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Original Research

Evaluation and Obstacle Factors of the Green Development Level of China's Oil and Gas Resource-Based Cities Based on DPSIR-TOPSIS Model

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Abstract

The green development of oil and gas resource-based cities is not only a necessary choice to address resource depletion, protect the ecological environment, promote economic transformation, and improve residents' quality of life but also a crucial approach to ensuring long-term, stable, and sustainable urban economic development. This paper constructs an evaluation index system for the green development of oil-and-gas resource-based cities based on the DPSIR model. The system includes five sub-systems: driving forces, pressures, status, impacts, and responses. By utilizing the entropy weight TOPSIS model and obstacle degree model, this study evaluates and analyzes the level of green development as well as obstacle factors in 17 oil-and-gas resource-based prefecture-level cities in China from 2011 to 2021. The findings indicate that: (1) Overall, the green development level of oil and gas resource-based cities is relatively low, with significant regional disparities. (2) Both the driving force system and pressure system generally exhibit a declining trend in terms of green development level, while the state system shows improvement over time; meanwhile, both the influence system and response system demonstrate fluctuations. (3) Major obstacles faced by oil-and-gas resource-based cities include per capita green space availability, accessibility of public transport vehicles per 10k people, coverage area per capita for urban roads, R&D expenditure proportion in GDP, as well as social security subsidies proportion in general public budget expenditure. Based on these evaluation results and analysis outcomes, it is recommended that city governments optimize their policy systems, prioritize training programs for attracting talents specializing in green industries, and enhance efficiency regarding urban green development.

Keywords: oil and gas resource-based city, green development level, DPSIR-TOPSIS model, obstacle model

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Introduction

At present, the concept of green development has gained consensus in global governance, and the "development before governance" model cannot resolve the contradiction between China's economic development and the ecological environment. Compared with the traditional development model, the green development model is based on the constraints of ecological environmental capacity and resource carrying capacity. It pays more attention to the integrated, systematic, and coordinated operation of the social system, economic system, natural system, and other aspects to maximize comprehensive benefits [1]. Oil and gas resource-based cities are cities developed for the extraction and utilization of oil and natural gas resources. As the primary sources of oil and natural gas energy provided by the state, they play a crucial role in supporting the modern economic system and serve as a key starting point for regionally coordinated development strategies. Oil and gas resource cities, as a significant category of resource-based cities, have made remarkable contributions to China's oil and gas supply security and national economic development. According to the energy consumption data for 2022, oil and gas consumption in China accounts for 27.4% of the country's total energy consumption. China's demand for oil and gas remains substantial, indicating broad prospects for the oil and gas market. Due to the oil and gas industry's mining, transportation, processing, and other heavy industries, they occupy a dominant position in the economic structure of oil and gas resource-based cities [2]. This dominance can easily lead to an imbalance in the economic structure and also put significant pressure on the ecological environment. In order to mitigate the impact of the depletion of oil and gas resources on urban economic development, cities reliant on oil and gas resources need to pursue a green and low-carbon transformation path. They should aim to enhance environmental conditions, conserve resources, and foster economic development simultaneously. The green development mode emphasizes a growth strategy that coordinates the development of the economy, resources, and environment. It requires oil and gas resource-based cities to allocate resource consumption rationally, enhance scientific and technological innovation capabilities, improve resource allocation efficiency, and achieve coordinated development of the economy, resources, and environment. This approach aims to promote green economic growth in cities and optimize the layout of urban economic structures further [3].

According to the summary, despite extensive research by domestic and foreign scholars on urban green development, there are still some issues. The assessment of the level of green development: Since the Organization for Economic Cooperation and Development (OECD) introduced a green development evaluation system in 201 [4], focusing on economic development, ecological environment, and human welfare, the green development of resource-based cities has emerged as a prominent research area in academia. The DPSIR model proposed by the OECD and the three-system model proposed by UNEP provide powerful tools for the analysis and evaluation of green development (OECD, 2021) [5]. In terms of research methods, scholars have adopted a variety of quantitative analysis methods, such as chromatographic analysis [6, 7], the vertical and horizontal separation grade method [8, 9], the entropy weight method [10, 11], and the projection pursuit method [12], to build an urban index evaluation system and calculate the level of green development in resource-based cities. Sunfei et al. constructed an evaluation index system for the level of industrial green development from four dimensions: resource consumption intensity, environmental impact and treatment, economic benefit and structure, technological innovation, and investment, providing an effective tool for measuring the level of industrial green development [13]. Yin Long et al., based on the Entropy Weight-TOPSIS Model, constructed a green development evaluation index system with four dimensions: economic green development, social green development, resource green development, and environmental green development. They achieved a dynamic evaluation of the level of green development [14]. Green development efficiency evaluation: Currently, empirical methods in this research field primarily concentrate on three approaches: data envelopment analysis, spatial econometric analysis, and comprehensive analysis. For example, the super-efficient SBM model of undesired output [15], the spatial Durbin model [16], the geographical weighted regression model [17], and the differentially differential model [18]. From the national [18] and provincial levels [19], scholars have developed empirical models to analyze the influencing factors [20], spatial and temporal differences [21] of green development efficiency, etc. They have found that the enhancement of urbanization levels and the rise in energy consumption can impede the progress of green development efficiency [22]. Additionally, government intervention policies exhibit regional variations [23].

To conclude, despite the extensive attention and research on urban green development by scholars both domestically and internationally, there are still evident shortcomings in evaluating the green development of oil and gas resource-based cities. Existing studies primarily focus on assessing the transformation of individual or regional cities, lacking a comprehensive, systematic, and holistic evaluation framework to comprehensively evaluate the green development of oil and gas resource-based cities. Secondly, the evaluation index system mostly relies on subjective judgment and lacks the support of objective models, which leads to certain issues in the comprehensiveness and representativeness of the evaluation index system. Thirdly, current research typically analyzes influencing factors of green development from a single perspective, making it difficult to provide a comprehensive generalization from multiple angles. Considering the reasons mentioned above, this paper adopts a combination of qualitative and quantitative analysis methods to construct an evaluation index system for assessing the level of green development in major oil and gas resource-based cities in China based on the DPSIR model. By integrating regional analysis with a developmental stage assessment approach, this study reveals the current situation concerning green development in oil and gas resource-based cities. It utilizes an obstacle degree model to identify key obstacles that impede such progress. Finally, based on our research findings presented herein, this paper provides targeted suggestions for high-quality developments, aiming to offer beneficial references and guidance for achieving sustainable transformations within oil and gas resource-based cities.

