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Optimisation Study of Green Evaluation System of Port Logistics Considering Economic Development

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Abstract: To establish an evaluation system for the green development of ports, we integrated insights from multiple expert groups using a comprehensive evaluation method. The indicators were screened using the Spearman correlation coefficient and principal component analysis. Subsequently, an ANP model was adopted, and Super Decisions software was utilized to determine the weights of each indicator and construct the model. This model comprehensively evaluates both the economic and green development aspects of ports, providing accurate assessments of their green development status. This model comprehensively evaluates both the economic and green development aspects of ports, providing accurate assessments of their green development status. Additionally, the ideal solution method (TOPSIS) was employed to conduct empirical analysis on ten selected ports. The results indicate that Shanghai Port has largely achieved balanced economic and green development, while other ports exhibit issues in specific areas, aligning The results indicate that Shanghai Port has largely achieved balanced economic and green development, while other ports exhibit issues in specific areas, aligning with real-world observations. These findings validate the effectiveness of the evaluation model and offer recommendations for enhancing port green development. These findings validate the effectiveness of the evaluation model and offer recommendations for enhancing port green development.

Keywords:port green development;Spearman correlation coefficient;principal component analysis;ANP;TOPSIS

1 Introduction

In the context of the development of global economic integration, the continuous expansion of international trade has put forward higher requirements for port development. In order to achieve higher freight carrying capacity as well as to reduce the impact on the environment, China urgently needs to promote the construction of green ports and construct a perfect green port evaluation standard and evaluation system to promote the sustainable development of ports[1]. The establishment of green port evaluation index system needs to consider a variety of dimensions[2], analyse the impact of different factors on emission reduction[3], and can evaluate the degree of green development of ports based on the index system[4]. Wang Xi constructed a world-class green port indicator system through hierarchical analysis and applied it in Tianjin Port[5].Son Tung Le studied Vietnamese container ports using a variety of methods and found that cooperation and environmental regulation had the greatest impact on green port development[6].Ramos Velasco Eduardo studied the scenario of a green port in the context of fishing ports , using the example of Vigo Port in Spain[7].Perwira Mulia Tarigan A studied the selection of renewable energy sources for green ports using hierarchical analysis and concluded that solar energy is the best alternative energy source[8].

In the current academic and industrial world, the discussion on the evaluation system of green ports has attracted a lot of attention. Many researchers in this field mainly focus on the impact of port development on the natural environment. However, the research direction of this paper is different, and we are committed to constructing a more comprehensive and integrated green port evaluation system. In the process of designing the evaluation indicators, we not only consider environmental factors, but also integrate economic indicators, which is the first attempt to combine the green development of ports with economic growth. By adopting the ANP (Analytical Network Hierarchy) model, we are able to deeply analyse and assess the mutual influence between green development and economic development, as well as the feedback effect of economic growth on green development. This methodological innovation enables us to understand and evaluate the sustainable development capability of green ports in a more comprehensive way.

With the serious challenge of global climate change and the increasing awareness of environmental protection, the concept of green ports has gradually taken root in people's minds. Green ports not only require the reduction of environmental pollution and resource consumption in the operation process, but also need to take into account the improvement of economic efficiency, so as to achieve a harmonious symbiosis between ports and the environment. However, most of the current evaluation systems for port logistics focus on a single dimension, either emphasising economic benefits or environmental protection, and there is a lack of a comprehensive evaluation system to assess the green development of ports in a comprehensive manner. Therefore, this study aims to provide a scientific basis and decision support for the sustainable development of ports by constructing a green port logistics evaluation system that considers both economic development and environmental protection[9].

2 Construction of Green Port Evaluation Indicator System

This study strictly follows the principles of scientificity, systematicity, comprehensiveness and operability in the process of constructing the green port evaluation index system. Firstly, a series of potential indicators that may affect the green development of the port were initially screened out through literature review and expert consultation. These indicators include economic, environmental, social and other dimensions, aiming to comprehensively reflect the green development status of the port [10].

On the economic dimension, this study incorporates key indicators such as the port's throughput, cargo variety, economic efficiency, and operating costs, which collectively reflect the port's economic strength and operational efficiency. The port's throughput is an important data to measure the busyness of its business, while the diversity of cargo types reflects the port's business scope and market adaptability. Economic efficiency indicators reveal the profitability of the port, while operating costs are directly related to the financial health of the port. These indicators are not only key references for measuring the economic development of ports, but also the basis for evaluating the green development capability of ports [11].

On the environmental dimension, this study focuses on key indicators such as pollution emission, resource consumption and ecological impact of the port. These indicators directly reflect the negative impact of the port on the environment during operation and are key to evaluating the level of green development of the port. Pollution emission indicators include emissions of waste gas, waste water, solid waste, etc. Resource consumption indicators relate to the efficiency of energy use and the utilisation of raw materials, while ecological impact indicators focus on the damage that port activities may cause to the surrounding ecosystem. By monitoring and evaluating these indicators, it is possible to assess the extent and effectiveness of the port's efforts to protect the environment, and thus to promote the adoption of more environmentally friendly operational measures.

In addition, this study also incorporates indicators of social dimensions, such as the social contribution of ports, public satisfaction, and job creation. These indicators are not directly related to economic and environmental aspects, but they also have an important impact on the green development of ports. The social contribution of a port can be measured through its contribution to the local economy, improvement of social infrastructure, etc. Public satisfaction, on the other hand, reflects the quality of port services and the acceptance of port activities by the community. By assessing these indicators, it is possible to get a more comprehensive picture of the port's performance in terms of sustainable development and to ensure that the port's development is widely supported and recognised by the community.

After the initial screening of the indicators, this study further adopted Spearman correlation coefficient and principal component analysis to screen and optimise the indicators. Through the combined use of these two methods, a green port evaluation indicator system that is both concise and representative was finally determined. The system not only covers multiple aspects of green development of ports, but also fully considers the correlation and importance between different indicators, providing a solid foundation for the subsequent ANP model establishment[12].

