Construction and Comprehensive Evaluation of the High-quality Development Indicator System for Marine Economy in Guangdong Province

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Abstract: This article initially dissects the contemporary status of the development of Guangdong's marine economy, and based on the new development concept, develops a framework of evaluation indicators aimed at assessing the high-quality advancement of the marine economy. Then, it utilizes the entropy method to compute the high-quality development index and employs a linear regression model to analyze the key determinants influencing high-quality development. The research outcomes manifest that the trajectory of high-quality development of Guangdong's marine economy is steadily progressing, accompanied by marginal fluctuations in the interim period. The key factors affecting high-quality development include: R&D investment intensity, marine industrial structure upgrading index, marine industrial structure advancement level, industrial wastewater discharge, coastal port cargo throughput, actual utilization of foreign capital, urbanization level, and urban-rural consumption gap. Finally, targeted suggestions are proposed based on the above research results.

Keywords: Marine Economy; High-Quality Development; Entropy Method; Multiple Linear Regression

1. Preface

As the resources needed for the development of the land economy become increasingly scarce, the ocean economy has become a new field of economic development for countries around the world. Guangdong Province, as a major marine economy province in China, had an oceanic GDP of 187,781 million yuan in 2023, accounting for 18.9% of the national oceanic GDP, making an important contribution to the economic development of Guangdong Province and the whole country.

However, concurrently, certain predicaments remain in the progression of Guangdong's marine economy, such as an unreasonable structure of marine industries, uneven regional development, insufficient drive from innovation, and an increasingly prominent contradiction between marine environmental protection and development.These problems are caused by the pursuit of speed in early development and excessive dependence on fixed investment and factor drive. Therefore, we need to change our approach to ocean economic development to address these issues.

Currently, Guangdong Province has issued a proposal for comprehensively building a strong maritime province and formulated the "Three-Year Action Plan for Building a Strong Maritime Province (2023-2025)", laying a solid policy foundation for further promoting the high-quality development of the marine economy.

Therefore, it is very important to comprehensively grasp the current situation and development trends of high-quality marine economic development in Guangdong Province, identify the key factors that influence its high-quality development, and explore the driving mechanisms and improvement paths for achieving high-quality marine economic development in Guangdong Province.

2. Literature Review

Since the term "high-quality development" was first proposed domestically, there is no direct research literature related to "high-quality development" abroad. However, some research content involves the development efficiency of marine economy, green marine economy, and other related aspects. For example, some scholars have used the Malmquist efficiency

index model and its expanded model to study the changes in marine economic efficiency during the economic transformation stage[1]; The research of Peter Ehlers et al. shows that humans must balance the use and protection of the ocean to achieve long-term development[2]; Giulio Pontecorvo explored the interrelationship between the national and marine economies, and proposed suggestions to enhance their development quality[3].

Domestic research in this area primarily focuses on the following five aspects:

The first aspect is about the research on sustainable development. For example, Li Jingyao and Cao Fei developed a system of evaluation indicators grounded in the principles of sustainable development, evaluated the sustainable development capacity of Shanghai and Hainan Province respectively, and proposed corresponding development strategies[4,5];

The second aspect focuses on the measurement of marine ecological efficiency. Some scholars employed DEA and SBM models to investigate the influence of industrial structure and technological innovation on marine ecological efficiency[6];

The third aspect focuses on the study of the connotation and features of high-quality development. For example, scholars such as Liu Shuai have constructed an evaluation indicator system for high-quality development from five aspects: "innovation, coordination, green, openness, and development", and have analyzed the current situation of high-quality development with the provincial marine economies as the research object[7];

The fourth aspect is related to the assessment and appraisal of the current state of high-quality development. Relevant scholars have employed different evaluation models for analysis, such as the entropy method, analytic hierarchy process, grey relational analysis, and principal component analysis, to measure the level of high-quality development of the marine economy in various regions[8];

The fifth aspect focuses on studying the factors influencing high-quality development. For instance, Cui Xiwen's study in Liaoning Province utilized PCA method and discovered that: the top five factors with the highest impact were education, employment, foreign trade, marine-land coordination, and technology[9]; Chang Yu Miao used panel data models to find that: the main factors affecting the development of China's marine economy include the structure, scale, technology, ports, and policies of the marine industry[10].

To summarize, current studies on this subject primarily concentrate on comparative development between eastern coastal provinces, with less emphasis on specific provinces and comparative analyses of the development of coastal cities within a province. This paper focuses on the development of the marine economy in Guangdong Province, comprehensively evaluates its current situation of high-quality development by establishing an evaluation indicator system, and points out the main factors affecting high-quality development, providing a reference basis for the formulation of marine economic development strategies.

3. Construction of a High-quality Development Indicator System for the Marine Economy

In order to conduct an objective assessment of the present state of high-quality development in the marine economy of Guangdong Province, it is necessary to first construct an objective and scientific evaluation indicator system. The indicator system should not only consider the actual situation of Guangdong's marine economy development, but also take into account the principles of availability and comparability of relevant indicator data. Therefore, based on the existing research findings[11,12], this paper develops a system of evaluation indicators based on five dimensions: innovation, coordination, green, opening-up, and sharing, as shown in Table 1.

