Research on Performance Assessment of High Quality Development in Urban Green and Low Carbon Transformation

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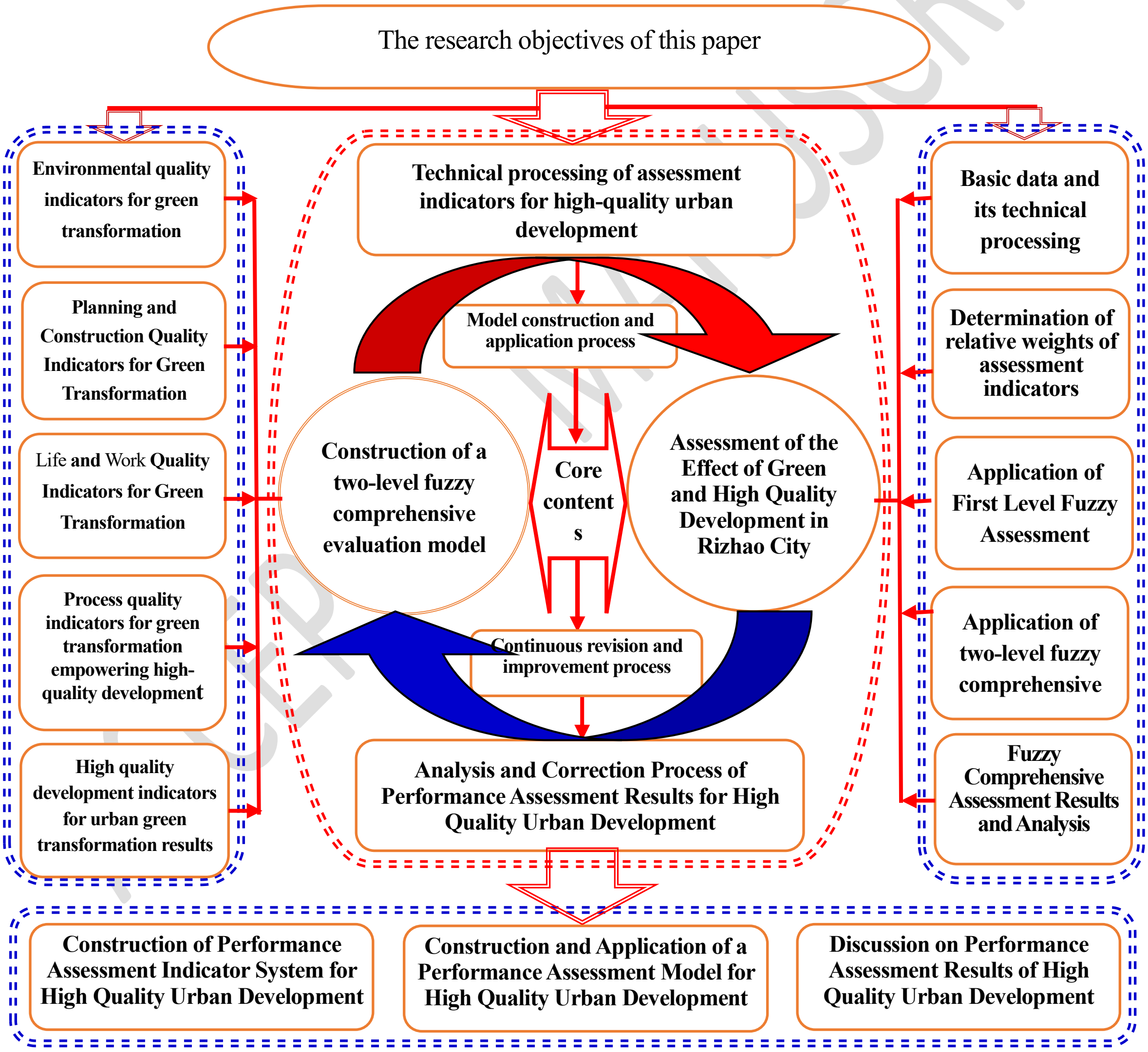
Graphical abstract



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Abstract

In order to study the effective methods of green and low-carbon transformation in Chinese cities, this paper takes Rizhao City, Shandong Province, China, as the object of study. Based on the analysis of the research background and the literature review, and taking into account the characteristics of Rizhao City, the following five categories with a total of 25 indicators were selected to construct the assessment indicator system: the environmental quality of green and low-carbon transformation, the quality of the planning and construction of green and low-carbon transformation, the quality of the life and work in the green and low-carbon transformation, the quality of the process of the green transformation empowering the development of high-quality, and the quality of the results of the green transformation empowering high-quality development. Based on this, the two-level fuzzy comprehensive assessment model is reconstructed, and the relevant statistical data provided by the government is used to comprehensively assess the high-quality development performance of the green transformation and empowerment cities in Rizhao City from 2012 to 2022. It is found that the performance of high-quality development empowered by green transformation in Rizhao City, China, has shown a continuous upward trend, having risen from Level Ⅳ in 2012, to Level II by 2022, and remained at Level II during 2018-2022, with its assessment results and showing an upward trend. Finally, based on the specific research results, the policy suggestions to improve the high-quality development performance of cities empowered by the green and low-carbon transformation of Rizhao City, China are discussed.

Keywords: Green transformation；Green transformation empowerment；High-quality development performance；Overall assessment；Rizhao City

1. Introduction

The green and low-carbon transformation of Chinese cities refers to the transformation of the development model towards sustainable development under the premise of lower greenhouse gas emissions, with the construction of an ecological civilization as the leading role, a circular economy as the basis, and green management as the safeguard, so as to achieve resource-saving, environmentally friendly, ecologically balanced, and harmonious development of human beings, nature and society (Ding and Li, 2023). Its core content is the transformation from the traditional development model to the scientific development model, that is, the transformation from the deviation between man and nature to the harmonious coexistence between man and nature, and the transformation from the development form separated by economy, society and ecology to the coordinated development form of economy, society and ecology, making the connotation of green transformation more three-dimensional and intuitive(Du, 2023). Greenhouse gases mainly include: water vapor, carbon dioxide (CO_2), ozone (O3), nitrous oxide (N_2O), methane (CH4), hydro chlorofluorocarbons (CFCs, HFCs, and HCFCs), perfluorocarbons (PFCs) and sulfur hexafluoride (SF6), etc. The main sources of greenhouse gas emissions are the result of human activities or natural phenomena, and the greenhouse gases produced by human activities are mainly caused by the energy consumption of urban residents and the development of heavy industry (Kongboon et al., 2022). Once greenhouse gases exceed atmospheric standards, they will produce a greenhouse effect, causing global temperatures to rise and threatening human survival. Therefore, one of the top priorities for urban green and low-carbon transformation is to control greenhouse gas emissions (Zhang et al., 2023). Since the 18th National Congress of the Communist Party of China proposed the concept of "green and low-carbon transformation" of the Chinese economy on November 8, 2012, China's economic development has embarked on a new journey of "green and high-quality development" (Zhang, 2022). On March 12, 2021, the 14th Five Year Plan for National Economic and Social Development of the People's Republic of China and the Outline of Long Range Goals for 2035 were announced, which made "unwavering implementation of the new development concept of innovation, coordination, green, openness, and sharing" an important content of the guiding ideology for economic and social development during the 14th Five Year Plan period, and made specific arrangements around "promoting green development" and "promoting harmonious coexistence between humans and nature", Higher requirements have been put forward for "accelerating the green transformation of urban residents' lifestyles" (Xu and Liu, 2023). The report of the 20th National Congress of the Communist Party of China proposes to build a regional economic layout and land spatial system with complementary advantages and high-quality development, improve the system of main functional zones, and optimize the development pattern of land spatial development (Wei and Yang, 2023); On January 19, 2023, the State Council issued a white paper titled "Green Development in China in the New Era", which pointed out: to play the role of land and resource planning, promote the formation of a green spatial pattern, coordinate land development and protection, and promote the green transformation of development methods (Luo et al., 2023). In order to achieve the goals of "carbon peak" in 2030 and "carbon neutrality" in 2060 proposed by the Chinese government, the green and low-carbon transformation of China's economic development is crucial(Ye and Deng, 2023). Therefore, in this situation, it is particularly important and urgent to study the comprehensive assessment of the high-quality development performance of Chinese cities empowered by green and low-carbon transformation, and effectively control the greenhouse gas emissions of cities based on specific assessment results.