2.1 Introduction to the indicator screening methodology

(1) Spearman correlation coefficient

Spearman correlation coefficient is a non-parametric statistical method, which is widely used to measure the rank correlation between two variables. In the process of constructing green port evaluation index system, Spearman correlation coefficient can play an important role, which can help us assess the degree of correlation between different indicators. Through this method, we can effectively screen out those indicators with lower correlation and stronger independence, so as to ensure the comprehensiveness and accuracy of the evaluation system. By calculating the Spearman correlation coefficient between indicators, we can identify those indicators that are highly correlated, avoiding repeated consideration of the same factor in the evaluation system, and thus improving the efficiency of evaluation. In addition, a significant advantage of the Spearman correlation coefficient is that it is not limited by the distribution pattern of data, which means that it is applicable to all types of data, whether they are normally or non-normally distributed. This feature makes the indicator screening process more flexible and extensive, and can be adapted to different data environments and research needs.

(2) Principal component analysis (PCA)

Principal Component Analysis, a mathematical technique widely used in the field of statistics, has as its core purpose to convert a set of variables that might otherwise be correlated with each other, by performing orthogonal transformations, into a new set of variables that are called principal components. These principal components are linearly uncorrelated, and they are arranged in the order of the magnitude of the variance of the data set they explain, with the principal component with the largest variance being able to contain the largest proportion of information in the original data set. In the process of constructing the green port evaluation index system, principal component analysis plays a crucial role, which is used to further refine and optimise the index set to ensure that the final evaluation system is both concise and efficient. By applying Principal Component Analysis to an in-depth analysis of the initially screened indicator set, the researcher is able to identify those indicators that contribute most significantly to the evaluation results, i.e., those major components. In this way, those redundant information can be effectively eliminated, thus enhancing the relevance and practicality of the entire evaluation system and ensuring a more accurate and efficient evaluation process.

2.2 Selection of indicators

Green port is an intricate system involving economic, social and ecological aspects, so it is crucial to construct a comprehensive indicator system in order to fully depict the development and change of the system. When constructing the evaluation system of green ports, there will be many options for selecting indicators; if too few indicators are selected, it will be more difficult to describe the state and change of the system; if too many indicators are selected, the reflection of the role of the key factors on the system will not be obvious enough; therefore, the following principles need to be followed in the selection of indicators for the evaluation system of green ports ([13]):

① Principles for development

The new development concept has become the core guidance for China's economic development, covering key areas such as sustainable, green and innovation-driven development. In implementing the new development concept, it is important to strike a balance between the improvement of the ecological environment, the efficient use of resources and the competitiveness and resilience of the economy, so as to prevent the pursuit of environmental friendliness alone from having a negative impact on economic development. In selecting relevant indicators, all aspects of port economic development and environmental impact should be comprehensively assessed to ensure that they fully reflect the interaction and balance between the economy and the environment.

② Feasibility principle

In the process of selecting indicators, it is important to ensure that the indicators selected are objective and comprehensive, while at the same time being simple and easy to quantify and measure. This is the only way to ensure that the quantification of indicators can be successfully achieved and to avoid difficulties in assessment due to overly complex or difficult to quantify indicators.

③ Scientific principle

In the process of selecting indicators for the economic and ecological selection of ports, it is important to ensure that the indicators are selected in strict accordance with scientific criteria and methodology. These indicators need to be able to comprehensively and objectively reflect the economic situation and ecological environment of the port as well as their characteristics of development and change. In addition, in order to ensure the accuracy and reliability of the results of the analyses, the data used must be authentic and reliable, and must never be dependent on subjective or inaccurate sources of information.

④ The principle of relevance

The principle of relevance is crucial in the selection of port development indicators, which need to be tailored to the specific circumstances of each port. Indicators should comprehensively reflect the geographic, economic and environmental needs of ports and accurately reflect their green and sustainable development. At the same time, the indicators should be quantifiable, so that they can be scientifically assessed through data and statistical methods.

At present, scholars from all walks of life have not yet reached a consensus on the selection of indicators for the green evaluation system of ports. In this paper, by consulting with experts in the field and referring to relevant literature [14-17], the evaluation system of green ports is established based on the overall objective and the scope covered by the evaluation system, which selects evaluation indicators from four aspects, including: green policy, green facilities, green transport and green benefits. benefits. The specific indicators are as follows (see Table I):

Table 1 Green port evaluation system indicators

Dimension	Target level	Indicator layer	Causality	Positive and negative
green concepts	green culture	strategic planning	qualitative	+

		programme of work	qualitative	+
		green port awareness	qualitative	+
		education and training coverage	qualitative	+
		prevalence of environmental publicity	qualitative	+
		percentage of environmental investment	quantitative	+
		port operations assessment	qualitative	+
	green management	incentive constraints on environmental practices	qualitative	+
		regulatory and evaluation mechanisms effectiveness	qualitative	+
		percentage of new projects with EIA	quantitative	+
		rate of pollution of water resources	quantitative	-
		cultivated land area as a percentage	quantitative	+
		percentage of wetland area	quantitative	+
		rate of change of species in marine areas	quantitative	-
		substitution rate for seawater resource use	quantitative	+
		energy consumption per unit of handling production	quantitative	-
	depletion of resources	energy consumption per unit of auxiliary production	quantitative	-
		energy consumption per unit of ancillary production	quantitative	-
		comprehensive energy consumption per unit of production	quantitative	-
green resource		energy consumption per unit of energy-using equipment	quantitative	-
		comprehensive energy consumption per unit	quantitative	-
		hydrodynamic effects	qualitative	-
		effects of suspended solids in water	qualitative	-
		sewage impact	qualitative	-
		acid rain frequency	quantitative	-
		carbon footprint	quantitative	-
		carbon intensity	qualitative	-
	environmental quality	production waste generation	quantitative	-
		domestic waste generation	quantitative	-
		hazardous solid waste generation	quantitative	-
		terrestrial ecosystem impacts	qualitative	-
		marine ecosystem impacts	qualitative	-
		impacts on ecologically sensitive areas	qualitative	-
green logistics	green facility	completeness rate of environmental	quantitative	+

