structure (ECS). Derived from the share of coal in energy consumption in the current year. Energy consumption structure reflects the preference and efficiency of regional energy use. For the ocean economy, optimizing the energy consumption structure helps reduce energy consumption and environmental pollution in the ocean industry. By supporting the development of clean energy and renewable energy, green finance helps to optimize the energy consumption structure and reduce the dependence on traditional energy, thus reducing carbon emissions and environmental pollution in the ocean industry (Rui, 2025).

Scale of tertiary industry (STI). It is expressed by the proportion of the output value of the tertiary industry to the GDP in the current year. The scale of tertiary industry reflects the change of regional economic structure and the trend of industrial upgrading. For ocean economy, the rapid development of tertiary industry helps to improve the overall quality and efficiency of ocean economy. Green finance can promote the optimization and upgrading of the structure of ocean economy by supporting the development of tertiary industries such as ocean tourism and ocean information service (Ding et al., 2022).

Size of secondary industry (SSI). It is expressed by the proportion of the output value of the secondary industry to the GDP in the current year. The scale of the secondary industry reflects the level of regional industrialization and the strength of the manufacturing industry. For the ocean economy, the development of the secondary industry is an important force to promote the growth of the ocean economy. Although the secondary industry is often accompanied by higher energy consumption and environmental pollution, green finance can realize a win-win situation in terms of economic and environmental benefits by supporting its green transformation and upgrading (Li and Huang, 2022).

To avoid the problem of heteroskedasticity and multicollinearity, the variables are logarithmized in this paper, so there are cases where the variables are negative. Below are the descriptive statistics (Table 4) and the correlation test (Figure 5) for the variables selected in this paper.

TABLE 4 Descriptive statistical analysis of variables.

Variable	Obs	Mean	Std. Dev.	Min	Max.
GMP	165	-.0978179	.8762697	-2.752002	1.806894
GFI	165	-.3143129	.131507	-.5764243	-.0348523
FMR	165	12.2171	1.455464	8.304	14.99342
NPG	165	4.39989	1.773788	0	7.159292
GRI	165	4.683119	.032786	4.579852	4.765587
SMA	165	8.997614	1.162214	6.915723	11.47077
SMI	165	-1.884524	.5899212	-3.912723	-.5621189
ECS	165	-1.28128	.5822702	-3.491037	-.3227622
STI	165	-.7416248	-1833772	-1.10262	-.2997547
SSI	165	-.8656963	.2441876	-1.655482	-.5091603

As can be seen in Figure 5, the absolute value of the correlation test coefficients among the variables are all below 0.7, indicating that there is no multicollinearity problem. In addition, the results show that the correlation between Gross Maritime Product per capita (GMP) and other variables is significant.

4.4.2 Data sources

The data used in this paper come from the China Marine Statistical Yearbook, the China Ocean Economy Statistical Bulletin, the Statistical Yearbooks of China's provinces and cities, the Bulletin on the State of the Environment, as well as the China Science and Technology Statistical Yearbook, the China Energy Statistical Yearbook, the China Financial Yearbook, the China Agricultural Statistical Yearbook, the China Industrial Statistical Yearbook, and the China Tertiary Industry Statistical Yearbook.

4.5 Unit root test

The data series adopted in this paper are time series, and smoothness is an important characteristic of time series data, which means that the statistical characteristics of the time series do not change over time, while the non-smooth series may show the characteristics of trend, seasonality or random fluctuations, which will make the empirical results produce "pseudo-regression" results. In addition, homogeneous panel data have similar statistical characteristics, while heterogeneous panel data have different characteristics, which may lead to biased estimation and erroneous statistical inference if heterogeneous panel data are mistakenly treated as homogeneous panel data. In order to avoid "pseudo-regression" and ensure the validity of the estimation results, it is necessary to analyze the smoothness of the time

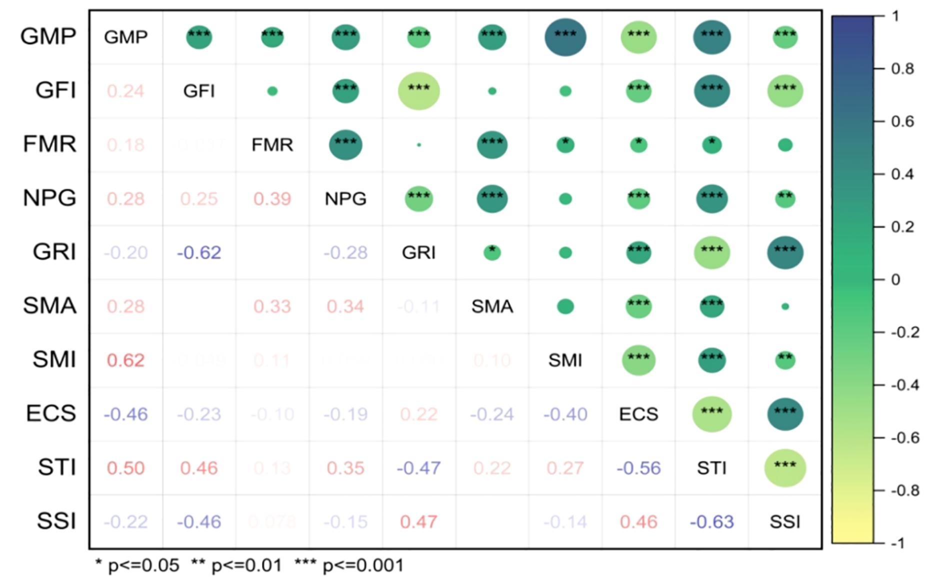

FIGURE 5
Correlation test.

TABLE 5 LLC test and Fisher-ADF test.

Variables	Fisher-ADF				LLC	Result
	Inverse chi-squared	Inverse normal	Inverse logit	Modified inv. chi-squared		
GMP	53.9448***	-2.5157***	-3.1289***	4.8159***	-3.8087***	Reject
GFI	89.2720***	-5.5049***	-6.8288***	10.1416***	-7.1908***	Reject
FMR	47.0065***	-2.9042***	-3.0034***	3.7699***	-1.6864**	Reject
NPG	54.0054***	-3.0673***	-3.5418***	4.8250***	-2.0516**	Reject
GRI	64.5952***	-3.8772***	-4.6803***	6.4215***	-4.7078***	Reject
SMA	47.9987***	-1.5964*	-1.6753**	3.9194***	-8.0928***	Reject
SMI	43.8804***	-1.8625**	-2.2715**	3.2986***	-3.2208***	Reject
ECS	87.7141***	-5.5109***	-6.9204***	9.9068***	-4.9923***	Reject
STI	35.2320**	-1.6795**	-1.7443**	1.9948**	-4.3581***	Reject
SSI	47.3317***	-3.0767***	-3.1517***	3.8189***	-3.0084***	Reject

*** indicates 1% significant, ** indicates 5% significant, and * indicates 10% significant.

series data and panel data, i.e., to test whether the data process is smooth through the unit root test. In this paper, we use both the LLC test for the homogeneous panel hypothesis and the Fisher-ADF test for the heterogeneous panel hypothesis, and the results of both tests reject the original hypothesis of the existence of a unit root, indicating that the series is smooth (Table 5).

5 Empirical analysis

5.1 Analysis of fixed effects regression results

In this paper, based on the fixed-effect model, the Gross Maritime Product per capita (GMP), Green Finance Index (GFI), Marine research funding revenue (FMR), Scale of Marine Industry (SMI), Number of Granted Patents (NPG), Gross Regional Index (GRI), Stock Market Activity (SMA), Energy Consumption Structure (ECS), Scale of tertiary industry (STI), Size of secondary industry (SSI), and Size of secondary industry (SSI) 10 indicators to construct two models (1) and model (2). Among them, model (1) is the regression of Gross Maritime Product per capita (GMP) and all variables, and model (2) is the regression of Gross Maritime Product per capita (GMP) and green financial index (GFI), and the fixed effect regression results of models 1 and 2 are shown in Table 6.

From the regression results of model (1) and model (2), it can be seen that the coefficients of Green Finance Index (GFI) are both significant and positive, which proves the stability of the positive promotion effect of green finance (GFI) on Gross Maritime Product per capita (GMP), and with the increase of Green Finance Index (GFI), the Gross Maritime Product per capita (GMP) grows as well. This positive relationship reflects the fact that green finance guides the flow of funds to environmentally friendly and low-carbon projects, which not only accelerates the green growth of the Ocean Economy, but also effectively promotes carbon emission reduction. Green finance-supported projects tend to use cleaner and more efficient technologies, reducing dependence on fossil fuels and directly lowering carbon emissions. In addition, the positive contribution of green finance (GFI) to Gross Maritime Product per capita (GMP) in model (2) emphasizes the robustness of the regression using fixed effects in this paper.

