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Vulnerability evaluation and barrier degree analysis of marine economic system based on SDGs

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Abstract: *In recent years, the rapid development of Marine economy in Guangdong Province has become one of the main pillar industries. Therefore, it is particularly important to study the sustainable development of Marine economy in Guangdong Province. This paper is based on the 2030 Sustainable Development Goals (SDGs) proposed by the United Nations Commission on Sustainable Development. The vulnerability index system of the Marine economic system of Guangdong Province was constructed from four aspects: coercion (P), sensitivity (S), elasticity (E) and adaptability (A). TOPSIS model and obstacle degree model were used to analyze the vulnerability and obstacle factors of the Marine economic system of Guangdong Province from 2007 to 2018.The results show that compared with 2014, the transformation of Marine economy optimization in Guangdong Province is the most obvious in 2015. In the criterion layer, sensitivity proximity showed an upward trend. Sensitivity had the greatest impact on the vulnerability of the system from 2014 to 2018, elasticity had the greatest impact on the vulnerability of the system in 2011, and stress had the greatest impact on the vulnerability of the system in the remaining years. The order of obstacle degree in each criterion layer from high to low is: stress, elasticity, adaptability and sensitivity. The main obstacle factors in the index layer are the import and export value of goods in the coastal area according to the location of the business unit, and the area of Marine nature reserves.*

Keywords: *vulnerability; marine economy; TOPSIS model; barrier degree analysis*

1. Introduction

In September 2015, the United Nations Sustainable Development Summit adopted the 2030 Agenda for Sustainable Development (hereinafter referred to as the "2030 Agenda"), which defines the Sustainable Development Goals (SDGs) consisting of 17 goals and 169 sub-goals. SDGs) system [1]. Sustainable development has gradually become the research object of scholars. The importance of the sustainable development of the Marine ecological economy system and the sustainable development of mankind is self-evident. The 21st century is called the century of the sea, with the further deepening of people's understanding of the ocean, the value of the ocean is gradually valued by the country. However, during the rapid development of the Marine economy, it is inevitable to be affected by external interference and the instability of the internal structure of the system itself, which makes the sustainable development system of the Marine economy vulnerable to many uncertain factors [2].

The concept of vulnerability first appeared in the study of natural disasters [3]. Each scholar has a different understanding of vulnerability. The earliest concept is similar to "risk", which refers to the possibility that a system or component will be damaged by exposure to adverse impacts [4][5], and is often used in the study of natural disasters. Studies in social, economic, ecological and other fields consider vulnerability to be a set of concepts including sensitivity, resilience and coping ability, and consider vulnerability to be the degree to which a system is vulnerable to damage when exposed to pressure and its ability to deal with and adapt to such pressure [6]. However, in the field of climate change research, it is emphasized that the result of system facing interference, and the vulnerability is the degree of damage to the vulnerable system, and the key lies in its sensitivity, adaptation potential and exposure [7]. With the rise of vulnerability research in the fields of ecology, disaster science, economics and sustainable development, the interpretation of the concept of vulnerability is constantly enriched. Although scholars still have some differences on the concept of vulnerability, the overall development trend is to integrate the relevant concepts such as "exposure", "risk", "sensitivity" and "coping ability" into a comprehensive conceptual system that includes multiple elements such as nature, environment, society and economy [8].

In 1999, the United Nations Development Program (CNDP) officially put forward the concept of "economic vulnerability" and took it as an important indicator to measure sustainable economic development [9]. Current studies on the vulnerability of Marine economic system mainly focus on the connotation, evaluation, early warning mechanism and policy orientation of industrial security [10], but there are not enough studies on the environment, ecology, structure and security of the industry. The main research methods are comprehensive index method [11], data envelopment model [12], BP neural network [13], set pair analysis model [14] and triangle model [15]. This paper adopts TOPSIS model suitable for the study of multi-objective decision-making problems, which can make full use of the original index data to accurately calculate the distance between each index and the positive and negative ideal solutions [16]. According to the distance between the comparison and positive and negative ideal solutions, the results of each scheme are sorted, and the results are clear and clear.This paper selects the data related to the Marine economy of Guangdong Province from 2007 to 2018, constructs the vulnerability index system of the Marine economic system from the four aspects of *coercion*, sensitivity, elasticity and adaptability based on SDGs, and uses the entropy weight method and analytic hierarchy process to calculate the comprehensive weight. TOPSIS model and obstacle degree model were used to calculate the vulnerability and obstacle factors of Marine economy in Guangdong Province.