		protection facilities		
		prevalence of green work processes	quantitative	+
		proportion of green energy use	quantitative	+
		automatic monitoring rate of key pollutant sources	quantitative	+
		pollutant acceptance capacity of ships in port	qualitative	+
		port logistics intelligence level	qualitative	+
		port emergency response system readiness rate	quantitative	+
		proportion of green means of transport	quantitative	+
		percentage of green cargo throughput	quantitative	+
	green transport	percentage of multimodal transport	quantitative	+
		marine evacuation capacity (mec)	qualitative	+
		road capacity	qualitative	+
		air excellence rate	quantitative	+
		noise compliance coverage	quantitative	+
		solid waste disposal rate	quantitative	+
		water environment excellence rate	quantitative	+
		ecological excellence rate	quantitative	+
	green development for efficiency	proportion of recycled resources recovered	quantitative	+
		protection of marine biodiversity	qualitative	+
		compliance rate for major pollutant emissions	quantitative	+
		risk of oil spills from ships in maritime areas	quantitative	+
green benefits		risk of accidental spills of dangerous goods	quantitative	+
		marine red tide disaster preparedness	quantitative	+
		contribution to employment expansion	quantitative	+
		human health hazards caused by pollution	quantitative	+
		temporary land reclamation rate	qualitative	+
		public satisfaction	qualitative	-
	economic development for efficiency	increase in cargo throughput	quantitative	+
		increase in containers	quantitative	+
		port gdp growth rate	qualitative	-
		increase in tertiary sector as a percentage	qualitative	-
		increase in agriculture, forestry and fisheries as a percentage	qualitative	+

*"+" represents positive indicators, "-" represents negative indicators.

2.3 Indicator screening

After initially constructing the framework of the green development indicator system, in order to ensure the scientific and practicality of the indicator system, it is necessary to carry out a meticulous screening of indicators. The main purpose of this process is to eliminate those redundant, repetitive, or difficult to obtain data in actual operation. At the same time, we also need to retain those key indicators that most accurately reflect the state of green development of ports and are highly representative. Through this screening process, we can ensure that the final indicator system is both comprehensive and refined, and can provide strong data support and decision-making basis for the green development planning of ports [18].

2.3.1 Initial screening of indicators

Considering that the indicators are divided into qualitative and quantitative indicators, the indicators need to be processed. This paper adopts the expert scoring method to score the qualitative indicators, and invites the relevant practitioners of the green research institute department of an enterprise to score the relevance of each indicator to the green evaluation of the port, with the scoring interval of 1-10 points, 1 being completely irrelevant and 10 being completely relevant; because the Spearman correlation coefficient is based on the rank order of the numbers, and it is not sensitive to the specific value of the data itself, so no additional processing is needed for the quantitative indicators. indicators no additional processing is required. These data are organised into the form of a matrix for calculation, with the specific formula:

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)}, \quad (1)$$

whered_i denotes the difference between the ranks of the two variables and$n$ denotes the sample size.

The Spearman correlation coefficients between each variable and the target variable were calculated, and then the correlation matrix between the indicators was generated and then screened. The absolute value of correlation coefficientρ is more than 0.8, which means that the degree of correlation is high, there is a high rate of information repetition, and duplicated indicators will be excluded; the absolute value of correlation coefficientρ is less than 0.3, which means that the indicators are not correlated, there may be anomalies in the indicators, and the indicators under the same factor layer characterise the same factor, and the lack of correlation indicates that there is no significance of the same factor, and the weakly correlated indicators will be excluded. Meanwhile, for qualitatively important indicators, if the correlation is low but the expert score is high, it can also be retained appropriately. Forty-seven indicators were retained in the first indicator screening, and the results are shown in table II:

Table 2. Green port evaluation system indicators

Dimension	Target level	Indicator layer	Causality	Positive and negative
green concepts	green culture	strategic planning	qualitative	+
		programme of work	qualitative	+
		green port awareness	qualitative	+
		education and training coverage	qualitative	+
	green management	incentive constraints on environmental practices	qualitative	+
		regulatory and evaluation mechanisms effectiveness	qualitative	+
		percentage of new projects with eia	quantitative	+
green resource	depletion of resources	rate of pollution of water resources	quantitative	-
		cultivated land area as a percentage	quantitative	+
		percentage of wetland area	quantitative	+
		rate of change of species in marine areas	quantitative	-
		substitution rate for seawater resource use	quantitative	+
		comprehensive energy consumption per	quantitative	-

		unit		
		energy consumption per unit of energy-using equipment	quantitative	-
		hydrodynamic effects	qualitative	-
		effects of suspended solids in water	qualitative	-
		sewage impact	qualitative	-
		carbon footprint	quantitative	-
		carbon intensity	qualitative	-
	environmental quality	production waste generation	quantitative	-
		domestic waste generation	quantitative	-
		hazardous solid waste generation	quantitative	-
		terrestrial ecosystem impacts	qualitative	-
		marine ecosystem impacts	qualitative	-
		impacts on ecologically sensitive areas	qualitative	-
green logistics	green facility	completeness rate of environmental protection facilities	quantitative	+
		prevalence of green work processes	quantitative	+
		proportion of green energy use	quantitative	+
		port logistics intelligence level	qualitative	+
		port emergency response system readiness rate	quantitative	+
	green transport	proportion of green means of transport	quantitative	+
		percentage of green cargo throughput	quantitative	+
		percentage of multimodal transport	quantitative	+
green benefits	green development benefits	air excellence rate	quantitative	+
		noise compliance coverage	quantitative	+
		solid waste disposal rate	quantitative	+
		water environment excellence rate	quantitative	+
		ecological excellence rate	quantitative	+
		proportion of recycled resources recovered	quantitative	+
		risk of accidental spills of dangerous goods	quantitative	+
		marine red tide disaster preparedness	quantitative	+
	economic development benefits	contribution to employment expansion	quantitative	+
		temporary land reclamation rate	qualitative	+
		public satisfaction	quantitative	+
		increase in cargo throughput	quantitative	+
		port gdp growth rate	qualitative	-
		increase in tertiary sector as a percentage	qualitative	+

2.3.2 Fine screening of indicators

In this study, Principal Component Analysis (PCA) will be used in combination with Spearman's correlation coefficient method to further optimise the evaluation index system of green ports. By analysing the port-related data in the last decade, PCA can help identify the key factors that are most influential to the green performance of the port, thus providing data support and decision-making basis for the green transformation and sustainable development of the port, the specific steps are as follows:

① Calculate the matrix of correlation coefficients between variables

After passing the applicability test of principal component analysis, the correlation coefficient matrix R of the retained indicators within each target stratum was calculated, where n is the number of retained indicators within each target stratum of the initial screening of the indicator:

$$R = \begin{pmatrix} r_1^1 & \cdots & r_n^1 \\ \vdots & \ddots & \vdots \\ r_1^n & \cdots & r_n^n \end{pmatrix}, \quad (2)$$