Methods, Data, and Indicators

The DPSIR Model

The DPSIR model is a framework composed of five parts: Driving forces (D), Pressures (P), Status (S), Impacts (I), and Responses (R). The model is further derived and developed by the European Environment Agency (EEA) based on the PSR (Pressures-Status-Responses) and DSR (Driving Forces-Status-Responses) models [24]. At present, the DPSIR model has become an important methodological tool for domestic and foreign scholars in the study of economic, social, environmental, and other fields.

In the DPSIR model of the green development level of oil-and-gas resource-based cities (1.), the driving force mainly refers to the demand for economic and social development of oil-and-gas resource-based cities. As a driving force, these demands will also exert pressure on social, resource, and environmental systems. These pressures lead to changes in the state of economic, social, resource, and environmental systems and have specific impacts. In order to enhance the state and make a positive impact, a range of proactive policies and measures are required to address issues, thus steering the city towards sustainability. The DPSIR model can comprehensively analyze the internal mechanisms and external responses of green development in oil and gas resource-based cities. It can also provide theoretical support for formulating effective sustainable development strategies.

Entropy Weight-TOPSIS Model

The Entropy Weight-TOPSIS model is a multi-attribute decision-making method first proposed by Hwang et al. in 1981 [25]. The main idea is to assess the ranking of each index by calculating the distance between each index and the best and worst solutions. This method makes full use of the information from the raw data and can accurately reveal the differences between the indicators [26]. The following are the main calculation steps of the entropy weight TOPSIS model:

(1) Normalized data. The extreme value method is adopted to standardize the collected data and eliminate the influence of different index dimensions. The specific methods are as follows:

Positive indicators:

$$X'_{ij} = \left(X_{ij} - X_{i\min}\right) / \left(X_{i\max} - X_{i\min}\right) \tag{1}$$

Negative indicator:

$$X'_{ij} = \left(X_{i\max} - X_{ij}\right) / \left(X_{i\max} - X_{i\min}\right) \tag{2}$$

In the formula: $X_{i\ max}$ represents the maximum value of index i in all study years; $X_{i\ min}$ represents the minimum value of index i in all study years, and X'_{ij} represents the data obtained by X_{ij} after standardized processing.

(2) Determine the weight of indicators: The entropy method is used to determine the weight of indicators W = (W_1, W_2, ..., W_m), and establish the weighted normalized matrix as:

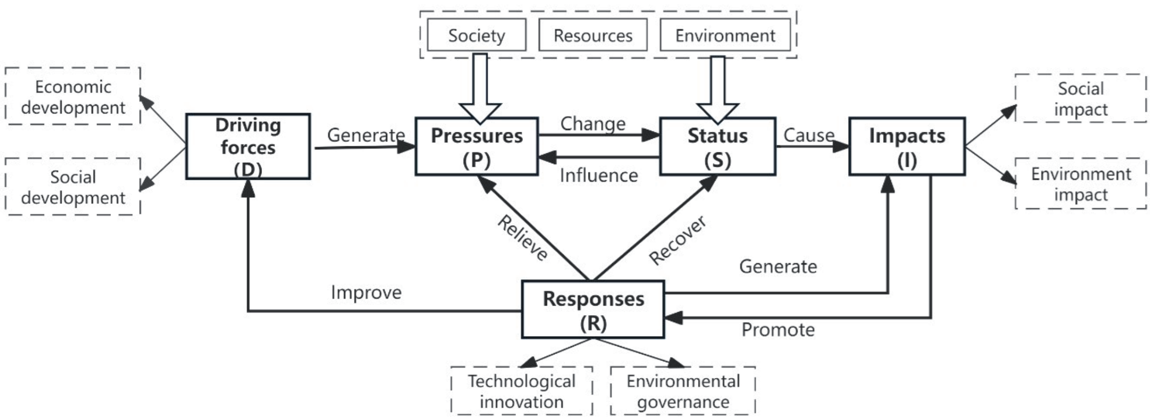

Fig. 1. Framework of DPSIR for the green development level of oil-gas resource-based cities.

$$\mathbf{V} = X_{ij} \times \mathbf{W} = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1n} \\ v_{21} & v_{22} & \cdots & v_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ v_{m1} & v_{m2} & \cdots & v_{mn} \end{bmatrix} \quad (3)$$

(3) Determine the optimal solution and the worst solution: according to the standardized data and the weights of each index, the optimal solution and the worst solution of the index are obtained.

The optimal solution:

$$V^+ = \left\{ \max \left| V_{ij} \right| i = 1,2,\cdots,m \right\} = \left\{ V_1^+, V_2^+ \cdots, V_m^+ \right\} \quad (4)$$

The worst solution:

$$V^- = \left\{ \min V_{ij} \mid i = 1,2,\cdots,m \right\} = \left\{ V_1^-, V_2^-, \cdots, V_m^- \right\} \quad (5)$$

In the formula: V_{ij}, is the value of the j year of the $i$index in the weighted decision evaluation matrix V; V_i^+ and V_i^+ are the best and worst solutions of the c index, respectively.

(4) Calculation distance: the distance from the index of each city to the best solution is:

$$D_j^+ = \sqrt{\sum_{i=1}^{n} \left(V_{ij} - V^+ \right)^2} \quad (6)$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} \left(V_{ij} - V^- \right)^2} \quad (7)$$

In the formula: D_j^+ represents the distance to the positive ideal solution, and the smaller D_j^+ is, the closer it is to the positive ideal solution; D_j^- is the distance from the negative ideal solution in year j, and the smaller D_j is, the closer it is to the negative ideal solution.