In the model (1), the variables with significant coefficients of are six variables: Green Finance Index (GFI),Number of Granted Patents (NPG),Stock Market Activity (SMA), Scale of Marine Industry (SMI), Scale of tertiary industry (STI) and Size of secondary industry (SSI); the variables with insignificant coefficients are three variables, namely, Marine research funding revenue (FMR), Gross Regional Index (GRI) and Energy Consumption Structure (ECS). The coefficients are not significant for three variables: Marine research funding revenue (FMR), Gross Regional Index (GRI) and Energy Consumption Structure (ECS).

The significant and negative coefficient on the Number of Granted Patents (NPG) suggests that, although there is a high number of patents granted, it is likely that the conversion of patents into actual productivity is inefficient in the marine industry sector. A large number of patents remain only on paper and are not effectively transformed into products or services to promote the growth of the Ocean Economy. Instead, the large amount of R&D resources invested in acquiring these patents takes away other resources that could have been used to promote the growth of the Ocean Economy, resulting in a negative correlation between the Gross Maritime Product per capita (GMP) and the Number of Granted Patents (NPG).

The coefficient of Stock Market Activity (SMA) is significant and positive, indicating the importance of the capital market in supporting the green transition and low-carbon development of the

TABLE 6 Fixed effects regression results.

	Model (1)	Model (2)
GFI	2.394***	2.155***
	(0.244)	(0.154)
FMR	-0.002	
	(0.013)	
NPG	-0.052**	
	(0.020)	
GRI	-0.553	
	(0.614)	
SMA	0.049**	
	(0.023)	
SMI	0.853***	
	(0.059)	
ECS	0.064	
	(0.074)	
STI	0.734**	
	(0.369)	
SSI	1.172***	
	(0.294)	
_cons	5.856**	0.580***
	(2.886)	(0.052)

***indicates 1% significant, ** indicates 5% significant.

marine industry. An active capital market provides marine enterprises committed to green transformation and low-carbon development with the necessary financial support for research and development of new technologies, improvement of production processes, enhancement of energy efficiency, and facilitation of scale expansion and competitiveness enhancement, thus playing a key role in realizing the "dual-carbon" goal.

The coefficient of the Scale of Marine Industry (SMI) is significant and positive, reflecting that the growth of the gross marine product can further attract capital to the marine industry. As the Scale of Marine Industry (SMI) expands, more capital and resources are invested in environmentally friendly and low-carbon projects, promoting the green transformation of the whole industrial chain. At the same time, the growth of the marine industry also drives the economic prosperity of coastal areas, providing a broader space and more possibilities for carbon emission reduction.

The coefficient of the Scale of tertiary industry (STI) is significant and positive, indicating that the prosperity of the marine service industry can drive the development of related industries and provide more services and support for the Ocean Economy. Driven by the "dual-carbon" goal, the marine service industry needs to continuously innovate its service mode and improve its service quality to meet the growing green and low-carbon demand. For example, the marine tourism industry can develop more green tourism projects to attract tourists while reducing carbon emissions. The marine transportation industry can optimize shipping routes and improve the energy efficiency of ships to reduce carbon emissions during transportation.

The coefficient on the size of the Size of secondary industry (SSI) is significant and positive, indicating that the development of industry remains an important driver of ocean economic growth. Although the rise of the service sector has contributed more and more to the growth of the ocean economy in recent years, industry is still an indispensable part of the Ocean Economy. In the context of the "dual-carbon" goal, industry needs to pay more attention to energy conservation, emission reduction and green transformation, and contribute to carbon emission reduction while realizing economic growth.

5.2 Heterogeneity analysis

In order to explore the potential heterogeneity of green finance on China's ocean economic growth, this paper firstly analyzes the level of green finance development in China's coastal provinces and cities in a comparative manner (Figure 6).

As can be seen in Figure 6, the Green Finance Index (GFI) of most cities shows an upward trend from 2008 to 2022, indicating that the development of these cities in the field of green finance has achieved positive results, in particular, the level of green finance development in Hainan and Liaoning has improved most rapidly. The growth of Shanghai, Shandong and Jiangsu is also more significant, indicating that the development of green finance in these regions is also more effective.

Next, this paper analyzes the spatial heterogeneity of China's ocean economy from three regions: the Northern Ocean Economic Zone, the Eastern Ocean Economic Zone, and the Southern Ocean Economic Zone (Table 7).

The empirical results in Table 7 show that:

In terms of green finance, both the Eastern Ocean Economic Zone and the Southern Ocean Economic Zone show a significant positive contribution. Every 1% increase in the Green Finance Index (GFI) of the Eastern Ocean Economic Zone will lead to a 1.809% increase in Gross Maritime Product per capita (GMP), demonstrating the high level of green finance development in the region and its significant role in promoting the Ocean Economy. Although the Southern Ocean Economic Zone started later, every 1% increase in its Green Finance Index (GFI) will also lead to a 2.121% increase in Gross Maritime Product per capita (GMP), demonstrating the region's rapid development and positive dynamics in green finance. However, the coefficient of the Green Finance Index (GFI) in the Northern Ocean Economic Zone is not significant, indicating that the development of green finance in the region has not yet fully revealed its role in promoting the Ocean Economy.

Despite the high green financial index (GFI) of the Northern Ocean Economic Zone, the role of green finance in promoting the ocean economy is not significant, which is essentially the result of

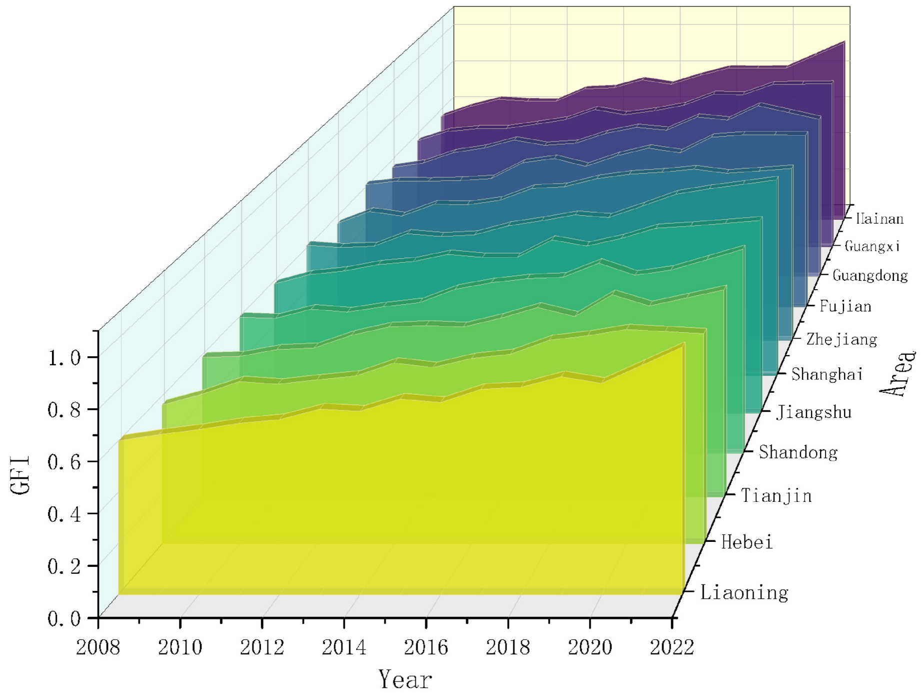

FIGURE 6
Level of green finance development in China's coastal provinces and municipalities.

