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*Original Research*

# Empirical Study of Industrial Green Development Level of Oil and Gas Resource-Based Prefecture-Level Cities in China Based on Entropy Weight-TOPSIS Model

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## Abstract

The industrial green development of oil and gas resource-based cities is a way towards "green industry" and an essential process in industrial development. Based on the actual situations of oil and gas resource-based cities, the entropy weight-TOPSIS model is used to measure the industrial green development levels of oil and gas resource-based cities in China during 2004-2018, and the evolution trend and characteristics of the industrial green development of the oil and gas resource-based cities were evaluated from two perspectives of overall system and sub-system. The results demonstrate that the industrial green development levels of the oil and gas resource-based cities are generally low and vary significantly among cities; According to the variation of the industrial green development levels of the oil and gas resource-based cities, some cities show a similar variation trend over the 15 years, while some cities show great differences in the industrial green development level over the 15 years; The ranking of the sub-system nearness degrees of the industrial green development levels of different oil and gas resource-based cities in China varies greatly over the 15 years. In view of the findings, we recommend that cities increase investments in environmental protection projects, introduce clean production, and establish foundations of industrial green development.

**Keywords**: oil and gas resource-based city, industrial green development level, nearness degree, entropy weight-TOPSIS model, resource consumption intensity

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## Introduction

According to Plan for Industrial Green Development (2016-2020) (Ministry of Industry and Information Technology of the People's Republic of China, 2016), promoting green growth and implementing new green policies are common choices of major global economies, and promoting green development is an inevitable way to enhance international competitiveness. Nevertheless, China's industry has not yet escaped from the development mode of "high input, high consumption, and high emission", with low resource and energy utilization efficiency and prominent ecological and environmental issues [1]. Oil and gas resource-based cities are resource-based cities with oil and gas extraction and processing as their mainstay industries, and resource extraction and related industries take a great part in their industrial structure. Therefore, the development of these cities is limited by serious ecological environmental issues. For instance, oil field development can cause air pollution in oil and gas resource-based cities, and the pollutants mainly include $SO_2$ and dust, which can also pollute soil, and the pollutants contain large amounts of NaCl, NaOH, and $Na_2CO_3$, which can deteriorate the physical properties of soil and even make soil unable to grow plants. Therefore, with the worsening of the resource environment in China and under the constraints of resource-environmental carrying capacity, it is inevitable for the oil and gas resource-based cities to walk toward industrial green development.

Industrial green development is the crucial way to promote the high-quality development of China's economy. It can change the mode of industrial economic growth and make it change to the direction of "two low and one high", namely "low emission, low input, high output" [2]. The green development of industry should aim at eradicating poverty, improving employment, and achieving sustainable development of industry. In the process of industrial production, it also should improve industrial energy efficiency, reduce pollution, and reduce carbon emissions. Therefore, the measurement of industrial green development level should be considered from the aspects of economy, environment, society, science and technology, etc. [3-4].

With regard to the construction of the evaluation index system of industrial green development level, many scholars selected various relevant indicators from five aspects of green production, green emissions, green protection, green innovation, and green quality and efficiency in combination with the requirements of modern industrial green development, and finally built the evaluation index system of industrial green development level after repeated screening [5]. On the basis of previous studies, some scholars have drawn on some of the indicators in the Green Development Indicator System (2016) formulated by the National Development and Reform Commission. And after selection, they have built an evaluation indicator system for the level of industrial green development, which mainly covers the indicators of industrial growth level, industrial research and development intensity, government support, industrial energy consumption level, pollution control efficiency and other aspects [6-7]. At present, level evaluating of the industrial green development are still focused on quantitative analysis methods, such as entropy method, TOPISI method [8], dynamic panel system GMM estimation method [9], factor analysis model synthesis, k-means clustering analysis method, etc. and the green development level and supply-side power structure of industry are evaluated in Hebei Province, the Yangtze River Economic Belt of our country.

To sum up, the research on the evaluation index system of industrial green development level mainly focuses on the evaluation from the perspective of economic development, ecological environment, resource consumption, social life, etc. with the constructed index system generally including resources and environment, social progress, ecological civilization, scientific and technological innovation and other indicators, which are combined with economic development indicators to jointly measure the level of industrial green development level. While the research on evaluation methods of industrial green development level focuses on TOPISIS method, entropy method, dynamic panel system GMM estimation method, factor analysis method, k-means clustering analysis and other methods. From the perspective of research objects, most of the research is carried out in regions or individual provinces, with less research on resource-based cities, and less research on oil and gas cities. Therefore, it has certain practical significance for this paper to take oil and gas cities as the research object, uses entropy weight-TOPSIS model to measure the level of industrial green development of oil and gas cities, and evaluates the evolution trend and characteristics of industrial green development of oil and gas cities from the two aspects of total system and subsystem.

## Materials and Method

### Data Source

Considering the availability and comparability of data from various cities, this paper selects 2004-2018 as the research period, and selects China's prefecture-level oil and gas cities as the empirical evaluation object. There are 18 prefecture-level oil and gas cities in China, of which Hami, Qingyang, Zhaotong and Fushun have serious lack of research index data. Therefore, this paper collected the index data of 14 prefecture-level oil and gas cities in the eastern, central and western regions (Table 1) for research. The data comes from the EPS database, China Urban Statistical Yearbook and the official website, and the OLS trend analysis method is used to fill in the missing data.

Table 1. Distribution areas and types of oil and gas cities in China.

| Region | Province | Oil and gas city | City level |
|---|---|---|---|
| Eastern | Heilongjiang | Daqing | City at prefecture level |
| | Hebei | Tangshan | City at prefecture level |
| | Liaoning | Panjin | City at prefecture level |
| | Shandong | Dongying | City at prefecture level |
| | Jilin | Songyuan | City at prefecture level |
| Central | Inner Mongolia | Ordos | City at prefecture level |
| | Henan | Nanyang | City at prefecture level |
| | | Puyang | City at prefecture level |
| Western | Sichuan | Nanchong | City at prefecture level |
| | | Luzhou | City at prefecture level |
| | | Dazhou | City at prefecture level |
| | Shaanxi | Yan'an | City at prefecture level |
| | | Yulin | City at prefecture level |
| | Xinjiang | Karamay | City at prefecture level |

## Entropy Weight-TOPSIS Model

The level evaluation of industrial green development needs to follow the idea of system analysis [10]. And this article intends to adopt the entropy weight TOPSIS model. TOPSIS model is a distance comprehensive evaluation method, which defines a measure in the target space and calculates the weighted distance between a certain evaluation object and a positive ideal solution and a negative ideal solution to measure the degree to which the target is close to the positive ideal solution and away from the negative ideal solution, thereby evaluating the level of industrial green development. The combination of TOPSIS model and entropy method is called entropy weight TOPSIS model. The entropy method is used to determine the weight, relying on the objective value of indicators, avoiding subjective judgment, and the results are objective, which can objectively and comprehensively reflect the dynamic changes in the green development level of oil and gas city industry. The basic steps of entropy weight TOPSIS model are as follows [11].