(5) Calculate relative proximity degree: Calculate the relative proximity degree (T_j) of each index of green development level of oil and gas resource-based cities over the years, and its expression is as follows:

$$T_j = \frac{D_j^-}{D_j^+ + D_j^-} \quad (8)$$

In the formula: the greater the value of $T_j \in [0,1]$, the closer the level of green development in year j is to the optimal level.

(6) Ranking of advantages and disadvantages: According to the relative proximity degree of different years, the level of green development of each city is determined, and the size is sorted.

Obstacle Degree Model

Through the obstacle degree model, each factor is diagnosed and analyzed to determine the impact of factors on the whole system, so as to find out the main obstacle factors affecting each city [27]. The specific calculation formula for obstacle degree is as follows:

$$O_{ij} = \frac{\left(1 - X_{ij}\right) \times W_i \times 100\%}{\sum_{i=1}^{m} \left(1 - X_{ij}\right) \times W_i} \quad (9)$$

In the formula, O_{ij} is the obstacle degree of the j index to the green development level in the j year; W_i is the weight of the i indicator

Based on the analysis of the influence degree of each single factor on each city, the influence of each subsystem on the obstacle degree of urban green development is further studied. The formula is as follows:

$$U_i = \sum O_{ij} \quad (10)$$

In the formula: U_i is the obstacle degree of the total goal.

Study Area and Data Sources

According to the National Sustainable Development Plan for Resource-Based Cities (2013-2020), there are a total of 29 oil and gas resource-based cities in China, out of which 18 are prefecture-level cities [13]. Xinjiang is the wealthiest region in China in terms of oil and gas resources. It is home to seven oil and gas cities and holds 17% and 19% of the country's primary reserves of oil and natural gas, respectively. In recent years, the region has promoted the transformation and upgrading of the petroleum and petrochemical industries. The city of Karamay stands out as a model of diversified development, boasting a GDP per capita of 247,500 yuan. The Ordos Basin, spanning five provinces and abundant in oil and gas resources, has made a significant contribution to the country's energy supply. As an important energy industrial base in China, the region is rich in coal, natural gas, and other resources, providing solid support for the local economy. Yulin, located in Shaanxi Province, is rich in resources and has great economic potential. The Ji Plateau oil field is a significant discovery, with 700 million tons of newly proven oil resources. Qingyang City is renowned for its three billion-ton oilfields, which yield nearly 10 million tons of oil and gas each year, earning it the title of "New Capital of Oil and Gas". Daqing City, as the cornerstone of the oil industry, is actively transitioning and developing strategic emerging industries. Panjin was once a stable production site for the Liaohe Oilfield. However, in recent years, it has encountered the challenge of declining oil and gas production and has been designated as a resource-exhausted city. However, through industrial transformation and the development of petrochemicals and other industries, Panjin is gradually moving towards a new stage of development. Puyang City, located in Henan Province, is also grappling with the challenge of declining oil and gas production. In recent years, the city has made significant advancements in the petrochemical industry by utilizing its energy resources to implement proactive reforms, enhance enterprise capacities, and extend the industrial value chain.

Considering data availability and the characteristics of the research objects, this study focuses on investigating 17 specific prefecture-level cities in China with oil and gas resources, excluding Hami City due to insufficient data collection. The names and types of the cities under study are listed in Table 1. The research period for this study ranges from 2011 to 2021. The primary data source is the China Urban Statistical Yearbook, supplemented by provincial and city statistical yearbooks. In cases where certain data points were missing, adjacent years' averages or moving average methods were employed for appropriate data processing.

Construction of Indicator System

Based on the references to relevant research articles [6, 8, 10, 11, 13, 14], this paper deeply analyzes the actual development of oil and gas resource-based cities. Based on the principles of scientificity, practicability, systematization, and operability, the index system of the green development level of oil and gas resource-based cities is established with the DPSIR model. The index system is divided into four levels: The first level is the target level, which mainly evaluates the green development level of each oil and gas resource-based city; The second level is the criterion level, covering the driving forces, pressures, status, impacts, responses, and five systems; The third level is the factor level, which involves many factors such as urban economy, society, resources, environment, and technology; The fourth level is the index level, which is composed of 28 sub-indexes that comprehensively and concretely reflect the green development status of oil and gas resource-based cities. The specific indicator construction is shown in Table 2.

Table 1. Distribution and type of oil and gas cities in China.

Province	Oil and gas city	City level
Heilongjiang	Daqin	Prefecture-level city
Hebei	Tangshan	Prefecture-level city
Liaoning	Panjin	Prefecture-level city
Liaoning	Fushun	Prefecture-level city
Shandong	Dongying	Prefecture-level city
Ji Lin	Songyuan	Prefecture-level city
Inner Mongolia	Ordos	Prefecture-level city
Henan	Nanyang	Prefecture-level city
Henan	Puyang	Prefecture-level city
Sichuan	Nanchong	Prefecture-level city
Sichuan	Luzhou	Prefecture-level city
Sichuan	Dazhou	Prefecture-level city
Shanxi	Yan'an.	Prefecture-level city
Shanxi	Yulin	Prefecture-level city
Gansu	Qingyang	Prefecture-level city
Yunnan	Zhaotong	Prefecture-level city
Xinjiang	Karamay	Prefecture-level city

Based on research related to the construction of a green development evaluation system, this paper systematically constructs a green development evaluation system for oil and gas resource cities. It is based on five core dimensions: driving force, pressure, state, impact, and response, while considering the specific characteristics of oil and gas resource cities. The system is hierarchical. Firstly, the target level is set to comprehensively assess the degree of green development in oil and gas resource cities. Then, it is refined to the standard level, covering the five core dimensions. Next, it is deepened into the factor level, involving economic, social, resource, environment, and technology. Finally, it is implemented with 28 sub-indicators to ensure the comprehensiveness and accuracy of the evaluation. See Table 2 for the detailed indicator structure.