the superposition of multiple factors such as lagging development of green financial infrastructure, lack of implementation of green financial policies, mismatch between the rigidity of the industrial structure and the demand for green finance, and differences in the market conditions for green finance: first of all, the development of green financial infrastructure is lagging behind. The financial system of the Northern Ocean Economic Zone is relatively closed, with a single green financial product, mainly traditional green credit, and a lack of specialized green financial institutions and talents. Unclear certification standards for green projects have led to banks being cautious about green credit, making it difficult for funds to be effectively injected into the ocean economy. The Eastern Ocean Economic Zone and the Southern Ocean Economic Zone have mature financial markets and internationalized financial centers, with abundant green financial products, such as green credits, blue bonds, carbon financial derivatives, etc., and financial institutions have stronger risk assessment and pricing capabilities for green projects. Secondly, the implementation of green financial policies and the implementation effect is poor. The Northern Ocean Economic Zone is relatively lagging behind in the synergistic planning of "dual-carbon" target and industrial transformation, and the development of ocean economy in some provinces still relies on petrochemical and other high-energy-consuming industries, so the green financial policies and industrial transformation policies have failed to form a synergy, resulting in the flow of funds to the traditional industries' "pseudo-green" projects instead of the real green projects. Local governments in the Eastern Ocean Economic Zone and the Southern Ocean Economic Zone are more active in the implementation of green financial policies, and the supporting measures are perfect. Zhejiang, Guangdong and other places through the construction of the "green financial reform pilot zone", the policy objectives are closely integrated with the development of the local community, and promote the rapid implementation of green financial tools. Third, the rigidity of the industrial structure of the Northern Ocean Economic Zone does not match the demand for green finance. Green finance is more effective in supporting technology-intensive industries, while the Northern Ocean Economic Zone is dominated by heavy chemical industries and resource-based industries, with strong rigidity of industrial structure, high cost and long cycle of green transformation. Green finance funds may be used more for the environmental transformation of traditional industries than for emerging areas of the ocean economy such as marine renewable energy and marine eco-tourism, resulting in a limited pulling effect on the growth of the ocean economy. The Eastern Ocean Economic Zone and the Southern Ocean Economic Zone have formed modern ocean industry clusters, such as Zhejiang's marine biopharmaceutical industry cluster and Fujian's ocean engineering equipment industry cluster, with a lighter and more diversified industrial structure, and a high proportion of service and high-tech industries, which are more compatible with green finance, such as green bonds supporting offshore wind power projects and blue carbon sink trading, directly promoting ocean economy's High value-added growth. In addition, the Eastern Ocean Economic Zone and the Southern Ocean Economic Zone have more mature financial market conditions, with a large number of financial institutions, a perfect financial service system, and a wider range of innovation and application of green financial products and tools.

TABLE 7 Fixed effects regression results for each region of China's Ocean Economy.

	Northern Ocean Economic Zone	Eastern Ocean Economic Zone	Southern Ocean Economic Zone
GFI	0.461	1.809***	2.121***
	(0.357)	(0.333)	(0.429)
FMR	0.016	0.040***	-0.003
	(0.019)	(0.011)	(0.019)
NPG	0.026	-0.039	0.078***
	(0.032)	(0.026)	(0.028)
GRI	-4.054***	-0.086	-0.601
	(0.855)	(0.729)	(1.041)
SMA	-0.098**	-0.021	-0.002
	(0.040)	(0.024)	(0.043)
SMI	0.814***	1.119***	0.884***
	(0.051)	(0.132)	(0.199)
ECS	-0.398**	0.109**	0.054
	(0.174)	(0.056)	(0.107)
STI	4.516***	3.949***	2.689***
	(0.659)	(0.678)	(0.791)
SSI	5.381***	0.984***	2.676***
	(0.707)	(0.331)	(0.548)
_cons	28.427***	6.538**	9.298*
	(4.809)	(3.233)	(4.885)

***indicates 1% significant, ** indicates 5% significant, and * indicates 10% significant.

This enables green finance to more effectively guide the flow of funds to ocean economy-related industries and promote ocean economy growth. In contrast, the development of the financial market in the Northern Ocean Economic Zone is relatively lagging behind, financial institutions and products are relatively single, and the penetration and influence of green finance is insufficient, resulting in the promotion of its role in the ocean economy not yet fully manifested.

In terms of research investment, the coefficient of Marine research funding revenue (FMR) in the Eastern Ocean Economic Zone is significant and positive, and every 1% increase will lead to a 0.04% increase in Gross Maritime Product per capita (GMP), which indicates that the increase in research investment effectively promotes technological innovation and industrial upgrading. In contrast, the coefficients of the Nouthern and Southern Ocean Economic Zones are not significant in this aspect. The Northern Ocean Economic Zone, such as Shandong and Liaoning, is dominated by traditional marine heavy industries like shipbuilding and marine chemicals. Research funding may flow more towards technological improvements in these traditional industries rather than emerging marine technology fields such as marine biomedicine and deep-sea exploration. The disconnection between scientific research projects and market demand has led to a low conversion rate of achievements. State-owned enterprises and large scientific research institutions dominate the Northern Ocean Economic Zone, with low participation from small and medium-sized enterprises, making it difficult for scientific research results to be realized through market-oriented mechanisms. The provinces within the Northern Ocean Economic Zone face homogenized competition in marine scientific research, resulting in dispersed funding and a challenge in forming a scale effect. In the Southern Ocean Economic Zone, provinces like Guangdong and Fujian are dominated by the private economy and export-oriented industries. Local governments tend to support manufacturing or service industries with short-term results and have limited budgets for long-term marine scientific research. The ocean economy in the Southern Ocean Economic Zone is centered around service industries such as port logistics and coastal tourism, with enterprises focusing their research and development needs on technology introduction or equipment upgrading rather than original technology innovation. As a result, the marginal contribution of local research funding to marine economic growth is relatively low. Additionally, the Southern Ocean Economic Zone is weak in research areas such as marine environment monitoring and deep-sea resource exploration, with scientific research institutions mostly focusing on short-term application projects, making it difficult to break through key technological bottlenecks. Furthermore, the migration of high-end marine research talents to core cities in the east, such as Shanghai and Hangzhou, further weakens local innovation capabilities.

In terms of authorized patents, the coefficient of the Number of Granted Patents (NPG) in the Southern Ocean Economic Zone is significant and positive, and every 1% increase in the number of authorized patents will lead to an increase in the Gross Maritime Product per capita (GMP) by 0.078%, which suggests that an increase in technological innovation capacity has a significant positive impact on the ocean economy of the region. The coefficients for the Nouthern and Eastern Ocean Economic Zone are not significant in this regard. The Northern Ocean Economic Zone relies more on ocean traditional industries such as ocean fishery, ocean transportation and ocean oil and gas development, and the demand for technological innovation in these industries is relatively low and the speed of technological updating is slow, resulting in the insignificant pulling effect of patents on economic growth. Although the Eastern ocean economic Zone is economically developed, its ocean economy may rely more on the service industry and high-end manufacturing industry, such as marine engineering equipment, marine biology and medicine, etc. The technological innovation in these fields relies more on external technology introduction or cooperation rather than local independent research and development, resulting in the direct impact of the number of local patents on the growth of the ocean economy is not significant. The market environment of the Northern Ocean Economic Zone and the Eastern Ocean Economic Zone is relatively closed or not competitive enough, and enterprises lack the motivation of technological innovation, resulting in the insignificant pulling effect of the number of patents on the growth of the ocean economy. The Southern Ocean Economic Zone has a strong advantage in technological innovation, especially in the field of ocean high-tech industry, the region has more scientific research institutions and high-tech enterprises, stronger technological innovation ability, and the transformation efficiency of patents is higher, so the number of patents has a significant role in promoting economic growth. At the same time, the market environment in the Southern Ocean Economic Zone is more open and active, and competition among enterprises is more intense, which prompts enterprises to pay more attention to technological innovation and patent protection and promotes the growth of the ocean economy.

In terms of regional production, the coefficient of the Gross Regional Product Index (GRI) of the Northern Ocean Economic Zone is significant and negative, and every 1% increase in the Gross Regional Product Index (GRI) will reduce the Gross Maritime Product per capita (GMP) by 4.054%, which suggests that the green finance in the Northern Ocean Economic Zone may be misallocated, and that the green financial resources have not been efficiently allocated to the ocean economy-related green industries or technological innovation areas, and funds flow more to traditional energy-intensive industries such as heavy industry and energy extraction rather than supporting the green transformation of the ocean economy. This misallocation has led to a shortage of funds in the ocean economy and inhibited its development potential, resulting in a negative effect as the growth of the Gross Regional Product Index (GRI) fails to drive the synchronized growth of the ocean economy. The Northern Ocean Economic Zone may suffer from an imperfect regulatory mechanism for green finance and a lack of tracking and evaluation of the use of green funds, leading to the diversion of funds or their failure to be used to support the development of green industries. This lack of regulation weakens the supportive role of green finance for the ocean economy, leading to the continued expansion of highly polluting and energy-intensive ocean industries and crowding out the resource space for the green transformation of the ocean economy. This regulatory failure further exacerbates the negative correlation between the Gross Regional Index (GRI) and ocean economy growth. The Northern Ocean Economic Zone may experience delays in policy implementation under the “dual-carbon” goal, with green financial support policies failing to materialize in a timely manner or insufficiently enforced, resulting in the ocean economy not receiving sufficient policy dividends. At the same time, green financial policies may lack coordination with other economic policies, such as ocean industry development policies and regional economic policies, resulting in offsetting policy effects. For example, the growth of the Gross Regional Index (GRI) may rely mainly on the expansion of traditional industries and fail to synergize with the green transformation of the ocean economy, resulting in a negative hindering effect on the ocean economy.