If the sample size of the study is m and the relevant evaluation index is n, the original evaluation matrix of the sample is:

$$(X_{ij})_{m\times n} = \begin{bmatrix} X_{11} & X_{12} & \cdots & X_{1n} \\ X_{21} & X_{22} & \cdots & X_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ X_{m1} & X_{m2} & \cdots & X_{mn} \end{bmatrix}_{m\times n} \quad (1)$$

(1) Data standardization

Each indicator represents different evaluation types and has different dimensions. In order to perform unified operation on all indicators, the extreme value method is selected to process the relevant data. The formula is as follows:

Positive indicator (the larger the better type):

$$V_{ij} = \frac{X_{ij} - \min(X_j)}{\max(X_j) - \min(X_j)} \quad (i = 1, 2, ..., m; j = 1,2, ..., n) \quad (2)$$

Negative indicator (the smaller the better type):

$$V_{ij} = \frac{\max(X_j) - X_{ij}}{\max(X_j) - \min(X_j)} \quad (i = 1, 2, ..., m; j = 1, 2, ..., n) \quad (3)$$

(2) Calculating entropy weight

$$\omega_j = \frac{1 + k \times \sum_{i=1}^{m}\left(\frac{V_{ij}}{\sum_{i=1}^{m} V_{ij}}\right)\ln\left(\frac{V_{ij}}{\sum_{i=1}^{m} V_{ij}}\right)}{\sum_{j=1}^{n}\left[1 + k \times \sum_{i=1}^{m}\left(\frac{V_{ij}}{\sum_{i=1}^{m} V_{ij}}\right)\ln\left(\frac{V_{ij}}{\sum_{i=1}^{m} V_{ij}}\right)\right]}$$

(j is the number of indicators, j = 1, 2, ..., n; i is the number of samples, i = 1, 2, …, m)

(4)

(3) Build weighted decision matrix

The index weight vector $w_j$ determined by entropy weight method is considered in the decision matrix, and the weighted normalized decision matrix $R = (R_{ij})_{m\times n}$

is calculated. The weighted decision matrix $R = (R_{ij})_{m\times n}$ is obtained by multiplying each row of matrix V by its corresponding weight $w_j$, that is $\boldsymbol{R} = (R_{ij})_{m\times n} = w_j * \boldsymbol{V}_{ij}$.

$$\boldsymbol{R}=\begin{bmatrix} R_{11} & R_{12} & \cdots & R_{1n} \\ R_{21} & R_{22} & \cdots & R_{2n} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ R_{m1} & R_{m2} & \cdots & R_{mn} \end{bmatrix} = \begin{bmatrix} V_{11}\omega_1 & V_{12}\omega_2 & \cdots & V_{1n}\omega_n \\ V_{21}\omega_1 & V_{22}\omega_2 & \cdots & V_{2n}\omega_n \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ V_{m1}\omega_1 & V_{m2}\omega_2 & \cdots & V_{mn}\omega_n \end{bmatrix} \quad (5)$$

(4) Determine positive and negative ideal solutions

The positive ideal solution is the optimal index value of each index, that is, the most preferred scheme. While the negative ideal solution is the worst index value of each index, that is, the least preferred scheme. Let $R^+$ represent positive ideal solution and $R^-$ represent negative ideal solution, then there is:

$$R^+ = \{\max R_{i1}, \max R_{i2}, \max R_{i3} \ldots \max R_{in}\} \quad i=1, 2, \ldots, m$$
$$R^- = \{\min R_{i1}, \min R_{i2}, \min R_{i3} \ldots \min R_{in}\} \quad (6)$$

Rij is the weighted normalized value of index j of the ith sample; Rj+and Rj - are the most preferred and least preferred values of the jth index in the evaluation.

(5) Calculate relative closeness $\eta_i$

$$\eta_i = \frac{\sqrt{\sum_{i=1}^{m}(R_{ij}-R_j^-)^2}}{\sqrt{\sum_{i=1}^{m}(R_{ij}-R_j^+)^2}+\sqrt{\sum_{i=1}^{m}(R_{ij}-R_j^-)^2}} \quad (i = 1, 2, \ldots, m) \quad (7)$$

Where, $\eta_i$ represents the closeness of the index to the optimal solution, $0\leq\eta_i\leq1$. The larger the value of $\eta_i$, the closer to the optimal solution, indicating the higher the level of industrial green development in the region; On the contrary, the closer to the worst solution, the lower the level of industrial green development in the region. When $\eta_i = 1$, the level of industrial green development is the highest, reaching the optimal state of industrial green development; When $\eta_i = 0$, the green development of industry is in a highly disordered state [4].

### Establishment of Index System

In this study, an evaluation index system of industrial green development level of oil and gas resource-based cities is developed on the basis of previous reported industrial green development evaluation index system [12-15], Green Development Index System (2016) issued by National Development and Reform Commission, the current policy orientation, the representativeness of the selected indicators, and the availability of each indicator. Specifically, the developed system consists of one objective layer (overall system), four criterion layers (sub-systems), and 19 evaluation indexes, wherein the influence directions of the three layers of indicators are labeled, as shown in Table 2.

## Study Area

Based on the National Plan for Sustainable Development of Resource-based Cities (2013-2020) and the List of 262 Resource-based Cities in China, referring to the oil and gas cities defined in the existing literature, this paper defines a total of 29 oil and gas cities in China (see Table 3), including 8 in the east, 5 in the center, and 16 in the west. Among them, 18 cities are prefecture-level cities. And Xinjiang has the largest distribution of oil and gas cities, with 7 oil and gas cities, accounting for about 1/4 of the country.

In order to measure the efficiency of industrial green development in oil and gas cities better, the time selected for this study are 15 years from 2004 to 2018. Considering the comparability of data of each city, this paper takes prefecture-level oil and gas cities as the object of empirical evaluation, and there are 18 prefecture-level cities among 29 oil and gas cities, as shown in Table 3 and Fig. 1. Due to the serious lack of data on research indicators in Hami, Qingyang, Zhaotong and Fushun, considering the availability of data, this paper collects the indicator data of 14 representative oil and gas cities in the eastern, central and western regions for the study. The data are obtained from EPS database, China City Statistical Yearbook, provincial and municipal statistical yearbooks and official websites, and this paper uses OLS trend analysis to fill in the missing data.

## Results and Discussion

### Evolution Trend and Characteristics of Overall System of Industrial Green Development Level

The weight of each evaluation index was calculated, and the entropy weight-TOPSIS model was used to calculate the nearness degrees of industrial green development levels of different oil and gas resource-based cities in China, and the variation trend of the nearness degrees was plotted (Fig. 2, Table 4) to analyze its evolution trend and characteristics.

As shown in Fig. 1, the nearness degrees of industrial green development levels of oil and gas resource-based cities in China fall in the range of 0.1-0.8, particularly in the range of 0.2-0.5. Among the oil and gas resource-based cities in China, Karamay, Dongying, Daqing, and Ordos have a relatively high industrial green development level; Dazhou, Luzhou, Nanchong, and Tangshan have a relatively low industrial green development level. According to the variation trend of the industrial green development levels of the oil and gas resource-based cities, Karamay, Puyang,

Table 2. Evaluation index system of industrial green development level of oil and gas resource-based cities.

| Objective layer | Criterion layer | Index layer (unit) | Influence direction |
|---|---|---|---|
| Industrial green development level of oil and gas resource-based cities (A) | Resource consumption intensity (B1) | Energy consumption per unit industrial added value (tons of standard coal/10,000 yuan) (C1) | Negative |
| | | Electricity consumption per unit industrial added value (kWh/10,000 yuan) (C2) | Negative |
| | | Water consumption per unit industrial added value ($m^3$/10,000 yuan) (C3) | Negative |
| | | Fixed asset investment consumption per unit industrial added value (no unit) (C4) | Negative |
| | | Land area per unit industrial added value ($km^2$/100 million yuan) (C5) | Negative |
| | Environmental impact and treatment (B2) | Wastewater discharge intensity per unit industrial added value (tons/10,000 yuan) (C6) | Negative |
| | | $SiO_2$ and gas and dust emissions intensity per unit industrial added value (tons/yuan) (C7) | Negative |
| | | Comprehensive utilization rate of general industrial solid waste (%) (C8) | Positive |
| | | Harmless treatment rate of domestic waste (%) (C9) | Positive |
| | | Centralized treatment rate of sewage treatment plants (%) (C10) | Positive |
| | Economic benefits and structure (B3) | Industrial added value per capita (10,000 yuan/person) (C11) | Positive |
| | | Growth rate of industrial added value above designated size (%) (C12) | Positive |
| | | Average profit of industrial enterprises above designated size (10,000 yuan/enterprise) (C13) | Positive |
| | | Liabilities to assets ratio of industrial enterprises above designated size (%) (C14) | Negative |
| | | Income profit margin of industrial enterprises above designated size (%) (C15) | Positive |
| | | Share of the secondary industry in GDP (%) (C16) | Negative |
| | Technological innovation and investment (B4) | Share of R&D expenditure in the main business income of industrial enterprises above designated size (%) (C17) | Positive |
| | | Average number of valid invention patents of industrial enterprises above designated size (patents/enterprise) (C18) | Positive |
| | | Number of valid invention patents of industrial enterprises above designated size per capita (patents/10,000 persons) (C19) | Positive |

Tangshan, and Dazhou show a similar variation trend over the 15 years, which is stable in general except for a peak in 2016; Daqing and Dongying show a fluctuating downward trend. The remaining cities show a fluctuating upward trend, among which Ordos, Yulin, Yan'an, Luzhou, Tangshan, and Nanyang show a rapid increase.