Technological innovation serves as the primary catalyst for advancing the high-quality development of the marine economy. Three indicators are selected from both input and output perspectives: R&D investment intensity, technology trading activity, and the number of authorized invention patents. R&D investment intensity reflects the government's emphasis on technological innovation; Technology trading activity reflects the activity of technical innovation and the intensity of market competition, which helps to formulate more reasonable strategies for technical innovation and market competition; The quantity of granted invention patents serves as a key indicator of the results achieved through technological innovation.

Table 1. Evaluation Indicator System for

High-quality Development of Mmarine Economy in Guangdong Province

Primary indicator	Secondary indicator
Innovation	R&D investment intensity (X1)
	Technology trading activity (X2)
	Number of authorized invention patents (X3)
Coordination	Degree of marine-land economic correlation (X4)
	Advancement coefficient of the marine industrial structure (X5)
	Upgrading index of the marine industrial structure (X6)
Green	Energy consumption change per unit of GDP in coastal areas (X7)
	Elastic coefficient of energy consumption (X8)
	Industrial wastewater discharge (X9)
Opening-up	Total import and export of goods in coastal areas (X10)
	Coastal port cargo throughput (X11)
	Number of inbound tourists received by coastal areas (X12)
	Foreign capital in actual use (X13)
Sharing	Urbanization level (X14)
	Urban-rural consumption gap (X15)
	Proportion of fiscal expenditure on people's livelihood (X16)

Coordination and stability are essential prerequisites for the high-quality advancement of the marine economy. From the two aspects, including the degree of marine-land economic correlation and the optimization of the marine economic industrial structure, three indicators are selected: the degree of marine-land economic correlation, the advancement coefficient of marine industrial structure, and the upgrading index of marine industrial structure. The degree of marine-land economic correlation reflects the correlation between the marine economy and the social economy; The advancement coefficient of marine industrial structure reflects the proportional change trend among the three major industries; The upgrading index of the marine industrial structure precisely mirrors the extent of improvement achieved in aspects such as industrial structure adjustment and technological innovation.

Green ecology constitutes the fundamental principle that must be upheld in the advancement of the marine economy. The changes in unit GDP energy consumption reflect the changing dependence of economic development on energy consumption. The elastic coefficient of energy consumption reflects the relative changes between the growth rate of energy demand and the growth rate of GDP. The scale of industrial wastewater discharge reflects the extent of pollution that industrial production inflicts upon the ecological environment.

Opening-up and cooperation is the only way for high-quality development of the marine economy. Only by adhering to opening-up can we achieve "bringing in and going global". Four indicators have been selected from three aspects: total goods import and export, port cargo throughput, number of inbound tourists, and foreign capital in actual use. The total goods import and export and cargo throughput reflect the scale and development level of Guangdong's foreign trade; Marine tourism is an important part of the marine economy, and the number of inbound tourists is one of the important standards to measure the development level of tourism in a country or region; The foreign capital in actual use can make up for the lack of domestic construction funds, obtain international advanced technology and management experience, and expand exchanges and integration with the world economy.

Shared well-being is the goal of high-quality development of the marine economy, aimed at benefiting people's livelihoods by enhancing the living standards of the people and improving social public service capabilities. Three indicators have been selected: the urbanization level, the urban-rural consumption gap, and the proportion of fiscal expenditure on people's livelihood. Urbanization is an important indicator of a region's economic development, as well as an important indicator for measuring its degree of social organization and its level of management. The urban-rural consumption disparity manifests the dissimilarity in the livelihoods of urban and rural residents. The smaller the gap, the more balanced the social development. The increase in the proportion of fiscal expenditure on people's livelihood is of great significance for improving people's livelihood, promoting social equity, stabilizing economic growth, and enhancing national competitiveness.

4. Research Methods and Data Sources

The aforedescribed evaluation index system comprises five first-level indicators, with a total of 16 second-level indicators. Determining the weight of indicators at all levels is key. According to existing literature research results, the determination of indicator weights can be achieved through subjective assignment or objective weighting. Subjective weighting mainly involves setting the weight of each indicator based on the experience of experts, which is relatively easy to operate in practice, but lacks objectivity and stability. Objective weighting mainly determines the weight based on the inherent relationship between indicator data, without relying on personal subjective judgment, and has good objectivity and versatility.

This study integrates the attributes of evaluating high-quality development within the marine economy, use the entropy method to compute the high-quality development index of the marine economy of Guangdong Province over recent years, and it is regarded as the basis for determining the situation of high-quality development.

On this basis, in order to further ascertaining the crucial factors influencing the high-quality development of the marine economy, this paper uses a multiple linear regression model to identify the main indicators affecting high-quality development through stepwise regression, providing a reference basis for the formulation of subsequent development strategies.

4.1 Entropy Method

In information theory, entropy is a measure of uncertainty. The greater the amount of information, the less uncertainty, and the lower the entropy; the less information, the greater the uncertainty, and the greater the entropy. Therefore, in practical application, the weight of an indicator can be determined based on the variability of the indicator data. Generally, a lower entropy value indicates greater variability in the indicator data, the more diverse the information contained, indicating more diverse information, and the more significant role it plays in evaluation, resulting in a higher weight. Conversely, the weight is smaller[13]. The calculation process of the entropy method includes four steps:

(1) Data normalization

First, normalize the data of each indicator. Assume there are K indicators, $X_1, X_2 \ldots\ldots X_k$, where $X_i = \{x_1, x_2, \ldots . x_n\}$. Assume that the normalized value of each indicator is $Y_1, Y_2 \ldots\ldots Y_k$, then

$$Y_{i,j} = \frac{x_{i,j} - \min(x_i)}{\max(x_i) - \min(x_i)} \quad (1)$$

(2) Ascertain the entropy values of each indicator.