Meanwhile, in terms of stock market activity, the coefficient of Stock Market Activity (SMA) in the Northern Ocean Economic Zone is also significant and negative, with a 1 per cent increase in Stock Market Activity (SMA) reducing Gross Maritime Product per capita (GMP) by 0.098 per cent. Under the “double carbon” goal, uncertainties such as green financial policies, structural adjustment of the ocean economy and environmental protection requirements have increased, and investors are skeptical about the investment prospects in the ocean economy, leading to a decline in confidence. Investors are overly concerned about green financial policies and their actual impact on the ocean economy, resulting in capital not effectively flowing into the ocean economy when Stock Market Activity (SMA) increases, but rather flowing out due to risk aversion. In addition, an increase in Stock Market Activity (SMA) may be accompanied by an increase in capital market volatility, and this uncertainty may discourage companies from investing in the ocean economy sector over the long term, especially in green technology innovations and sustainable development projects.

The coefficients of Gross Regional Index (GRI) of the Eastern Ocean Economic Zone and the Southern Ocean Economic Zone are not significant. The Eastern Ocean Economic Zone has a diversified industrial structure, with the ocean economy accounting for only a small portion of the overall economy, and the growth of the Gross Regional Product Index (GRI) is likely to be driven more by non-ocean sectors, such as the manufacturing and service industries, resulting in its insignificant impact on ocean economy growth. The ocean economy in the Southern Ocean Economic Zone is more dependent on technological innovation and external markets than on local GDP growth. As a result, the Gross Regional Product Index (GRI) has a weak direct impact on ocean economy growth. The ocean economy in the Southern region is more concentrated in ocean high-tech industries such as ocean biomedicine and ocean new energy, and these areas are less sensitive to traditional GDP growth. In addition, the Eastern and Southern Ocean Economic Zone may rely more on external technology importation than on local independent research and development. This technological dependence may lead to a weaker direct impact of Gross Regional Product Index (GRI) growth on ocean economy growth.

The coefficients on Stock Market Activity (SMA) are not significant for the Eastern and Southern Ocean Economic Zone. The Eastern Ocean Economic Zone has a more developed economy, a high degree of marketization, and diversified corporate financing channels, and the marginal contribution of stock market activity to economic growth has been saturated. The ocean economy in the Eastern region relies more on technological innovation and industrial upgrading, and the demand for capital in these areas comes more from venture capital or policy finance than from the stock market. Although the Southern Ocean Economic Zone has a faster economic growth rate, the stock market development is relatively lagging behind, the maturity of the capital market is low, and the conduction effect of stock market activity on the real economy is weak. The ocean industries in the Southern Ocean Economic Zone are more concentrated in traditional areas such as ocean fisheries and ocean tourism, which are less dependent on stock market financing. In addition, governments in the Eastern and Southern Ocean Economic Zone are more inclined to promote the development of the ocean economy through direct policy support, such as green finance policies and industry support funds, rather than relying purely on the stock market. This policy orientation may have weakened the direct impact of stock market activity on ocean economy growth.

With regard to the marine industry, the coefficients of the Scale of Marine Industry (SMI) in the Nouthern, Eastern and Southern Ocean Economic Zones are all significant and positive, indicating that the comprehensive strength and competitiveness of the ocean economy will continue to improve as the Scale of Marine Industry (SMI) expands, thus promoting the realization of higher-quality development in the Ocean Economic Zone. Among them, every 1% increase in the Scale of Marine Industry (SMI) in the Northern Ocean Economic Zone will lead to a 0.814% increase in Gross Maritime Product per capita (GMP); the Eastern Ocean Economic Zone has a stronger enhancement effect of 1.119%; and the Southern Ocean Economic Zone is 0.884%.

In addition, the expansion of the Scale of tertiary industry (STI) and the size of the Size of secondary industry (SSI) also has a significant positive promotion effect on the Ocean Economy, and shows different strengths of effect in different regions. Specifically, the Nouthern, Eastern and Southern marineic economic zones all show significant positive promotion effects in the Scale of tertiary industry (STI). Among them, every 1% increase in the Scale of tertiary industry (STI) in the Northern Ocean Economic Zone will lead to a 4.516% increase in Gross Maritime Product per capita (GMP); every 1% increase in the Eastern Ocean Economic Zone will lead to a 3.949% increase; and every 1% increase in the Southern Ocean Economic Zone will lead to a 2.689% increase. Similarly, all three Ocean Economic Zones also show significant positive contribution in terms of Size of secondary industry (SSI) improvement. For every 1% increase in Size of secondary industry (SSI) in the Northern Ocean Economic Zone, the Gross Maritime Product per capita (GMP) will be boosted by 5.381%, showing the strong driving force of the secondary industry on the ocean economy in the region. Although the lifting effect of the Eastern Ocean Economic Zone is relatively low, every 1% increase in the Size of secondary industry (SSI) can also lead to a 0.984% increase in Gross Maritime Product per capita (GMP). The Southern Ocean Economic Zone is in between, with every 1% increase in the Size of secondary industry (SSI) driving a 2.676% increase in Gross Maritime Product per capita (GMP). In the future, the synergistic development of the tertiary and secondary sectors should continue to be strengthened to promote sustainable, healthy and green growth of the Ocean Economy.

In terms of Energy Consumption Structure (ECS), different Ocean Economic Zones show very different effects. The negative and significant coefficient of the Nouthern marineic Economic Zone implies that the unreasonable Energy Consumption Structure (ECS) has a significant negative hindering effect on the Ocean Economy. A 1% increase in the Energy Consumption Structure (ECS) of the Northern Ocean Economic Zone reduces the Gross Maritime Product per capita (GMP) by 0.398%. Energy consumption in the Northern Ocean Economic Zone is dominated by high-carbon energy sources, such as coal and oil, and the irrational Energy Consumption Structure (ECS) has led to the exacerbation of environmental pollution problems, such as air pollution and ocean pollution. These environmental problems directly damage the ocean ecosystem, which in turn affects the sustainable development of the ocean economy. The over-reliance on high-carbon energy may limit the green transformation of the ocean economy, leading to a negative impact on the Gross Maritime Product per capita (GMP) as a result of the increase in the Energy Consumption Structure (ECS). Under the “dual carbon” target, the Northern Ocean Economic Zone is facing great pressure to save energy and reduce emissions. Due to the irrational Energy Consumption Structure (ECS), the region faces greater challenges in realizing the dual-carbon target, thus further inhibiting the growth of the ocean economy. In contrast, the coefficient of the Eastern Ocean Economic Zone is positive and significant. A 1% increase in the Energy Consumption Structure (ECS) of the Eastern Ocean Economic Zone is associated with a 0.109% increase in Gross Maritime Product per capita (GMP). This indicates that the region has made positive progress in energy conservation and emission reduction, and the optimization of the Energy Consumption Structure (ECS) provides strong support for the sustainable development of the Ocean Economy. However, the coefficient on the Energy Consumption Structure (ECS) is not significant in the Southern Ocean Economic Zone, which has a relatively diverse ECS, making the impact of changes in ECS on economic growth complex and difficult to capture. For example, traditional energy sources such as coal and oil play a fundamental role in supporting economic growth, but their increased consumption may lead to problems of environmental pollution and carbon emissions, which is contrary to the “dual-carbon” goal, while clean energy sources such as natural gas and renewable energy can help to promote green economic growth, but the level of development and cost-effectiveness of such energy sources also affect their role in the Energy Consumption Structure (ECS). The level of development and cost-effectiveness of clean energy sources, such as natural gas and renewable energy, also affect their share of the Energy Consumption Structure (ECS).