The coastal area is the fastest developing area of Marine economy. However, even in the process of rapid development of Marine economy, the Marine environment is also undergoing great challenges, such as shortage of Marine resources, environmental pollution and land and sea space competition. At present, further studies on the vulnerability of the natural - social - economic system and the influencing factors of Marine economic vulnerability based on human-land relationship are needed [17].

This paper selects the data of Marine economy in Guangdong Province from 2007 to 2018. Based on the Sustainable Development Goals (SDGs), the vulnerability index system of the Marine economic system is constructed from four aspects: coercion (P), sensitivity (S), elasticity (E) and adaptability (A). On the basis of the comprehensive weight obtained by entropy weight method and analytic hierarchy process, TOPSIS model and obstacle degree model were used to calculate the vulnerability and obstacle factors of Marine economy in Guangdong Province. By analyzing the comprehensive vulnerability approximation of the Marine economic system calculated by TOPSIS model, we can see the variation amplitude of the Marine economic vulnerability of Guangdong Province, and clearly know whether the vulnerability of the Marine economic system is developing in the direction of optimization or aggravating every year. Through the calculation of the obstacle degree model, the obstacle degree of each indicator in each criterion layer and indicator layer can be obtained, and the obstacle degree of each indicator in the criterion layer and indicator layer can be sorted from the largest to the smallest, and the main influencing factors of the Marine economic system vulnerability in Guangdong Province from 2007 to 2018 can be seen. By analyzing the vulnerability of the Marine economic system of Guangdong Province from 2007 to 2018 and the obstacle degree of the criterion layers and indicators, we can observe the problems that have occurred in the Marine economic system of Guangdong Province in recent years and the problems that still exist now, and Guangdong Province can adopt direct and effective methods to solve these problems in the process of developing the Marine economy in the future. It is of reference significance to the development of Marine economy in other coastal provinces.

2. Index system and research methods

2.1. Construction of evaluation index system

Based on the Sustainable Development Goals (SDGs), this paper refers to the achievements of other scholars in constructing the index system [13][14][15][17]. The index system was constructed from four aspects: coercion (P), sensitivity (M), elasticity (E) and adaptability (A) (Table 1). In order to more accurately reflect the sustainable development capability of Marine economy, this paper not only refers to SDG14 but also other sustainable development goals closely related to Marine economy and environment, such as SDG17, SDG9 and SDG8.

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Table 1: Vulnerability index system of Marine economic system.

Rule layer	Number	Index layer	Index of the unit	The weight
Coercion	P_1	Total wastewater discharge	million tons	0.083
	P_2	Water resources per capita	Cubic meter per person	0.066
	P_3	Electricity consumption in coastal areas	Billion kWh	0.050
	P_4	Cargo throughput of coastal ports	million tons	0.039
	P_5	Industrial smoke (dust) emissions	million tons	0.055
	P_6	Number of inbound tourists received by coastal cities	person-time	0.041
Sensitivity	S_1	Share of marine GDP in regional GDP	%	0.032
	S_2	Import and export of goods in coastal areas by location of business units	Million dollars	0.028
	S_3	The proportion of marine primary industry in GOP	%	0.029
	S_4	Share of marine secondary industry in GOP	%	0.024
	S_5	Share of marine tertiary sector in GOP	%	0.029
	S_6	Coastal Regional GDP	Billion	0.032
Elasticity	E_1	Wetland area	Thousands of hectares	0.037
	E_2	Number of people involved in maritime employment	10,000 people	0.025
	E_3	Per capita consumption expenditure of urban residents in coastal regions	Yuan	0.026
	E_4	Number of marine nature reserves established	a	0.050
	E_5	Mariculture area	hectares	0.032
	E_6	Marine Nature Reserve Area	Square kilometers	0.070
Adaptability	A_1	General public budget revenue in coastal areas	Billion	0.031
	A_2	General public budget expenditure in coastal areas	Billion	0.031
	A_3	Comprehensive utilization of industrial solid waste per unit of gross marine product	Tons/billion yuan	0.061
	A_4	Number of scientific and technical topics in marine research institutions	item	0.042
	A_5	Number of science and technology patents granted by marine research institutions	Pieces	0.046
	A_6	Number of scientific papers published by marine research institutions	Part	0.043

2.2. Data source

The research data in this paper are obtained from the China Marine Statistical Yearbook, China Statistical Yearbook, Guangdong Statistical Yearbook and statistical bulletins of relevant departments in Guangdong Province from 2007-2018.