Based on the concept of entropy, the entropy value associated with a given dataset is $E_j = -\ln(n)^{-1} \sum_{i=1}^{n} p_{i,j} \ln p_{i,j}$, where

$$p_{i,j} = \frac{Y_{i,j}}{\sum_{i=1}^{n} Y_i} \quad (2)$$

If $p_{i,j}$=0, then

$$\lim_{p_{i,j} \to 0} p_{i,j} \ln p_{i,j} = 0 \quad (3)$$

(3) Determine the weight of each indicator

According to the calculation formula of information entropy, the information entropy of each indicator is $E_1, E_2 \ldots\ldots E_k$, and the weight of each indicator is calculated through information entropy:

$$W_i = \frac{1 - E_i}{K - \sum E_i} (i = 1,2 \ldots\ldots K) \quad (4)$$

(4) Determine the comprehensive score of the indicator

$$Z_j = \sum_{i=1}^{K} X_i * W_i \, (j = 1,2, \ldots\ldots m) \quad (5)$$

4.2 Multiple Linear Regression Analysis

Multiple linear regression analysis is a statistical approach employed to examine the linear connections between a single dependent variable and several independent variables. It attempts to find the linear combination of these independent variables that can best predict or explain changes in the dependent variable by building a mathematical model. In this analysis, the coefficients of each independent variable are estimated to determine their effect on the dependent variable in terms of magnitude and direction.

Generally, a linear regression model with k explanatory variables can be expressed as:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots . + \beta_k X_{ki} + \varepsilon \quad (6)$$

Among them, $\beta_0, \beta_1 \ldots \beta_k$ are $k+1$ unknown parameters, β_0 is called the regression constant, $\beta_1 \ldots \beta_k$ are called the regression coefficients, Y_i is called the dependent variable, $X_1, X_2 \ldots X_k$

are k general variables that can be precisely controlled, called the explanatory variables. In the multiple linear regression equation, the regression coefficients can be estimated by employing the least squares method, and it is essential to assess the goodness of fit of the equation, evaluate the significance of both the regression equation and its coefficients.

4.3 Data Collection and Organization

The data utilized in this study primarily originates from the Guangdong Statistical Yearbook(2005-2022), the China Marine Economic Statistical Yearbook(2005-2022), among other sources. Any missing data have been supplemented using interpolation methods based on real-world conditions. The descriptive statistics of the indicators are shown in Table 2.

Table 2. Statistical Description of Indicators

Indicator name	Sample size	Maximum value	Minimum value	Average value	Standard deviation
R&D investment intensity (X1)	18	0.071	0.03	0.056	0.014
Technology trading activity (X2)	18	0.217	0.017	0.056	0.058
Number of authorized invention patents (X3)	18	0.179	0.003	0.056	0.052
Upgrading index of the marine industrial structure (X4)	18	0.059	0.053	0.056	0.002
Advancement coefficient of the marine industrial structure (X5)	18	0.101	0.037	0.056	0.024
Degree of marine-land economic correlation (X6)	18	0.063	0.044	0.056	0.006
Energy consumption change per unit of GDP in coastal areas (X7)	18	0.091	0.02	0.056	0.017
Industrial wastewater discharge (X8)	18	0.082	0.032	0.056	0.016
Elastic coefficient of energy consumption (X9)	18	0.124	0.001	0.056	0.027
Total import and export of goods in coastal areas (X10)	18	0.076	0.032	0.056	0.013
Coastal port cargo throughput (X11)	18	0.077	0.026	0.056	0.017
Number of inbound tourists received by coastal areas (X12)	18	0.079	0.004	0.056	0.025
Foreign capital in actual use (X13)	18	0.071	0.037	0.056	0.009
Urbanization level (X14)	18	0.061	0.049	0.056	0.004
Urban-rural consumption gap (X15)	18	0.072	0.038	0.056	0.012
Proportion of fiscal expenditure on people's livelihood (X16)	18	0.079	0.034	0.056	0.012
Gross output value of marine economy (X17)	18	0.089	0.019	0.056	0.025

5. Empirical Analysis

5.1 Comprehensive Evaluation of High-quality Development

Taking the data from 2005 to 2022 as the research object, the entropy approach is employed to calculate the weights of the indicator system, resulting in the high-quality development index for the marine economy in Guangdong Province. The findings are presented in Table 3 and Figure 1.

From 2005 to 2022, it is evident that the overall high-quality development index of Guangdong Province's marine economy exhibited a significant upward trend, rising from 0.43 in 2005 to 1 in 2022. This indicates substantial progress in the high-quality development of the marine economy within the province. From the perspective of a macro level, the gross marine production of Guangdong Province was 428.8 billion yuan in 2005, and 1.8033 trillion yuan in 2022, which was more than four times that of 2005; By analyzing the industrial structure, the distribution of the three sectors within the marine economy was 4%:39%:57% in 2005 and transformed to 3%:32%:65% by 2022. This indicates a further optimization of the industrial structure and an expansion in the share of the tertiary sector.