On the driving force dimension, this study explores the synergistic relationship between economic growth and social governance as a core element in measuring the development dynamics of oil and gas resource cities. Specifically, the study adopts economic indicators such as GDP per capita [26-29], GDP growth rate [20, 23] and fixed asset investment [1, 30] to comprehensively reflect the economic development of oil and gas resource cities. At the same time, the study combines social indicators such as urbanization rate [23-25], natural population growth rate [27], and average wage of employees [1, 20, 24] to comprehensively assess the impact of the level of social governance on the development dynamics of cities.

On the pressure dimension, the study focuses on three major sources of pressure, namely population, resources, and environment, and identifies the main pressures facing oil and gas resource cities through quantitative analyses of multi-dimensional indicators. Among these, population density [5, 31] is used to measure population pressure, and energy consumption per unit of GDP [11, 19] and electricity consumption [29, 30] are used as quantitative indicators of resource pressure. In addition, environmental indicators such

Table 2. Indicators of green development level of oil-gas resource-based cities.

Target layer	Criterion layer	Element level	Index level/units	Properties	Variable
Green development level of oil-gas resource-based cities	Driving forces (D)	Economic development	Per capita GDP (10,000 yuan/person)	+	X1
			GDP Growth rate (%)	+	X2
			Investment in fixed assets (10,000 yuan)	+	X3
		Social development	Urbanization rate (%)	+	X4
			Natural population growth rate (‰)	-	X5
			Average salary of working staff (RMB)	+	X6
	Pressures (P)	Population pressure	Population density (person /km2)	-	X7
		Resource pressure	Energy consumption per unit GDP (tons of standard coal / 10,000 yuan)	-	X8
			Power consumption per unit GDP /(kW·h/ ten thousand yuan)	-	X9
		Environmental pressure	Industrial sulfur dioxide emissions (tons)	-	X10
			Industrial wastewater discharge (10,000 tons)	-	X11
			Industrial smoke (powder) dust emissions (tons)	-	X12
	Status (S)	Social state	Per capita urban road area (m2/ person)	+	X13
			Number of hospital beds per 10,000 people (per 10,000 people)	+	X14
			Public transport vehicles per 10,000 people (units per 10,000 people)	+	X15
		Resource state	Water resources per capita (m3/ person)	+	X16
			Per capita green park area (m2/ person)	+	X17
	Impacts (I)	Social impact	Share of tertiary industry in GDP (%)	+	X18
			Urban registered unemployment rate (%)	-	X19
			Share of Social security subsidies in general public budget expenditure (%)	+	X20
		Environmental impact	Proportion of days with good air quality (%)	+	X21
			Green coverage rate of built-up area (%)	+	X22
	Response (R)	Technological innovation	Number of invention patents granted by 10,000 people (items / 10,000 people)	+	X23
			Internal R&D expenditure as a percentage of GDP (%)	+	X24
		Environmental governance	Sewage treatment rate (%)	+	X25
			Investment in pollution control as a percentage of GDP (%)	+	X26
			Comprehensive utilization rate of general industrial solid waste (%)	+	X27
			Harmless treatment rate of domestic waste (%)	+	X28

as industrial sulfur dioxide [6, 12], wastewater [12, 30] and smoke (dust) emissions [2, 17] are included in the scoring system to fully reflect the constraints of environmental pressures on urban development.

On the status dimension, the study focuses on residents' life satisfaction and the level of urban infrastructure development. Social status indicators such as urban road area per capita [13, 14] and the number of hospital beds per 10,000 people [27, 32] are used to analyze the quality of life and social services for residents in oil and gas resource cities. Meanwhile, resource status indicators such as public transport vehicle ownership [24, 33], water resources per capita [25, 34], and green space per capita [4, 27, 32] are introduced to further assess the level of urban infrastructure construction.

On the impact dimensions, this study comprehensively examines the transformation effect of oil and gas resource cities from both social and environmental aspects. Specifically, social impact indicators such as the proportion of tertiary industry [17, 24], the urban registered unemployment rate [35] and the proportion of social security subsidies [36] are used to assess the impact of urban transformation on social development. Meanwhile, environmental impact indicators such as the proportion of days with good air quality [37] and the proportion of built-up areas covered by greenery [35, 38] are introduced to comprehensively reflect the impact of urban transformation on improving the ecological environment.

On the response dimension, the study emphasizes the importance of science and technology advancement and environmental governance in the green development of oil and gas resource cities. To this end, the study utilizes technological innovation indicators such as the number of patents authorized per 10,000 people [12, 24] and the percentage of R&D expenditure to assess the scientific and technological innovation capacity of oil and gas resource cities [8, 15]. At the same time, it combines environmental governance indicators such as the sewage treatment rate [30], the percentage of investment in pollution control [11], the comprehensive utilization rate of general industrial solid waste [30], and the rate of harmless treatment of domestic rubbish to jointly reveal the efforts and effectiveness of oil and gas resource cities in responding to green development [20].

Results and Discussion

Comprehensive Green Evaluation Results

Based on the entropy weight TOPSIS model, the green development indicators of 17 oil and gas resource-based cities in China from 2011 to 2021 are calculated, and the green development level values of each city are obtained (Fig. 2).

Overall, the level of green development in China's oil and gas resource-based cities mainly falls within the range of 0.1 to 0.6, with most cities ranging from 0.2 to 0.4. Among them, Karamay, Ordos, and Dongying exhibit relatively high levels of green development, while Qingyang, Puyang, and Songyuan show relatively low levels of green development [33]. The green development changes in Ordos City, Luzhou City, Zhaotong City, and Qingyang City are relatively stable, while Yan'an City, Yulin City, and Luzhou City show a fluctuating trend. On the other hand, the level of green development in Daqing City, Panjin City, Tangshan City, Nanyang City, Nanchong City, and Dazhou City initially decreased and then increased. Karamay City, Ordos City, and Dongying City have maintained a high Flevel of green development, especially after 2015. This has been achieved through increased technological innovation and government investment in science and technology. The number of patent grants has continuously increased, leading to improvements in economic development, social basic security, and social services. These efforts