The “dual-carbon” goal is an important guideline for promoting the green and high-quality development of China’s Ocean Economy. The rapid development of green finance in the Eastern Ocean Economic Zone has not only significantly reduced the carbon emission intensity of the marine industry, but also accelerated the widespread application of clean energy and environmental protection technologies, laying a solid foundation for the sustainable development of the Ocean Economy. Compared with the Eastern part of the region, the Southern Ocean Economic Zone is lagging behind in the development of green finance, but it has also shown a positive trend in recent years. In response to the “double carbon” goal, the regional government has introduced a series of policies and measures aimed at encouraging financial institutions to increase green financial support for the marine industry, and has effectively promoted the green transformation and upgrading of the marine industry, improved the green competitiveness of the Ocean Economy, and also provided more investment opportunities and market demand for green finance, forming a virtuous zone. At the same time, it also provides more investment opportunities and market demand for green finance, forming a virtuous zone. Driven by the "dual-carbon" goal, green finance and the ocean economy in the Southern Ocean Economic Zone have shown a good trend of synergistic development. However, in the Northern Ocean Economic Zone, the interaction between green finance and the ocean economy has not yet fully emerged. On the one hand, the development of green finance has not yet fully met the financing needs of the marine industry, especially in the context of the "dual-carbon" goal, the marine industry's demand for green finance is more urgent; on the other hand, the development of the ocean economy has not been able to provide more investment opportunities and market demand for green finance, resulting in the development of green finance in the region relatively lagging behind. On the other hand, the development of ocean economy fails to provide more investment opportunities and market demand for green finance, leading to the relatively lagging development of green finance in the region. In view of the problems in the development of green finance in the Northern Ocean Economic Zone, the government should introduce more policies and measures to support the development of green finance, especially in the context of the "dual-carbon" goal, and pay more attention to the important role of green finance in promoting the green and low-carbon development of the Ocean Economy. For example, special funds for green finance can be set up to provide financial support for the green transformation and upgrading of the marine industry; preferential policies such as tax breaks and loan subsidies can be provided to reduce the cost of financial institutions in supporting the green transformation of the marine industry; and at the same time, attempts should be made to set up a green financial risk compensation mechanism to compensate financial institutions for loan losses incurred due to the support of the green transformation of the marine industry, so as to further promote the development of green finance and the greening of the ocean economy in the Nouthern part of the country. At the same time, try to establish a green financial risk compensation mechanism to compensate financial institutions for loan losses arising from supporting the green transformation of the marine industry, so as to further promote the synergistic development of green finance and the ocean economy in the Northern Ocean Economic Zone, and jointly move towards the goal of "double carbon".

TABLE 8 Endogeneity test results.

Instrumental variables	
GFI	3.838***(0.395)
GFIt-1	0.590***(0.077)
Kleibergen-Paap rk LM statistic	Chi-sq(1)=8.331 P-val=0.0039
Kleibergen-Paap Wald rk F statistic	57.973
Hansen J statistic	0.000

***indicates 1% significant.

5.3 Endogeneity test

In order to solve the endogeneity problem of the model, this paper uses the instrumental variable method to test the core explanatory variable lagged 1 period (GFIt-1) as an instrumental variable through the existing research (Yu and Fan, 2022), and the regression results are shown in Table 8.

The results of the first-stage regression indicate that the instrumental variable is significantly and positively related to the Green Finance Index (GFI), and the coefficient of the green finance index with 1-period lag (GFIt-1) is 0.590, and it is significant at the 99% confidence level. The two-stage regression results show that the Green Finance Index (GFI) is significantly and positively correlated with the Gross Maritime Product per capita (GMP), and the coefficient of the Green Finance Index (GFI) is 3.838 and is significant at 99% confidence level, which is basically the same as the previous results. In addition, this paper also carried out the unidentifiable test and weak instrumental variable test for instrumental variables. Among them, Kleibergen-Paap rk LM statistic significantly rejects the hypothesis of "insufficient identification of instrumental variables" at 99% confidence level, and the value of Kleibergen-Paap Wald rk F statistic is 57.973, which is larger than the critical value at 10% bias. The Kleibergen-Paap Wald rk F statistic obtained a value of 57.973, which is greater than the critical value of 16.38 at 10% bias, significantly rejecting the original hypothesis of "weak instrumental variables". This shows that green finance has a lagged positive effect on ocean economy and excludes potential endogenous effects.

5.4 Analysis of regression results for threshold effects

5.4.1 Threshold effect test

It has been shown that the Threshold Model has significant advantages in analyzing the nonlinear relationship between financial policy and economic growth (Li, 2023). In this paper, we choose the Green Finance Index (GFI) as the core explanatory variable, which can comprehensively reflect the development level of green finance in each region; we choose the Marine research funding revenue (FMR) and the Scale of Marine Industry (SMI) as the threshold variables. It has been shown that ocean scientific research investment and the Scale of Marine Industry (SMI) are key influencing factors of green finance, and there is a threshold effect on the growth of the ocean economy (Gong et al., 2019; Qiao et al., 2021).

Ocean-based Marine research funding revenue (FMR) is a key indicator of research investment in the ocean sector. Higher FMR means more resources for ocean technology innovation. Under the "dual-carbon" goal, green finance tends to support ocean projects with innovative capacity and environmental potential. The level of investment in scientific research directly affects the technological innovation ability and green transformation speed of ocean industry, which in turn affects the effect of green finance and the growth potential of ocean economy. The relationship between Green Finance Index (GFI) and Gross Maritime Product per capita (GMP) may change depending on the level of scientific

TABLE 9 Threshold effect test results.

Variables	FMR		SMI	
	F	P	F	P
Single	13.39**	0.0167	33.83***	0.0000
Double	4.59	0.6833	14.85	0.1267
Result	Existence of a single threshold		Existence of a single threshold	
Threshold	11.2497		-1.9661	
95% Conf. Interval	11.1389	11.2674	-2.2830	-1.9661

***indicates 1% significant, ** indicates 5% significant.

research investment; the Scale of Marine Industry (SMI) reflects the overall strength and development potential of the ocean economy. With the expansion of Scale of Marine Industry (SMI), its economy of scale effect and green synergistic effect gradually appear, which in turn attracts more green financial investment. Different Scale of Marine Industry (SMI) will lead to different ways and effects of green finance in it. When the Scale of Marine Industry (SMI) is small, it may not be able to fully utilize green financial funds to carry out large-scale production expansion or technological upgrading, while when the Scale of Marine Industry (SMI) reaches a certain degree, it will produce economies of scale, thus making the Gross Maritime Product per capita (GMP) grow rapidly. The choice of ocean-based research Marine research funding revenue (FMR) and Scale of Marine Industry (SMI) as threshold variables can more accurately capture the stage characteristics and threshold effects of the impact of green finance on China's ocean economy growth. This paper analyzes the nonlinear relationship between Green Finance Index (GFI) and Gross Maritime Product per capita (GMP) by taking two variables as threshold variables, i.e., Marine research funding revenue (FMR) and Scale of Marine Industry (SMI), respectively, and uses the "300-time Bootstrap Sampling Method," 300 sub-samples were randomly drawn with replacement from the original sample, and the threshold value was re-estimated for each sub-sample. Through multiple sampling and estimation, the distribution of threshold values was obtained, allowing for an assessment of its stability and confidence interval. Further tests were conducted to examine the significance of the existence of a single, double, or triple threshold for each threshold variable. The test results indicate (see Table 9) that when ocean-based Marine research funding revenue (FMR) is used as the threshold variable, there is a single threshold with a value of 11.2497, and a 95% confidence interval ranging from 11.1389 to 11.2674. When the Scale of Marine Industry (SMI) is used as the threshold variable, there is also a single threshold with a value of -1.9661, and a 95% confidence interval ranging from -2.2830 to -1.9661.

5.4.2 Analysis of regression results for threshold effects

Threshold regression results show that the Green Finance Index (GFI) has a positive effect on Gross Maritime Product per capita (GMP) (Table 10).

When the index of Marine research funding revenue (FMR) of the ocean category is less than or equal to 11.2497, every 1% increase in the Green Finance Index (GFI) will lead to an increase of 2.579% in the Gross Maritime Product per capita (GMP). This indicates that the development of green finance promotes ocean economy growth more significantly at the stage of relatively low research funding. In the case of limited scientific research funding, the financial support of green finance can more effectively promote the green transformation and technological innovation of the ocean industry, and provide strong support for the realization of the "dual-carbon" goal; when the index of ocean scientific Marine research funding revenue (FMR) is greater than 11.2497, each 1% increase in the Green Finance Index (GFI) will lead to an increase of 2.225% in the Gross Maritime Product per capita (GMP). Although green finance still has a facilitating effect on ocean economic growth, the ocean economy may face structural bottlenecks, such as low efficiency of technological transformation, imperfect industrial chain, insufficient market demand, etc. With the increase of the income of Marine research funding revenue (FMR) in the ocean category, the absorptive capacity of the main body of the ocean economy for the technology and funds supported by green finance may be saturated, resulting in the weakening of the marginal effect of green finance. With the increase of scientific research funding, ocean research institutions may face more research directions and project choices, leading to a decrease in the proportion of green finance's financial support in the overall scientific research funding, thus weakening its promotion effect. The existence of the ocean-based Marine research funding revenue (FMR) threshold, in terms of policy implications, for regions with lower ocean-based Marine research funding revenue (FMR), priority should be given to increasing green financial inputs and green financial support to promote technological innovation and industrial upgrading, to make up for the lack of scientific research funding, and to promote the green transformation and high-quality development of the ocean economy; for regions with higher ocean-based Marine research funding revenue (FMR) areas, while maintaining green financial support, it should focus on optimizing the structure of ocean industries, enhancing the efficiency of technology transformation and avoiding the waste of resources. In addition, the government should also increase investment in ocean economy infrastructure and promote the

TABLE 10 Threshold effect regression results.