China's research on "green transformation" began in the early 21st century. On September 17, 2002, Chen Wei and Wang Chunguang reported on the "green" transformation of Daxing'anling in

China Information News, which kicked off the research on China's green transformation. Subsequently, Wang (2006) analyzed the current research status of "green transformation" in Chinese society; Wu (2008) analyzed the relationship between green transformation, tax system, and sustainable development, advocating the use of taxation to regulate the green transformation of China's economy; Zhang and Liu (2009) analyzed the costs and actual options of green transformation of resource-based cities in China, and advocated that the planning of green transformation of resource-based cities in China should be strengthened; Yan (2011) analyzed the current situation of green and low-carbon development in Qilin District, Yunnan Province, and believed that energy consumption is the focus of low-carbon transformation; Yao (2017) proposed a green and low-carbon transformation approach for the power industry guided by carbon emission indicators, and advocated that attention should be paid to the impact of China's green transformation on sustainable development; Zeng and Duan (2018) argued that the green transformation of resource-based cities in China should pay special attention to the green transformation performance of coal resource cities. Based on cluster analysis, they used the "entropy weight method" to assess the green transformation effect of exhausted coal resource cities; Song et al. (2020) used inductive methods to conduct research mainly from three aspects: urban agglomeration, measurement of green transformation collaborative development capacity, and construction of green transformation capacity; Fan and Mi (2021) used the basic data of 284 prefecture-level cities in China from 2004 to 2016, and used multi-phase DID model to empirically test the influencing factors of the green economy transformation effect of smart city construction, identified the main influencing factors and put forward policy suggestions.Kong and Liu (2023) used empirical research methods to test the impact of digital economy development on the green transformation of Chinese cities; On the basis of analyzing the relationship between new energy transformation policies and industrial green transformation innovation, Li et al. (2023) used empirical research methods to study the impact of China's new energy transformation policies on the vitality of urban green transformation innovation. China's research on "high-quality development" also began with oil exploration in the 1970s, pursuing the construction of "high-quality oil wells". The true research on "green and high-quality" development began in 2017 when the 19th National Congress of the Communist Party of China first proposed the requirement of "establishing a sound economic system for green, low-carbon and circular development". Han (2018) studied how green manufacturing can promote high-quality economic development. Faced with the global trend of green development, China should accelerate the green development of its manufacturing industry and promote industrial transformation and upgrading; Peng and Wen (2019), based on their analysis of the relationship between green innovation and high-quality development, believe that green innovation is an important path to promote high-quality development; Yu and Tian (2021) used the super efficiency DEA model to measure the efficiency of green and high-quality development in cities in the upper reaches of the Yellow River, and studied specific improvement strategies based on the measurement results; Fang et al. (2021) studied the comprehensive evaluation of urban green and high-quality development on the basis of eco-efficiency analysis by combining input-output and data envelopment; Liu and Wang (2022) used empirical testing methods to examine the impact of driving factors on the efficiency of digital economy empowering high-quality urban development, and further analyzed the mechanism of digital economy's impact on high-quality urban development.

The performance assessment of high-quality development in urban green and low-carbon transformation is a research topic with Chinese characteristics. Other countries outside of China have not conducted research on urban green and low-carbon transformation, only on high-quality urban development. Back in the early 70s of the last century, American scholar Jack (1970) studied the application of pattern recognition technology in satellite city quality analysis; Ludwig et al. (1970) analyzed the impact of industrial development on urban air quality and believed that with the development of industry, urban air quality has a trend of deepening pollution; In the mid-1970s, American scholars used questionnaire surveys to study measurement tools for urban environmental quality in the San Francisco Bay Area, which were useful for evaluating urban planners and various environmental interventions (Carp, 1976). The research on low-carbon urban development in developed countries began in the late 1960s. Johnson et al (1968) analyzed the current situation of CO and automobile exhaust emissions in New York City, USA, and believed that control of harmful gas emissions in cities should be strengthened; Taniguchi et al. (1994) analyzed the current status of CO_2 emissions in Japanese cities and predicted the scale of CO_2 emissions in major cities using life cycle and collected basic data. Other countries outside of China have conducted separate studies on high-quality and low-carbon urban development. According to literature searches, no research on low-carbon and high-quality urban development has been found abroad, and only Chinese scholars have conducted research on low-carbon and high-quality urban development. Scholars from other countries outside of China mainly focus on the private quality of life of urban residents, and there are few research results on the high-quality development of urban construction. Kirby (2012), on the basis of analyzing the relationship between the private system and the quality of life of urban residents, concluded that the private system facilitates the quality of life of the residents, and at the same time, concluded that the residents have a high level of satisfaction with the quality of life; Rebecca's (2013) study suggests that improving the ecological quality of urban residents in the United States requires consideration of sustainable development, not only focusing on the basic quality of life of residents, but also considering the impact of environmental pollution. In recent years, influenced by Chinese scholars' research on green and low-carbon transformation empowering high-quality development of cities, many scholars from countries have also begun to study the topic of promoting high-quality development of cities through green transformation. Farinmade et al. (2018) studied the assessment of the impact of informal economic activities on the quality of sustainable urban development building environment in Lagos, Nigeria, and began to study the impact of environmental pollution on the quality of urban construction; Ralevic et al. (2019) studied the comprehensive development of urban quality in the Danube region, considering the combination of local and global processes to explore effective ways to achieve high-quality urban development; Теодор et al. (2020) used Graz, Austria as an example to study that urban design, function and adaptation to the needs of residents have a significant impact on the quality and atmosphere of urban coexistence. The importance of urban planning on the quality of life of residents was emphasized; Hafiz et al. (2021) studied the relationship between sustainable urban tourism development and the quality of life of urban residents, taking Kampong Baru in Kuala Lumpur as an example, and emphasized the role of sustainable development in continuously improving the living standards of urban residents; Setareh (2022) used the Group of Seven developed countries as an example to assess the role of environmental quality in urban development; Ludmila et al. (2023) used the example of Brno, Czech Republic, to analyze the living standards of residents in urban development using a multi perspective quality of life index.

From the above literature review, it can be clearly seen that the research on green transformation empowering high-quality development of cities has obvious Chinese characteristics. This topic is a historic proposition proposed by the Chinese government during the process of China's economic development. The research on empowering high-quality development of cities through green transformation, which truly includes the above, began in the early 21st century. Its development boom period is from 2016 to 2023, and there is a trend of gradually deepening research topics. According to the literature review, 95% of the research results on this topic were completed by Chinese experts and scholars. After 2018, with the continuous deepening of research on this topic by Chinese experts and scholars, other scholars outside of China have also begun to have similar or similar research results. The Chinese government's white paper on green transformation was released in January 2023, and China's research on green transformation empowering high-quality urban development has a progressive trend. Therefore, in this context, it is of particular importance and general urgency to study the issue of China's green transition empowering high-quality urban development.

2. Materials and Methods

2.1 Study area and data sources

On March 14, 2023, the corresponding author of this paper applied for a key project of the Social Science Foundation to the Social Science Federation of the Rizhao Social Science Federation in Shandong Province, China. In order to complete the research task of this project, this research paper was written based on the phased research results. Rizhao is a well-known coastal city in Shandong Province, China, and was transformed into a prefecture-level city in June 1989. Rizhao City is located on the coast of the Yellow Sea in the southeast of Shandong Province, facing Japan and South Korea across the Yellow Sea to the east, adjacent to Linyi City to the west, Qingdao and Weifang City to the north, and Lianyungang City to the south. The total area is 5374.90 square kilometers, with a permanent population of 2.9683 million people. In 2022, it created a GDP of 23.0677 billion yuan, an increase of 3.8% compared to the previous year. According to administrative divisions, the location and regional structure of Rizhao City in China are shown in Figure 1.

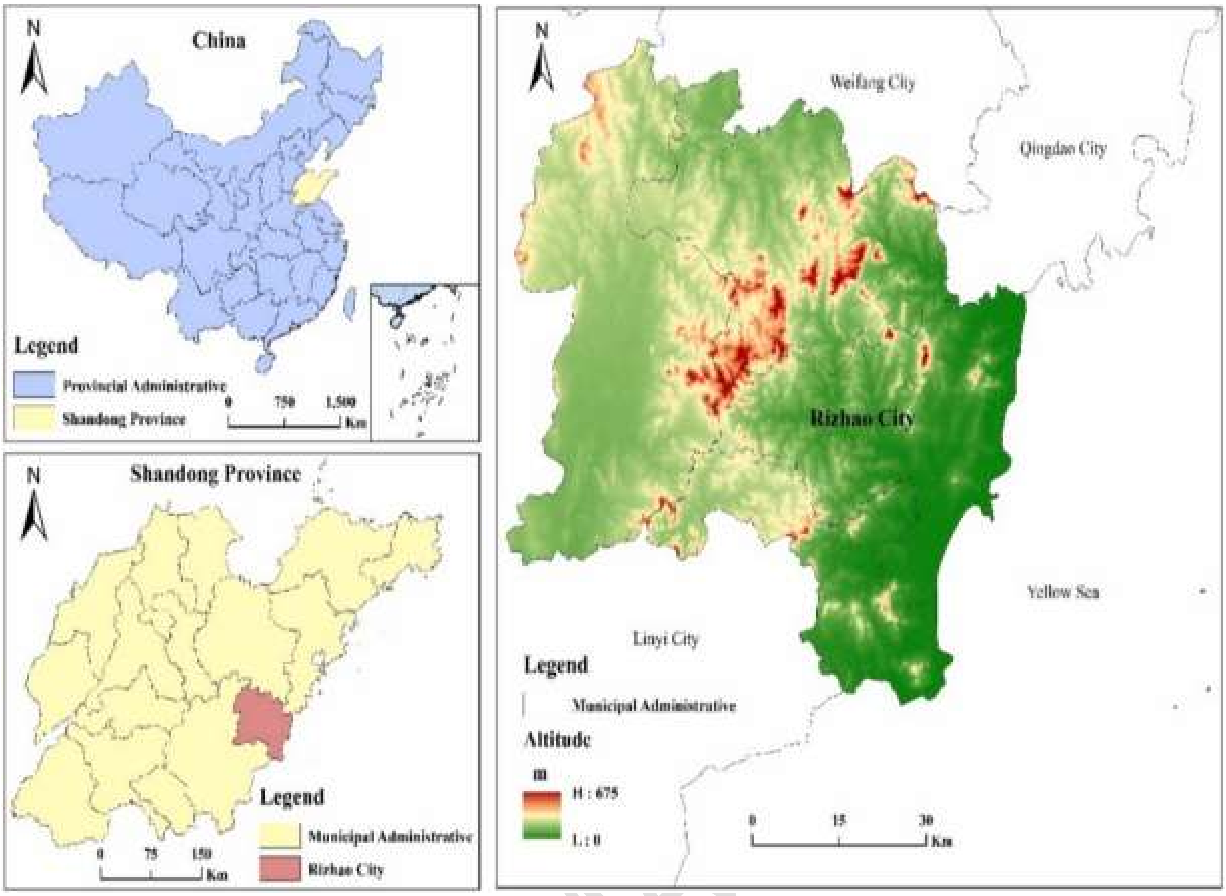

Fig. 1. Administrative Division Map of Rizhao City in China's Shandong Province

Rizhao City is located in the eastern part of Shandong Province, China. It is a famous coastal city with good basic conditions for green transformation. Considering the characteristics of the green transformation in Rizhao City, statistical data from the two levels of government in Shandong Province and Rizhao City were used in the study. The main sources of data include: statistical yearbooks of the two levels of government, energy statistical yearbooks, ecological environment status bulletins, as well as relevant green transformation documents, statistical data, compilation of results, bulletins, and other resources. The Chinese government only began to publish statistics on the state of the environment in 2012, and statistics for 2022 have not yet been released. However, the monthly report for 2022 has been released, and the annual report for 2022 can be obtained through the collation and calculation of monthly statistics. Therefore, this study selected 11 years of basic statistical data from 2012 to 2022, and the specific basic data is detailed in Table 1.