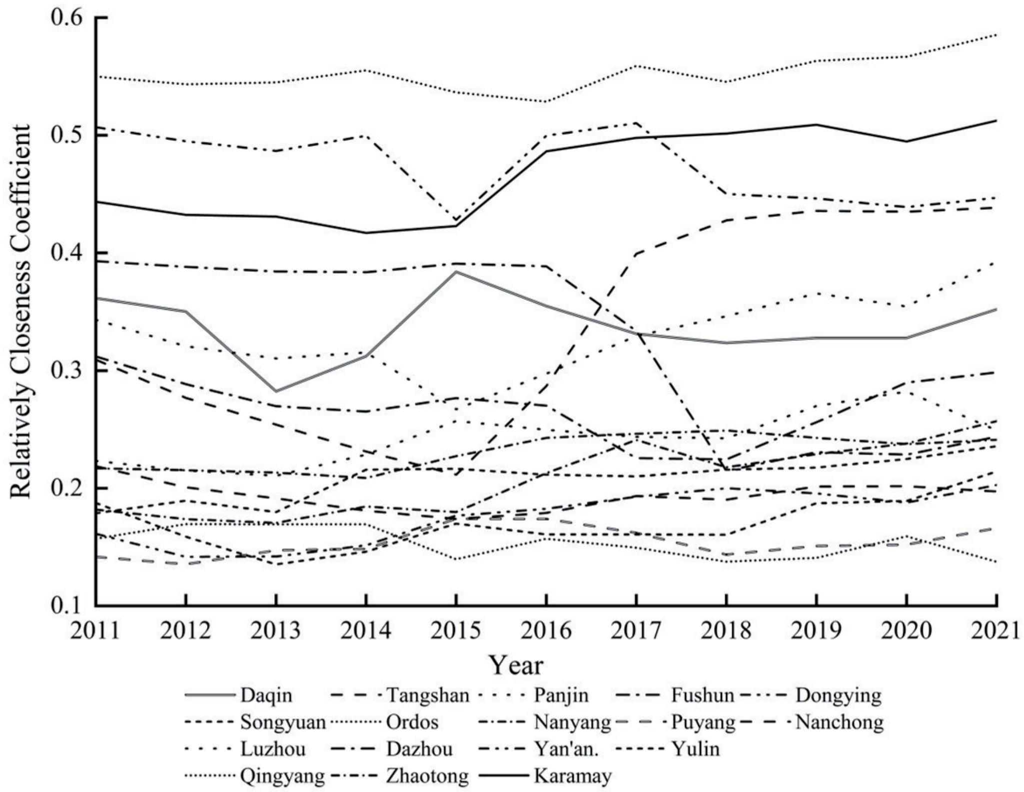

Fig. 2. The green development level of seventeen oil and gas resource-based cities in China from 2011 to 2021.

have resulted in an overall enhancement of the level of green development. Qingyang City, Puyang City, and Songyuan City are at a low level of green development. This is because their economies heavily rely on the oil and gas industry, and they have not implemented strict measures for the discharge and treatment of industrial pollutants. Consequently, this has led to more severe environmental issues. The level of green development in Daqing, Panjin, Tangshan, Nanyang, Nanchong, and Dazhou exhibited a downward trend from 2011 to 2013 but gradually increased after 2014. These cities have started to enhance environmental protection supervision and policy support, gradually implementing advanced environmental protection technologies and green production methods. It has improved the efficiency of resource utilization and environmental protection, thus promoting the green development of the city.

DPSIR Subsystem Green Development Calculation Results

By systematically comparing the evaluation values of 17 oil and gas resource cities in China in terms of the DPSIR subsystem of green development level between 2011 and 2021, both horizontally and vertically, and by considering the specific conditions of these cities related to resource utilization, environmental protection, and socio-economic development, we have analyzed the variations in the performance of the DPSIR subsystem and the underlying reasons across different oil and gas resource cities. The specific results are shown in Fig. 3.

Driving Forces in the Subsystem of Green Development

From 2011 to 2021, the proximity degree of the driving force subsystem generally shows a fluctuating downward trend, as illustrated in Fig. 3a). Among them, the driving force of Ordos City is higher, staying above 0.7, indicating that its economic development is rapid. Its per capita GDP continues to rise, and its urbanization progress continues to advance. The proximity index of Nanyang City, Panjin City, Yulin City, and Qingyang City exhibited a downward trend from 2011 to 2013 but gradually increased after 2014. This suggests that these cities gradually identified new economic and social development momentum and direction following a period of policy adjustment. The proximity of Tangshan City, Dongying City, Nanchong City, and Dazhou City showed an upward trend from 2011 to 2014 but gradually decreased after 2015. This trend may indicate that these cities are encountering bottlenecks and challenges in economic and social development after reaching a certain level of advancement. Consequently, they may need to explore new development paths and make breakthroughs. The proximity of Fushun City,