Of course, the high-quality development of Guangdong's marine economy has not always maintained a linear increase, but has shown a characteristic of jumping increase. The entire

time span can be divided into three stages:

The first stage extended from 2005 to 2009. During the period ranging from 2005 to 2007, the high-quality development index of the marine economy in Guangdong witnessed a marked augmentation, indicating that the high-quality development of the marine economy was in good condition. However, the development index fell back in 2008 and 2009. There were two main reasons for this: one was the negative impact of the Asian Financial Crisis, which led to the deterioration of the socio-economic development environment at home and abroad, and the other was the negative impact of domestic natural disasters.

The second stage was from 2010 to 2016. From 2010 to 2013, the index maintained an increasing trend, while it declined from 2014 to 2016. The main reason was that Guangdong Province began to implement industrial transformation and upgrading, adjust the mode of economic development, and shifting its focus from development speed to development quality. Some industries with high energy consumption and low added value were shut down or relocated to other provinces, which affected the development speed and quality in the short term;

The third stage was from 2017 to 2022, a period in which Guangdong Province successfully completed the transformation and enhancement of its industries. As a result, between 2017 and 2019, the high-quality development coefficient of the marine economy manifested a state of rapid accretion. In 2020, due to the negative impact of the epidemic, the data fell back, but it returned to a growth state in 2021 and 2022.

Table 3. High-quality Development Index from 2005 to 2022

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013
High-quality development index	0.4278	0.5124	0.5878	0.5803	0.5105	0.6486	0.7190	0.7572	0.8218
Year	2014	2015	2016	2017	2018	2019	2020	2021	2022
High-quality development index	0.8082	0.7746	0.7739	0.8312	0.8703	0.8737	0.8473	0.9938	1.0000

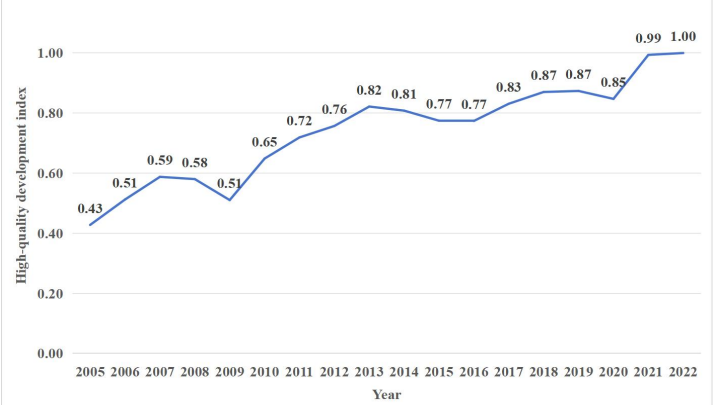

Figure 1. Curve Chart of High-quality Development Index

5.2 Analysis of Evaluation Scores for Primary Indicators

To further understand the high-quality development of Guangdong's marine economy in terms of innovation, coordination, green, opening-up, and sharing, the high-quality development index of each primary indicator over the past years was calculated with reference to the entropy method mentioned earlier. The results are shown in Table 4 and Figure 2. It can be seen that from 2005 to 2022, the data of the five indicators of innovation, coordination, green, opening-up, and sharing all showed a continuous increase, indicating that the above indicators contributed positively to the high-quality development of Guangdong's marine economy. However, the trends of each indicator over time were not consistent, as shown below:

(1) The high-quality development index of innovation grew slowly between 2005 and 2014, indicating that the investment in marine technological innovation was not high, entailing that marine science and technology achievements were incapable of efficaciously facilitating the progress of the marine economy. However, since 2015, Guangdong Province has implemented industrial transformation and upgrading, increased investment in the field of marine science and technology, and strengthened the output and application of marine science and technology achievements. Consequently, from 2015 to 2022, the index reflecting high-quality development in innovation exhibited a swift upward trend.

(2) The changes in the high-quality development

index of coordination were relatively smooth. From 2005 to 2012, the index showed little variation, suggesting that the connection between Guangdong's marine economy and its socio-economic development was quite stable. From 2013 to 2022, the index experienced an increased growth rate, suggesting that the swift advancement of the marine economy has emerged as a new driving force for enhancing high-quality socio-economic development.

(3) The high-quality development index of green has been maintaining a rapid growth state, increasing from 0.615 to 1.435, indicating that Guangdong Province has attached great importance to the protection of the marine ecological environment while vigorously developing the marine economy, and has achieved good results.

(4) The open high-quality development index witnessed a decline in 2008, 2014, 2015, and 2020; however, on the whole, it presented an increasing state. Statistics showed that Guangdong Province has opened 450 international container liner routes, connecting more than 300 ports in more than 120 countries and regions, indicating that Guangdong's marine economy has achieved remarkable results in promoting high-level opening-up to the outside world and is more proactively integrating into the global economic and trade pattern.