The reason why Karamay, Dongying, Daqing, and Ordos have high industrial green development levels is that the municipal governments paid great attention to technological innovation over the 15 years. Compared with other cities, Karamay and Dongying invested more in technological innovation over the 15 years; Although the investment in technological innovation in Daqing is not as high as that in Karamay and Dongying, Daqing has the highest proportion of scientific research and technical service personnel among all cities, and the number of patent applications shows a significantly increasing trend, indicating that Daqing has attached great importance to the construction of its scientific and technological innovation system; Ordos has taken measures to improve the innovation mechanism of enterprises in recent years and achieved significant success, and the proportion of scientific research and technical service personnel has increased significantly since 2013. Meanwhile, influenced by the reduced crude oil production, the crude oil production in Daqing has been decreasing from 2004 to 2018. Also, the crude oil production in Dongying has been decreasing slightly since 2012, as a result of which the industrial green development levels of Daqing and Dongying are high but show a fluctuating downward trend in general. The industrial green development levels of Dazhou, Luzhou, and Nanchong are low, which may be because no effective measures have been taken in environmental management in Dazhou and Luzhou; in recent years, both cities have realized the problem and started to take relevant measures to manage the environmental problem, which have achieved some results. Meanwhile, the unit industrial added values of Luzhou and Nanchong are lower than other cities and show a slightly fluctuating trend, indicating a low degree of

Table 3. Distribution areas and types of oil and gas cities in China.

| Region | Province | Oil and gas city | City level |
|---|---|---|---|
| Eastern | Heilongjiang | Daqing | City at prefecture level |
| | Hebei | Renqiu | County-level city |
| | | Tangshan | City at prefecture level |
| | Liaoning | Panjin | City at prefecture level |
| | | Fushun | City at prefecture level |
| | Shandong | Dongying | City at prefecture level |
| | Jilin | Songyuan | City at prefecture level |
| | Hainan | Dongfang | County-level city |
| Central | Inner Mongolia | Ordos | City at prefecture level |
| | | Xilinhot | County-level city |
| | Henan | Nanyang | City at prefecture level |
| | | Puyang | City at prefecture level |
| | Hubei | Qianjiang | County-level city |
| Western | Sichuan | Nanchong | City at prefecture level |
| | | Luzhou | City at prefecture level |
| | | Dazhou | City at prefecture level |
| | Shaanxi | Yan'an | City at prefecture level |
| | | Yulin | City at prefecture level |
| | Gansu | Qingyang | City at prefecture level |
| | | Yumen | County-level city |
| | Ningxia | Lingwu | County-level city |
| | Yunnan | Zhaotong | City at prefecture level |
| | Xinjiang | Hami | City at prefecture level |
| | | Shanshan | County |
| | | Fukang | County-level city |
| | | Bayingolin | Autonomous prefecture |
| | | Korla | County-level city |
| | | Karamay | City at prefecture level |
| | | Baicheng | County |

intensive land use among the oil and gas resource-based cities. This has a great impact on the industrial green development levels of the two cities, and compared with other oil and gas resource-based cities, the two cities still need further improvement in the scale of the industrial economy.

## Evolution Characteristics of Sub-systems of Industrial Green Development Levels

The weights of different evaluation indicators were calculated, and the entropy weight-TOPSIS model was used to calculate the nearness degrees of resource consumption intensity, environmental impact and treatment, economic benefits and structure, and technological innovation and investment of different oil and gas resource-based cities in China (see Figs 3-6, Tables 5-12).

In the ranking of nearness degrees of resource consumption intensity, the first places in 2004-2018 are Dazhou (2004), Yan'an (2005-2006, 2008-2009, 2015, 2018), Daqing (2007), Yulin (2010-2014), Ordos (2016) and Karamay (2017), indicating that the resource consumption intensity of the cities is close to the optimal value. The last place is Nanchong (2004-2008, 2012), Tangshan (2009-2011), Panjin (2013-2016), Yulin (2014),

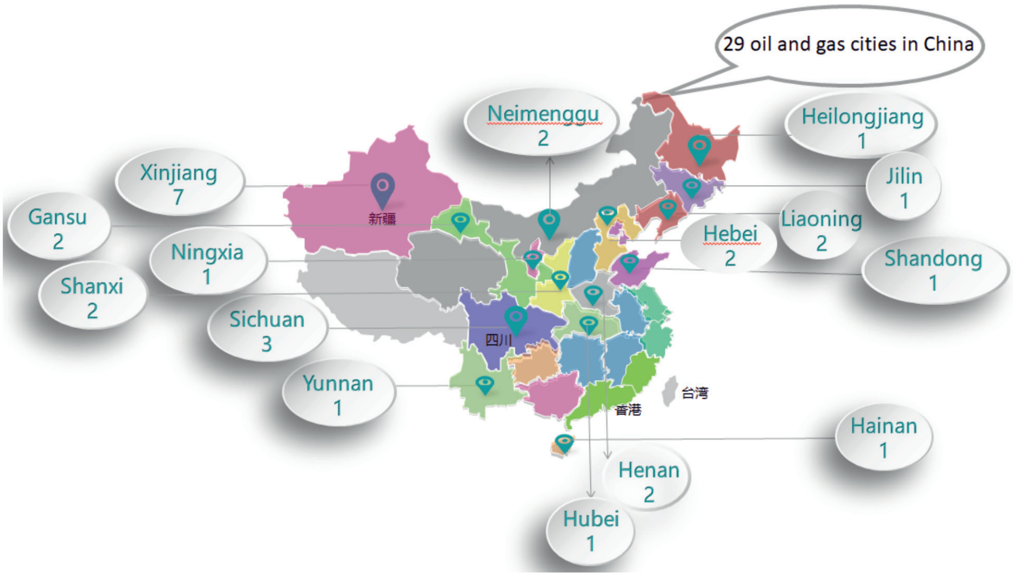


Fig. 1. Spatial Distribution Map of Oil and Gas Cities in China.

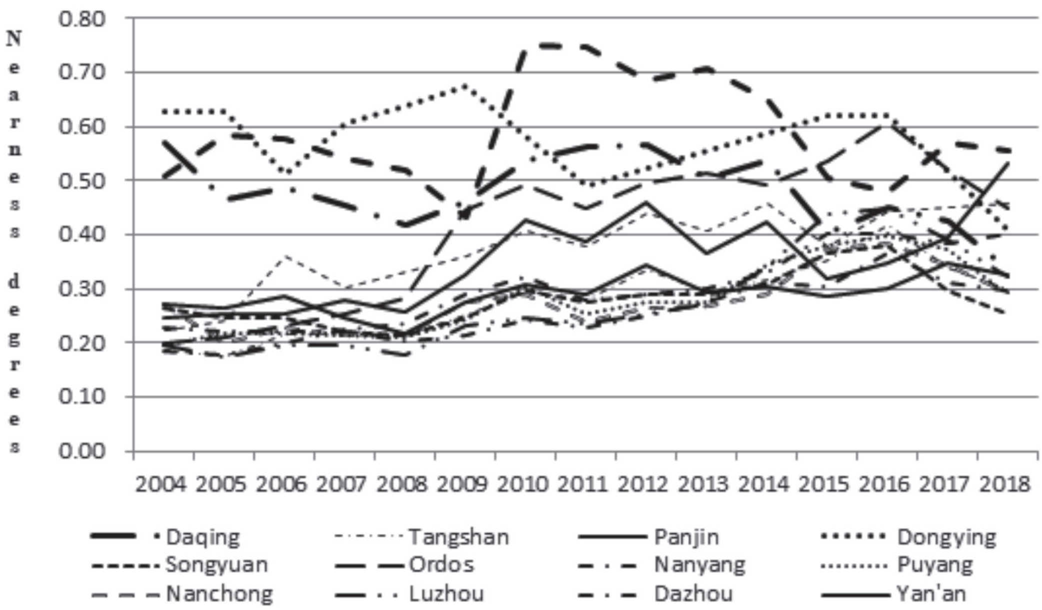


Fig. 2. Trend of nearness degrees of industrial green development levels of different oil and gas resource-based cities in China during 2004-2018.

and Nanchong (2018), indicating that the resource consumption intensity of the cities is large. The smallest extreme difference is 0.3769 (2009), and the largest is 0.5118 (2017). Also, the difference is basically stable between 2004 and 2016, but the difference increases significantly in 2017 and decreases slightly in 2018. Overall, different oil and gas resource-based cities in China show an insignificant difference in the resource consumption intensity before 2016, and after 2017, the difference between cities gradually increases.