Table 1. Basic Data of Performance Assessment Cases for High Quality Development of Chinese Cities

Criterion layer	Indicators	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Environmental quality indicators（X_1）	X_{11}	1.6973	1.6852	1.5042	1.3684	1.2063	1.0654	0.9805	0.9536	0.9334	0.9203	0.8896
	X_{12}	5.5625	5.9248	6.2826	6.7828	7.0562	7.6842	7.7369	8.2363	8.1548	7.9735	7.8656
	X_{13}	136.28	128.37	114.28	102.37	95.28	91.28	88.67	92.57	101.28	95.46	98.27
	X_{14}	128.37	121.56	119.37	116.53	108.37	95.37	89.27	92.36	97.28	96.27	90.52
	X_{15}	131.27	123.56	112.54	106.37	97.37	92.38	89.72	88.67	85.64	81.38	79.37
Planning and construction quality indicators（X_2）	X_{21}	88.28	90.32	91.27	92.64	93.67	94.68	92.37	90.28	92.89	94.57	95.26
	X_{22}	86.26	88.03	89.27	90.86	92.18	93.68	94.06	94.78	95.38	94.47	95.84
	X_{23}	85.287	86.56	85.63	86.74	87.27	88.28	89.02	89.67	90.27	90.52	91.04
	X_{24}	86.85	87.16	87.86	88.02	88.67	89.56	90.17	90.91	91.67	91.86	92.37
	X_{25}	87.27	88.37	88.06	89.62	89.37	88.85	88.48	87.37	86.57	86.02	85.98
Quality of life and work indicators（X_3）	X_{31}	88.26	89.37	88.56	89.63	90.37	91.27	90.64	93.27	92.45	91.37	90.75
	X_{32}	2.2817	2.5090	2.7540	1.9547	2.1291	2.2386	2.5377	2.7577	2.8695	3.1059	3.2490
	X_{33}	85.28	86.41	87.04	87.86	88.27	89.67	90.46	90.85	91.26	90.47	91.68
	X_{34}	88.57	89.28	89.85	90.46	90.79	90.52	89.65	88.35	87.67	87.42	86.57
	X_{35}	46.38	51.28	55.72	61.28	65.38	71.27	75.37	81.27	86.27	88.95	80.56
Process quality indicators（X_4）	X_{41}	72.28	78.38	80.36	84.47	89.38	90.28	91.86	90.53	92.03	92.78	91.56
	X_{42}	48.37	51.38	53.16	53.75	54.86	55.52	57.02	57.26	58.17	58.89	59.03
	X_{43}	85.25	84.57	85.83	86.38	87.27	88.24	89.37	90.17	91.84	90.95	92.04
	X_{44}	84.15	84.85	85.62	86.03	86.56	87.07	87.62	88.16	88.92	89.05	89.27
	X_{45}	85.48	86.02	86.89	87.27	89.36	90.27	92.36	91.89	92.81	93.28	93.75
Indicators in the category of quality of results（X_5）	X_{51}	47.36	49.62	52.38	55.83	57.26	59.73	62.38	64.37	66.72	67.26	68.73
	X_{52}	68.51	69.05	69.72	71.37	75.38	81.27	84.37	86.26	88.17	89.05	88.62
	X_{53}	48.37	49.36	51.28	52.62	53.36	54.03	54.72	55.38	56.27	57.34	58.91
	X_{54}	85.36	85.87	86.04	86.31	86.89	87.06	87.83	88.63	89.32	91.21	90.27
	X_{55}	86.95	87.28	88.24	88.93	89.05	89.86	90.64	91.28	92.07	92.45	93.46

The assessment data for this paper comes from the "Statistical Yearbook", "Energy Statistical Yearbook", "Urban Statistical Yearbook", and "Ecological Environment Status Bulletin" of the Chinese government, Shandong Provincial government, and Rizhao city. At the same time, this article refers to the five-year plans and annual plans of governments at all levels, as well as circulars and briefings issued by governments at all levels.

2.2 Basic framework of this paper

The performance assessment of green transformation empowering high-quality urban development is an important issue that urgently needs to be addressed in China's urban development. The research on this topic is not only related to the effectiveness of green transformation, but also to the high-quality development of urban problems. Based on the comprehensive analysis of the author's research on this topic, a total of 25 indicators were selected, including the environmental quality of urban green and low-carbon transformation, the planning and construction quality of urban green and low-carbon transformation, the living and working quality of urban green and low-carbon transformation, the process quality of urban green transformation empowering high-quality development, and the result quality of urban green transformation empowering high-quality development. On the basis of the above, a comprehensive index system for the high-quality development performance of cities empowered by green transformation is constructed. Based on the index processing, the TOPSIS ecological niche model was constructed, and the high-quality development performance of the green transformation of Rizhao City, China was comprehensively evaluated and studied. According to this research idea, the basic idea framework for constructing a comprehensive assessment study of green transformation enabling high-quality development performance in Rizhao City, China, is shown in Figure 2.

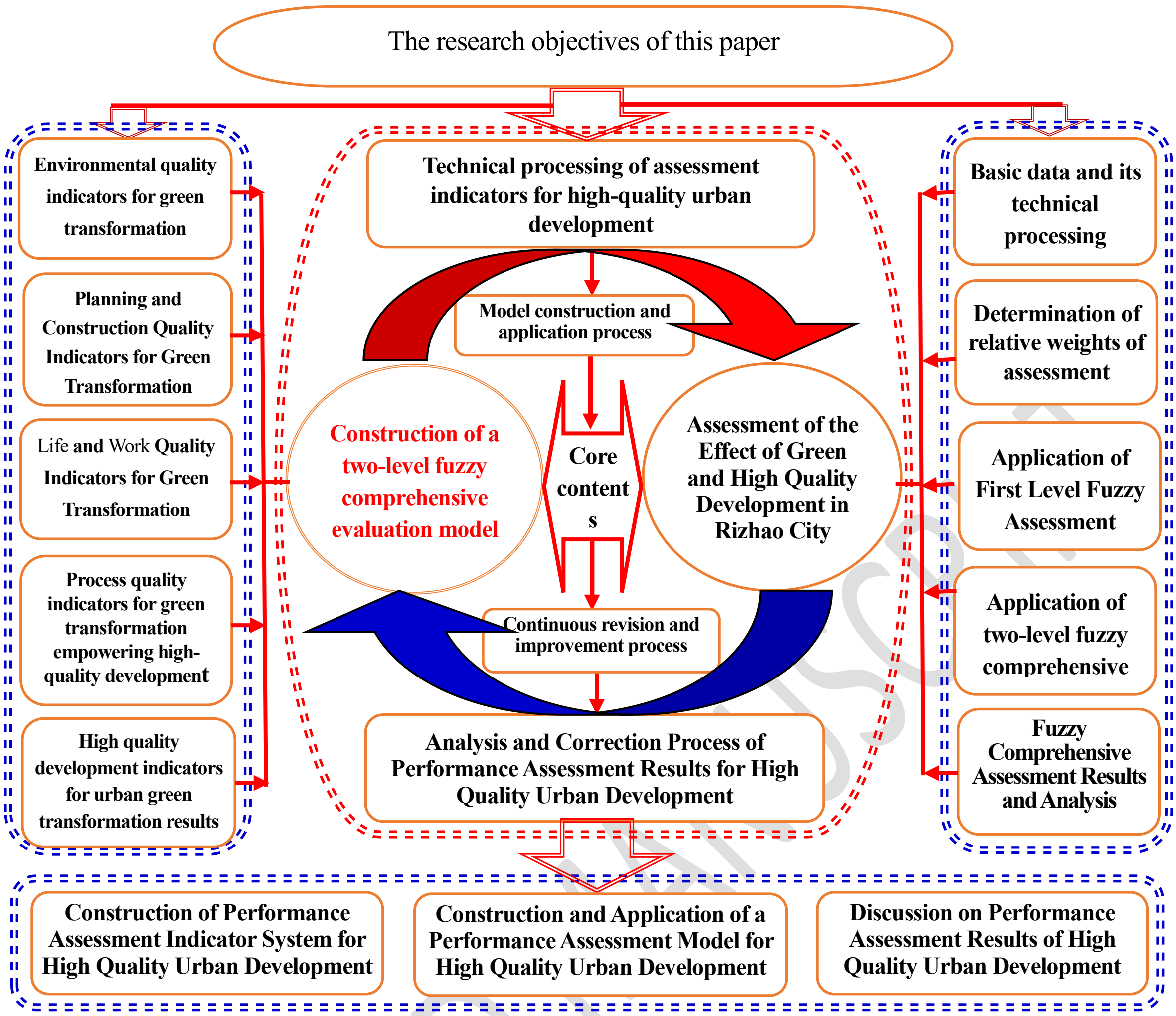

Fig.2. Basic research framework of this paper

This research framework map reflects the technical roadmap and core research content of this paper. This research topic is of great significance in addressing the key issues in the performance assessment of green transformation empowering high-quality development of Chinese cities and promoting high-quality and sustainable development of Chinese cities.