2.3. Research method

2.3.1. Entropy method

The weight of the index can reflect the importance of an index in the index layer to the construction of Marine economic system in Guangdong Province. In order to make the weight of the index more accurate, this paper adopts two methods, entropy method and analytic hierarchy process, respectively to calculate the weight, and finally takes the average value of the weight calculated by entropy method and analytic hierarchy process as the comprehensive weight.

Before the analysis, the evaluation indexes need to be standardized by min-max to make the indexes more comparative. In order to prevent meaningless logarithmic calculation, a positive number slightly greater than zero was added to the calculation results of all data. In this paper, 0.001 translation was selected for the data.

Standardized treatment:

$$X_{ij}^* = \frac{X_{ij} - X_{j\,min}}{X_{j\,max} - X_{j\,min}} + 0.001 \tag{1}$$

$$X_{ij}^* = \frac{X_{j\,max} - X_{ij}}{X_{j\,max} - X_{j\,min}} + 0.001 \tag{2}$$

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The proportion of item j in year i:

$$Y_{ij} = \frac{X_{ij^*}}{\sum_{i=1}^{m} X_{ij^*}} \tag{3}$$

The formula is used to calculate the information entropy of item j:

$$e_j = -k\sum_{i=1}^{n}(Y_{ij} \times lnY_{ij}) \tag{4}$$

Information entropy was used to calculate the difference coefficient of item j:

$$d_j = 1 - e_j \tag{5}$$

Use the difference coefficient to calculate the weight of item j:

$$W_j = \frac{d_j}{\sum_{i=1}^{n} d_j} \tag{6}$$

2.3.2. The analytic hierarchy process

The hierarchical analysis method is a multi-indicator hierarchical evaluation method that invites experts to score the relationship between two indicators in each criterion layer, and finally determines the discriminant matrix of two-comparison relationship of all indicators, so as to decide the weight of each indicator (Table 1).

2.3.3. TOPSIS model

TOPSIS model is one of the commonly used comprehensive evaluation methods, which can fully utilize the information of the original data to calculate the distance between the evaluated object and the corresponding ideal target, and can accurately reflect the advantages and disadvantages between each evaluation scheme.

Constructing a normalized weighted decision matrix.

$$Z_{ij} = {X_{ij}}^* \times W_{ij} \tag{7}$$

In the formula: ${X_{ij}}^*$ is the standardized value of the jth indicator in the ith year, and W_{ij} is the weight of the jth indicator in the ith sample.

Determine the positive and negative ideal solutions.

$$Z^+ = \left\{\max_{1\le i\le n} Z_{ij} \middle| i = 1,2,3,\cdots,n\right\} = \{Z_1^+, Z_2^+, Z_3^+, \cdots, Z_n^+\} \tag{8}$$

$$Z^- = \left\{\min_{1\le i\le n} Z_{ij} \middle| i = 1,2,3,\cdots,n\right\} = \{Z_1^-, Z_2^-, Z_3^-, \cdots, Z_n^-\} \tag{9}$$

In the formula Z^+ and Z^- are set as positive and negative ideal solutions, respectively

Determine the distance between the indicator and the positive and negative ideal solution using the Euclidean calculation method.

Distance of the indicator to the positive ideal solution:

$$D_j^+ = \sqrt{\sum_{i=1}^{n}(Z_j^+ - Z_{ij})^2} \tag{10}$$

Distance between the indicator and the negative ideal solution:

$$D_j^- = \sqrt{\sum_{i=1}^{n}(Z_j^- - Z_{ij})^2} \tag{11}$$

In the formula: $D_j^+$and D_j^- are the distance between the indicator and $Z_j^+$and Z_j^- the distance between.