Table 4. High-Quality Development Index of Primary Indicators

Time	Innovation	Coordination	Green	Openinh-up	Sharing
2005	0.016	1.003	0.615	0.428	1.341
2006	0.021	1.005	0.628	0.513	1.389
2007	0.032	1.007	0.652	0.588	1.399
2008	0.066	1.008	0.763	0.581	1.397
2009	0.099	1.026	0.803	0.511	1.403
2010	0.119	1.018	0.855	0.649	1.460
2011	0.159	1.018	0.864	0.719	1.457
2012	0.193	1.016	1.020	0.757	1.476
2013	0.175	1.023	1.115	0.822	1.465
2014	0.194	1.033	1.131	0.808	1.468
2015	0.291	1.042	1.137	0.775	1.480
2016	0.336	1.052	1.181	0.774	1.511
2017	0.397	1.063	1.154	0.831	1.522
2018	0.463	1.069	1.207	0.870	1.535
2019	0.519	1.105	1.337	0.874	1.553
2020	0.614	1.112	1.483	0.847	1.582
2021	0.894	1.114	1.423	0.994	1.591
2022	1.000	1.116	1.435	1.000	1.592

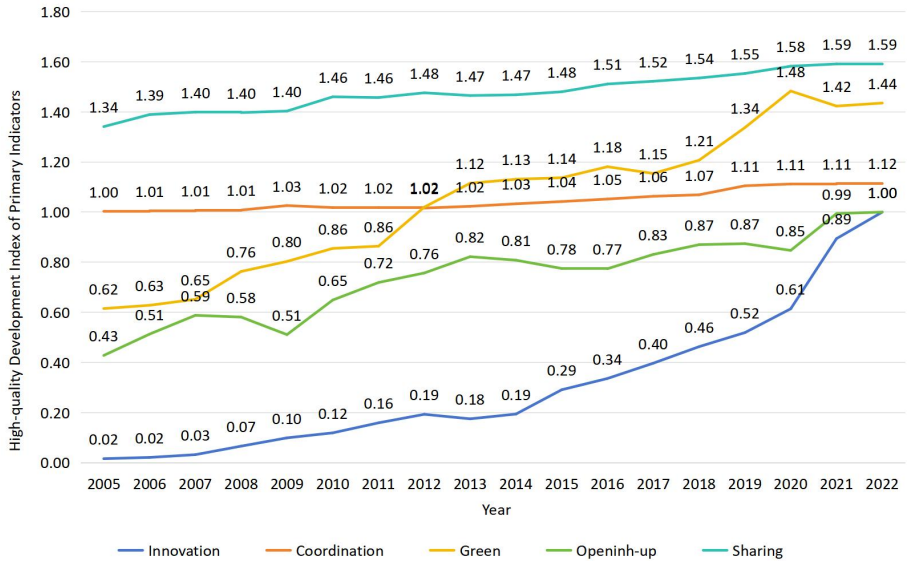

Figure 2. Curve Chart of High-quality Development Coefficient of Primary Indicators

Table 5. Results of Unit Root Test

Variable	Differential order	t	P	Stationarity
R&D investment intensity (X1)	2	-4.466	0.000***	Stable
Technology trading activity (X2)	2	-5.325	0.000***	Stable
Number of authorized invention patents (X3)	2	-4.015	0.004**	Stable
Upgrading index of the marine industrial structure (X4)	2	-6.513	0.000***	Stable
Advancement coefficient of the marine industrial structure (X5)	2	-3.034	0.032**	Stable
Degree of marine-land economic correlation (X6)	2	-5.019	0.000***	Stable
Energy consumption change per unit of GDP in coastal areas (X7)	2	-3.152	0.023**	Stable
Industrial wastewater discharge (X8)	2	-15.394	0.000***	Stable
Elastic coefficient of energy consumption (X9)	2	-3.454	0.002**	Stable
Total import and export of goods in coastal areas (X10)	2	-5.222	0.000***	Stable
Coastal port cargo throughput (X11)	2	-3.867	0.002***	Stable
Number of inbound tourists received by coastal areas (X12)	2	-4.188	0.001***	Stable
Foreign capital in actual use (X13)	2	-5.169	0.002***	Stable
Urbanization level (X14)	2	-7.043	0.000***	Stable
Urban-rural consumption gap (X15)	2	-71.917	0.000***	Stable
Proportion of fiscal expenditure on people's livelihood (X16)	2	-4.011	0.001***	Stable

(5) The shared high-quality development index showed a linear increase from 1.314 in 2005 to 1.592 in 2022, indicating that the high-quality development of the marine economy played a very positive role in improving people's living standards and the quality of social public services.

5.3 Analysis of Factors Influencing High-quality Development

Based on the previous data analysis, it can be seen that the trend of high-quality development of the marine economy in Guangdong Province was continuously improving. However, due to the impact of external market environment, industrial transformation and upgrading, and the epidemic, the high-quality development index has slightly decreased in some years. In order to further clarify which factors play a key decisive role in the high-quality development of the marine economy in Guangdong Province, this study considers the total production of the marine economy as the dependent variable, while treating indicators from five dimensions—innovation, coordination, sustainability, openness, and inclusivity as independent variables to formulate a multiple linear regression model. Through stepwise regression, the indicators with high correlation can be identified, providing data support for subsequent suggestions on high-quality development of the marine economy.

5.3.1 Unit root test

Due to potential issues of intercept and trend among variables, non-stationarity may be observed during data test, ultimately leading to spurious regression. Therefore, a unit root test was conducted before regression analysis. This paper uses the ADF test method, and the test results are shown in Table 5. It can be seen that all variables are of second-order integration, allowing further cointegration test.