2.3 Construction of a Fuzzy Comprehensive Assessment Model for High Quality Development Performance

2.3.1 Construction of a comprehensive assessment indicator system

Based on the literature review and research design above, an assessment indicator system was constructed by analyzing the performance of green transformation empowering high-quality development in Rizhao City, China. Combining the current status of green transformation and high-quality development in Rizhao City, China, a total of 25 indicators from five categories were selected to fully reflect the status of green transformation empowering high-quality development in Chinese cities. The specific indicators are detailed in Table 2.

Table 2 Assessment Indicator System for the Effect of Green Transformation Empowering High Quality Development in City

target	Criterion layer	variable	Measure layer	unit	Indicator Properties	Weight
Assessment of the High Quality Development Performance of RI Zhao ' s Green Transformation Empowering Cities in China	Environmental quality indicators for urban green and low-carbon transformation （X_1）	X_{11}	Annual energy consumption intensity of cities	Tons/10000 yuan	Reverse indicators	0.0402
		X_{12}	Per capita EC CO_2 emission scale	Tons per person	Reverse indicators	0.0406
		X_{13}	Urban Annual Air Quality Index	index	Reverse indicators	0.0397
		X_{14}	Annual Urban Sewage Discharge TI	index	Reverse indicators	0.0393
		X_{15}	Urban Ground EE Quality Index	index	Positive indicators	0.0388
	Planning and construction quality indicators for urban green and low-carbon transformation （X2）	X_{21}	Satisfaction index of urban planning	%	Positive indicators	0.0420
		X_{22}	Implementation Effectiveness Index of UP	%	Positive indicators	0.0415
		X_{23}	Urban Building Construction Quality Index	%	Positive indicators	0.0411
		X_{24}	QI of urban roads and public facilities	%	Positive indicators	0.0406
		X_{25}	QI of public facilities and leisure places	%	Positive indicators	0.0402
	Life and Work quality Indicators for Urban Green and Low Carbon Transformation （X_3）	X_{31}	Employment rate of urban residents	%	Positive indicators	0.0384
		X_{32}	PCDI of urban residents	10000 yuan/year	Positive indicators	0.0379
		X_{33}	Satisfaction index of urban residents' lives	%	Positive indicators	0.0386
		X_{34}	Job satisfaction index of urban residents	%	Positive indicators	0.0382
		X_{35}	Green transformation ratio of urban energy	%	Positive indicators	0.0408
	Process quality indicators for enabling high-quality development through urban green transformation （X_4）	X_{41}	The actual situation of empowerment	Score	Positive indicators	0.0404
		X_{42}	Environmental Regulation Intensity Index	%	Neutral indicators	0.0395
		X_{43}	Production or service process quality index	%	Positive indicators	0.0404
		X_{44}	Degree of process standardization	Score	Reverse indicators	0.0399
		X_{45}	Urban Development Potential Index	%	Positive indicators	0.0408
	Quality indicators for empowering high-quality development through urban green transformation （X_5）	X_{51}	The proportion of urban green GDP	%	Positive indicators	0.0413
		X_{52}	Green transformation ratio	%	Positive indicators	0.0417
		X_{53}	urban green coverage	%	Neutral indicators	0.0395
		X_{54}	Implementation status of ESER targets	Score	Positive indicators	0.0382
		X_{55}	Landscape Index of Urban Construction	%	Positive indicators	0.0405

Notes: ESER: energy-saving and emission reduction; EC: energy consumption; EE: Ecological environment; PCDI: Per capita disposable income; QI: Quality index; UP: Urban Planning; TI: Treatment Index.

The performance assessment indicators for high-quality of urban development in Table 2 are mostly quantitative indicators that can be directly obtained f from the statistical data of the national, Shandong Province, and Rizhao City three-level governments, or calculated using basic data. In order to reflect the characteristics of combining quantitative and quantitative performance assessment indicators for high-quality urban development, a small number of qualitative indicators were selected in the indicator system. The values of these qualitative indicators were mainly determined through expert surveys or relevant personnel questionnaires. In order to facilitate the comprehensive assessment of high-quality urban development performance in China, percentage values were used according to the habits of Chinese people to determine the value of the assessment indicators, with a minimum value of 0 points, and the maximum value is 100 points. The priority and scientificity of the selection of the above indicators and methods lies in the comprehensive selection of evaluation indicators, the characteristics of combining qualitative predetermined quantities, and the evaluation index system is highly scientific. The research method is innovative, combining expert investigation with fuzzy mathematics, using nonlinear membership function and two-level model comprehensive evaluation model for evaluation, and the effect of solving problems is very ideal.

2.3.2 Determination of relative weights of assessment indicators

There are various methods for determining the relative weight of assessment indicators, including expert survey method, analytic hierarchy process, entropy weight method, etc. This paper chooses the expert survey method; it is a method of determining the relative weight of assessment indicators by using pre designed questionnaires to distribute anonymous surveys to different types of experts who have been determined in advance. The statistical data of the survey results is used to calculate the relative weight of assessment indicators. After several rounds of questionnaire surveys, the relative weight of expert opinions is determined to reach a consensus. If W_j is used to represent the relative weight of the j_{th} assessment indicator, according to assessment theory, the range of relative weights of the assessment indicator is: $W_j \in [0, 1]$. When using the expert survey method to determine the relative weight of assessment indicators, S_{ij} represents the score of the i_{th} expert on the j_{th} assessment indicator, and the formula for calculating the relative weight of assessment indicators can be expressed as:

$$W_j = \left(\sum_{j=1}^{m} S_{ij}\right) \cdot \left(\sum_{i=1}^{n} \sum_{j=1}^{m} S_{ij}\right)^{-1} \quad (1)$$

In the equation: $i = 1,2,\cdots,n$, $j = 1,2,\cdots,m$ According to the requirements of the expert survey, 200 questionnaires were distributed to the experts based on the relative weight of the assessment indicators in this paper. The selected questionnaire experts are divided into four categories: the first category includes leaders related to urban green transformation and high-quality development in Rizhao City, frontline professional and technical personnel, experienced workers, and experts from universities and research institutes. 50 questionnaires were distributed to each of the selected four categories of experts, and 189 valid expert questionnaires were collected. The survey questionnaires were conducted through various methods such as email, WeChat, mail, and on-site interviews. On the basis of collecting, organizing, and analyzing the survey results, the relative weights of the assessment indicators were calculated using formula (1). After two rounds of questionnaire and relative weight calculation of the assessment indicators, the relative weights of the final assessment indicators were included in the last column of Table 1.

2.4 Construction of Fuzzy Comprehensive Assessment Model

2.4.1 Determination of Positive Indicator Membership Function

Assessment model is the core content of this paper's research. Due to the assessment of China's urban green transformation empowering high-quality development performance, each assessment indicator has a great deal of ambiguity regarding the assessment object, and the high-quality development performance of cities also has a strong fuzzy attribute. Therefore, based on in-depth analysis of the research problem, a fuzzy comprehensive assessment model was selected. According to the results of literature review, Zadeh (1965) first proposed the concept of fuzzy functions. And he first constructed and used the fuzzy comprehensive evaluation model. Since then, the fuzzy comprehensive assessment model gradually developed. According to the comprehensive assessment theory, multiple assessment indicators should be selected for assessment items, which can be divided into three basic types: positive indicators, reverse indicators, and neutral indicators. Positive indicators refer to indicators that show an upward trend in assessment results as the value of the indicator gradually increases, that is, indicators that show a positive correlation with the assessment results. If $f_i^+(X)$ is used to represent the positive membership function of the i th assessment indicator, $i=1,2,\cdots,n$. According to the properties of the positive membership function, when the positive indicator value reaches its maximum value, the membership function value is 1. When the positive indicator value reaches its minimum value, the positive indicator value is 0. This limits the membership function values of all indicators to the range of [0, 1]. The positive indicator membership function values of assessment indicators can be calculated using the following formula:

$$f_i^+(X)=\begin{cases}0 & X_i \le ZX \\ (\lambda X_i-\omega)^2 & ZX < X_i < ZD \\ 1 & X_i \ge ZD\end{cases} \tag{2}$$

In the equation: λ， ω is the parameter of the positive indicator membership function, $\mathrm{ZX} = \min X_i$, $\mathrm{ZD} = \max X_i$. According to the properties of the membership function, when $X_i = ZD$, $\mu_i(ZD) = 0$; When $X_i = ZX$, $\mu_i(ZX) = 1$. Determine the parameters of the membership function by combining two equations, with $DV' = \max X_i - minX_i$, and substitute the determined membership function parameters back to （2） to obtain:

$$f_i^+(X)=\begin{cases}0 & X \le ZX \\ DV^{-2}(X_i-ZX)^2 & ZX \le X < ZD \\ 1 & X \ge ZD\end{cases} \tag{3}$$

The membership degree of all positive indicators can be calculated using formula （3）, and the membership degree of assessment indicators can be classified into the interval [0,1] for comprehensive assessment of urban high-quality development performance.