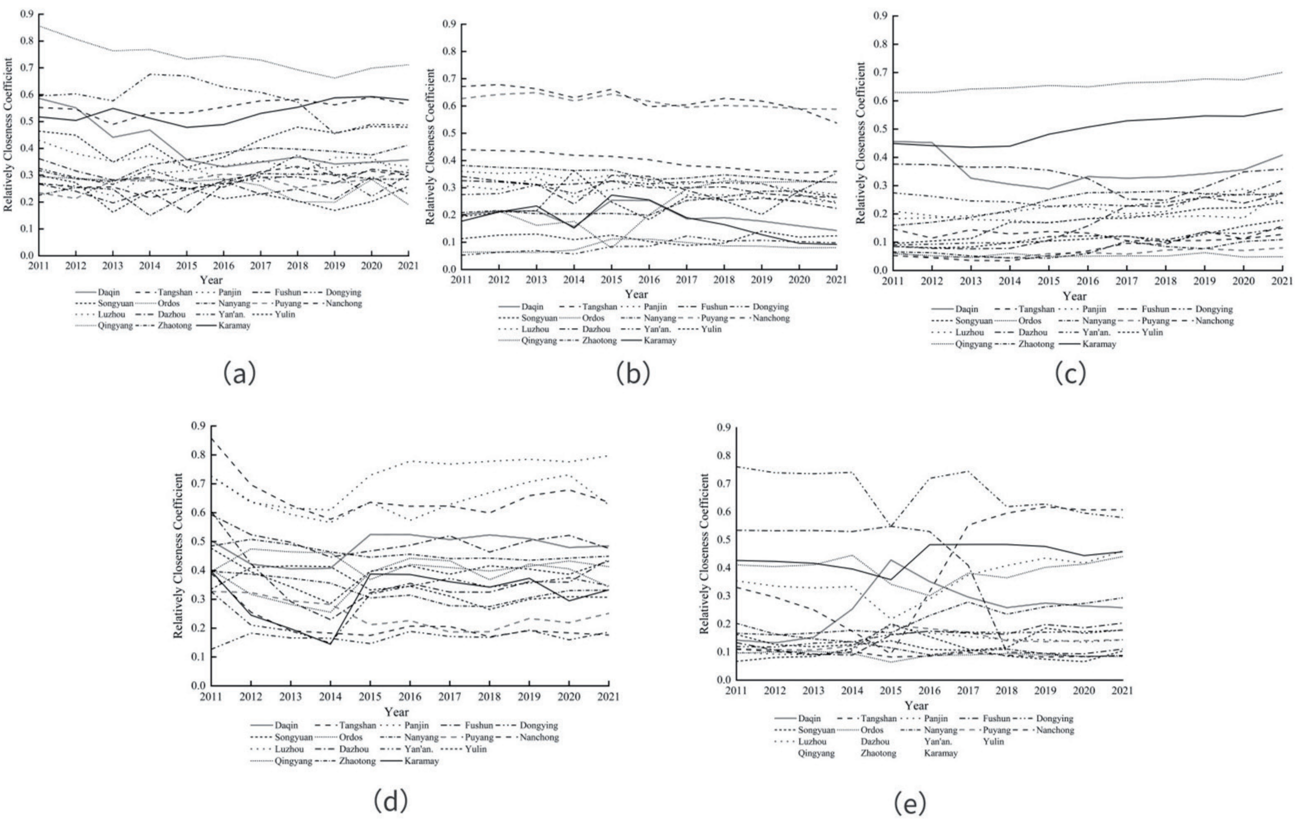

Fig. 3. a) driving forces subsystem; b) pressures subsystem; c) status subsystem; d) impacts subsystem; e) responses subsystem. Subsystem of green development level of seventeen oil and gas resource-based cities in China from 2011 to 2021.

Songyuan City, Puyang City, Luzhou City, Yan'an City, and Zhaotong City to the driving force is relatively low, consistently below 0.3. This suggests that these cities exhibit weaknesses in economic development, resource utilization, social infrastructure, and other aspects. Therefore, there is a pressing need for these cities to enhance their development initiatives and receive policy support.

Pressures Subsystem of Green Development

From 2011 to 2021, the proximity degree of the driving force subsystem generally shows a downward trend, as illustrated in Fig. 3b). The pressure proximity degree of Tangshan City each year remains relatively high, consistently above 0.6. This may suggest that Tangshan City is encountering significant pressure in economic development, resource utilization, social infrastructure, and other areas. The pressure proximity degree of Nanyang City, Panjin City, and Qingyang City showed a downward trend from 2011 to 2013 but gradually increased after 2014. The pressure proximity between Ordos City and Yulin City is relatively low, but it exhibits a fluctuating trend. In Karamay City, Songyuan City, Yan'an City, and Qingyang City, the proximity to pressure sources has been consistently low, despite facing significant resource and environmental pressures. Issues such as resource overexploitation, insufficient environmental management, and protection inadequacies are evident. Overall, environmental pollution in oil and gas resource-based cities has increased pressure on resources and the environment. Although each city has actively responded to environmental policies in recent years to strengthen the construction of ecological civilization and has gradually increased investment in environmental governance, it is challenging to make significant improvements to environmental problems in a short period of time.

Status Subsystem of Green Development

From 2011 to 2021, the degree of closeness of the state subsystems has generally shown an increasing trend, suggesting that the social and resource states are in good condition. See Fig. 3c) for details. The spatial proximity of Ordos in different years consistently remains above 0.6, indicating a relatively high level and a trend of continuous increase. This trend can be attributed to Ordos' proactive cultivation of emerging industries, the establishment and enforcement of the red line system for resource ecological protection, and the effective implementation of main function zone division. These efforts have enabled Ordos to sustain a favorable state of resources and the environment. The spatial proximity index of Nanyang City, Panjin City, and Qingyang City exhibited a declining trend from 2011 to 2013 but started to gradually increase after 2014. The state proximity degree of Dazhou, Luzhou, and Yulin showed an upward trend from 2011 to 2021. Nanyang City, Fushun City, Songyuan City, Nanchong City, Yan'an City, and Zhaotong City have consistently maintained a low level of state proximity index value. In the face of the challenge of industrial transformation, the effectiveness of management measures taken is not evident, leading to inadequate resource supply and a failure to keep pace with development. Key indicators such as per capita water resources and per capita green space are under significant pressure, highlighting the need for further improvement.

Impacts Subsystem of Green Development

From 2011 to 2021, the overall correlation between the subsystems affected by the level of green development in oil and gas resource-based cities will initially decrease and then increase. See Fig. 3d). for details. Among them, the proximity of the impact subsystem in Panjin City has consistently been high over the years, staying above 0.6 and displaying a rising trend annually. The interconnectedness of the impact subsystems between Nanyang City and Ordos City exhibited a declining trend from 2011 to 2013, but steadily rose thereafter. Similarly, the interconnectedness of the impact subsystem in Dazhou City declined from 2011 to 2015, but began to increase from 2016 onwards. These cities have successfully overcome adverse geographical conditions and industrial disadvantages. They have developed high-tech industries through precise positioning and overall planning, actively promoted carbon reduction and emission reduction work, and significantly improved the impact subsystem. The proximity of the impact subsystems in Dongying City, Tangshan City, and Puyang City has consistently remained at a relatively low level. This trend may suggest that these cities have been adversely impacted by excessive resource exploitation and industrial pollution emissions, leading to a decline in air quality. At the same time, due to industrial restructuring, traditional industries have gradually declined, while emerging industries have not yet developed, leading to an increase in unemployment.