	FMR single threshold	SMI single threshold
FMR ≤ 11.2497	2.579*** (0.331)	
FMR > 11.2497	2.225*** (0.284)	
SMI≤-1.9661		3.188*** (0.526)
SMI>-1.9661		1.858*** (0.329)

***indicates 1% significant.

synergistic development of the industrial chain, in order to enhance the utilization efficiency of green financial funds and break through structural bottlenecks.

When the Scale of Marine Industry (SMI) index is less than or equal to -1.9661, every 1% increase in the Green Finance Index (GFI) will lead to a 3.188% increase in the Gross Maritime Product per capita (GMP). This indicates that the marginal effect of green finance is higher when the Scale of Marine Industry (SMI) is small. Small-scale ocean industries usually face capital shortages and technological bottlenecks, and the injection of green finance can significantly improve their financing environment and technological level, thus generating a stronger pulling effect on economic growth; when the Scale of Marine Industry (SMI) index is greater than -1.9661, every 1% increase in the Green Finance Index (GFI) will lead to an increase in the per capita gross domestic product (GDP) of ocean by 1.858%. Similarly, green finance still contributes to ocean economy growth, but this effect is relatively weaker. When the Scale of Marine Industry (SMI) is large, the efficiency of resource utilization has been relatively high, the further input of green finance has limited space to enhance the efficiency of resource utilization, the marginal effect of green finance is relatively weakened, and the growth of ocean economy relies more on the optimization of the existing industrial structure and efficiency enhancement instead of relying on the capital input alone. The existence of the Scale of Marine Industry (SMI) threshold indicates that for regions with smaller Scale of Marine Industry (SMI), priority should be given to promoting the rapid development of the ocean economy through green finance; for regions with larger Scale of Marine Industry (SMI), attention should be paid to the synergistic effect of green finance and industrial upgrading, and while maintaining green financial support, it should be focused on improving the efficiency of capital utilization and promoting the structure of the ocean industry optimization and green transformation to achieve high-quality development of the ocean economy. The results of the study show that green finance has a more significant role in promoting small-scale ocean industries. Policymakers should prioritize the investment of green financial resources in smaller-scale ocean industries to maximize their economic pulling effect; design differentiated green financial support policies for ocean industries of different scales, and provide more favorable financing conditions and more flexible policy support for small-scale ocean industries. Green financial policies should be coordinated with other economic policies (e.g. industrial policies, regional development policies) to avoid policy conflicts and enhance policy effects. The marketization level of green finance should be enhanced through the improvement of the carbon trading market and the green finance regulatory mechanism, so as to strengthen its role in promoting the growth of the ocean economy.

The above results show that the impact of Green Finance Index (GFI) on Gross Maritime Product per capita (GMP) is affected by the thresholds of the Marine research funding revenue (FMR) and the Scale of Marine Industry (SMI). Within different threshold intervals, there are significant differences in the contribution of green finance to ocean economic growth (Figures 7, 8). Therefore,

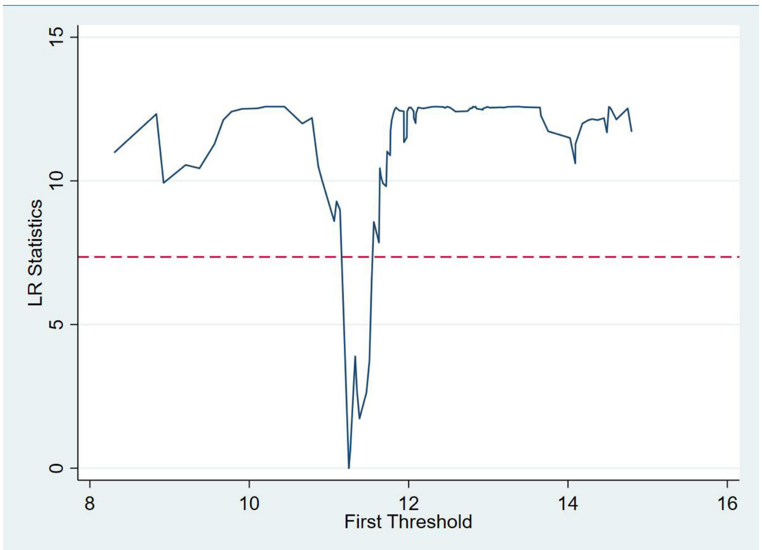

FIGURE 7
Income from the funding of marine scientific research institutions as a threshold.

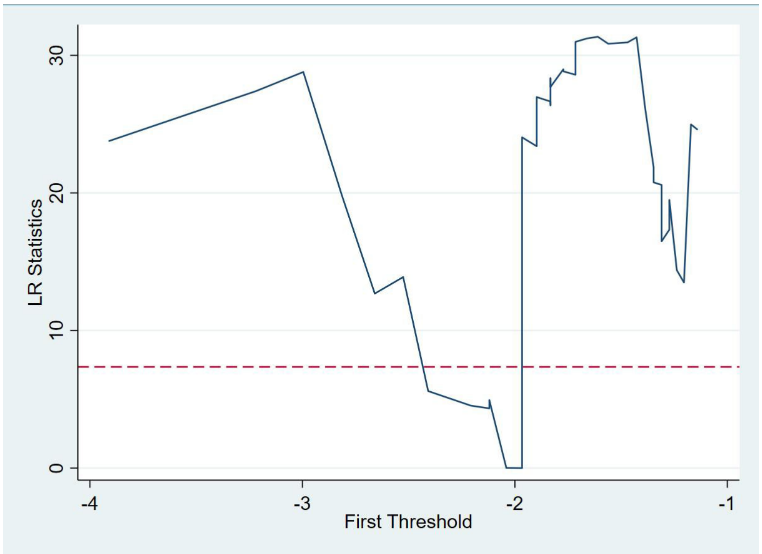

FIGURE 8
Marine industry size as a threshold.

when formulating green financial policies, full consideration should be given to the Marine research funding revenue (FMR) of marine scientific research institutions and the Scale of Marine Industry (SMI) in different regions, in order to maximize the contribution of green finance to the growth of the Ocean Economy, and to promote the realization of the goal of "double carbon".

6 Conclusions and policy recommendations

6.1 Conclusions of the study

This paper aims to investigate the relationship between green finance and China's ocean economic growth under the "dual-carbon" goal, and draws the following conclusions based on 15 years of data from 11 provinces and cities along the coast of China from 2008 to 2022:

(1) Green finance has positively contributed to the growth of China's Ocean Economy. As a whole, every 1% increase in the green finance index will lead to a 2.394% increase in per capita gross marine product. The results show that green finance has a significant positive effect in both the Eastern and Southern Ocean Economic Zones, but has an insignificant positive effect in the Northern Ocean Economic Zone. Specifically, every 1% increase in the green finance index of the Eastern Ocean Economic Zone will lead to a 1.809% increase in GDP per capita, while every 1% increase in the green finance index of the Southern Ocean Economic Zone will lead to a 2.121% increase in GDP per capita. Compared with the Eastern Ocean Economic Zone, the Southern Ocean Economic Zone's green finance has a stronger role in promoting ocean economic growth. For the Eastern Ocean Economic Zone with stronger financial development, the marine industry in the Southern Ocean Economic Zone is more lacking in financing channels, and green finance provides important financial support for the development of the local marine industry, while the Eastern Ocean Economic Zone already has a relatively perfect financial system and financing channels, which makes the promotion role of green finance to a certain extent limited. This conclusion is essentially the result of the superposition of multiple factors, such as the lagging development of green financial infrastructure, the lack of implementation of green financial policies, the mismatch between the rigidity of the industrial structure and the demand for green finance, and the variability of green financial market conditions. The financial system of the Northern Ocean Economic Zone is relatively closed, with a single green financial product, mainly traditional green credit, and a lack of specialized green financial institutions and talents. The Eastern and Southern Ocean Economic Zone have mature financial markets and internationalized financial centers, with abundant green financial products and strong risk assessment and pricing capabilities of financial institutions for green projects. The Northern Ocean Economic Zone is relatively lagging behind in the synergistic planning of "dual-carbon" target and industrial transformation, and the green financial policies and industrial transformation policies have failed to form a synergy, resulting in the flow of funds to the "pseudo-green" projects of traditional industries instead of truly supporting the low-carbon transformation of the ocean economy. Local governments in the Eastern Ocean Economic Zone and the Southern Ocean Economic Zone are more active in the implementation of green financial policies, and have perfect supporting measures. Zhejiang and Guangdong, through the

construction of the "Green Financial Reform Pilot Zone", have closely integrated the policy objectives with the development of their localities, and have promoted the rapid implementation of green financial tools. The Northern Ocean Economic Zone is dominated by heavy chemical industries and resource-based industries, with strong rigidity in industrial structure, high cost and long cycle of green transformation. Green financial funds may be used more for the environmental transformation of traditional ocean industries than for emerging areas of the ocean economy such as ocean renewable energy and ocean eco-tourism, resulting in a limited pulling effect on the growth of the ocean economy. The Eastern Ocean Economic Zone and the Southern Ocean Economic Zone have formed modern ocean industry clusters, with a lighter and more diversified industrial structure, and a high proportion of service and high-technology industries, which are more compatible with green finance. In addition, the Eastern and Southern Ocean Economic Zone have more mature financial markets, with a large number of financial institutions, a sound financial service system, and a wider range of innovation and application of green financial products and tools, while the development of the financial market in the Northern Ocean Economic Zone is relatively lagging behind, with a single financial institution and product, and insufficient penetration and influence of green finance.