② Calculate eigenvalues and eigenvectors

Find the eigenvalues of the correlation coefficient matrix R using Jacobi's method, i.e. $|R - \lambda_i| = 0$:

$$\begin{pmatrix} r_1^1 - \lambda & \cdots & r_n^1 \\ \vdots & \ddots & \vdots \\ r_1^n & \cdots & r_n^n - \lambda \end{pmatrix} = 0, \quad (3)$$

where λ_i represents the raw information content contained in the ith principal component, and the obtained eigenvalues will be sorted by the size of the smooth

Arrange $\lambda_1 \geq \lambda_i \geq \cdots \geq \lambda_p \geq 0$; Calculate the eigenvector corresponding to each eigenvalue λ_i $.e_i(i = 1,2,\cdots,p)$

③ Calculation of principal component contribution and cumulative contribution

The formula for calculating the contribution margin is as follows:

$$\frac{\lambda_i}{\sum_{i=1}^{p} \lambda_i}, \quad (4)$$

The formula for calculating the cumulative contribution margin is as follows:

$$\frac{\sum_{i=1}^{p} \lambda_i}{\sum_{i=1}^{l} \lambda_i}, \quad (5)$$

Using the above formula for principal components, the cumulative contribution of the current l principal components reached 85 %

When the first l principal components are extracted. At this point, λ_1 is called the 1st principal component, λ_2 is called the 2nd principal component, and so on.

Push, λ_i is called the l principal component.

④ Calculate principal component loadings

O_{ij} is the factor loading of the i th principal component on the j th indicator $(i = 1,2,\cdots p, j = 1,2,\cdots n)$, and the factor loading matrix is calculated as follows:

$$O_{ij} = p(z_i, x_j) = \sqrt{\lambda_i} e_{ij}, \quad (6)$$

Based on the factor loadings in the factor loading matrix O_{ij} screening indicators, the following principles of fine screening were determined:

(1) Indicators with factor loadings O_{ij} absolute values greater than 0.9 in the 1st principal component were retained;

(2) Retain the indicator with the largest absolute value of the factor loading O_{ij} in the 2nd,3rd...,l principal component.

The applicability test of principal component analysis is carried out with each target layer as a unit, and the test results are all passed, so the indicators can be finely screened using principal component analysis. According to the principle of fine screening, to determine the indicators of fine screening results, the final screening to 24 indicators, see Table 3:

Table 3. Green port evaluation system indicators

Target level	Indicator layer	Causality	Positive and negative
green concepts	green port awareness	qualitative	+
	incentive constraints on environmental practices	qualitative	+
	regulatory and evaluation mechanisms effectiveness	qualitative	+
	percentage of new projects with eia	quantitative	+
green resource	terrestrial ecosystem impacts	qualitative	-
	comprehensive energy consumption per unit	quantitative	-
	carbon footprint	quantitative	-
	marine ecosystem impacts	qualitative	-
green logistics	completeness rate of environmental protection facilities	quantitative	+
	prevalence of green work processes	quantitative	+
	proportion of green energy use	quantitative	+
	port logistics intelligence level	qualitative	+
	port emergency response system readiness rate	quantitative	+
	percentage of green cargo throughput	quantitative	+
	percentage of multimodal transport	quantitative	+
green benefits	noise compliance coverage	quantitative	+
	solid waste disposal rate	quantitative	+
	water environment excellence rate	quantitative	+
	proportion of recycled resources recovered	quantitative	+
	increase in cargo throughput	quantitative	+
	port gdp growth rate	quantitative	+
	contribution to employment expansion	qualitative	+
	temporary land reclamation rate	quantitative	+
	public satisfaction	quantitative	+

After the initial screening of indicators using Spearman's correlation dilution, the optimised and screened indicator system shows significant advantages in avoiding redundancy and repetitive information, achieving a streamlined and efficient evaluation system. Through the detailed screening of principal component analysis, the key factors that have a decisive impact on the green development of ports are retained, thus significantly improving the accuracy and effectiveness of the evaluation process. This process not only reduces the complexity and workload of the evaluation, but also ensures the scientificity and reliability of the evaluation results.

3 Establishment of ANP model for green port evaluation system

3.1 Introduction to the ANP model

ANP (Analytic Network Process) model is a network analysis method used to deal with complex decision-making problems, proposed by Thomas L. Saaty in 1996, which is based on the hierarchical analysis method, and is an effective tool for in-depth analysis of non-independent hierarchical structures.The ANP model replaces the hierarchical structure with a network structure and adds a feedback mechanism compared with AHP model. model, it replaces the hierarchical structure with a network structure and adds a feedback mechanism, and the ANP model not only takes into account the dominant role of the network layer on the control layer, but also takes into account the mutual influences between groups of elements.When dealing with multi-indicator decision-making problems, the ANP model gives full consideration to the interdependence between indicators and the problem of weight allocation, and has strong practicality and reliability [19].

3.2 Constructing the ANP model

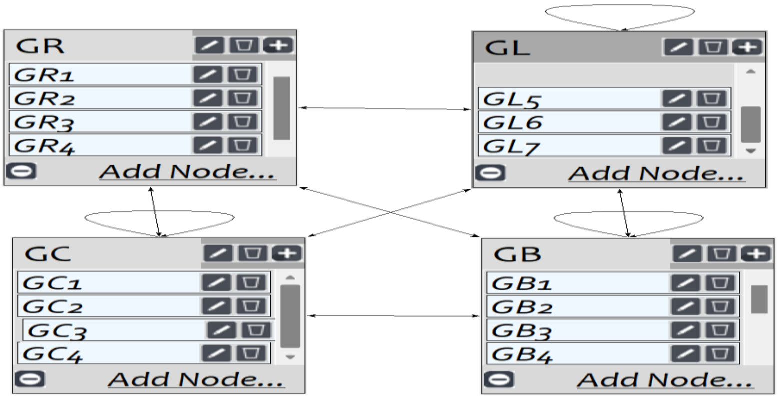
When constructing the ANP model for the green port evaluation system, the control layer and network layer need to be clarified. The control layer includes objectives and decision criteria, and the network layer is the group of elements and their interrelated network structure. The objective layer of the green port evaluation system evaluates the comprehensive performance of green ports without a criterion layer, and the network layer covers four aspects: green concept, resources, logistics and benefits. These four aspects are interrelated and form a complex network structure from which indicators are established (see Table 4):