Responses to the Subsystem of Green Development

The overall proximity of the response subsystem to the green development level of oil and gas resource-based cities fluctuated in a "W" shape from 2011 to 2021. See Fig. 3e) for details. Among them, the overall connectivity of the response subsystem in Daqing City exhibited an increasing trend from 2011 to 2013, but gradually declined after 2014. The overall proximity of the response subsystem in Tangshan City exhibited a declining trend from 2011 to 2013 but gradually increased after 2014. The response subsystems of Panjin, Dongying, Nanyang, Puyang, Nanchong, Luzhou, Dazhou, Yan'an, Yulin, Qingyang, Zhaotong, and Karamay exhibit relatively stable overall closeness, minimal fluctuation, and stability. The overall proximity of the response subsystems in Fushun City, Ordos City, and Dazhou City has fluctuated significantly in certain years.

Calculation of Barriers to Green Development in Oil-Gas Resource-Based Cities

Analysis of the Barriers to Individual Indicators

On the basis of the above evaluation, the obstacle degree model is used to further identify the main obstacles affecting the sustainable development of oil and gas resource-based cities. In light of the extensive number of cities and indicators examined, this paper focuses on analyzing the top five indicators of obstacle degree in each city in 2021. Using the barrier degree calculation formula, we measured the barrier degree of the individual indicators of green development levels in 17 oil and gas resource-based cities in 2021.

As indicated in Table 3, specific indicators of significant obstacles to the green development of oil and gas resource-based cities in 2021 consist of per capita green space (X17), public transport vehicles per 10,000 people (X15), per capita urban road area, internal expenditure of R&D funds in GDP (X24), and social security subsidies in general public budget expenditure (X20). These indicators reflect the primary weaknesses and challenges in the process of green development in oil and gas resource-based cities. Combining the changes in the green development level in 17 oil and gas resource-based cities from 2011 to 2021, we find that despite these cities adopting and implementing numerous policy measures, the implementation effect of existing policies remains limited in the face of rapid economic and social development. In order to promote the economic and environmentally sustainable development in oil and gas resource-based cities, more comprehensive and effective measures must be implemented. This involves the rational development of oil and gas resources, enhancing ecological environmental governance, boosting investment in research and development of carbon emission reduction technologies and environmental protection technologies, and reshaping the traditional oil and gas industry structure to minimize the adverse effects on ecological resources and the environment during economic development.

Analysis of Obstacles to Classification Indicators

According to the measurement results of the obstacle degree of various indicators (Table 4), the status subsystem is identified as the main obstacle to the green development of China's oil and gas resource-based cities, followed by the response system and driving force

Table 3. The main obstacle factors and obstacle degree of green development in seventeen oil and gas resource-based cities in 2021.

City	Index obstacle degree/%				
	1	2	3	4	5
Daqin	X17(13.99%)	X24(10.42%)	X20(8.43%)	X3(8.23%)	X13(7.97%)
Tangshan	X17(16.15%)	X13(10.63%)	X20(10.37%)	X15(8.96%)	X26(8.61%)
Panjin	X17(18.52%)	X13(11.1%)	X3(7.89%)	X24(7.88%)	X1(7.32%)
Fushun	X17(11.95%)	X24(9.57%)	X13(9.4%)	X1(8.44%)	X20(7.65%)
Dongying	X17(17.63%)	X20(12.01%)	X13(9.2%)	X3(9.01%)	X24(7.37%)
Songyuan	X17(14.53%)	X24(9.68%)	X15(9.34%)	X20(8.52%)	X1(8.47%)
Ordos	X20(15.94%)	X15(14.3%)	X24(11.71%)	X26(7.98%)	X23(7.3%)
Nanyang	X17(14.99%)	X15(10.26%)	X13(8.59%)	X1(8.39%)	X26(7.68%)
Puyang	X17(13.8%)	X15(8.81%)	X24(8.24%)	X13(8.08%)	X1(7.57%)
Nanchong	X17(14.72%)	X15(9.81%)	X24(9.38%)	X13(9.17%)	X1(8.05%)
Luzhou	X17(14.69%)	X15(9.66%)	X24(9.54%)	X13(9.44%)	X1(8.09%)
Dazhou	X17(13.13%)	X15(10.71%)	X13(10.71%)	X24(9.74%)	X1(8.6%)
Yan'an.	X17(12.91%)	X20(9.09%)	X13(8.88%)	X24(8.61%)	X15(8.55%)
Yulin	X17(11.02%)	X24(9.78%)	X15(9.7%)	X20(9.41%)	X26(8.11%)
Qingyang	X17(12.64%)	X15(9.22%)	X24(8.94%)	X13(8.17%)	X1(7.37%)
Zhaotong	X17(13.21%)	X15(9.37%)	X24(9.2%)	X13(8.57%)	X20(8.15%)
Karamay	X17(25.36%)	X20(18.41%)	X24(18.01%)	X3(13.55%)	X18(8.53%)

Table 4. Obstacle degree of green development level subsystem of 17 oil and gas resource-based cities in 2021.