In addition, one of the core objectives of green finance is to promote environmentally sustainable development through financial guidance, which can be used to reduce ocean pollution and improve the health of marine ecosystems by supporting clean energy, pollution management and ecological protection projects, and green credits and green bonds can provide financial support for the restoration of marine ecosystems, the construction of wastewater treatment facilities, as well as sustainable fisheries projects, thereby directly or indirectly reducing pollution of the ocean environment. Attention should also be paid to the fact that green finance aims to promote sustainable development, but in practice, due to reasons such as insufficient implementation of green finance policies, some funds may still flow to high-environmental-risk projects, leading to a disconnect between economic growth and environmental protection. Therefore, future policy design should pay more attention to the 'green' attributes of green finance, ensure that funds flow to truly sustainable projects, and avoid 'greenwashing' through strict regulation and assessment mechanisms.

(2) In the Northern Ocean Economic Zone, the scale of the marine industry, the scale of the tertiary industry, and the scale of the secondary industry have a positive effect on the growth of the Ocean Economy, of which the scale of the secondary industry has the most obvious positive effect, and for every 1% increase in the scale of the secondary industry, the per capita gross domestic product (GDP) of the marine rises by 5.381%. In the Eastern Ocean Economic Zone, green finance index, marine scientific research expenditure income, marine industry scale, energy consumption structure, tertiary industry scale, secondary industry scale have significant positive promotion effect on ocean economic growth, among which the positive promotion effect of tertiary industry scale is the most obvious, and for every 1% increase in the scale of tertiary industry, the GDP per capita is increased by 3.949%. In the Southern Ocean Economic Zone, the green financial index, the number of authorized patents, the scale of the marine industry, the scale of the tertiary industry, and the scale of the secondary industry have a significant positive contribution to the ocean economic growth, in which the positive contribution of the scale of the tertiary industry is the most obvious, and the gross domestic product of the marines is increased by 2.689% for every 1% enhancement of the scale of the tertiary industry. The scale of the marine industry, the scale of the tertiary industry and the scale of the secondary industry in the Nouthern, Eastern and Southern Ocean Economic Zone as well as the whole country play a significant positive role in promoting the growth of the ocean economy, and the diversified development of the industry not only promotes the sustained growth of the Ocean Economy, but also mitigates the problem of environmental pollution in the process of economic development. Nationally, stock market activity has a positive effect on ocean economic growth, while in the Northern Ocean Economic Zone, stock market activity has a negative effect on ocean economic growth, indicating that the over-activity of the stock market has attracted a large amount of capital and resources, but has not been able to effectively channel them to the marine industry, thus affecting the healthy growth and sustainable development of the ocean economy in the Northern Ocean Economic Zone.

(3) In the Nouthern marineic economic zone, the GDP index, stock market activity and energy consumption structure have typical negative impediments to the growth of the marineic economy, among which the GDP index has the greatest negative impediment to per capita GDP, with per capita GDP decreasing by 4.054% for every 1% increase in the GDP index, which reveals the potential risk of diminishing marginal benefits, and suggests that there is a need to This indicates the need to focus on the optimization of economic structure, quality improvement and green transformation in order to meet the requirements of sustainable development under the "dual-carbon" goal. In the Eastern Ocean Economic Zone, the number of authorized patents, GDP index, stock market activity on the growth of the ocean economy is a negative impediment to the role of the negative but not significant, the reason is that the patent authorization although the scale of the lack of an effective transformation platform and mechanism; the second is in the transition of the industrial structure, the alternation of new and old industries so that the negative effect of the GDP index does not stand out; the third is that investors in the Southern Ocean Economic Zone of the marine industry, high-risk, Thirdly, investors are concerned about the high risk and long return cycle of the marine industry in the Southern

Ocean Economic Zone and have expectations for its development potential, which makes it difficult to significantly present the hindering effect of stock market activity. In the Southern Ocean Economic Zone, the income of marine scientific research institutions, GDP index and stock market activity also have a negative but not significant hindering effect on the growth of the Ocean Economy, because scientific research funding tends to the theoretical research projects, which is difficult to promote the upgrading of the marine industry in the short term, however, the potential value of the theoretical research in the long term has weakened the negative hindering effect. In terms of GDP index and stock market activity, the problem is similar to that of the Nouthern marineic Economic Zone. In China as a whole, the number of granted patents has a negative impediment to ocean economic growth, suggesting that a large amount of resources may be used for inefficient patent development or conversion, resulting in resources not being used in more efficient and promising areas, whereas in the Southern Ocean Economic Zone, the increase in the number of granted patents has a significant positive impact on the growth of the Ocean Economy. The increase in the number of patents not only reflects the degree of activity in technological innovation, but is also an important impetus for industrial upgrading and the promotion of low-carbon technologies.

(4) From the perspective of China's ocean economy as a whole, the intensity of the promotion effect of green finance on the growth of the ocean economy does not remain unchanged when the income of marine scientific research institutions and the size of the marine industry are taken as the thresholds, and the promotion effect of green finance on the growth of the ocean economy will be slightly weakened when the index of income of marine scientific research institutions reaches 11.249; and the promotion effect of green finance on the growth of the ocean economy will be obviously weakened when the index of the size of the marine industry reaches -1.9661. After the index of marine industry scale reaches -1.9661, the promotion effect of green finance on ocean economic growth will be significantly weakened. Therefore, the Nouthern, Eastern and Southern marineic economic zones need to formulate relevant development countermeasures tailored to the regional development situation.

6.2 Policy recommendations

Based on the findings of this paper, the following policy recommendations exist:

6.2.1 Developing green finance to drive the green transformation of the ocean economy

In the implementation of green finance policies, complex approval processes and inefficient decision-making by government departments may lead to delays in the allocation of funds and affect the implementation of green finance projects. Green finance funds may be misappropriated or inefficiently utilized due to mismanagement, resulting in the funds not being truly used to support the green transformation of the ocean economy. Private sector participation in green finance projects is low, possibly due to insufficient policy incentives, higher risks or longer return cycles. In order to give full play to the positive role of green finance in realizing "dual carbon" in the ocean and promoting ocean economy growth, in the Northern Ocean Economic Zone, the government should increase its support for marine scientific research institutes, but it should pay attention to the appropriateness of funding, optimize the structure of the use of funds, and strengthen the supervision of the use of funds by marine scientific research institutes to ensure that the funds are used for key scientific research projects and the transformation of results. Introduce a third-party auditing organization to conduct regular financial audits of scientific research projects to prevent misuse of funds. Encourage cooperation between scientific research institutions and enterprises, simplify the approval process of scientific research projects, reduce unnecessary administrative interventions and improve decision-making efficiency. At the same time, establish a performance evaluation mechanism for scientific research projects to ensure the effective utilization of scientific research funds. In the Eastern Ocean Economic Zone, its geographical location and resource advantages should be fully utilized to promote the clustering and upgrading of ocean industries. Encourage the private sector to participate in the investment and operation of ocean industry projects, and promote the clustering and upgrading of ocean industries through the public-private partnership (PPP) model. While expanding the scale of the ocean industry, focus on improving the quality and efficiency of the ocean industry, clarify the planning objectives of ocean industry agglomeration and upgrading, and avoid excessive intervention in market operation and waste of resources caused by blind expansion. In the Southern Ocean Economic Zone, ocean industries with local characteristics should be developed based on its rich biological resources and unique geographical location. On the premise of protecting the ecological environment, it should rationally develop marine resources and promote the sustainable development of the ocean economy. At the same time, cooperation and exchanges between the private sector and scientific research institutions should be promoted through policy guidance and market mechanisms, and the private sector should be encouraged to invest in marine scientific research projects, promote the commercial application of scientific research results, and enhance the scientific and technological content and innovation capacity of the ocean industry.