Table 4. Green port evaluation system indicators

Target level	Indicator layer
green concepts (GC)	green harbour awareness (GC1)
	environmental practices incentive constraints (GC2)
	regulatory and assessment mechanisms effectiveness (GC3)
	proportion of new projects with eia (GC4)
green resources (GR)	terrestrial ecosystem impacts (GR1)
	comprehensive energy consumption per unit (GR2)
	carbon emissions (GR3)
	ecological impacts in marine areas (GR4)
green logistics (GL)	completeness rate of environmental protection facilities (GL1)
	prevalence of green work processes (GL2)
	proportion of green energy use (GL3)
	port logistics intelligence level (GL4)
	port emergency response system readiness rate (GL5)
	green cargo throughput share (GL6)
	share of multimodal transport (GL7)
green benefits (GB)	noise compliance coverage (GB1)
	solid waste disposal rate (GB2)
	water environment excellence rate (GB3)
	recycling ratio (GB4)
	increase in cargo throughput (GB5)
	port gdp growth rate (GB6)
	contribution to employment expansion (GB7)
	temporary site reclamation rate (GB8)
	public satisfaction (GB9)

After identifying the groups of elements and their interrelationships, the ANP model of the green port evaluation system is operated using Super Decision software (SD software for short). This paper includes four first-level indicators and twenty-one second-level indicators, all of which are network-level elements, and the dependence and feedback relationship between the elements is shown in Figure 1 (some of the second-level indicators are not shown due to software limitations).

Fig.1. Network structure diagram of green port evaluation system



3.2 Construction of unweighted matrices

In the green port evaluation system, the first level indicator set$S_I = (S_1, S_2, S_3, S_4)$, whereS_1, S_2, S_3, S_4 represents the green concept, green resources, green logistics and green benefits, respectively, and the second level indicator set$S_{II} = (S_{I1}, S_{I2}, \cdots, S_{IJ})$, whereS_{IJ} represents the second level indicatorj under the first level indicatori in the indicator set. Therefore, the unweighted matrix obtained in this paper is a 15×15 matrix consisting of a 4×4 fourth-order square matrix. In constructing the unweighted supermatrix, it is necessary to establish the relative importance (weights) of the groups of elements and between their elements. The weights can be obtained through expert assessment, questionnaire survey, and statistical analysis. In the green port evaluation system, the weights of the first-level and second-level indicators can be determined by the above methods. Then, taking the elements in the first-level element setS_I as the main criterion and the elements in the element groupS_{ji} as the sub-criteria$(j = 1,2,3,4; i = 1,2,\cdots,n)$, based on whether the two elements in the second-level indexes affect each other or not, the judgement matrix is constructed and the normalized eigenvectors are calculated, so that the chunking matrix of the un-weighted supermatrix can be derivedw_{ij} , and by combining allw_{ij} , the un-weighted matrix can be obtained$w$. Using SD software to operate and solve the ANP model of the green port evaluation system, the unweighted matrix can be obtained (see Figure 2).

$$w_{ij} = \begin{vmatrix} w_{i1}^{j1} & \cdots & w_{i1}^{jn} \\ \vdots & \ddots & \vdots \\ w_{in}^{j1} & \cdots & w_{in}^{jn} \end{vmatrix} \qquad w = \begin{vmatrix} w_{11} & \cdots & w_{1n} \\ \vdots & \ddots & \vdots \\ w_{n1} & \cdots & w_{nn} \end{vmatrix}, \quad (7)$$

Fig.2. Unweighted matrix results based on SD software

Clusters	Nodes	GB1	GB2	GB3	GB4	GB5	GB6	GB7	GB8	GB9	GC1
GB	GB1	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB4	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB5	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB6	0.000000	0.000000	0.000000	0.000000	0.666667	0.000000	0.000000	0.000000	0.000000	0.000000
	GB7	0.000000	0.000000	0.000000	0.000000	0.333333	1.000000	0.000000	0.000000	0.000000	0.000000
	GB8	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB9	1.000000	0.000000	1.000000	0.000000	0.000000	0.000000	1.000000	1.000000	0.000000	0.000000
GC	GC1	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.333333	0.000000
	GC2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.500000
	GC3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.666667	0.500000
	GC4	0.000000	0.000000	0.000000	0.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000
GL	GL1	0.000000	0.000000	0.000000	0.000000	0.000000	0.270707	0.000000	0.000000	0.000000	0.000000
	GL2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GL3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GL4	0.000000	0.000000	0.000000	0.000000	0.000000	0.120500	0.000000	0.000000	0.000000	0.000000
	GL5	0.000000	0.000000	0.000000	0.000000	0.000000	0.418161	0.000000	0.000000	0.000000	0.000000
	GL6	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GL7	0.000000	0.000000	0.000000	0.000000	0.000000	0.190632	0.000000	0.000000	0.000000	0.000000
GR	GR1	0.000000	0.666667	0.000000	0.333333	0.000000	0.000000	0.000000	0.666667	0.000000	0.000000
	GR2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GR3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GR4	0.000000	0.333333	1.000000	0.666667	0.000000	0.000000	0.000000	0.333333	0.000000	0.000000

* Space constraints have limited the presentation of only some of the results

3.3 Construction of the weighting matrix

After finding the unweighted matrix, the SD software can be used to find the weighted matrix $\overline{w}$, the specific results of the operation are shown in Fig. 3, the sum of the elements of each column of the matrix is 1.

$$\overline{\mathrm{w}} = \begin{vmatrix} \overline{w}_{11} & \cdots & \overline{w}_{1n} \\ \vdots & \ddots & \vdots \\ \overline{w}_{n1} & \cdots & \overline{w}_{nn} \end{vmatrix}, \quad (8)$$