2.4.2 Determination of inverse indicator membership function

Reverse indicators refer to indicators that have a higher numerical value and a lower assessment value for assessment results, which are inversely related to the performance of high-quality urban development. If $f_i^-(X)$ is used to represent the inverse membership function of the i_{th} assessment indicator, then :

$$f_i^-(X)=\begin{cases} 0 & X_i \le ZX' \\ (\lambda' X_i - \omega')^2 & ZX' < X_i < ZD' \\ 1 & X_i \ge ZD' \end{cases} \qquad (4)$$

In the equation： λ' and ω' are parameters of the inverse indicator membership function, $\mathrm{ZX} = \min X_i$, $\mathrm{ZD} = \max X_i$. According to the properties of the membership function, when $X_i = ZD$, $\mu_i(ZD) = 1$; When $X_i = ZX$, $\mu_i(ZX) = 0$. Determine the parameters of the membership function by combining the equations formed by two points, with $\mathrm{DV} = \max X_i - minX_i$. Substitute the determined membership function parameters back to（2） after simplification to obtain:

$$f_i^-(X)=\begin{cases} 1 & X \le ZX' \\ 1-(DV')^{-2}(X_i - ZX)^2 & ZX' < X < ZD' \\ 0 & X \ge ZD' \end{cases} \qquad (5)$$

2.4.3 Determination of membership function for neutral indicators

A neutral indicator refers to an indicator whose value reaches a specific value, which maximizes the assessment result. Within this specific value, the value of the assessment indicator is positively correlated with the assessment result of the assessment object, while after this specific value, the value of the assessment indicator is inversely correlated with the assessment result of the assessment object. If $f_i^m(X)$ is used to represent the membership degree of the neutral membership function of the i_{th} assessment indicator, then:

$$f_i^m(X)=\begin{cases}0 & X_i \le ZX, or X_i \ge ZD \\ (\lambda X_i-\omega)^2 & ZX < X_i < M \\ 1-(\lambda' X_i-\omega')^{-2} & M < X_i < ZD \\ 1 & X = M\end{cases} \quad (6)$$

In the equation: M is the optimal value of the indicator, also known as the median, named after its position between the maximum and minimum values. λ and ω are the parameters of the membership function in the variable interval [0, M]. λ' and ω' are parameters of the membership function in the variable interval [0, M] segment. Determine the equation coefficients of the neutral membership function using the two point method, and substitute the parameters back to equation （6） to obtain the following expression of the neutral membership function:

$$f_i^m(X)=\begin{cases}0 & X_i \le ZX, or X_i \ge ZD \\ (M-ZX)^{-2}\cdot(X_i-ZX)^2 & ZX < X_i < M \\ (ZD-M)^{-2}\cdot(ZD-X_i)^2 & M < X_i < ZD \\ 1 & X = M\end{cases} \quad (7)$$

2.4.4 Fuzzy Comprehensive Assessment Model for High Quality Development Performance

The above combines the assessment indicator system of high-quality development performance under the conditions of green transformation in Chinese cities, and studies the relative weight of urban high-quality development performance assessment indicators using expert survey methods in Rizhao City, China. Based on the assessment indicators and Correlation status of assessment indicators, a specific assessment indicator membership function is constructed. In order to achieve a comprehensive assessment of the high-quality development performance of Chinese cities in the context of green transformation, it is necessary to construct an effective fuzzy comprehensive assessment model on this basis. The performance assessment indicator system for high-quality urban development constructed in this paper consists of three levels: objectives, criteria, and measures. The assessment indicators at the measure level directly reflect the high-quality development performance of the assessment object, while the indicators at the criterion level are jointly reflected by the assessment indicators at multiple measure levels. The indicators at the target level are jointly reflected by the selected criteria level indicators. Therefore, this requires the study of a comprehensive assessment model for the high-quality development performance of Chinese cities in the context of green transformation at both the guideline and target levels.

（1）Constructing a fuzzy comprehensive assessment model based on criteria hierarchy. If there are k criterion level indicators, there are h measure level assessment indicators under each criterion level indicator. By treating the criteria level assessment object as the assessment object, the high-quality development performance of the criteria level indicators can be directly assessd using the measure level indicators under the criteria level indicators. In order to make the assessment results comparable, it is necessary to convert the relative weights of the assessment indicators according to the caliber of the criterion hierarchy, and meet the condition that the sum of the relative weights of the assessment indicators at each criterion hierarchy is equal to 1. The method of conversion is to divide the relative weight of each assessment indicator at the criterion level by the sum of the relative weights of all assessment indicators at that criterion level, that is $w'_{ij} = w_{ij} \Big/ \sum_{i=1} w_{ij}$. In this situation, the assessment model of criterion level indicators ($Results(C)_i$) can be represented as follows:

$$\text{Results}(C)_i = \begin{bmatrix} X_1 \\ X_2 \\ \vdots \\ X_k \end{bmatrix}^T = \begin{bmatrix} w'_1 \\ w'_2 \\ \vdots \\ w'_h \end{bmatrix}^T \circ \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1h} \\ f_{21} & f_{22} & \cdots & f_{2h} \\ \vdots & \vdots & \ddots & \vdots \\ f_{k1} & f_{k2} & \cdots & f_{kh} \end{bmatrix} \tag{8}$$

（2）Constructing a fuzzy comprehensive assessment model for the target hierarchy. The assessment results of the target level can be weighted using the assessment results of the criteria level indicators. However, due to the increased level of assessment that increases the error in the assessment results, it is not adopted in the actual assessment process. In the performance assessment of high-quality development of cities at the target level, all assessment indicators are usually directly regarded as influencing factors of the assessment results at the target level, and the assessment is conducted using the quantity and relative weight indicators of all indicators. The assessment results of the target level can be expressed as follows:

$$\mathrm{Re}\,sults(G)_t = \mathrm{W} \circ \mathrm{U} = \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_m \end{bmatrix}^T \circ \begin{bmatrix} f_{11} & f_{12} & \cdots & f_{1n} \\ f_{21} & f_{22} & \cdots & f_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ f_{m1} & f_{m2} & \cdots & f_{mn} \end{bmatrix} \tag{9}$$

If the assessment object selected in the assessment has a period of T , the weighted average method can be used to calculate and determine the average assessment results within the period. The specific calculation formula is as follows：

$$\bar{R} = \sum_{t=1}^{T} \left[\mathrm{Re}\,sults(G) \right] \cdot t \Big/ \left(\sum_{k=1}^{n} t \right) \tag{10}$$

2.5 Comprehensive assessment criteria for the performance of high-quality development

To assess the high-quality development performance of cities in the context of China's green transformation, specific assessment criteria need to be determined in advance based on the latest research results of the country, local governments, and a large number of experts and scholars. The assessment criteria are the direct basis for comprehensive assessment of the high-quality development performance of Chinese cities, and the Chinese government has not yet announced the assessment criteria for the high-quality development performance of cities. However, many cities in China have begun to design their own assessment standards, and intermediary agencies have begun to formulate specific assessment standards for the high-quality development performance of cities. Many experts and scholars in China have also begun to study the assessment criteria for high-quality urban development. This paper draws on the assessment criteria for the high-quality development performance of these cities, fully considers the specific situation of green transformation to promote high-quality urban development. Moreover, the hierarchical evaluation standard for the performance evaluation of urban high-quality development under the background of green transformation of Rizhao City, China was determined.

（1）Specific assessment criteria for the level of measures. The assessment criteria at this level are the specific standards for assessment indicators, determined according to the requirements of the green transformation and high-quality development performance assessment in Rizhao City, China. Based on the 25 specific assessment indicators identified above, the following five level assessment standards are determined based on the comprehensive assessment of their meanings and the reference of existing assessment standards, as shown in Table 3.

Table 3. Specific Standards for Performance Assessment Indicators of High Quality Urban Development

Indicator Name	Level I	Level II	Level III	Level IV	Level V
X_{11}	0-1.0	1.0-1.5	1.5-2.0	2.0-3.0	>3.0
X_{12}	0-3	3-6	6-9	9-12	>12
X_{13}	0-70	70-100	100-150	150-300	>300
X_{14}	0-70	70-100	100-150	150-300	>300
X_{15}	0-70	70-100	100-150	150-300	>300
X_{21}	90-100	80-90	70-80	60-70	<60
X_{22}	90-100	80-90	70-80	60-70	<60
X_{23}	90-100	80-90	70-80	60-70	<60
X_{24}	90-100	80-90	70-80	60-70	<60
X_{25}	90-100	80-90	70-80	60-70	<60
X_{31}	90-100	80-90	70-80	60-70	<60
X_{32}	>3.5	3-3.5	2.5-3	2-2.5	0-2
X_{33}	90-100	80-90	70-80	60-70	<60
X_{34}	90-100	80-90	70-80	60-70	<60
X_{35}	85-100	70-85	55-70	40-55	0-40
X_{41}	90-100	80-90	70-80	60-70	<60
X_{42}	60-65	65-70	70-80	80-90	90-100
	55-60	50-55	40-50	30-40	0-30
X_{43}	90-100	80-90	70-80	60-70	<60
X_{44}	90-100	80-90	70-80	60-70	<60
X_{45}	90-100	80-90	70-80	60-70	<60
X_{51}	80-100	60-80	40-60	20-40	0-20
X_{52}	80-100	70-80	55-70	40-55	0-40
X_{53}	60-65	65-70	70-80	80-90	90-100
	55-60	50-55	40-50	30-40	0-30
X_{54}	90-100	80-90	70-80	60-70	<60
X_{55}	90-100	80-90	70-80	60-70	<60

Data source: Determined based on statistical data provided by the China Bureau of Statistics, Shandong Provincial Bureau of Statistics, and Rizhao City Bureau of Statistics

（2）Specific assessment criteria for the target level. The assessment objective of this paper is to achieve effective assessment of the high-quality development performance of cities empowered by China's green transformation. Based on relevant regulations, policies, and systems formulated by the Chinese government, provincial and municipal governments, and cities. Learn from the research results of experts and scholars at home and abroad. The assessment criteria for enabling high-quality development performance through green transformation in Rizhao City, China are divided into five levels: excellent performance, good performance, moderate performance, qualified performance, and unqualified performance. The assessment results determined using a fuzzy comprehensive assessment model. The five level assessment criteria for the performance of high-quality urban development driven by green transformation in Rizhao City, China are listed in Table 4.