5.3.2 Cointegration test

Based on the results of the unit root test mentioned above, for the purpose of examining whether a long-term cointegration relationship exists among all variables, uses the Johansen test method for cointegration testing of all variables, drawing on previous relevant empirical research results[14]. If the trace statistic surpasses the critical value at a precise significance level, it manifestly suggests that a profoundly significant long-term cointegration relationship prevails among the variables, otherwise there is no cointegration relationship.

Taking innovation indicators as an example, a regression model was constructed with the intensity of R&D investment, the activity level of technology transactions, and the number of authorized invention patents as independent variables, and the gross marine production as the dependent variable. The model structure is

defined as follows:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \varepsilon \quad (7)$$

The test results of the cointegration relationship are shown in Table 6. Taking a 5% significance level as an example, because the value 11.857 in the third column of the fifth row is greater than the critical value of 3.841 corresponding to 5%, all null hypotheses are rejected, indicating that there are three cointegration relationships. Therefore, there is a long-term stable cointegration relationship among marine gross production and the intensity of R&D investment, the activity level of technology transactions, and the number of authorized invention patents.

Table 6. Results of Cointegration Test

Null hypothesis	Characteristic root	Trace (maximum root)	10% critical value	5% critical value	1% critical value
No cointegration relationship	1	NaN	51.649	55.246	62.52
At most 1 cointegration	1	512.535	32.065	35.012	41.081
At most 2 cointegrations	0.799	35.926	16.162	18.398	23.148
At most 3 cointegrations	0.546	11.857	2.705	3.841	6.635

By repeating the aforementioned operation, the cointegration relationship test between the gross marine production of Guangdong Province and the indicators of coordination, green, opening-up, and sharing was completed, revealing the existence of a long-term stable cointegration relationship. Therefore, the key factors affecting the change of gross marine production of Guangdong Province can be analyzed through a linear regression model.

5.3.3 Regression analysis

(1) Regression analysis of the gross marine production of Guangdong Province and innovation indicators

A regression model with R&D investment intensity, technology trading activity, and number of authorized invention patents as independent variables, and the gross marine production of Guangdong Province as the dependent variable, was conducted. The model structure is defined as follows:

$$Y_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \beta_3 X_{3i} + \varepsilon \quad (8)$$

Stepwise regression is a method based on linear regression. The approach involves introducing variables sequentially, conducting individual tests on the previous variables selected in the regression model after introducing a new variable, and removing those deemed insignificant until no further new variables are introduced and no previous variables are removed. This ensures that each variable in the regression model retains its significance. The computational results of the regression model are presented as in Table 7.

Table 7. Results of Linear Regression Analysis

	Non-standardized coefficient		Standardized coefficient	t	P	VIF	R^2	Adjusted R^2	F
	B	Standard error	Beta						
Constant	-0.041	0.009	0	-4.716	0.000***	-	0.892	0.885	F=131.77, P=0.000***
R&D investment intensity	1.732	0.151	0.944	11.479	0.000***	1			
Dependent variable: total output value of marine economy									
Note: ***, **, * represent the significance levels of 1%, 5%, and 10% respectively (Subsequent remarks all convey the same meaning.)									

As shown in Table 7, the regression model demonstrates a high level of statistical significance (F=131.77, P<0.001), indicating that a significant linear relationship exists between the two types of variables. The stepwise regression results show that only R&D investment intensity remains as an independent variable in the final model, while technology trading activity and the number of authorized invention patents have been excluded due to their insignificant contribution to the explanatory power of the model. The adjusted R^2 value is 0.885, indicating that R&D investment intensity explains up to 88.5% of the variability in the total output value of the marine economy. The VIF value is under 10, meaning that the model does not have multicollinearity issues, indicating that the model has a good fit.

Specifically, the standardized regression coefficient (Beta) of R&D investment intensity

is 0.944, and its t-value (11.479) is highly significant at an extremely high level (P<0.001), strongly supporting that R&D investment is an important factor in promoting total output growth. The coefficient value indicates that, while considering other potential influencing factors, for every unit increase in R&D investment intensity, the total output will increase by an average of 0.944 units, demonstrating a strong positive impact and reflecting the key role of R&D investment in promoting technological progress, industrial upgrading, or economic growth.

The final linear regression model is:

$$y = -0.041 + 1.732 * X1 \quad (9)$$

(2) Regression analysis of the gross marine production of Guangdong Province and coordination indicators

A regression model with upgrading index of the marine industrial structure(X1), advancement coefficient of the marine industrial structure(X2), and degree of marine-land economic correlation(X3) as independent variables, and the gross marine production of Guangdong Province(Y) as the dependent variable, was conducted.

The results of the regression analysis are presented in Table 8. The model exhibits high statistical significance and great goodness of fit (R2=0.969, adjusted R2=0.964), indicating that the selected variables can well explain the changes in the total output value of the marine economy. The stepwise regression results show that two variables, X1 and X2 are retained in the final model, while X3 is excluded on account of its insignificant contribution to the explanatory capacity of the model.