City	Driving forces (D) sum	Pressures (P) sum	Status (S) sum	Impacts (I) sum	Responses (R) sum
Daqin	24.92%	1.67%	31.51%	15.05%	26.86%
Tangshan	16.28%	5.45%	44.05%	18.83%	15.40%
Panjin	28.49%	2.07%	41.25%	10.30%	17.89%
Fushun	24.06%	2.50%	33.27%	14.70%	25.47%
Dongying	19.38%	3.11%	40.95%	21.44%	15.13%
Songyuan	22.76%	1.06%	41.27%	11.86%	23.05%
Ordos	15.83%	7.89%	16.20%	31.43%	28.66%
Nanyang	19.88%	1.48%	44.54%	12.29%	21.81%
Puyang	20.10%	2.28%	41.54%	13.27%	22.81%
Nanchong	21.21%	1.65%	41.30%	9.06%	26.77%
Luzhou	22.16%	1.31%	40.45%	10.74%	25.35%
Dazhou	22.33%	1.03%	37.16%	12.50%	26.98%
Yan'an.	20.90%	1.12%	37.95%	17.54%	22.49%
Yulin	16.11%	2.56%	35.63%	18.70%	27.00%
Qingyang	22.01%	0.47%	40.25%	13.94%	23.33%
Zhaotong	21.52%	3.93%	37.15%	13.05%	24.36%
Karamay	17.83%	1.89%	28.31%	29.37%	22.60%

system. The specific ranking is as follows: status system > response system > driving force system > influence system > pressure system. This result highlights the fundamental problems and challenges in the process of green development of oil and gas resource-based cities. In order to effectively enhance the green development level in oil and gas resource-based cities, priority should be given to improving the governance system while also balancing the development of the response system and driving force system. The process entails transforming and upgrading the traditional oil and gas industry structure, ensuring the scientific and effective planning of industrial functional areas, achieving the rational use of energy, and promoting the transformation and application of scientific and technological advancements.

Conclusions

Based on the DPSIR model, this paper constructs an evaluation system for the green development level of oil-and-gas resource-based cities. It adopts the entropy weight TOPSIS model and obstacle degree model to evaluate and analyze the green development level and obstacle factors of 17 oil-and-gas resource-based cities in China from 2011 to 2021. The following conclusions are drawn:

(1) The green development level of China's oil and gas resource-based cities is generally low, with most cities having a green development index ranging between 0.2 and 0.4. The results reveal common challenges faced by cities in the process of transitioning to green practices and also highlight significant differences in the level of environmental development among cities. Among them, Karamay City, Ordos City, and Dongying City stand out for their effective resource management and environmental protection measures, demonstrating a higher level of green development. Comparatively speaking, Qingyang City, Puyang City, and Songyuan City have low levels of green development due to various factors. It is worth noting that since 2015, the level of green development in Tangshan, Panjin, Fushun, Nanyang, and Karamay has significantly increased, demonstrating the positive efforts of these cities on the path of green development.

(2) From the perspective of each subsystem of green development, the driving force system and pressure system generally exhibit a downward trend. This reflects the challenges faced by oil and gas resource-based cities in the process of economic development transformation, such as resource exhaustion, a single industrial structure, and other issues that have a negative impact on the green development of cities. At the same time, the state of the system is showing improvement, indicating that some cities have made progress in environmental protection and ecological restoration. However, the influence system and response system exhibit fluctuations, which may be attributed to various factors such as policy adjustments and changes in the market environment. This indicates the instability

and uncertainty in the process of green development in oil and gas resource-based cities.

(3) From the perspective of obstacles, it is evident that the state system poses the main hindrance to the green development of oil and gas resource-based cities. At the individual level, factors such as per capita green space, public transport vehicles per 10,000 people, per capita urban road area, the proportion of internal R&D expenditure in GDP, and the proportion of social security subsidies in the general public budget expenditure are considered the primary obstacles restricting the green development of oil and gas resource-based cities. Therefore, future policy formulation and implementation should focus on these key factors to promote more comprehensive and in-depth green development in oil and gas resource-based cities.

The green development level of oil and gas resource-based cities is assessed through measurement and analysis, followed by targeted suggestions tailored to the current situation:

(1) Enhance policies and systems and refine the development evaluation mechanism. During the development of oil and gas resource-based cities, environmental issues such as air and water pollution have become increasingly prominent. It is imperative to strengthen supervision, reinforce water resource protection, and enhance the treatment and monitoring mechanisms for wastewater, waste gas, and solid waste. Additionally, it is crucial to prudently restrict excessive development in industries with high energy consumption and water usage while promoting adjustments in energy structure, industrial transformation, and upgrading. When assessing urban development, we should abandon the practice of solely relying on GDP as a standard. Instead, we should incorporate factors such as economic growth, environmental pollution levels, resource consumption patterns, and pragmatic policies into a comprehensive evaluation system for urban economic and social progress. This approach ensures that policy formulation becomes more scientifically grounded and effective.

(2) Emphasize the development and recruitment of talents in the green industry. The development of oil and gas resource-based cities requires professionals with expertise, skills, and innovative abilities to advance. The government and its relevant departments should pay more attention to the advancement of green and low-carbon science and technology education in colleges and institutions. They should establish related majors and provide training for professional talents to improve social awareness and the application of green and low-carbon science and technology. At the same time, by fostering cross-regional cooperation and optimizing the talent policy environment, we aim to attract high-level talents to the green oil and gas industry. This will provide a conducive working environment and living conditions for talents in the green industry, ultimately steering the traditional oil and gas sector in a high-end, intelligent, and environmentally friendly direction [34].

(3) Enhance the efficiency of green development. In the process of promoting green development, government departments should optimize the allocation of key resources to regions with outstanding innovation capacity and high production efficiency. Through centralized resource allocation, it promotes integrated development and large-scale production in the region. This improves the overall efficiency of energy and resource utilization and steers the oil and gas industry in a low-carbon, efficient, and sustainable direction.

This study focuses on the sustainable development of oil and gas resource cities. It establishes a comprehensive and scientific evaluation index system through in-depth analysis and by integrating the DPSIR model. The system covers several key dimensions, ensuring the accuracy and completeness of the evaluation and offering rich theoretical support for the field of assessing the level of green development. In the empirical analyses, the evaluation index system demonstrates excellent applicability and accuracy. It effectively identifies and evaluates the problems and challenges faced by resource cities during the process of green development. In addition, this study introduces and optimizes the entropy weight TOPSIS model, which offers a more robust theoretical framework for decision-making analysis. The innovation of the model lies in its ability to clearly distinguish the ideal solution from the worst solution, thereby demonstrating the relative advantages and disadvantages of different scenarios more intuitively. This theoretical contribution not only enhances the explanatory power of the model but also provides new ideas and directions for subsequent research.

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Conflict of Interest

The authors declare no conflict of interest.

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