Table 4 Performance Assessment Standards for High Quality Urban Development in Rizhao City

assessment grade	Level I	Level Ⅱ	Level Ⅲ	Level Ⅳ	Level Ⅴ
Results_i	[0.90-1.00]	[0.80-0.90）	[0.70-0.80）	[0.60-0.70）	[0-0.60）
Performance status	Excellent	Good	Medium	Pass	Fail

The assessment criteria for the high-quality development performance of Rizhao City, China, based on the promotion of green transformation include three aspects: assessment results, assessment levels, and quality status. It is determined based on the actual situation of high-quality development performance assessment in Rizhao City, China, and has strong reference value for high-quality development performance assessment in other cities.

3. Results and Discussion

3.1 Determination of assessment indicators function and calculation of membership degree

Due to the non-linear relationship between assessment indicators and assessment objects, based on the results of comprehensive analysis, the membership function is determined to be a quadratic nonlinear function. The specific form is detailed in 2.4.1. The membership degree range of the assessment indicators determined by the membership function belongs to the interval [0, 1]. In order to reasonably determine the parameters of the membership function, the minimum value of the assessment indicator is selected as zero except for the environmental pollution index. The maximum value of the positive indicator is selected as the upper boundary value of level I, while the reverse indicator is selected as the lower boundary value of level V. The optimal value of the two neutral indicators is selected as 60%, and the maximum values of various indicators are adjusted appropriately based on the nature of the indicators and the actual situation. Therefore, the specific expression of the membership function of the assessment indicators are shown in Table 5.

Table 5. The membership function Parameters for performance assessment indicators of high-quality development in Cities

Criterion layer	Indicators	Minimum value	Maximum value or Median value	Membership function
Environmental quality indicators for urban green and low-carbon transformation（X_1）	X_{11}	0	3	f_i^{-}=1-0.111111X_i^2
	X_{12}	0	12	f_i^{-}=1-0.0.00694X_i^2
	X_{13}	30	300	f_i^{-}=1-0.000014$(X_i-30)^2$
	X_{14}	30	300	f_i^{-}=1-0.000014$(X_i-30)^2$
	X_{15}	30	300	f_i^{-}=1-0.000014$(X_i-30)^2$
Planning and construction quality indicators for urban green and low-carbon transformation（X_2）	X_{21}	0	100	f_i^{+}=0.0001X_i^2
	X_{22}	0	100	f_i^{+}=0.0001X_i^2
	X_{23}	0	100	f_i^{+}=0.0001X_i^2
	X_{24}	0	100	f_i^{+}=0.0001X_i^2
	X_{25}	0	100	f_i^{+}=0.0001X_i^2
Life and Work Quality Indicators for Urban Green and Low Carbon Transformation（X_3）	X_{31}	0	100	f_i^{+}=0.0001X_i^2
	X32	0	3.5	f_i^{+}=0.0625X_i^2
	X_{33}	0	100	f_i^{+}=0.0001X_i^2
	X_{34}	0	100	f_i^{+}=0.0001X_i^2
	X_{35}	0	90	f_i^{+}=0.000123X_i^2
Process quality indicators for enabling high-quality development through urban green transformation（X_4）	X_{41}	0	100	f_i^{+}=0.0001X_i^2
	X_{42}	0	60	f_i^{m}=0.000278X_i^2
	X_{43}	0	100	f_i^{+}=0.0001X_i^2
	X_{44}	0	100	f_i^{+}=0.0001X_i^2
	X_{45}	0	100	f_i^{+}=0.0001X_i^2
Quality indicators for empowering high-quality development through urban green transformation（X_5）	X_{51}	0	80	f_i^{+}=0.000156X_i^2
	X_{52}	0	100	f_i^{+}=0.0001X_i^2
	X_{53}	0	60	f_i^{m}=0.000278X_i^2
	X_{54}	0	100	f_i^{+}=0.0001X_i^2
	X_{55}	0	100	f_i^{+}=0.0001X_i^2

The membership functions of all assessment indicators are determined in Table 5, and the parameters of the membership function are determined using the determined expression of the membership function of the assessment indicators and the basic data of the assessment indicators in Table 1. Four decimal places are retained for data with one or less decimal places, two decimal places are retained for basic data with ten or hundred decimal places, and basic data with thousand or more decimal places is retained to an integer. Using the determined membership function and basic data to calculate 25 evaluation indicators, the membership degree for the period 2012-2022 is detailed in Table 6.

Table 6 Calculation results of Membership Degree of assessment Indicators in Rizhao City from 2012 to 2022

indicators	2012	2013	2014	20115	2016	2017	2018	2019	2020	2021	2022
X_{11}	0.6799	0.6845	0.7486	0.7919	0.8383	0.8739	0.8932	0.8990	0.9032	0.9059	0.9121
X_{12}	0.7851	0.7562	0.7259	0.6805	0.6543	0.5900	0.5843	0.5289	0.5382	0.5585	0.5704
X_{13}	0.8419	0.8645	0.9006	0.9267	0.9403	0.9474	0.9518	0.9452	0.9289	0.9400	0.9347
X_{14}	0.8645	0.8826	0.8882	0.8952	0.9140	0.9402	0.9508	0.9456	0.9366	0.9385	0.9487
X_{15}	0.8564	0.8775	0.9046	0.9183	0.9365	0.9455	0.9501	0.9518	0.9567	0.9630	0.9659
X_{21}	0.7793	0.8158	0.8330	0.8582	0.8774	0.8964	0.8532	0.8150	0.8629	0.8943	0.9074
X_{22}	0.7441	0.7749	0.7969	0.8256	0.8497	0.8776	0.8847	0.8983	0.9097	0.8925	0.9185
X_{23}	0.7274	0.7493	0.7332	0.7524	0.7616	0.7793	0.7925	0.8041	0.8149	0.8194	0.8288
X_{24}	0.7543	0.7597	0.7719	0.7748	0.7862	0.8021	0.8131	0.8265	0.8403	0.8438	0.8532
X_{25}	0.7616	0.7809	0.7755	0.8032	0.7987	0.7894	0.7829	0.7634	0.7494	0.7399	0.7393
X_{31}	0.7790	0.7987	0.7843	0.8034	0.8167	0.8330	0.8216	0.8699	0.8547	0.8348	0.8236
X_{32}	0.4250	0.5139	0.6191	0.3119	0.3700	0.4091	0.5257	0.6208	0.6722	0.7875	0.8617
X_{33}	0.7273	0.7467	0.7576	0.7719	0.7792	0.8041	0.8183	0.8254	0.8328	0.8185	0.8405
X_{34}	0.7845	0.7971	0.8073	0.8183	0.8243	0.8194	0.8037	0.7806	0.7686	0.7642	0.7494
X_{35}	0.2646	0.3234	0.3819	0.4619	0.5258	0.6248	0.6987	0.8124	0.9154	0.9732	0.7983
X_{41}	0.5224	0.6143	0.6458	0.7135	0.7989	0.8150	0.8438	0.8196	0.8470	0.8608	0.8383
X_{42}	0.6504	0.7339	0.7856	0.8032	0.8367	0.8569	0.9039	0.9115	0.9407	0.9641	0.9687
X_{43}	0.7268	0.7152	0.7367	0.7462	0.7616	0.7786	0.7987	0.8131	0.8435	0.8272	0.8471
X_{44}	0.7081	0.7200	0.7331	0.7401	0.7493	0.7581	0.7677	0.7772	0.7907	0.7930	0.7969
X_{45}	0.7307	0.7399	0.7550	0.7616	0.7985	0.8149	0.8530	0.8444	0.8614	0.8701	0.8789
X_{51}	0.3499	0.3841	0.4280	0.4863	0.5115	0.5566	0.6070	0.6464	0.6944	0.7057	0.7369
X_{52}	0.4694	0.4768	0.4861	0.5094	0.5682	0.6605	0.7118	0.7441	0.7774	0.7930	0.7854
X_{53}	0.6504	0.6773	0.7310	0.7697	0.7915	0.8115	0.8324	0.8526	0.8802	0.9140	0.9648
X_{54}	0.7286	0.7374	0.7403	0.7449	0.7550	0.7579	0.7714	0.7855	0.7978	0.8319	0.8149
X_{55}	0.7560	0.7618	0.7786	0.7909	0.7930	0.8075	0.8216	0.8332	0.8477	0.8547	0.8735

3.2 Specific assessment results

3.2.1 Assessment results of criterion layer

The assessment indicators of the criteria level determined in this paper mainly include five categories: environmental quality of urban green and low-carbon transformation, planning and construction quality of urban green and low-carbon transformation, life and work quality of urban green and low-carbon transformation, process quality of urban green transformation empowering high-quality development, and result quality of urban green transformation empowering high-quality development. Each category includes five specific assessment indicators, with the assessment object being the annual comprehensive performance of high-quality urban development. Firstly, normalize the relative weights of each category of indicators, and use the normalized relative weights of assessment indicators and the assessment results in Table 6 to calculate the assessment results of criterion level indicators for each category from 2012 to 2022. Please refer to Table 7 for details.