In the ranking of nearness degrees of environmental impact and treatment, the first places in 2004-2018 are Karamay (2004, 2017), Yan'an (2005), Dongying (2006-2007), Panjin (2008-2010), Daqing (2011-2015), Songyuan (2015), and Dazhou (2018), indicating that these cities have a smaller environmental impact and achieve better treatment results than other cities; The last places are Dazhou (2004, 2010-2012), Luzhou (2005-5009, 2018), Tangshan (2013-2014), Yulin (2015, 2017), and Panjin (2016), indicating that these cities have a greater environmental impact and achieve fewer treatment results than other cities. The smallest extreme difference is 0.3918 (2018), and the largest is 0.7830 (2010). The results demonstrate that the difference between the environmental impact and treatment sub-system of different oil and gas resource-based cities

Table 4. Calculation results of proximity degree of industrial green development level in oil and gas resource-based cities from 2004 to 2018.

| City | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Daqing | 0.5700 | 0.4640 | 0.4869 | 0.4538 | 0.4182 | 0.4617 | 0.5380 | 0.5606 | 0.5659 | 0.5034 | 0.5372 | 0.4042 | 0.4501 | 0.4239 | 0.3335 |
| Tangshan | 0.1862 | 0.1746 | 0.2161 | 0.2201 | 0.2159 | 0.2500 | 0.2937 | 0.2791 | 0.3355 | 0.2943 | 0.3149 | 0.3520 | 0.4193 | 0.3384 | 0.2970 |
| Panjin | 0.2707 | 0.2626 | 0.2877 | 0.2446 | 0.2160 | 0.2766 | 0.3058 | 0.2910 | 0.3448 | 0.2920 | 0.3055 | 0.2872 | 0.3001 | 0.3483 | 0.3250 |
| Dongying | 0.6270 | 0.6274 | 0.5128 | 0.6070 | 0.6371 | 0.6742 | 0.5813 | 0.4892 | 0.5209 | 0.5549 | 0.5868 | 0.6185 | 0.6200 | 0.5158 | 0.4082 |
| Songyuan | 0.2651 | 0.2445 | 0.2449 | 0.2202 | 0.2134 | 0.2477 | 0.2959 | 0.2741 | 0.2909 | 0.2894 | 0.3091 | 0.3663 | 0.3781 | 0.2967 | 0.2537 |
| Ordos | 0.2004 | 0.2117 | 0.2313 | 0.2551 | 0.2824 | 0.4448 | 0.4908 | 0.4479 | 0.4972 | 0.5121 | 0.4905 | 0.5337 | 0.6073 | 0.5222 | 0.4474 |
| Nanyang | 0.1846 | 0.1792 | 0.2006 | 0.2251 | 0.2339 | 0.2880 | 0.3227 | 0.2776 | 0.2901 | 0.3000 | 0.3285 | 0.4015 | 0.4002 | 0.3825 | 0.4004 |
| Puyang | 0.1957 | 0.2177 | 0.2179 | 0.2139 | 0.2114 | 0.2442 | 0.3028 | 0.2534 | 0.2752 | 0.2756 | 0.3428 | 0.3796 | 0.3987 | 0.3744 | 0.2890 |
| Nanchong | 0.2722 | 0.2010 | 0.2280 | 0.2129 | 0.2131 | 0.2743 | 0.2898 | 0.2404 | 0.2646 | 0.2668 | 0.2880 | 0.3714 | 0.3821 | 0.3426 | 0.2935 |
| Luzhou | 0.1972 | 0.1741 | 0.1948 | 0.1974 | 0.1760 | 0.2305 | 0.2461 | 0.2355 | 0.2520 | 0.2729 | 0.3411 | 0.4386 | 0.4480 | 0.3903 | 0.3210 |
| Dazhou | 0.2291 | 0.2196 | 0.2226 | 0.2195 | 0.2024 | 0.2154 | 0.2424 | 0.2269 | 0.2504 | 0.2741 | 0.3118 | 0.3043 | 0.3655 | 0.3119 | 0.2969 |
| Yan’an | 0.2461 | 0.2529 | 0.2550 | 0.2784 | 0.2567 | 0.3248 | 0.4275 | 0.3859 | 0.4606 | 0.3660 | 0.4226 | 0.3174 | 0.3456 | 0.3930 | 0.5323 |
| Yulin | 0.2219 | 0.2425 | 0.3589 | 0.3032 | 0.3320 | 0.3608 | 0.4087 | 0.3784 | 0.4383 | 0.4072 | 0.4589 | 0.3781 | 0.4423 | 0.4515 | 0.4576 |
| Karamay | 0.5095 | 0.5854 | 0.5756 | 0.5396 | 0.5182 | 0.4328 | 0.7499 | 0.7470 | 0.6860 | 0.7065 | 0.6502 | 0.5045 | 0.4805 | 0.5687 | 0.5534 |

in China is increasing first and then decreasing (see Fig. 4). Hence, the oil and gas resource-based cities have made practical efforts in environmental treatment in recent years and taken relevant measures to reduce the differences between cities.

In the ranking of nearness degrees of economic benefits and structure, the first places in 2004-2018 are Karamay (2004-2008, 2010-2011, 2014, 2017-2018), and Ordos (2009, 2012-2013, 2015-2016), indicating that these oil and gas resource-based cities have better economic development than other cities over the 15 years; The last places are Yulin (2004-2006), Puyang (2007-2011), Nanyang (2012), Nanchong (2013, 2018), Panjin (2014, 2016), Yan'an (2015), and Songyuan (2017), indicating that the economic development of these oil and gas resource-based cities is poorer than other cities and needs improvement in these years. The smallest extreme difference is 0.3643 (2017), and the largest is 0.6557 (2005), and the difference shows a decreasing and then increasing trend (see Fig. 5, Table 9, Table 10), suggesting that the gap between the oil and gas resource-based cities in China in terms of economic development is gradually widening. Hence, the economic development of some oil and gas resource-

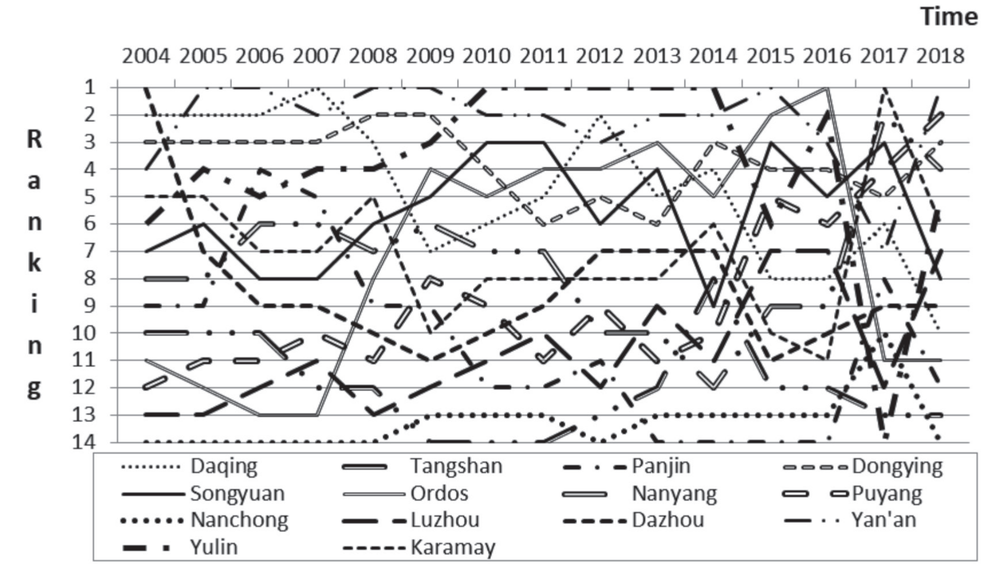


Fig. 3. Ranking of nearness degrees of resource consumption intensity of oil and gas resource-based cities in China during 2004-2018.