Calculate the comprehensive evaluation index.

$$C_j = \frac{D_j^-}{D_j^+ + D_j^-} \tag{12}$$

The formula C_j represents the distance of the jth indicator from the positive ideal solution. C_j The closer to the positive ideal solution, the closer the number is to 1. Conversely, the C_j the closer to the negative ideal solution, the closer the number is to 0.1.

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2.3.4. Barrier degree evaluation model

In order to understand the factors that increase the vulnerability of the system, we use the barrier model to calculate the factors that hinder the reduction of the vulnerability of the marine economic system, and we can not only analyze the impact of individual indicators on the reduction of system vulnerability, but also analyze the impact of each criterion layer on the reduction of system vulnerability. The calculation formula is as follows:

$$L_{ij} = 1 - X_{ij}^{*} \tag{13}$$

$$H_{ij} = \frac{W_{ij} \times L_{ij}}{\sum_{i=1}^{m}(W_{ij} \times L_{ij})} \times 100\% \tag{14}$$

$$U_i = \sum_{j=1}^{m} H_{ij} \tag{15}$$

$$\sum_{i=1}^{4} U_i = 1 \tag{16}$$

In the formula: W_{ij} denotes the weight of the jth indicator in the i-th criterion layer. L_{ij} ,H_{ij} and U_i (i=1,2,3,4) denote the distance of a single indicator from the target, the barrier degree of a single indicator in the indicator layer, and the barrier degree in the criterion layer, respectively.

3. Analysis of model results

3.1. Vulnerability Proximity Analysis of the Marine Economic System of Guangdong Province

In this paper, the combined proximity C of the vulnerability as well as coercion (P), sensitivity (S), Elasticity (E) and adaptability (A) of the marine economic system of Guangdong Province was calculated by using the TOPSIS model based on the entropy value method and the hierarchical analysis (AHP) to calculate the combined weights (Table 2 and Figure 1).

Table 2: D^+, D^- and C of the Marine economic System of Guangdong Province.

Guideline layer		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Coercion (P)	D^+	0.092	0.069	0.064	0.066	0.088	0.074	0.076	0.105	0.094	0.093	0.094	0.071
	D^-	0.095	0.117	0.107	0.092	0.076	0.075	0.078	0.043	0.062	0.090	0.078	0.102
	C	0.510	0.629	0.626	0.583	0.463	0.504	0.509	0.290	0.398	0.492	0.454	0.590
Sensitivity (S)	D^+	0.055	0.049	0.049	0.052	0.043	0.046	0.042	0.039	0.035	0.035	0.035	0.036
	D^-	0.036	0.034	0.026	0.031	0.035	0.042	0.044	0.048	0.049	0.050	0.055	0.060
	C	0.393	0.410	0.346	0.371	0.449	0.479	0.508	0.551	0.584	0.589	0.614	0.625
Elasticity (E)	D^+	0.097	0.088	0.086	0.096	0.066	0.092	0.086	0.086	0.085	0.085	0.090	0.075
	D^-	0.021	0.036	0.045	0.031	0.078	0.036	0.050	0.050	0.052	0.054	0.049	0.072
	C	0.178	0.291	0.343	0.243	0.543	0.281	0.369	0.371	0.379	0.389	0.352	0.491
Adaptability (A)	D^+	0.087	0.083	0.082	0.077	0.074	0.070	0.076	0.077	0.062	0.064	0.062	0.062
	D^-	0.061	0.058	0.049	0.044	0.044	0.039	0.033	0.034	0.056	0.062	0.076	0.083
	C	0.413	0.410	0.372	0.362	0.374	0.356	0.305	0.306	0.473	0.489	0.549	0.575
System	D^+	0.168	0.148	0.143	0.149	0.139	0.145	0.144	0.161	0.145	0.145	0.148	0.125
	D^-	0.120	0.140	0.128	0.111	0.123	0.101	0.108	0.088	0.110	0.131	0.131	0.162
	C	0.417	0.486	0.472	0.427	0.468	0.412	0.429	0.355	0.430	0.474	0.470	0.564