Table 7 Criteria layer assessment results of green transformation empowering high-quality development performance

X_i	High quality environment (X_1)	High quality planning and construction (X_2)	Quality of life and work (X_3)	High quality empowerment process (X_4)	High quality empowerment results (X_5)	Assessment Results (G)
2012	0.8048	0.7533	0.5881	0.6669	0.5887	0.6999
2013	0.8121	0.7762	0.6191	0.7044	0.6054	0.7229
2014	0.8325	0.7823	0.6424	0.7312	0.6308	0.7427
2015	0.8412	0.8031	0.6817	0.753	0.6584	0.7497
2016	0.8552	0.8152	0.7115	0.7893	0.6823	0.7702
2017	0.8577	0.8296	0.7479	0.805	0.7177	0.7865
2018	0.8643	0.8258	0.7742	0.8338	0.7479	0.8026
2019	0.8521	0.822	0.8236	0.8335	0.7716	0.8082
2020	0.8508	0.8362	0.8479	0.8571	0.7989	0.8218
2021	0.8593	0.8388	0.8587	0.8636	0.8193	0.8318
2022	0.8645	0.8504	0.8282	0.8665	0.8345	0.8416
mean value	0.8450	0.8121	0.7385	0.7913	0.7141	0.7798
W_i	0.1986	0.2054	0.1939	0.2010	0.2012	$\sum W_1=1$

The hierarchical assessment results obtained by using the fuzzy comprehensive assessment model of criterion hierarchy show that the environmental quality performance of Rizhao City in China is relatively good and has strong stability, but the improvement of performance is not stable; The effect of green transformation to empower the high-quality development performance of cities is relatively poor, mainly due to the late starting point of Rizhao's green transformation, but it has a relatively fast growth rate; The order of high-quality development performance of other categories of factors is: urban planning and construction quality, green transformation empowers high-quality development quality, and residents' life and work quality. According to the assessment results of the criteria level, the level and overall performance of green transformation empowering high-quality development in Rizhao City belong to a good level, with a relatively fast growth rate.

3.2.2 Assessment results of the target layer

Using a fuzzy comprehensive assessment model and relevant basic data to assess the performance of high-quality development in City, based on the goal hierarchy of green transformation empowering high-quality development. The specific assessment results are as follows:

$$
\mathrm{Re}\,sults(G)=\begin{bmatrix}0.0402\\0.0406\\0.0397\\0.0393\\0.0388\\0.0420\\0.0415\\0.0411\\0.0406\\0.0402\\0.0384\\0.0379\\0.0386\\0.0382\\0.0408\\0.0404\\0.0395\\0.0404\\0.0399\\0.0408\\0.0413\\0.0417\\0.0395\\0.0382\\0.0405\end{bmatrix}^{T}\circ\begin{bmatrix}
0.6799 & 0.6845 & 0.7486 & 0.7919 & 0.8383 & 0.8739 & 0.8932 & 0.8990 & 0.9032 & 0.9059 & 0.9121\\
0.7851 & 0.7562 & 0.7259 & 0.6805 & 0.6543 & 0.5900 & 0.5843 & 0.5289 & 0.5382 & 0.5585 & 0.5704\\
0.8419 & 0.8645 & 0.9006 & 0.9267 & 0.9403 & 0.9474 & 0.9518 & 0.9452 & 0.9289 & 0.9400 & 0.9347\\
0.8645 & 0.8826 & 0.8882 & 0.8952 & 0.9140 & 0.9402 & 0.9508 & 0.9456 & 0.9366 & 0.9385 & 0.9487\\
0.8564 & 0.8775 & 0.9046 & 0.9183 & 0.9365 & 0.9455 & 0.9501 & 0.9518 & 0.9567 & 0.9630 & 0.9659\\
0.7793 & 0.8158 & 0.8330 & 0.8582 & 0.8774 & 0.8964 & 0.8532 & 0.8150 & 0.8629 & 0.8943 & 0.9074\\
0.7441 & 0.7749 & 0.7969 & 0.8256 & 0.8497 & 0.8776 & 0.8847 & 0.8983 & 0.9097 & 0.8925 & 0.9185\\
0.7274 & 0.7493 & 0.7332 & 0.7524 & 0.7616 & 0.7793 & 0.7925 & 0.8041 & 0.8149 & 0.8194 & 0.8288\\
0.7543 & 0.7597 & 0.7719 & 0.7748 & 0.7862 & 0.8021 & 0.8131 & 0.8265 & 0.8403 & 0.8438 & 0.8532\\
0.7616 & 0.7809 & 0.7755 & 0.8032 & 0.7987 & 0.7894 & 0.7829 & 0.7634 & 0.7494 & 0.7399 & 0.7393\\
0.7790 & 0.7987 & 0.7843 & 0.8034 & 0.8167 & 0.8330 & 0.8216 & 0.8699 & 0.8547 & 0.8348 & 0.8236\\
0.4250 & 0.5139 & 0.6191 & 0.3119 & 0.3700 & 0.4091 & 0.5257 & 0.6208 & 0.6722 & 0.7875 & 0.8617\\
0.7273 & 0.7467 & 0.7576 & 0.7719 & 0.7792 & 0.8041 & 0.8183 & 0.8254 & 0.8328 & 0.8185 & 0.8405\\
0.7845 & 0.7971 & 0.8073 & 0.8183 & 0.8243 & 0.8194 & 0.8037 & 0.7806 & 0.7686 & 0.7642 & 0.7494\\
0.2646 & 0.3234 & 0.3819 & 0.4619 & 0.5258 & 0.6248 & 0.6987 & 0.8124 & 0.9154 & 0.9732 & 0.7983\\
0.5224 & 0.6143 & 0.6458 & 0.7135 & 0.7989 & 0.8150 & 0.8438 & 0.8196 & 0.8470 & 0.8608 & 0.8383\\
0.6504 & 0.7339 & 0.7856 & 0.8032 & 0.8367 & 0.8569 & 0.9039 & 0.9115 & 0.9407 & 0.9641 & 0.9687\\
0.7268 & 0.7152 & 0.7367 & 0.7462 & 0.7616 & 0.7786 & 0.7987 & 0.8131 & 0.8435 & 0.8272 & 0.8471\\
0.7081 & 0.7200 & 0.7331 & 0.7401 & 0.7493 & 0.7581 & 0.7677 & 0.7772 & 0.7907 & 0.7930 & 0.7969\\
0.7307 & 0.7399 & 0.7550 & 0.7616 & 0.7985 & 0.8149 & 0.8530 & 0.8444 & 0.8614 & 0.8701 & 0.8789\\
0.3499 & 0.3841 & 0.4280 & 0.4863 & 0.5115 & 0.5566 & 0.6070 & 0.6464 & 0.6944 & 0.7057 & 0.7369\\
0.4694 & 0.4768 & 0.4861 & 0.5094 & 0.5682 & 0.6605 & 0.7118 & 0.7441 & 0.7774 & 0.7930 & 0.7854\\
0.6504 & 0.6773 & 0.7310 & 0.7697 & 0.7915 & 0.8115 & 0.8324 & 0.8526 & 0.8802 & 0.9140 & 0.9648\\
0.7286 & 0.7374 & 0.7403 & 0.7449 & 0.7550 & 0.7579 & 0.7714 & 0.7855 & 0.7978 & 0.8319 & 0.8149\\
0.7560 & 0.7618 & 0.7786 & 0.7909 & 0.7930 & 0.8075 & 0.8216 & 0.8332 & 0.8477 & 0.8547 & 0.8735
\end{bmatrix}
$$

$$= (0.6818, 0.7065, 0.7288, 0.7381, 0.7613, 0.7820, 0.8014, 0.8124, 0.8307, 0.8435, 0.8461)$$

The assessment results of this model can only reflect the overall situation of high-quality development performance empowered by green transformation in Rizhao City, China from 2012 to 2022, and cannot reflect the assessment results of criterion level indicators. The combination of the two methods can achieve relatively satisfactory results. Organize the assessment results of the target level into Table 8.

Table 8 Analysis of the results of the performance assessment of high-quality development in Rizhao City

No.（year）	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Results（G）	0.6818	0.7065	0.7288	0.7381	0.7613	0.7820	0.8014	0.8124	0.8307	0.8435	0.8461
Level	Level IV	Level III	Level III	Level III	Level III	Level III	Level II	Level II	Level II	Level II	Level II
Performance status	Pass	Medium	Medium	Medium	Medium	Medium	Good	Good	Good	Good	Good

Comparing the assessment results of the criterion level assessment model and the target level assessment model, although there are differences, the difference is not significant. The error of the assessment results is within the allowable range, and the assessment results are on the same level.

3.3. Discussion

3.3.1 Discussion of Factors Influencing Assessment Results

This paper assesses the performance of green transformation in empowering high-quality development in Rizhao City, China, and selects 25 evaluation indicators in four categories. These assessment indicators basically reflect the status of high-quality development performance in Rizhao City, China, and ultimately determine the specific assessment results. The assessment indicator for the high-quality development performance of the green transformation empowerment in Rizhao City, China, is calculated through membership degree, and its value range is within the interval [0, 1], which is more convenient for comparing influencing factors. In order to reflect the influence of the 25 evaluation indicators on the assessment results, the changes of the 25 evaluation indicators during the period from 2012 to 2022 are plotted in Cartesian coordinates using curve families. The specific changes situations are shown in Figure 3.