Fig.3. Weighted matrix results based on SD software

Clusters	Nodes	GB1	GB2	GB3	GB4	GB5	GB6	GB7	GB8	GB9
GB	GB1	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB4	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB5	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB6	0.000000	0.000000	0.000000	0.000000	0.666667	0.000000	0.000000	0.000000	0.000000
	GB7	0.000000	0.000000	0.000000	0.000000	0.333333	0.178219	0.000000	0.000000	0.000000
	GB8	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GB9	1.000000	0.000000	0.657913	0.000000	0.000000	0.000000	1.000000	0.657913	0.000000
GC	GC1	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.333333
	GC2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GC3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.666667
	GC4	0.000000	0.000000	0.000000	0.000000	0.000000	0.288929	0.000000	0.000000	0.000000
GL	GL1	0.000000	0.000000	0.000000	0.000000	0.000000	0.144247	0.000000	0.000000	0.000000
	GL2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GL3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GL4	0.000000	0.000000	0.000000	0.000000	0.000000	0.064209	0.000000	0.000000	0.000000
	GL5	0.000000	0.000000	0.000000	0.000000	0.000000	0.222818	0.000000	0.000000	0.000000
	GL6	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GL7	0.000000	0.000000	0.000000	0.000000	0.000000	0.101579	0.000000	0.000000	0.000000
GR	GR1	0.000000	0.666667	0.000000	0.333333	0.000000	0.000000	0.000000	0.228058	0.000000
	GR2	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GR3	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	GR4	0.000000	0.333333	0.342087	0.666667	0.000000	0.000000	0.000000	0.114029	0.000000

* Space constraints have limited the presentation of only some of the results

3.4 Solving the Limit Matrix

After obtaining the weighting matrix, the SD software can be applied to further calculate the limit matrix and stabilising weight vector (see Figure 4 and Table 5 for details).

Fig.4. The result of limit matrix based on SD software

Clusters	Nodes	GB1	GB2	GB3	GB4	GB5	GB6	GB7	GB8	GB9
GB	GB1	0.024085	0.024085	0.024085	0.024085	0.024085	0.024085	0.024085	0.024085	0.024085
	GB2	0.022771	0.022771	0.022771	0.022771	0.022771	0.022771	0.022771	0.022771	0.022771
	GB3	0.042196	0.042196	0.042196	0.042196	0.042196	0.042196	0.042196	0.042196	0.042196
	GB4	0.015085	0.015085	0.015085	0.015085	0.015085	0.015085	0.015085	0.015085	0.015085
	GB5	0.008890	0.008890	0.008890	0.008890	0.008890	0.008890	0.008890	0.008890	0.008890
	GB6	0.016885	0.016885	0.016885	0.016885	0.016885	0.016885	0.016885	0.016885	0.016885
	GB7	0.009015	0.009015	0.009015	0.009015	0.009015	0.009015	0.009015	0.009015	0.009015
	GB8	0.038083	0.038083	0.038083	0.038083	0.038083	0.038083	0.038083	0.038083	0.038083
	GB9	0.147837	0.147837	0.147837	0.147837	0.147837	0.147837	0.147837	0.147837	0.147837
GC	GC1	0.065671	0.065671	0.065671	0.065671	0.065671	0.065671	0.065671	0.065671	0.065671
	GC2	0.036920	0.036920	0.036920	0.036920	0.036920	0.036920	0.036920	0.036920	0.036920
	GC3	0.175907	0.175907	0.175907	0.175907	0.175907	0.175907	0.175907	0.175907	0.175907
	GC4	0.041360	0.041360	0.041360	0.041360	0.041360	0.041360	0.041360	0.041360	0.041360
GL	GL1	0.024127	0.024127	0.024127	0.024127	0.024127	0.024127	0.024127	0.024127	0.024127
	GL2	0.027921	0.027921	0.027921	0.027921	0.027921	0.027921	0.027921	0.027921	0.027921
	GL3	0.021745	0.021745	0.021745	0.021745	0.021745	0.021745	0.021745	0.021745	0.021745
	GL4	0.029328	0.029328	0.029328	0.029328	0.029328	0.029328	0.029328	0.029328	0.029328
	GL5	0.005847	0.005847	0.005847	0.005847	0.005847	0.005847	0.005847	0.005847	0.005847
	GL6	0.019911	0.019911	0.019911	0.019911	0.019911	0.019911	0.019911	0.019911	0.019911
	GL7	0.007341	0.007341	0.007341	0.007341	0.007341	0.007341	0.007341	0.007341	0.007341
GR	GR1	0.075967	0.075967	0.075967	0.075967	0.075967	0.075967	0.075967	0.075967	0.075967
	GR2	0.035444	0.035444	0.035444	0.035444	0.035444	0.035444	0.035444	0.035444	0.035444
	GR3	0.024165	0.024165	0.024165	0.024165	0.024165	0.024165	0.024165	0.024165	0.024165
	GR4	0.083497	0.083497	0.083497	0.083497	0.083497	0.083497	0.083497	0.083497	0.083497

* Space constraints have limited the presentation of only some of the results

Table5. Stable weight vector based on SD software

Target level	Indicator layer	Local weight	Global weight	Group weight
green concepts (GC)	green harbour awareness (GC1)	0.35	0.08	0.22
	environmental practices incentive constraints (GC2)	0.16	0.04	
	regulatory and assessment mechanisms effectiveness (GC3)	0.11	0.02	
	proportion of new projects with eia (GC4)	0.38	0.08	
green resources (GR)	terrestrial ecosystem impacts (GR1)	0.21	0.06	0.31
	comprehensive energy consumption per unit (GR2)	0.12	0.04	
	carbon emissions (GR3)	0.55	0.17	
	ecological impacts in marine areas (GR4)	0.13	0.04	
green logistics (GL)	completeness rate of environmental protection facilities (GL1)	0.18	0.02	0.14
	prevalence of green work processes (GL2)	0.20	0.03	
	proportion of green energy use (GL3)	0.16	0.02	
	port logistics intelligence level (GL4)	0.22	0.03	
	port emergency response system readiness rate (GL5)	0.04	0.01	
	green cargo throughput share (GL6)	0.15	0.02	
	share of multimodal transport (GL7)	0.05	0.01	
green benefits (GB)	noise compliance coverage (GB1)	0.07	0.02	0.33
	solid waste disposal rate (GB2)	0.07	0.02	
	water environment excellence rate (GB3)	0.13	0.04	
	recycling ratio (GB4)	0.05	0.02	
	increase in cargo throughput (GB5)	0.03	0.01	
	port gdp growth rate (GB6)	0.05	0.02	
	contribution to employment expansion (GB7)	0.03	0.01	
	temporary site reclamation rate (GB8)	0.12	0.04	
	public satisfaction (GB9)	0.46	0.15	

Next, we will rank and assess the green port evaluation system based on the weight vector. The first-level indicators are sorted: green benefit > green concept > green resources > green logistics. The second-level indicators are also sorted, and finally the complete sorting is obtained to provide decision support for the construction of green ports.