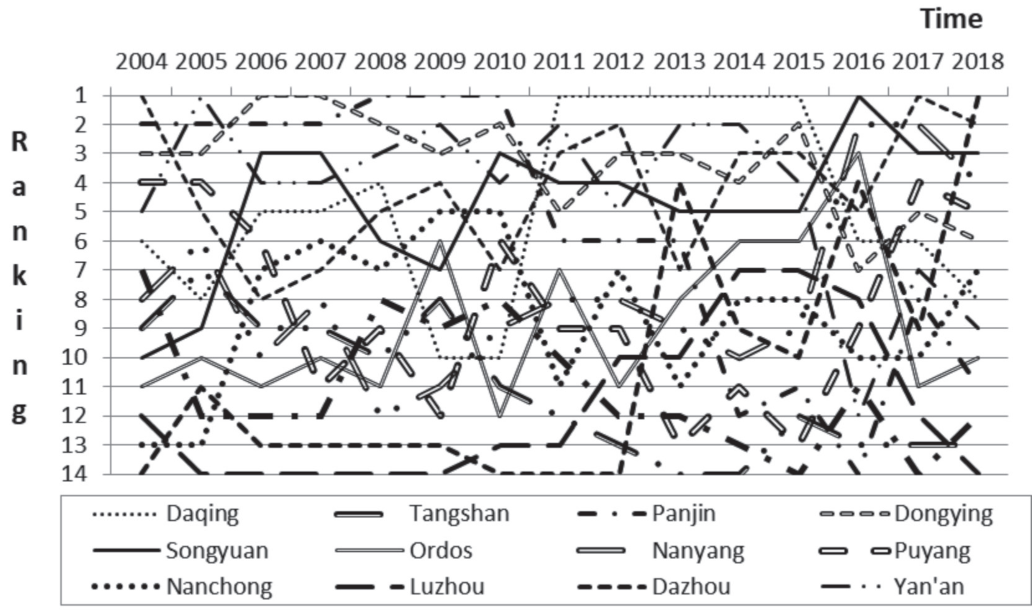


Fig. 4. Ranking of nearness degree of environmental impact and treatment of oil and gas resource-based cities in China during 2004-2018.

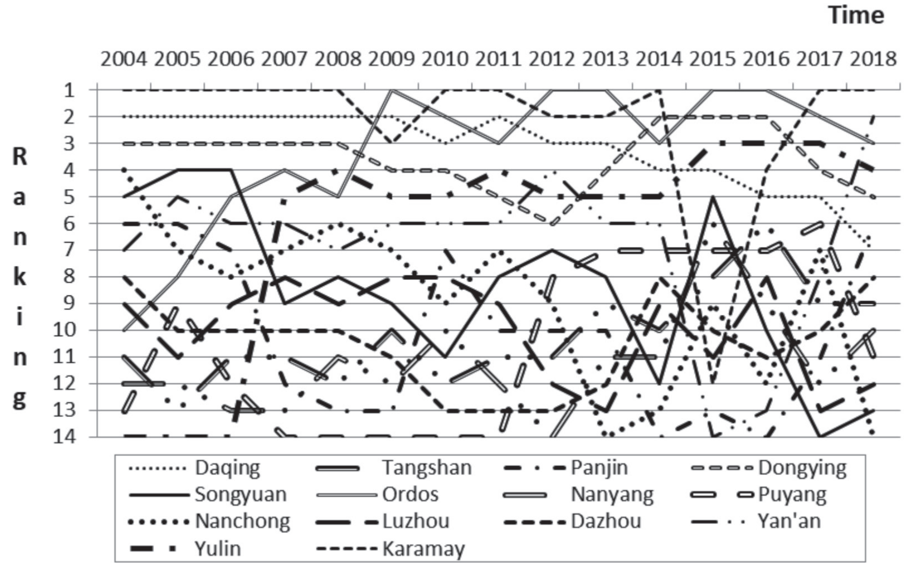


Fig. 5. Ranking of nearness degree of economic benefits and structure of oil and gas resource-based cities in China during 2004-2018.

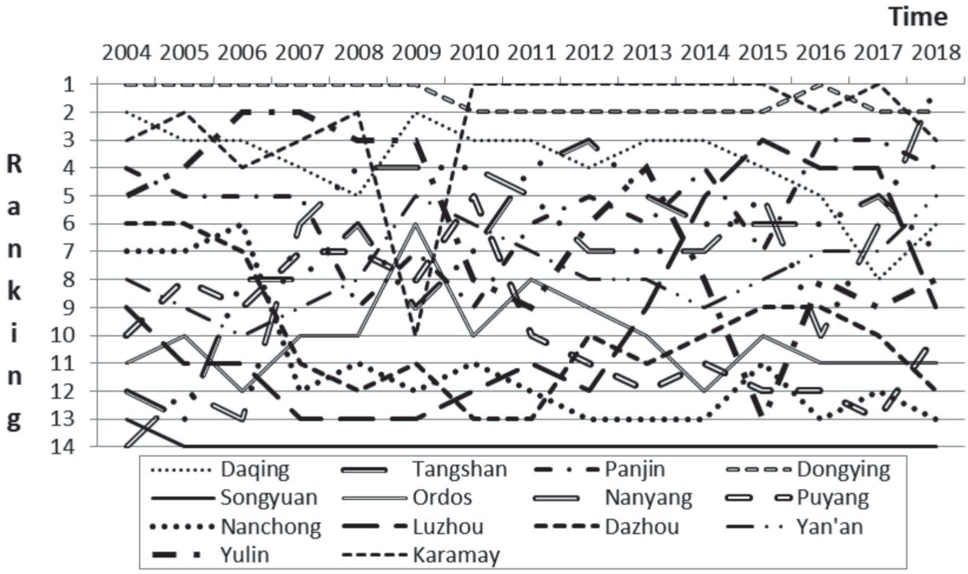


Fig. 6. Ranking of nearness degree of technological innovation and investment of oil and gas resource-based cities in China during 2004-2018.

based cities is good, while the economic development of some other cities is not optimistic, which will also directly affect the industrial green development levels of these cities.

In the ranking of nearness degrees of technological innovation and investment, the first places in 2004-2018 are Dongying (2004-2009, 2016), Karamay (2010-2015, 2017), and Nanyang (2018), and the last places are Nanyang (2004) and Songyuan (2005-2018). The smallest extreme difference is 0.4807 (2006), and the largest is 0.9230 (2004), and the difference first decreases, then gradually increases, and then decreases (see Fig. 6 Table 11, Table 12). The results demonstrate that different oil and gas resource-based cities in China differ greatly in terms of technological innovation and investment, but the difference is decreasing. Hence, promoting technological innovation and investment has become a common way for oil and gas resource-based cities to seek industrial green development, and all cities are taking active measures to increase technological innovation investment and enhance technological innovation capability.