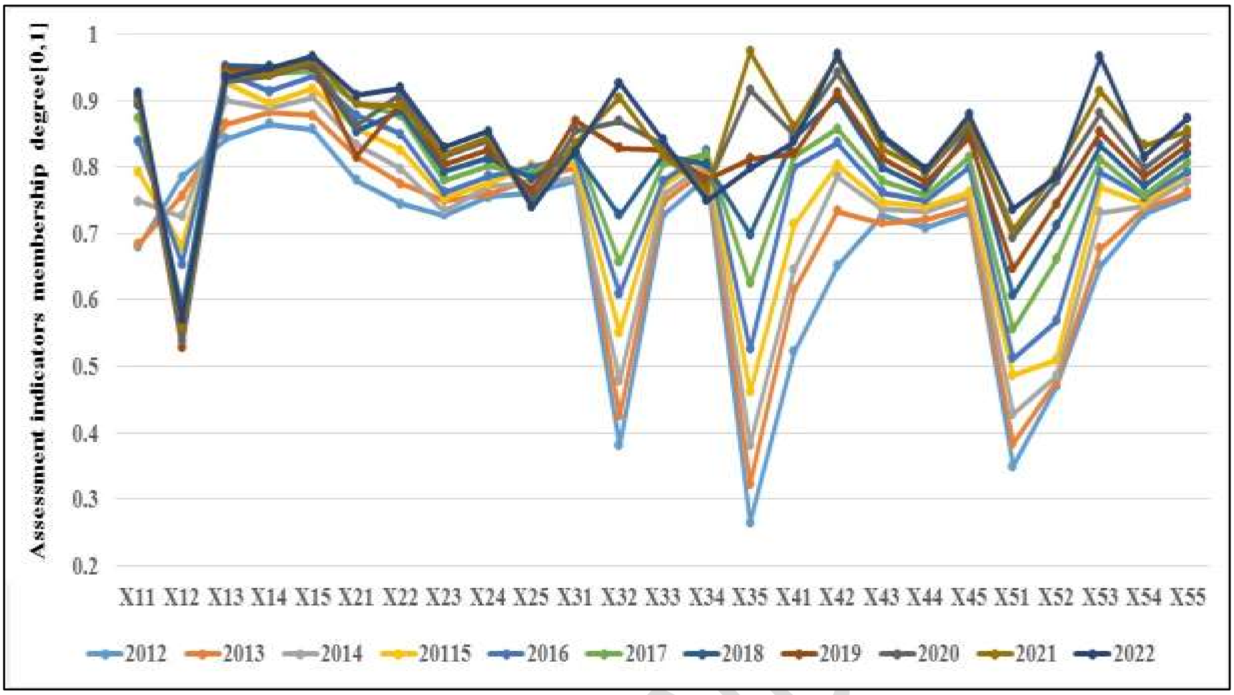

Figure 3. Trend of Assessment Indicator Changes

From Figure 3, it can be seen that according to the impact analysis of assessment indicators, the indicators that have a significant impact on the assessment results include X_{13}-X_{15}, X_{21}-X_{25}，X_{43} andX_{44}，X_{54} andX_{55}. The indicators that have less impact on the assessment results include X_{12}，X_{32}，X_{35} and X_{51}. According to the impact analysis of years, the impact from 2012 to 2013 is relatively small, and the impact from 2020 to 2022 is relatively large. Therefore, enhancing the green transformation and empowering high-quality development performance in Rizhao City.

3.3.2 Discussion on the Differences between Two Assessment Methods

This paper uses two methods, the criterion level fuzzy comprehensive assessment model and the target level fuzzy comprehensive assessment model, to comprehensively assess the high-quality development performance of the cities empowered by the green transformation in Rizhao City, China. The two methods are actually the same and use different calculation methods. The results and differences of the two assessment methods are shown in Table 9.

Table 8 Analysis of Differences in Results between Two Assessment Methods

No.（year）	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Results (C)	0.6999	0.7229	0.7427	0.7497	0.7702	0.7865	0.8026	0.8082	0.8218	0.8318	0.8416
Results (G)	0.6818	0.7065	0.7288	0.7381	0.7613	0.7820	0.8014	0.8124	0.8307	0.8435	0.8461
Difference	-0.0181	-0.0164	-0.0139	-0.0116	-0.0089	-0.0045	-0.0012	0.0042	0.0089	0.0117	0.0045
Ratio（%）	-2.5861	-2.2686	-1.8715	-1.5473	-1.1555	-0.5722	-0.1495	0.5197	1.0830	1.4066	0.5347

From Table 8, it can be seen that the assessment results of Method $Results(C)_i$ are slightly higher than those of Method $Results(G)_i$. The maximum annual difference rate between the two assessment results is -2.5861%, and the average annual difference rate during the period is -0.5281%. It can be seen that the assessment and results of the two assessment methods are basically the same and can be replaced by each other. In order to illustrate the differences between the two evaluation methods, the evaluation results of the two evaluation methods are plotted in the same coordinate system using a cone diagram in the same coordinate system, and the specific differences are detailed in Figure 4.

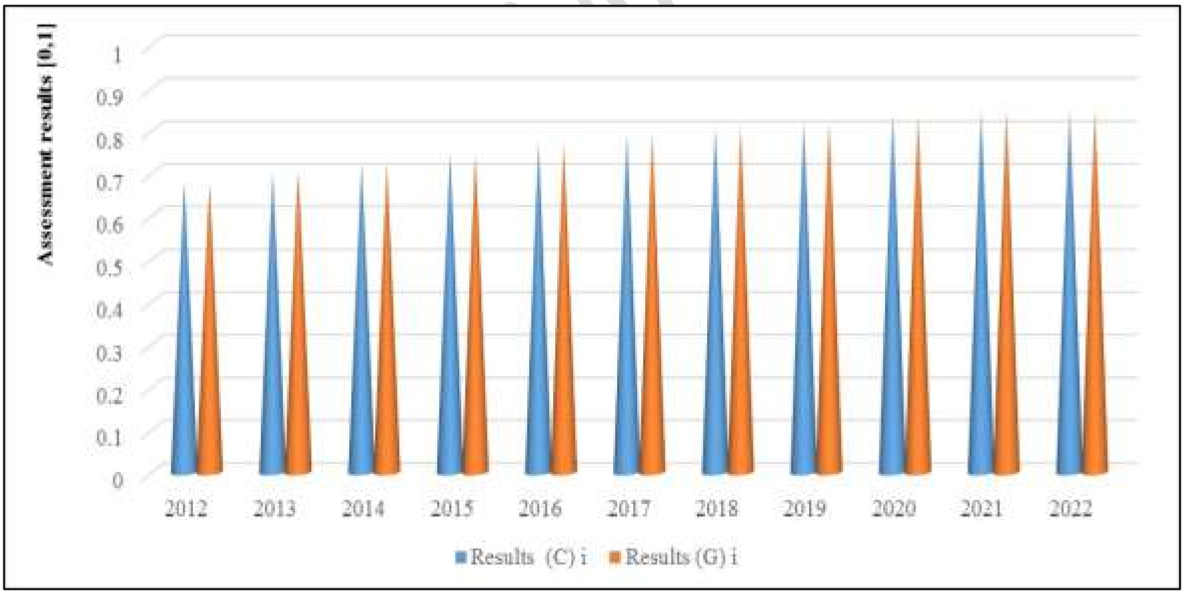

Figure 4. Cone chart of assessment results for two assessment methods

Figure 4 shows that there is a small difference between the two assessment methods, which can be ignored, meaning that the assessment results of the two assessment methods are basically the same and can be replaced by each other.

4. Conclusion and Suggestions

The high-quality comprehensive performance assessment of cities empowered by China's green transformation is a very important research topic, and studying and solving this problem is a long-term and arduous research task for Chinese scholars. In order to explore an effective methodology for comprehensive performance assessment of urban high-quality development in the context of China's green transition, this paper, based on the analysis of the research background, literature review, and theoretical analysis, through the comprehensive analysis of Rizhao City's green transition, green transition empowerment, and urban high-quality development, A total of 25 indicators in five categories, including the environmental quality of green and low-carbon transformation, the planning and construction quality of green and low-carbon transformation, the living and working quality of green and low-carbon transformation, the process quality of green transformation enabling high-quality development, and the outcome quality of green transformation enabling high-quality development, were selected to construct the assessment indicator system. On the basis of the evaluation index, the relative weight of the evaluation index was determined by using the expert survey method. Using fuzzy mathematical methods, the nonlinear membership function and the two-level fuzzy comprehensive evaluation model of criterion level and target level were determined. The statistical data provided by the government was used to comprehensively evaluate the high-quality development performance of cities empowered by the green transformation of Rizhao City, China. Regarding the limitations of this paper, the indicators selected in this paper are relatively comprehensive, and there are also indicators that cannot be considered or are not comprehensive. The data period used is only ten years and needs to be gradually increased；The parameters of the study method and the effectiveness of its use need to be further examined.

The study found that the high quality development performance empowered by green transformation in Rizhao City, China, has shown a continuous upward trend, having risen from Level Ⅳ in 2012, to Level II by 2022, and remained at Level II during the period of 2018-2022, with an upward trend in its assessment results. Based on the specific findings of the study, the following policy recommendations are proposed to maximize the high-quality development performance of Rizhao City, China, in the light of the actual situation of Rizhao City, China, where green transformation empowers high-quality urban development:

（1）Give full play to green transformation empowerment and improve the performance of high-quality urban development. Urban green transformation is not only a task for sustainable urban development, but also has an important enabling role for the improvement of high-quality urban development performance. Along with the development of green transformation in Chinese cities and the increase in the rate of green transformation, the high-quality development performance of Chinese cities can be continuously improved.

（2）Promote the improvement of urban high-quality development performance by selecting and optimizing the assessment indicator system. Evaluation indicators are the driving factors for urban green transformation and high-quality development. Improving the performance of high-quality urban development focuses on maintaining high-level indicators and significantly improving low-level indicators. Use the improvement of evaluation indicators and their continuous optimization to promote the performance of high-quality urban development.

（3）Improve the city's high-quality development performance through continuous improvement and optimization of evaluation models. The assessment model is an important factor in determining the outcome of the assessment as well as contributing to its effectiveness. Therefore, continuous low-correction, optimization and reconstruction of the assessment model is an important means to improve the performance of Chinese cities in green transition enabling high-quality development.

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