The ANP model can be solved to get the weights of the indicators and rank them, providing scientific decision support for green port construction. The model can also dynamically adjust the weights to adapt to changes in the evaluation system.

The green port evaluation system constructed based on the ANP model in this study comprehensively and scientifically assesses the weights of primary and secondary indicators, optimises the construction and development strategies, and helps the development of green ports. The evaluation system will continue to be improved in the future to provide stronger support for the sustainable development of green ports [20].

4. Empirical analyses and results

4.1 Evaluation process

According to the indicators of green port evaluation system, ten representative ports in China are selected as research objects, namely: Shanghai Port, Beibu Gulf Port, Tianjin Port, Qingdao Port, Ningbo Zhoushan Port, Guangzhou Port, Suzhou Port, Tangshan Port, Nantong Port and Lishui Port. The development of these ports is in a leading position in China, and at the same time, they have certain differences and representativeness in terms of geographic location, port size, and cargo volume. After collecting the relevant data of each port, the constructed ANP model and weighting matrix are used to calculate the scores and rankings of each port in the four aspects of green resources, green concept, green logistics and green benefits. Finally, based on the scores and ranking results, the green development level of each port is analysed and targeted improvement suggestions are put forward.

4.2 Data sources and processing

The source of data is mainly with the Delphi method, after collecting the official website of each port, annual reports, and data released by the environmental protection department, the quantitative indicators are directly adopted from the original data, and the qualitative indicators and evaluation criteria are handed over to the experts and invited to be scored by the experts, and the evaluation criteria for the qualitative indicators are as follows:

1. Green Port Awareness

High (90-100 points): port management and staff have in-depth understanding and knowledge of the green port concept, and actively participate in the practice of green port construction; Medium (60-89 points): port management and staff have some understanding of the green port concept, but there are still deficiencies in the specific practice; Low (0-59 points): port management and staff do not have sufficient knowledge of the green port concept, and less integration of green factors in the actual operation. Low (0-59): port management and staff are not aware of the green port concept, and less green factors are incorporated in the actual operation.

2. Incentive constraints on environmental practices

High (90-100 points): the port has constructed a complete system of incentives and constraints for environmental protection, which significantly promotes the process of green port construction; Medium (60-89 points): the port has certain incentives and constraints for environmental protection, but their implementation and effectiveness need to be further strengthened; Low (0-59 points): the port lacks incentives and constraints for environmental protection, which leads to a lack of motivation for green port construction.

3. Regulatory and evaluation mechanisms effectiveness

High (90-100 points): the port has constructed an efficient supervision and assessment system, and is able to identify and solve problems in the process of green port construction in real time; Medium (60-89 points): there are deficiencies in the port's supervision and assessment system, which need to be further optimised; Low (0-59 points): the port has not yet formed an effective supervision and assessment system, and there is insufficient safeguard for the construction of green ports.

4. Terrestrial ecosystem impacts

High (90-100 points): the port has implemented effective strategies in land-based ecological environmental protection, with excellent ecological quality and minimal impact on the neighbouring areas; Medium (60-89 points): the port has taken certain measures in land-based ecological environmental protection, but the ecological quality of some areas is still unsatisfactory or has a certain impact on the neighbouring areas; Low (0-59 points): the port has Low (0-59 points): the port has taken insufficient measures to protect the ecological environment in the land area, and the quality of the ecological environment is worrying and has significant negative impacts on the neighbouring areas.

5. Marine ecosystem impacts

High (90-100 points): the port has achieved remarkable results in marine ecological environmental protection, the water quality of the sea area is kept clear, the biodiversity is extremely rich, and the impact on the marine ecosystem is minimal; Medium (60-89 points): the port has taken certain measures in marine ecological environmental protection, but there are still some problems with the marine ecological environment, such as the decline of water quality in some areas or the reduction of biodiversity; Low (0-59 points): the port has serious problems in marine ecological environment protection, poor water quality in the sea area, loss of biodiversity, and serious damage to the marine ecosystem.

6. Port Logistics Intelligence Level

High (90-100 points): the port logistics system shows a high degree of intelligent features, with a significant level of automated operations and excellent data integration and analysis capabilities, significantly improving logistics efficiency and service quality; Medium (60-89 points): the port logistics system is in the stage of intelligent transformation, with automated operations in some parts of the system, but the data integration and analysis capabilities still need to be further improved; Low (0-): the port logistics system has a low level of intelligence, with a limited degree of automated operations and insufficient data integration and analysis capabilities, negatively affecting logistics efficiency and service quality. 59 points): the port logistics system has a low level of intelligence, limited automated operations, and insufficient data integration and analysis capabilities, which have a negative impact on logistics efficiency and service quality.

7. Contribution to employment expansion

High (90-100 points): The construction and expansion of the port has contributed significantly to the prosperity of the job market in the neighbouring region, creating many employment opportunities. At the same time, the construction of the green port also promotes the development of environmental protection industry, which further broadens employment channels; Medium (60-89 points): the port has made some efforts to promote employment, but the magnitude of employment growth and the quality of jobs need to be improved, and there is a need to strengthen the synergistic effect with the industries in the neighbouring regions; Low (0-59 points): the effectiveness of the port's construction in promoting employment is limited, and it has not been able to stimulate the employment growth of the neighbouring regions effectively. employment growth, in-depth reflection and adjustment of port development strategies are needed to more effectively serve the sustainable development of the local economy.