According to Fig. 2-5 (from Table 4 to Table 12), the ranking of the sub-system nearness degrees of industrial green development levels of different oil and gas resource-based cities in China varies significantly from year to year, and differences exist for the four indicators, and the differences vary, which is due to the uneven economic development, social progress, and natural environment of different

Table 5. Ranking of calculation results of proximity degree of resource consumption intensity in oil and gas resource-based cities from 2004 to 2018.

| City | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Daqing | 2 | 2 | 2 | 1 | 3 | 7 | 6 | 5 | 2 | 5 | 4 | 8 | 8 | 6 | 10 |
| Tangshan | 10 | 10 | 10 | 12 | 12 | 14 | 14 | 14 | 13 | 12 | 8 | 12 | 12 | 13 | 13 |
| Panjin | 9 | 9 | 4 | 5 | 9 | 9 | 12 | 12 | 11 | 14 | 14 | 14 | 14 | 8 | 12 |
| Dongying | 3 | 3 | 3 | 3 | 2 | 2 | 4 | 6 | 5 | 6 | 3 | 4 | 4 | 5 | 3 |
| Songyuan | 7 | 6 | 8 | 8 | 6 | 5 | 3 | 3 | 6 | 4 | 9 | 3 | 5 | 3 | 8 |
| Ordos | 11 | 12 | 13 | 13 | 8 | 4 | 5 | 4 | 4 | 3 | 5 | 2 | 1 | 11 | 11 |
| Nanyang | 8 | 8 | 6 | 6 | 7 | 6 | 7 | 7 | 10 | 10 | 12 | 9 | 9 | 2 | 4 |
| Puyang | 12 | 11 | 11 | 10 | 11 | 8 | 9 | 11 | 9 | 11 | 10 | 5 | 6 | 4 | 2 |
| Nanchong | 14 | 14 | 14 | 14 | 14 | 13 | 13 | 13 | 14 | 13 | 13 | 13 | 13 | 10 | 14 |
| Luzhou | 13 | 13 | 12 | 11 | 13 | 12 | 11 | 10 | 12 | 9 | 11 | 7 | 7 | 12 | 7 |
| Dazhou | 1 | 7 | 9 | 9 | 10 | 11 | 10 | 9 | 7 | 7 | 7 | 11 | 10 | 9 | 9 |
| Yan'an | 4 | 1 | 1 | 2 | 1 | 1 | 2 | 2 | 3 | 2 | 2 | 1 | 3 | 7 | 1 |
| Yulin | 6 | 4 | 5 | 4 | 4 | 3 | 1 | 1 | 1 | 1 | 1 | 6 | 2 | 14 | 5 |
| Karamay | 5 | 5 | 7 | 7 | 5 | 10 | 8 | 8 | 8 | 8 | 6 | 10 | 11 | 1 | 6 |

Explanation: The ranking of the calculation results of resource consumption intensity closeness in Table 5 is derived from Table 6 „Calculation Results of Resource Consumption Intensity proximity in Oil and Gas Resource-based Cities"

Table 6. Calculation results of resource consumption intensity proximity in oil and gas resource-based cities.

| Year | Daqing | Tangshan | Panjin | Dongying | Songyuan | Ordos | Nanyang | Puyang | Nanchong | Luzhou | Dazhou | Yan'an | Yulin | Karamay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 0.8948 | 0.7225 | 0.7605 | 0.8646 | 0.7940 | 0.5961 | 0.7907 | 0.5926 | 0.4566 | 0.5503 | 0.9194 | 0.8407 | 0.8048 | 0.8143 |
| 2005 | 0.8695 | 0.6490 | 0.7325 | 0.8695 | 0.7777 | 0.5872 | 0.7527 | 0.5988 | 0.4738 | 0.5246 | 0.7654 | 0.8916 | 0.8217 | 0.7825 |
| 2006 | 0.8668 | 0.6460 | 0.7841 | 0.8457 | 0.7227 | 0.5037 | 0.7519 | 0.6379 | 0.4476 | 0.5302 | 0.6775 | 0.8790 | 0.7572 | 0.7422 |
| 2007 | 0.8205 | 0.4786 | 0.6686 | 0.7997 | 0.6343 | 0.4549 | 0.6556 | 0.5844 | 0.4289 | 0.5177 | 0.6082 | 0.8090 | 0.7022 | 0.6372 |
| 2008 | 0.7918 | 0.5003 | 0.6427 | 0.8075 | 0.6820 | 0.6436 | 0.6609 | 0.5800 | 0.4442 | 0.4908 | 0.6414 | 0.8372 | 0.7475 | 0.7295 |
| 2009 | 0.6849 | 0.4596 | 0.6041 | 0.7915 | 0.7186 | 0.7195 | 0.6892 | 0.6080 | 0.4640 | 0.5516 | 0.5728 | 0.8365 | 0.7568 | 0.5761 |
| 2010 | 0.7143 | 0.4317 | 0.5350 | 0.7486 | 0.7625 | 0.7428 | 0.6291 | 0.5841 | 0.4734 | 0.5596 | 0.5636 | 0.8327 | 0.8404 | 0.6004 |
| 2011 | 0.7213 | 0.4595 | 0.5380 | 0.7044 | 0.7436 | 0.7257 | 0.6157 | 0.5573 | 0.4601 | 0.5609 | 0.5662 | 0.8121 | 0.8376 | 0.5942 |
| 2012 | 0.8148 | 0.5377 | 0.5708 | 0.7032 | 0.6876 | 0.7157 | 0.5841 | 0.5911 | 0.4134 | 0.5413 | 0.6083 | 0.8036 | 0.8195 | 0.5984 |
| 2013 | 0.7132 | 0.5413 | 0.4240 | 0.6906 | 0.7277 | 0.7480 | 0.5648 | 0.5501 | 0.4562 | 0.5752 | 0.6594 | 0.7870 | 0.8369 | 0.6357 |
| 2014 | 0.7144 | 0.6629 | 0.3949 | 0.7156 | 0.6592 | 0.6919 | 0.4452 | 0.5670 | 0.4090 | 0.5644 | 0.6739 | 0.7436 | 0.8281 | 0.6893 |
| 2015 | 0.5577 | 0.4408 | 0.3621 | 0.6998 | 0.7010 | 0.7162 | 0.5535 | 0.6446 | 0.4196 | 0.5771 | 0.4844 | 0.7486 | 0.6327 | 0.5077 |
| 2016 | 0.6125 | 0.5508 | 0.3300 | 0.6783 | 0.6687 | 0.7425 | 0.6081 | 0.6365 | 0.4937 | 0.6341 | 0.6079 | 0.7050 | 0.7199 | 0.5575 |
| 2017 | 0.6525 | 0.5023 | 0.6237 | 0.6894 | 0.7953 | 0.5797 | 0.8043 | 0.7613 | 0.5878 | 0.5369 | 0.6177 | 0.6511 | 0.3122 | 0.8240 |
| 2018 | 0.5398 | 0.4665 | 0.5118 | 0.7172 | 0.5715 | 0.5208 | 0.6953 | 0.7356 | 0.4455 | 0.6272 | 0.5604 | 0.9035 | 0.6839 | 0.6730 |

Table 7. Ranking of calculation results of proximity degree of environmental impact and governance in oil and gas resource-based cities from 2004 to 2018.

| City | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Daqing | 6 | 8 | 5 | 5 | 4 | 10 | 10 | 1 | 1 | 1 | 1 | 1 | 6 | 6 | 8 |
| Tangshan | 9 | 7 | 9 | 9 | 10 | 8 | 11 | 12 | 13 | 14 | 14 | 12 | 13 | 13 | 13 |
| Panjin | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 6 | 6 | 6 | 12 | 11 | 14 | 8 | 11 |
| Dongying | 3 | 3 | 1 | 1 | 2 | 3 | 2 | 5 | 3 | 3 | 4 | 2 | 7 | 5 | 6 |
| Songyuan | 10 | 9 | 3 | 3 | 6 | 7 | 3 | 4 | 4 | 5 | 5 | 5 | 1 | 3 | 3 |
| Ordos | 11 | 10 | 11 | 10 | 11 | 6 | 12 | 7 | 11 | 8 | 6 | 6 | 3 | 11 | 10 |
| Nanyang | 8 | 6 | 10 | 8 | 12 | 11 | 9 | 8 | 8 | 9 | 10 | 9 | 2 | 2 | 4 |
| Puyang | 4 | 4 | 6 | 11 | 9 | 12 | 6 | 9 | 9 | 13 | 11 | 13 | 9 | 4 | 5 |
| Nanchong | 13 | 13 | 7 | 6 | 7 | 5 | 5 | 11 | 7 | 11 | 8 | 8 | 10 | 10 | 7 |
| Luzhou | 12 | 14 | 14 | 14 | 14 | 14 | 13 | 13 | 10 | 10 | 7 | 7 | 8 | 12 | 14 |
| Dazhou | 14 | 11 | 13 | 13 | 13 | 13 | 14 | 14 | 14 | 4 | 9 | 10 | 4 | 9 | 1 |
| Yan'an | 5 | 1 | 4 | 4 | 3 | 2 | 4 | 2 | 5 | 2 | 2 | 4 | 12 | 7 | 9 |
| Yulin | 7 | 12 | 12 | 12 | 8 | 9 | 8 | 10 | 12 | 12 | 13 | 14 | 11 | 14 | 12 |
| Karamay | 1 | 5 | 8 | 7 | 5 | 4 | 7 | 3 | 2 | 7 | 3 | 3 | 5 | 1 | 2 |

Explanation: The ranking of the calculation results of environmental impact and governance closeness in Table 7 is derived from Table 8 „Calculation Results of Environmental Impact and Governance Closeness in Oil and Gas Resource-based Cities".