Specifically, the Indicator X1 has a pronounced and affirmative effect on the total output value (Beta=2.533, t=14.077, P<0.001), indicating that as indicator X1 increases, the total output value will significantly increase. The advancement coefficient of the marine industrial structure has a significant negative impact on the total output value of the marine economy (Beta=-1.706, t=-9.48, P<0.001). This finding may imply that in the current research context, there are some short-term adjustment costs or structural changes in the process of transforming the marine industrial structure to a higher level, which temporarily result in a negative direct contribution to the total economic output value.

Table 8. Results of Linear Regression Analysis

	Non-standardized coefficient		Standardized coefficient	t	P	VIF	R^2	Adjusted R^2	F
	B	Standard error	Beta						
Constant	-1.677	0.12	0	-13.971	0.000***	-	0.969	0.964	F=231.205, P=0.000***
Upgrading index of the marine industrial structure	32.979	2.343	2.533	14.077	0.000***	15.461			
Advancement coefficient of the marine industrial structure	-1.79	0.189	-1.706	-9.48	0.000***	15.461			
Dependent variable: total output value of marine economy									

(3) Regression analysis of the gross marine production of Guangdong Province and green indicators

A regression model with energy consumption change per unit of GDP in coastal areas, industrial wastewater discharge, and elastic coefficient of energy consumption as independent variables, and the gross marine production of Guangdong Province as the dependent variable, was conducted.

The results of the regression analysis are displayed in Table 9. After screening three variables, namely, energy consumption change per unit of GDP in coastal areas, industrial wastewater discharge, and the elastic coefficient of energy consumption, the model ultimately retains industrial wastewater charge as a significant influencing variable. The VIF value is less than 10, indicating that the model does not have a multicollinearity problem. The

overall fit of the model is good, and the adjusted R2 value is 0.915, indicating that the variable of industrial wastewater discharge can explain 91.5% of the variability in the total output value of the marine economy.

Table 9. Results of Linear Regression Analysis

	Non-standardized coefficient		Standardized coefficient	t	P	VIF	R^2	Adjusted R^2	F
	B	Standard error	Beta						
Constant	0.14	0.006	0	21.582	0.000***	-	0.92	0.915	F=182.922, P=0.000***
Industrial wastewater discharge	-1.521	0.112	-0.959	-13.525	0.000***	1			
Dependent variable: total output value of marine economy									

Specifically, the non-standardized coefficient of industrial wastewater discharge is -1.521, with a standard error of 0.112, and the corresponding standardized coefficient (Beta) is -0.959. This indicates that, while keeping other potential variables constant, a one-unit increase in industrial wastewater discharge will significantly reduce the total output value of marine economy by 1.521 units, and this reduction effect is highly statistically significant (t=-13.525, P<0.001, ***). The absolute value of the Beta coefficient is close to 1, further emphasizing the significant and direct negative impact of industrial wastewater discharge on the total output value of marine economy.

(4) Regression analysis of the gross marine production of Guangdong Province and opening-up indicators

A regression model with total import and export of goods in coastal areas, coastal port cargo throughput, number of inbound tourists received by coastal areas, and foreign capital in actual use as independent variables, and the gross marine production of Guangdong Province as the dependent variable, was conducted.

The results obtained from the regression analysis are presented graphically in Table 10. The model has identified two significant independent variables that affect the total output value through the stepwise regression method: coastal port cargo throughput and foreign capital in actual use. The overall goodness of fit of the model is excellent, evidenced by the R2 value (0.985) and the adjusted R2 value (0.984), both of which are very close to 1, indicating that the model can explain the majority of the variability in the dependent variable.

The standardized coefficient for the coastal port cargo throughput is 1.084, with a t-value of 25.246 and a P-value less than 0.001, indicating that an upsurge in the coastal port cargo throughput has a marked positive repercussion on the total output value, and this repercussion is highly statistically significant. The significance of the coastal port cargo throughput suggests that port activities, as important nodes in regional economic integration and international trade, cannot be ignored in their impact on the target variable. Their increase may reflect the enhancement of regional trade activities, thereby promoting positive changes in economic or social indicators.

The standardized coefficient of the foreign capital in actual use is -0.14, with a t-value of -3.268 and a P-value of 0.005, indicating that an increase in the foreign capital in actual use has a remarkable negative influence on the total output value, although the intensity of this impact is relatively small (the absolute value of Beta is small).

Table 10. Results of Linear Regression Analysis

	Non-standardized coefficient		Standardized coefficient	t	P	VIF	R^2	Adjusted R^2	F
	B	Standard error	Beta						
Constant	-0.009	0.005	0	-1.751	0.1	-	0.985	0.984	F=507.857, P=0.000***
Coastal port cargo throughput	1.584	0.063	1.084	25.246	0.000***	1.9			
Foreign capital in actual use	-0.415	0.127	-0.14	-3.268	0.005***	1.9			
Dependent variable: total output value of marine economy									

(5) Regression analysis of the gross marine production of Guangdong Province and sharing indicators

A regression model with urbanization level(X1), urban-rural consumption gap(X2), and proportion of fiscal expenditure on people's livelihood(X3) as independent variables, and the gross marine production of Guangdong Province as the dependent variable, was conducted.

As shown in Table 11, the stepwise regression process ultimately retained two variables: the indicator X1 and indicator X2, while the indicator X3 was discarded by the model because it failed the significance test. The goodness of fit of the model is relatively high, with an adjusted R2 value of 0.925, indicating that the model can explain the majority of the variability in the dependent variable (about 92.5%). The F statistic is significant (F=106.502, P=0.000<0.001), further verifying the overall validity of the model.