After obtaining the experts' scores on the ten qualitative indicators of the ports, the data were processed and the ports were ranked using the TOPSIS method in the following steps:

In the first step, the obtained data are listed as a decision matrixx_{mt} and the data in it are normalised to obtain a new matrixX_{mt} . X_{mt}represents the normalised value of the tth indicator for the mth port:

$$X_{mt} = \frac{x_{mt} - min(x_t)}{max(x_t) - min(x_t)}, \tag{9}$$

In the second step, the obtained normalisation matrixX_{mt} is weighted by multiplying it with the indicator weight matrix to obtain the weighted normalisation matrixY_{mt} :

$$Y_{mt} = R_q X_{mt} = \begin{vmatrix} y_{11} & \cdots & y_{1t} \\ \vdots & \ddots & \vdots \\ y_{m1} & \cdots & y_{mt1} \end{vmatrix}, \tag{10}$$

In the third step, the optimal and inferior solutions are determined, and the positive and negative ideal solutionsY^+ ,Y^- , whose values consist of the maximum and minimum values in each column of the matrixY_{mt} , respectively, are computed:

$$Y^+ = max\{Y_{m1}, Y_{m2} \cdots Y_{mt}\}, \tag{11}$$

$$Y^- = min\{Y_{m1}, Y_{m2} \cdots Y_{mt}\}, \tag{12}$$

In the fourth step, the distance between each port to be evaluated and the positive and negative ideal solutions is calculatedD_i^+ ,D_i^- :

$$D_i^+ = \sqrt{\sum_{j=1}^{m} \left(y_{ij} - Y_j^+\right)^2}, \quad i = 1,2 \cdots m, \tag{13}$$

$$D_i^- = \sqrt{\sum_{j=1}^{m} \left(y_{ij} - Y_j^-\right)^2}, \quad i = 1,2 \cdots m, \tag{14}$$

In the fifth step, the affinement of each port to be evaluated to the ideal solution is calculatedC_i :

$$C_i = \frac{D_i^-}{D_i^+ + D_i^-}, \quad i = 1,2 \cdots m, \tag{15}$$

In the sixth step, the results are sorted according to the size of the value ofC_i (see Table 6), the largerC_i is, the closer the port is to the optimal solution and the higher its green development level, and vice versa, the lower it is.

Table 6. The relative progress of green development level of ten ports

harbours	C	harbours	C
Shanghai port	0.9264	Guangzhou port	0.717
Gulf of Tonkin port	0.4701	Suzhou port (Suzhou, PRC state capital)	0.6396

TPD	0.7296	Tangshan port	0.7907
Qingdao port, subprovincial city in Shandong	0.7241	Nantong Port	0.5502
Ningbo Zhoushan Port	0.8776	Lishui port city in Zhejiang	0.6281

4.3 Empirical results and analyses

In terms of overall score, the Port of Shanghai performed the best in terms of green development, with an overall score of 0.9264, followed by the Port of Guangzhou, the Port of Tianjin and the Port of Qingdao. Ningbo Zhoushan Port ranked fifth with a score of 0.8776. Beibu Gulf Port and Nantong Port scored lower, while Suzhou Port, Tangshan Port and Lishui Port scored medium. The ports performed well in green benefits and were deficient in green logistics. It is recommended that ports strengthen environmental protection facilities, improve logistics intelligence, and enhance cooperation to promote green development. As verified by empirical analyses, the model of this study coincides with the real facts, thus confirming the scientificity and feasibility of the model.

5 Conclusions and recommendations

5.1 Conclusion

When assessing complex relationships, the Analytical Network Method (ANP) shows its unique advantages, ensuring the objectivity and scientificity of the assessment process. By combining the ANP method with the Approximate Ideal Solution Sorting (TOPSIS) method, the weighted TOPSIS method is used to assess the green development level of the port, revealing the correlation between the evaluation indicators and effectively reducing the influence of subjective factors. The constructed evaluation model has a high degree of coincidence in assessing regional logistics development capability, showing its strong applicability and scientific basis.

The level of greening of ports is influenced by a combination of key factors such as green policies, facilities, transport and efficiency, and is an important underpinning of sustainable port development. The performance of ports in these four areas varies from port to port and therefore needs to be strengthened on a case-by-case basis. The development of green ports has become an important trend as it contributes to economic efficiency, environmental protection and sustainable development.

This study is of great theoretical and practical significance for promoting the green development and sustainable development of port logistics. It not only deepens our understanding of the multidimensional influencing factors of green development in ports, but also provides a solid theoretical foundation for the formulation of more precise and effective green port development strategies. Looking into the future, as the construction of green ports continues to advance, we have reason to believe that more ports will make more significant achievements in environmental protection, economic development and the realisation of sustainable development goals. This will not only bring long-term benefits to the ports themselves, but also make positive contributions to global environmental protection and economic development [21].

5.2 Recommendations

The level of greening of ports is influenced by a combination of key factors such as green policies, facilities, transport and efficiency, and is an important underpinning of sustainable port development. The performance of ports in these four areas varies from port to port and therefore needs to be strengthened on a case-by-case basis. The development of green ports has become an important trend as it contributes to economic efficiency, environmental protection and sustainable development.

Government departments should enhance the publicity effect of environmental protection policies, raise the environmental awareness of port enterprises and ensure the effective implementation of green policies. Port enterprises should increase investment, introduce advanced green facilities and technologies, and enhance green transport capacity. Inter-port cooperation should be strengthened to popularise green transport means, such as river-sea intermodal transport and multimodal transport, so as to reduce costs and enhance benefits. Port enterprises should pay attention to green benefits and improve overall benefits from environmental protection, energy saving and emission reduction. China's ports should take the initiative to participate in the construction of international green ports, learn from experience and promote global sustainable development. Green development is the core of development in the port sector, and the government and port enterprises should work together to increase investment and policy support, enhance the level of green development in China's ports, and contribute to the construction of green ports around the world.

In addition, the green port evaluation system and optimisation strategies proposed in this study provide scientific decision-making support for port management and indicate the direction of how to effectively balance the relationship between economic development and environmental protection in practice. By implementing these strategies, ports can ensure steady growth in economic benefits while minimising negative impacts on the environment and achieving green transformation. Specifically, ports can gradually build an efficient, environmentally friendly and sustainable green port model through measures such as optimising resource allocation, promoting clean energy and enhancing logistics efficiency.

At the same time, the evaluation system also provides useful references and lessons for the green development of other industries or regions. Whether it is the manufacturing industry, the logistics industry or urban planning, they can learn from the experience and formulate a more scientific and reasonable green development path in the light of their own actual situation. Such cross-industry reference and application will undoubtedly help promote the green transformation process of the whole society.

In summary, this study is of great theoretical and practical significance for promoting the green development and sustainable development of port logistics. It not only deepens our understanding of the multidimensional influencing factors of green development in ports, but also provides a solid theoretical foundation for the formulation of more precise and effective green port development strategies. Looking into the future, as the construction of green ports continues to advance, we have reason to believe that more ports will make more significant achievements in environmental protection, economic development and the realisation of sustainable development goals. This will not only bring long-term benefits to the ports themselves, but also make positive contributions to global environmental protection and economic development [22].

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, author-ship, and/or publication of this article.

Data Sharing Agreement

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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