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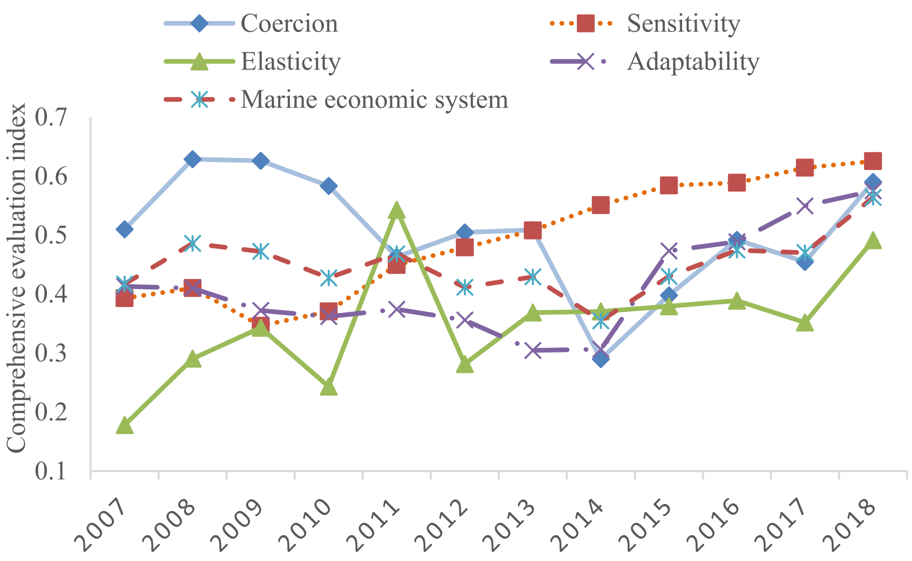

Figure 1: The variation trend of the proximity of the Marine economic system and its criterion layers in Guangdong Province from 2007 to 2018.

From Table 2, it can be seen from Table 2 that the comprehensive proximity of the sustainable development system of Marine economy in Guangdong Province is generally on the rise. In order of the degree of proximity, the comprehensive proximity in 2018 is the highest (0.564) and the vulnerability is the lowest. The main reason is that compared with the negative ideal solution, it is closer to the positive ideal solution, where the distance from the positive ideal solution (D^{+}) is 0.125, and the distance from the negative ideal solution (D^{-}) is 0.162, where the proximity of stress is 0.590, the proximity of sensitivity is 0.625, and the proximity of adaptability is 0.5749.The remaining years in descending order of combined proximity were:2008(0.486), 2016 (0.474), 2009 (0.472), 2017 (0.470), 2011 (0.468), 2015 (0.430), 2013 (0.429), 2010 (0.427), 2007 (0.417), 2012 (0.412), and 2014 (0.355).

The sensitivity showed a rising trend on the whole, and the coercion, elasticity and adaptability had a large fluctuation stage in the corresponding years. According to the proximity of each criterion layer from 2007-2018 in order from large to small, the sensitivity in 2014-2018 has the greatest impact on the vulnerability of the system, the elasticity in 2011 has the greatest impact on the vulnerability of the system, and the coercion in the remaining years has the greatest impact on the vulnerability of the system.

It can be seen from Figure 1 that the comprehensive proximity of the sustainable development system of Marine economy of Guangdong Province shows an overall upward trend, indicating that the Marine economy of Guangdong Province is developing in a good direction as a whole. It can be seen that the comprehensive proximity of the Marine economy sustainable development system of Guangdong Province showed an upward trend in 2007-2008, but the comprehensive proximity of the Marine economy sustainable development system suddenly showed a downward trend in 2008-2010 and 2013-2014, which was mainly caused by the world economic crisis in 2008. At that time, the economy of all parts of the country was affected, and the Marine economy of Guangdong Province was not spared. It can be concluded that Guangdong Province needs to continuously develop its own advantages, adjust the status and structure of foreign trade, reduce its dependence on foreign trade, and then alleviate the impact of the international economic crisis on the Marine economy of Guangdong Province. From 2013 to 2014, the ecological benefits of Marine economy in Guangdong Province were in a process of improvement, and problems such as sewage discharge were prominent, leading to a significant decline in the comprehensive evaluation index of the system. Therefore, in order to reduce the impact of these factors, more attention should be paid to the detection of Marine environment and a reasonable Marine environment assessment mechanism should be established. Strictly control the discharge of industrial pollutants in coastal areas.