Table 8. Calculation results of environmental impact and governance proximity in oil and gas resource-based cities.

| Year | Daqing | Tangshan | Panjin | Dongying | Songyuan | Ordos | Nanyang | Puyang | Nanchong | Luzhou | Dazhou | Yan'an | Yulin | Karamay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 0.8028 | 0.6798 | 0.9155 | 0.8718 | 0.6715 | 0.5834 | 0.7085 | 0.8638 | 0.5151 | 0.5156 | 0.3893 | 0.8043 | 0.7224 | 0.9669 |
| 2005 | 0.7366 | 0.7608 | 0.9283 | 0.9084 | 0.7290 | 0.6246 | 0.7729 | 0.8696 | 0.5210 | 0.4442 | 0.5557 | 0.9380 | 0.5518 | 0.8633 |
| 2006 | 0.8044 | 0.7444 | 0.9077 | 0.9276 | 0.8882 | 0.5819 | 0.7223 | 0.8003 | 0.7825 | 0.4609 | 0.4787 | 0.8449 | 0.5638 | 0.7654 |
| 2007 | 0.8521 | 0.7271 | 0.9083 | 0.9326 | 0.8813 | 0.6874 | 0.7463 | 0.6178 | 0.8160 | 0.3949 | 0.4988 | 0.8564 | 0.5883 | 0.8144 |
| 2008 | 0.8370 | 0.6851 | 0.8961 | 0.8952 | 0.7731 | 0.6710 | 0.6578 | 0.7232 | 0.7714 | 0.3775 | 0.4089 | 0.8424 | 0.7234 | 0.7954 |
| 2009 | 0.6012 | 0.7396 | 0.9011 | 0.8645 | 0.7416 | 0.7688 | 0.5840 | 0.5645 | 0.8131 | 0.2603 | 0.2763 | 0.8899 | 0.6496 | 0.8321 |
| 2010 | 0.7203 | 0.6755 | 0.9562 | 0.9239 | 0.8860 | 0.4767 | 0.7353 | 0.7812 | 0.7997 | 0.2043 | 0.1732 | 0.8711 | 0.7394 | 0.7793 |
| 2011 | 0.9284 | 0.4327 | 0.6680 | 0.7521 | 0.7547 | 0.5901 | 0.5379 | 0.5076 | 0.4984 | 0.4319 | 0.3913 | 0.8690 | 0.5042 | 0.8514 |
| 2012 | 0.9294 | 0.4585 | 0.7377 | 0.8176 | 0.7742 | 0.5189 | 0.6101 | 0.5642 | 0.6514 | 0.5281 | 0.4519 | 0.7387 | 0.5183 | 0.8335 |
| 2013 | 0.9386 | 0.4466 | 0.6624 | 0.7578 | 0.6859 | 0.6002 | 0.5804 | 0.4865 | 0.5538 | 0.5758 | 0.7482 | 0.8466 | 0.5273 | 0.6041 |
| 2014 | 0.9440 | 0.3924 | 0.4601 | 0.7612 | 0.6883 | 0.6769 | 0.4986 | 0.4766 | 0.6045 | 0.6090 | 0.5234 | 0.8707 | 0.4454 | 0.8209 |
| 2015 | 0.9208 | 0.4829 | 0.4907 | 0.7982 | 0.7466 | 0.7047 | 0.5851 | 0.4618 | 0.5980 | 0.6023 | 0.5040 | 0.7745 | 0.3828 | 0.7934 |
| 2016 | 0.6704 | 0.4167 | 0.3321 | 0.6600 | 0.9433 | 0.7176 | 0.7381 | 0.5507 | 0.5421 | 0.5966 | 0.6831 | 0.5028 | 0.5204 | 0.6722 |
| 2017 | 0.6525 | 0.5023 | 0.6237 | 0.6894 | 0.7953 | 0.5797 | 0.8043 | 0.7613 | 0.5878 | 0.5369 | 0.6177 | 0.6511 | 0.3122 | 0.8240 |
| 2018 | 0.6578 | 0.4911 | 0.5826 | 0.6939 | 0.7880 | 0.5930 | 0.7652 | 0.7233 | 0.6914 | 0.4255 | 0.8172 | 0.6572 | 0.5237 | 0.8010 |

Table 9. Ranking of calculation results of proximity degree of economic benefits and structures in oil and gas resource-based cities from 2004 to 2018.

| City | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Daqing | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 3 | 3 | 4 | 4 | 5 | 5 | 7 |
| Tangshan | 11 | 13 | 11 | 11 | 12 | 10 | 12 | 11 | 11 | 9 | 10 | 8 | 6 | 9 | 9 |
| Panjin | 6 | 6 | 7 | 12 | 13 | 13 | 7 | 10 | 10 | 10 | 14 | 13 | 14 | 11 | 6 |
| Dongying | 3 | 3 | 3 | 3 | 3 | 4 | 4 | 5 | 6 | 4 | 2 | 2 | 2 | 4 | 5 |
| Songyuan | 5 | 4 | 4 | 9 | 8 | 9 | 11 | 8 | 7 | 8 | 12 | 5 | 10 | 14 | 13 |
| Ordos | 10 | 8 | 5 | 4 | 5 | 1 | 2 | 3 | 1 | 1 | 3 | 1 | 1 | 2 | 3 |
| Nanyang | 12 | 12 | 13 | 13 | 11 | 12 | 10 | 12 | 14 | 11 | 11 | 6 | 9 | 12 | 10 |
| Puyang | 13 | 9 | 12 | 14 | 14 | 14 | 14 | 14 | 8 | 7 | 7 | 7 | 7 | 6 | 11 |
| Nanchong | 4 | 7 | 8 | 7 | 6 | 7 | 9 | 7 | 9 | 14 | 13 | 9 | 12 | 7 | 14 |
| Luzhou | 9 | 11 | 9 | 8 | 9 | 8 | 8 | 9 | 12 | 13 | 9 | 11 | 8 | 13 | 12 |
| Dazhou | 8 | 10 | 10 | 10 | 10 | 11 | 13 | 13 | 13 | 12 | 8 | 10 | 11 | 10 | 8 |
| Yan'an | 7 | 5 | 6 | 6 | 7 | 6 | 6 | 6 | 4 | 6 | 6 | 14 | 13 | 8 | 2 |
| Yulin | 14 | 14 | 14 | 5 | 4 | 5 | 5 | 4 | 5 | 5 | 5 | 3 | 3 | 3 | 4 |
| Karamay | 1 | 1 | 1 | 1 | 1 | 3 | 1 | 1 | 2 | 2 | 1 | 12 | 4 | 1 | 1 |

Explanation: The ranking of the calculation results of economic benefits and structural closeness in Table 9 is derived from Table 10 „Calculation Results of Economic Benefits and Structural Closeness of Oil and Gas Resource Based Cities".