Specifically, the urbanization level has a significant positive influence on the total output value (Beta=0.547, t=3.048, P=0.008<0.01), suggesting that enhancing the level of urbanization can significantly facilitate the growth of total output value under the condition of keeping other factors constant. This finding shows the key role of the urbanization process in developing the marine economy, and this can be achieved through mechanisms such as promoting resource agglomeration, industrial upgrading, and market demand expansion.

The urban-rural consumption gap has a significant negative impact on the total output value of the marine economy (Beta = -0.436, t = -2.43, P = 0.028 < 0.05), indicating that the widening of the urban-rural consumption gap is not conducive to the overall growth of the marine economy. This may imply that reducing the urban-rural consumption disparity and fostering balanced growth in the consumption market are crucial for enhancing total output value. The reduction of the urban-rural consumption gap may stimulate the growth of the marine economy by enhancing the purchasing power of rural residents and expanding the market demand for marine products.

Table 11. Results of Linear Regression Analysis

	Non-standardized coefficient		Sstandardized coefficient	t	P	VIF	R^2	Adjusted R^2	F
	B	Standard error	Beta						
Constant	-0.111	0.09	0	-1.229	0.238	-	0.934	0.925	F=106.502, P=0.000***
Urbanization level	3.896	1.278	0.547	3.048	0.008***	7.356			
Urban-rural consumption gap	-0.896	0.369	-0.436	-2.43	0.028**	7.356			
Dependent variable: total output value of marine economy									

In summary, based on the regression analysis of the total output value of the marine economy in Guangdong Province and five indicators including innovation, coordination, green, opening-up, and sharing, the key indicators affecting the high-quality development of the marine economy in Guangdong Province include: R&D investment intensity, upgrading index of the marine industrial structure, advancement coefficient of the marine industrial structure, industrial wastewater discharge, coastal port cargo throughput, foreign capital in actual use, urbanization level, and urban-rural consumption gap. Modifications in these eight indicators will have a profound impact on the current status of high-quality development within the marine economy. Therefore, the marine economic management department should give full consideration when formulating relevant industrial development strategies.

5.4. Development Strategies and Proposals

Based on the results of the aforementioned qualitative and quantitative analyses, the following targeted suggestions are proposed:

(1) Increase investment in marine science and technology research. With enterprises serving as the main pillar, the market functioning as the guiding impetus, and finance acting as the supporting element, concentrate innovation resource elements and establish a deeply integrated collaborative innovation system

encompassing industry, academia, and research. Actively encourage and guide marine-related enterprises, universities, and research institutions to increase R&D investment, while strengthening the accounting management and benefit evaluation of R&D funds.

(2) Build a modern marine industry system. Leveraging Guangdong's unique geographical and resource endowments fully, focus on the construction of marine industry clusters to cultivate and expand emerging marine industries including offshore wind power, marine engineering equipment, marine drugs and biological products; Accelerate the development of blue financial industry, advance the development of the specialized shipping service industry and construct marine tourism industry clusters, promote the extension of productive service industry to professionalization and high-end value chains, upgrade the life service industry to high quality and diversification, and improve the development level of marine service industry.

(3) Strengthen the protection and restoration of marine natural resources. Strictly implement the marine ecological red line control system to safeguard the boundary of natural ecological security. Continue to carry out the "Blue Bay" comprehensive improvement action and strengthen the monitoring and evaluation of the ecological environment restoration effect; Establish a comprehensive marine environmental governance system that integrates river basins, coastal areas, and marine areas, and significantly enhance the quality and stability of marine ecosystems.

(4) Strengthen the opening-up and cooperation in the marine economy. Fully leverage the comparative advantages and vigorously facilitate the in-depth integration of the marine economy of Guangdong and surrounding cities in the domain of marine infrastructure, marine science and technology, marine industries, and marine ecological protection. Foster the cooperation and exchanges with neighboring provinces and regions such as Hainan, Guangxi, and Fujian, enhance the connectivity of marine infrastructure, facilitate the unrestricted movement of production factors and enhance the coordinated and interconnected development of the marine economy within the Pan-Pearl River Delta region. Make full use of Guangdong's role as a strategic fulcrum in building a new development pattern and strengthen cooperation with countries and regions along the Maritime Silk Road.

6. Conclusion

This paper systematically analyzed the current situation of the development of the marine economy in Guangdong Province, pointed out the main problems, and on this basis, through collecting and organizing statistical data related to the marine economy, constructed an evaluation indicator system for the high-quality development of the marine economy in Guangdong Province. It also calculated the current situation of the high-quality development of the marine economy in Guangdong Province and the main factors affecting high-quality development through the entropy method and linear regression model, providing a reference basis for the marine economic management department to formulate development strategies.

In the research process of this paper, due to the constraints of insufficient marine statistical data, some representative indicators were excluded due to their inability to be accurately quantified, which had a certain impact on the evaluation results of the model. This paper will further strengthen the collection and organization of marine statistical data, improve the construction of the evaluation indicator system, enhance the objectivity and scientificity of the model analysis structure in subsequent research, thereby providing more robust data support for the proposal of development strategies.

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