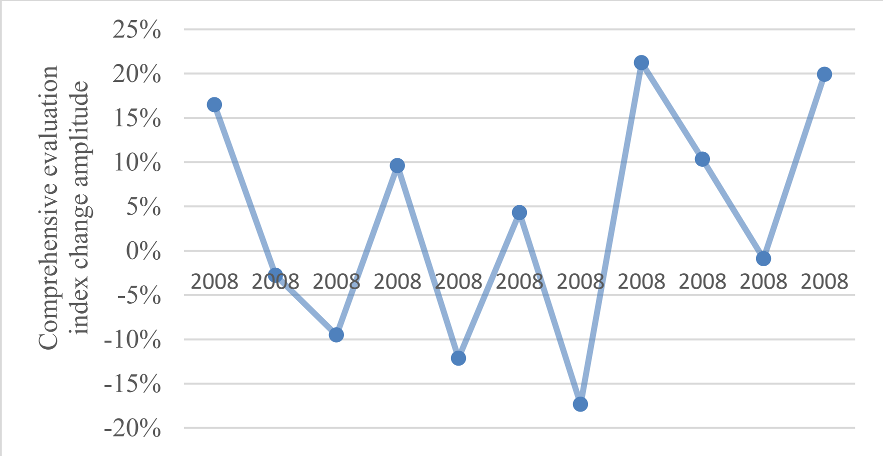

Figure 2: Change rate of vulnerability proximity of Marine economic system in Guangdong Province from 2007 to 2018.

Through the change rate of vulnerability comprehensive proximity of Marine economic system in Guangdong Province from 2007 to 2018, the change range of Marine economic vulnerability in Guangdong Province can be intuitively and clearly seen. As can be seen from Figure 2, the proximity ratio in 2015/2014 was the highest (21.22%), and there was a significant change in system vulnerability optimization compared with 2014. The change rate of proximity in 2008/2007, 2011/2010, 2013/2012 and 2018/2017 were all greater than zero, and the vulnerability optimization range was 16.47%, 9.59%, 4.29%, 10.32% and 19.91%, respectively. This indicates that vulnerabilities in 2008, 2011, 2013 and 2018 are all moving in the direction of optimization. However, the conversion rate of proximity in the remaining years is negative, indicating increased vulnerability compared to the previous year. The largest increases in vulnerability occurred in 2014/2013 and 2013/2011, with increases of -17.3% and -12.1%, respectively.

3.2. Analysis of the barrier degree of marine economic system

3.2.1. Obstacle degree analysis of single index in index layer

Based on the obstacle degree model, this paper calculates the obstacle degree of a single index of the Marine economy sustainable development system of Guangdong Province from 2007 to 2018. The top five indicators of the obstacle degree each year are listed below (Table 3).

Table 3: Ranking of obstacle degree of single index of Marine economy sustainable development.

Year	The first five major obstacle factors				
	First	Second	Third	Fourth	Fifth
2007	E_6	P_5	P_2	A_5	A_6
2008	S_2	A_6	S_3	A_3	P_3
2009	S_2	P_5	S_3	A_3	P_3
2010	S_2	E_3	S_3	A_4	A_1
2011	P_5	E_3	S_3	A_3	A_1
2012	S_2	E_6	E_3	A_1	S_3
2013	S_2	E_6	E_3	S_3	S_3
2014	E_6	S_2	P_5	P_1	E_3
2015	E_6	S_2	P_1	E_3	P_5
2016	E_6	S_2	P_1	E_3	P_2
2017	S_2	E_6	P_1	P_5	E_3
2018	S_2	P_1	P_2	P_5	E_1

As can be seen from Table 3, the main obstacles to the development of sustainable development system of Marine economy in Guangdong Province from 2007 to 2018 are the import and export of goods and the area of Marine nature reserves in coastal areas according to the location of business units. However, obstacles such as the comprehensive utilization of industrial solid waste per unit of gross Marine product, per capita consumption expenditure of urban residents in coastal areas, general public budget revenue in coastal areas and total waste water discharge cannot be ignored. However, in 2018, the main single indicator obstacle factors of the sustainable development system of Marine economy in

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Guangdong Province were the import and export volume of goods in coastal areas according to the location of the business unit, the total amount of wastewater discharge, the amount of water resources per capita, the amount of industrial smoke (powder) dust discharge and the area of wetlands. As can be seen from the above data, although Guangdong Province has actively carried out Marine environmental protection policies and testing measures in the early stage, but with the rapid economic development of coastal areas, the effectiveness of relevant policies and testing measures is not enough. In order to make the Marine economy of Guangdong Province develop sustainably, the influence of the rapid development of Marine economy on the Marine environment can be reduced through the rational utilization of Marine resources, the optimization of Marine industrial structure and the invention of Marine science and technology.