6.2.2 Promoting the deep integration of industry, academia and research and upgrading the level of ocean science and technology

The key to enhancing the innovation capacity of ocean science and technology lies in strengthening cooperation between ocean scientific research institutions and enterprises, promoting the in-depth integration of industry, academia and research, reinforcing intellectual property protection mechanisms, and fully stimulating the innovation vitality and enthusiasm of enterprises and scientific research institutions. In the Northern Ocean Economic Zone, the government should increase the funding for ocean research institutions in the key technology field of “double carbon”, encourage cooperation between research institutions and enterprises, establish innovation alliance for the deep integration of industry, academia and research, and accelerate the transformation and application of scientific and technological achievements. At the same time, strengthen the intellectual property protection mechanism, provide solid legal protection for ocean science and technology innovation, and ensure that green financial funds can be accurately invested and effectively promote the growth of the ocean economy. In the Eastern ocean economy, it is necessary to further deepen the cooperation among industries, universities and research institutes, establish an ocean science and technology innovation platform, and promote the research, development and application of technologies in the fields of ocean carbon sink technology and green low-carbon transformation of ocean energy. The government should guide financial institutions to provide long-term and stable financial support for ocean science and technology innovation projects, build a modern ocean industry system, and ensure that green finance can continue to play a positive role in promoting ocean economy growth. In the Southern Ocean Economic Zone, it should make full use of its regional resource advantages to focus on “dual-carbon” technology areas such as ocean ecological protection and restoration, renewable energy, and carbon capture and sequestration, and to promote ocean science and technology innovations and results transformation. The Government should introduce preferential policies to attract domestic and foreign high-end ocean science and technology talents and enterprises to settle in the area, form competitive ocean industry clusters, and improve the overall scientific and technological level of the Southern ocean economic Zone, so as to provide a strong impetus for the green development of the ocean economy and the realization of the “dual-carbon” goal.

6.2.3 Optimizing the stock market environment for the coordinated development of the ocean economy

In the context of the “dual-carbon” goal, the impact of stock market activity on China’s ocean economy growth shows significant regional differences in different ocean economic zones. In the Northern Ocean Economic Zone, stock market activity has a negative impact on ocean economic growth. In the Northern Ocean Economic Zone, the first task is to establish a sound stock market risk prevention and control system. The government should take the lead in setting up an investor education platform, organizing regular investment knowledge lectures and green investment seminars, and guiding investors to form rational investment concepts through case studies and expert interpretations. At the same time, it should formulate and publish a green investment guide to clarify the standards and scope of green investment and encourage investors to invest their funds in ocean green and low-carbon projects. In the Eastern Ocean Economic Zone, deepening financial reform is the core. The government should actively promote financial innovation, create a financial innovation demonstration zone, and encourage financial institutions to explore new financial products and service models. At the same time, it should strengthen the regional financial synergy mechanism, enhance information sharing and cooperation among financial institutions, and improve the efficiency and coverage of financial services. In terms of credit support and risk investment, the government should increase support for ocean high-tech enterprises, reduce the cost of enterprise financing, and promote the development of the ocean economy towards high-end and intelligentization. In the Southern Ocean Economic Zone, accelerating the construction of financial infrastructure is key. The government should increase investment in payment and settlement systems to improve system efficiency and reduce transaction costs. At the same time, it should establish an internationalized financial service platform to provide more convenient financial services for the ocean industry. In terms of credit tilting, the government should increase support for green ocean industries, stimulate financial market vitality through preferential loan policies and loan interest subsidies, and help new ocean industries flourish.

6.2.4 Adjusting the energy structure to reduce ocean pollution emissions

Energy consumption is a source of pollution from carbon emissions. In the Northern Ocean Economic Zone, energy transition policies have been formulated and implemented to optimize the energy consumption structure and accelerate the development and use of clean energy. A clean energy development fund has been set up to provide financial support and policy guarantees, a sound energy management system has been established, energy audits and energy efficiency assessments have been promoted, and enterprises have been encouraged to save energy and reduce consumption. At the same time, it has formulated energy industrial policies, promoted the optimization and upgrading of the energy industrial structure, and given preferential policies such as tax reductions, exemptions and capital subsidies to enterprises adopting advanced environmental protection technologies and equipment. In addition, environmental education and publicity should be strengthened to raise public awareness and support for environmental protection and energy transformation, and to jointly promote green development. In the Eastern ocean economy, the government should introduce policies to encourage clean petrochemical energy such as natural gas to replace highly polluting energy such as coal, and provide tax breaks and capital subsidies to incentivize enterprises to adopt energy-efficient equipment. Increase research and development on coal deep-processing and conversion technologies, promote advanced energy-saving technologies, and improve the efficiency of energy utilization. In addition, establish a strict system of environmental regulations, strengthen environmental supervision, and promote the implementation of environmentally friendly technological reforms by coal-consuming enterprises to reduce carbon emissions. In the Southern Ocean Economic Zone, its geographical location and resource advantages should be fully utilized to develop renewable energy, such as solar energy and wind energy. The Government should provide policy support and financial guidance to encourage enterprises to invest in renewable energy projects, and at the same time strengthen technological research and development and innovation to improve the efficiency and stability of renewable energy utilization.

6.2.5 Promoting the structural adjustment of the ocean industry and changing the mode of development of the ocean economy

Promoting the structural adjustment of the marine industry is the key to promoting the high-quality development of China's ocean economy and realizing the goal of "double carbon", and guiding the transformation and upgrading of the marine industry in the direction of high-end, intelligent and greening. In the Northern Ocean Economic Zone, the powerful driving force of tertiary and secondary industries on the growth of the ocean economy should be fully utilized, and the technological transformation and upgrading of traditional industries should be strengthened to enhance their added value and competitiveness. At the same time, it should actively cultivate and develop emerging industries, especially green and low-carbon industries, such as marine high-end equipment manufacturing industry, marine hydrogen energy industry, marine carbon sink fishery, etc., so as to inject new growth momentum into the ocean economy and help realize the goal of "double carbon". The Eastern Ocean Economic Zone should focus on the agglomeration and development of marine industries, promote the formation of internationally competitive marine low-carbon industry clusters through the construction of a perfect industrial chain and upstream and downstream synergistic mechanisms, and pay special attention to technological innovation and industrial upgrading while enhancing the scale and efficiency of marine industries, promoting green and low-carbon technologies, and facilitating the coordinated development of the ocean economy and environmental protection. The Southern Ocean Economic Zone should closely integrate with regional characteristic resources to develop marine industries with unique competitiveness. The Southern marine is rich in biological resources, and many marine organisms have unique medicinal value. While protecting marine organisms, new types of drugs and biological products can be extracted and developed from marine organisms through biotechnological means, such as genetic engineering and cellular engineering, to meet the health needs of mankind while reducing carbon emission pollution through the carbon sink function of marine organisms.

7 Limitations of the study

This study constructs a comprehensive evaluation system of green finance index, calculates the green finance index of China's coastal provinces and municipalities, adopts a fixed-effect model to study the role of green finance in realizing the "dual-carbon" goal and promoting the growth of China's ocean economy, and combines with the Threshold Model to further study the nonlinear role of green finance in China's ocean economy, which provides a reference for policy makers. Despite the contributions of this study, there are limitations. First, the construction of the green finance index relies on the selection and weighting of multiple sub-indicators, which may be somewhat subjective. Second, the study focuses on China's coastal provinces and cities, with a limited sample size, and does not adequately consider the impact of external environmental factors (e.g., global economic fluctuations, climate change) on the ocean economy, which limits the generalizability of the findings. Third, although this study provides empirical support for the impact of green finance on ocean economy growth, the environmental benefits of green finance and its role in sustainable development require further in-depth research. Future research could incorporate environmental indicators and construct a more comprehensive assessment framework to reveal the multiple roles of green finance in achieving the 'dual-carbon' goal and further enhance the validity and applicability of the conclusions.

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

YL: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing. YH: Data curation, Formal Analysis, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This work was supported by the Key Research Base of Humanities and Social Sciences of Universities in Guangxi Zhuang Autonomous Region "Beibu Gulf Ocean Development Research Center"; 2024 Guangxi Philosophy and Social Science Research Annual Project (24GJB003); 2024 Innovation Project of GuangXi Graduate Education (YCSW2024547).

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.

Generative AI statement

The author(s) declare that no Generative AI was used in the creation of this manuscript.

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