3.2.2. Criterion level obstacle degree analysis

In this paper, the obstacle degree model is used to calculate the obstacle degree of the four criterion layers of coercion, sensitivity, elasticity and adaptability respectively (Figure 3).

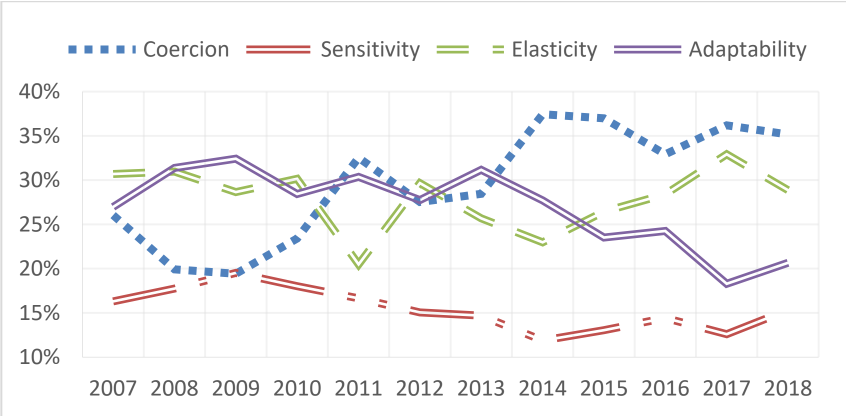

Figure 3: Criterion layer barrier degree of Marine economic system.

As can be seen from Figure 3, the criterion layer with the highest obstacle degree before 2014 is elasticity and adaptability, while the criterion layer with the highest obstacle degree from 2014 to 2018 is coercion. In 2018, the obstacle degree of the criterion layer of the Marine economic system of Guangdong Province was ranked as: coercion > elasticity > adaptability > sensitivity. We can see that with the rapid development of Marine economy, the Marine environment has also been affected to varying degrees. Therefore, the Marine economy of Guangdong Province should improve the ability of Marine environment management, pay more attention to the discharge of industrial sewage and industrial smoke (powder) dust in coastal areas, and reduce the impact on the Marine environment through Marine environment monitoring and other methods. We should pay attention to the stress subsystems, but also take into account the development of sensitivity, flexibility and adaptability subsystems, to achieve the common development of Marine economy and Marine environment.

4. Conclusion

Based on the comprehensive weights obtained by entropy weight method and analytic hierarchy process (AHP), TOPSIS model and obstacle degree model are adopted to evaluate and analyze the Marine economic system of Guangdong Province from 2007 to 2018. The conclusions are as follows:

1) The Marine economic system of Guangdong Province is ranked in order of comprehensive proximity: 2018 >2008 >2016 >2009 >2017 >2011 >2015 >2013 >2010 >2007 >2012>2014. However, in 2008 and 2013, the comprehensive proximity of the system showed a downward trend mainly due to the world economy and sewage discharge.

2) The sensitivity proximity in the criterion layer shows an increasing trend, and the coercion, resilience and adaptation proximity all have a large ups and downs phase in the corresponding years. By ranking the proximity of each criterion layer from 2007-2018 from largest to smallest it is seen that sensitivity has the greatest impact on the vulnerability of the system in 2014-2018, resilience has the greatest impact on the vulnerability of the system in 2011, and coercion has the greatest impact on the vulnerability of the system in the remaining years.

3) The criterion layer with greater barrier before 2014 is resilience and adaptability, and the greatest

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barrier in 2014-2018 is coercion. The ranking of the barrier of the criterion layer of the marine economic system of Guangdong Province in 2018 is in the order of: coercion > resilience > adaptability > sensitivity. The main barrier factors of the marine economic system of Guangdong Province in 2007-2018 are coastal areas by operating The amount of import and export of goods by location of units, and the area of marine nature reserve.

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