Table 10. Calculation results of economic benefits and structural closeness of oil and gas resource-based cities.

| Year | Daqing | Tangshan | Panjin | Dongying | Songyuan | Ordos | Nanyang | Puyang | Nanchong | Luzhou | Dazhou | Yan'an | Yulin | Karamay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 0.6253 | 0.1423 | 0.2212 | 0.3855 | 0.2807 | 0.1634 | 0.1296 | 0.1227 | 0.3532 | 0.1872 | 0.2000 | 0.2164 | 0.1007 | 0.6442 |
| 2005 | 0.5752 | 0.1382 | 0.2450 | 0.4046 | 0.2516 | 0.2051 | 0.1497 | 0.1938 | 0.2161 | 0.1756 | 0.1781 | 0.2498 | 0.1168 | 0.7725 |
| 2006 | 0.5936 | 0.1706 | 0.2207 | 0.3862 | 0.2492 | 0.2358 | 0.1577 | 0.1651 | 0.1960 | 0.1855 | 0.1839 | 0.2209 | 0.1390 | 0.7914 |
| 2007 | 0.5886 | 0.1998 | 0.1907 | 0.3799 | 0.2303 | 0.3004 | 0.1742 | 0.1446 | 0.2649 | 0.2516 | 0.2050 | 0.2792 | 0.2802 | 0.7245 |
| 2008 | 0.5830 | 0.1862 | 0.1846 | 0.4108 | 0.2457 | 0.3787 | 0.1921 | 0.1734 | 0.2742 | 0.2219 | 0.2000 | 0.2684 | 0.3875 | 0.6963 |
| 2009 | 0.6702 | 0.3100 | 0.2179 | 0.5671 | 0.3291 | 0.7374 | 0.2511 | 0.2109 | 0.3647 | 0.3518 | 0.3010 | 0.3664 | 0.4616 | 0.6381 |
| 2010 | 0.5024 | 0.2112 | 0.2960 | 0.4231 | 0.2194 | 0.5993 | 0.2195 | 0.1925 | 0.2197 | 0.2375 | 0.1988 | 0.3861 | 0.3982 | 0.7874 |
| 2011 | 0.5436 | 0.1840 | 0.2039 | 0.3578 | 0.2252 | 0.5392 | 0.1802 | 0.1658 | 0.3236 | 0.2127 | 0.1671 | 0.3267 | 0.4133 | 0.6450 |
| 2012 | 0.5911 | 0.2160 | 0.2203 | 0.4263 | 0.3212 | 0.6305 | 0.1985 | 0.2207 | 0.2206 | 0.2122 | 0.2017 | 0.4978 | 0.4883 | 0.6299 |
| 2013 | 0.5944 | 0.3241 | 0.3191 | 0.5272 | 0.3414 | 0.7418 | 0.3091 | 0.3554 | 0.2329 | 0.2933 | 0.3064 | 0.3860 | 0.4428 | 0.6592 |
| 2014 | 0.5956 | 0.3865 | 0.1887 | 0.6083 | 0.3251 | 0.6068 | 0.3261 | 0.4789 | 0.3095 | 0.4081 | 0.4099 | 0.4988 | 0.5941 | 0.6423 |
| 2015 | 0.4751 | 0.4550 | 0.3306 | 0.6084 | 0.4665 | 0.7501 | 0.4620 | 0.4562 | 0.4316 | 0.4030 | 0.4109 | 0.3104 | 0.5155 | 0.3458 |
| 2016 | 0.4639 | 0.4573 | 0.1551 | 0.6094 | 0.4146 | 0.7335 | 0.4281 | 0.4476 | 0.3936 | 0.4405 | 0.3954 | 0.3325 | 0.5057 | 0.4882 |
| 2017 | 0.4643 | 0.3724 | 0.3642 | 0.4886 | 0.2285 | 0.5508 | 0.3642 | 0.4050 | 0.3979 | 0.3124 | 0.3724 | 0.3849 | 0.5240 | 0.5928 |
| 2018 | 0.4016 | 0.3806 | 0.4021 | 0.4113 | 0.2767 | 0.5615 | 0.3586 | 0.3488 | 0.2124 | 0.3396 | 0.3815 | 0.5959 | 0.5348 | 0.6570 |

Table 11. Ranking of calculation results of proximity degree of technological innovation and investment in oil and gas resource-based cities from 2004 to 2018.

| City | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Daqing | 2 | 3 | 3 | 4 | 5 | 2 | 3 | 3 | 4 | 3 | 3 | 4 | 5 | 8 | 6 |
| Tangshan | 12 | 13 | 8 | 8 | 6 | 9 | 7 | 4 | 3 | 5 | 6 | 6 | 6 | 5 | 7 |
| Panjin | 4 | 5 | 5 | 5 | 9 | 7 | 9 | 6 | 5 | 6 | 4 | 7 | 3 | 3 | 4 |
| Dongying | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 2 | 2 |
| Songyuan | 13 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 | 14 |
| Ordos | 11 | 10 | 12 | 10 | 10 | 6 | 10 | 8 | 9 | 10 | 12 | 10 | 11 | 11 | 11 |
| Nanyang | 14 | 12 | 13 | 6 | 4 | 4 | 4 | 5 | 7 | 7 | 7 | 5 | 10 | 6 | 1 |
| Puyang | 10 | 8 | 9 | 7 | 7 | 8 | 5 | 10 | 11 | 12 | 11 | 12 | 12 | 13 | 10 |
| Nanchong | 7 | 7 | 6 | 12 | 11 | 12 | 11 | 12 | 13 | 13 | 13 | 11 | 13 | 12 | 13 |
| Luzhou | 9 | 11 | 11 | 13 | 13 | 13 | 12 | 11 | 12 | 9 | 5 | 3 | 4 | 4 | 9 |
| Dazhou | 6 | 6 | 7 | 11 | 12 | 11 | 13 | 13 | 10 | 11 | 10 | 9 | 9 | 10 | 12 |
| Yan’an | 8 | 9 | 10 | 9 | 8 | 5 | 6 | 7 | 8 | 8 | 9 | 8 | 7 | 7 | 5 |
| Yulin | 5 | 4 | 2 | 2 | 3 | 3 | 8 | 9 | 6 | 4 | 8 | 13 | 8 | 9 | 8 |
| Karamay | 3 | 2 | 4 | 3 | 2 | 10 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 1 | 3 |

Explanation: The ranking of the calculation results of technological innovation and investment closeness in Table 11 is derived from Table 12 „Calculation results of technological innovation and investment closeness in oil and gas resource-based cities”.

Table 12. Calculation results of technological innovation and investment proximity in oil and gas resource-based cities.

| Year | Daqing | Tangshan | Panjin | Dongying | Songyuan | Ordos | Nanyang | Puyang | Nanchong | Luzhou | Dazhou | Yan'an | Yulin | Karamay |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2004 | 0.4407 | 0.0863 | 0.2251 | 1.0000 | 0.0804 | 0.1045 | 0.0770 | 0.1339 | 0.1871 | 0.1341 | 0.1883 | 0.1474 | 0.2241 | 0.2768 |
| 2005 | 0.2726 | 0.0755 | 0.1852 | 0.9679 | 0.0638 | 0.1092 | 0.0906 | 0.1549 | 0.1555 | 0.1090 | 0.1794 | 0.1350 | 0.2723 | 0.3322 |
| 2006 | 0.3367 | 0.1734 | 0.2823 | 0.5598 | 0.0792 | 0.1284 | 0.1164 | 0.1706 | 0.1888 | 0.1349 | 0.1759 | 0.1633 | 0.4589 | 0.3218 |
| 2007 | 0.2448 | 0.1682 | 0.1742 | 0.7367 | 0.0210 | 0.1257 | 0.1691 | 0.1689 | 0.0953 | 0.0849 | 0.1151 | 0.1571 | 0.2728 | 0.2714 |
| 2008 | 0.2068 | 0.1868 | 0.1409 | 0.7589 | 0.0100 | 0.1115 | 0.2197 | 0.1762 | 0.0933 | 0.0518 | 0.0931 | 0.1440 | 0.2515 | 0.3151 |
| 2009 | 0.3155 | 0.1597 | 0.2050 | 0.7170 | 0.0174 | 0.2102 | 0.2580 | 0.1699 | 0.0773 | 0.0645 | 0.0817 | 0.2247 | 0.2835 | 0.1391 |
| 2010 | 0.4650 | 0.2830 | 0.2571 | 0.6916 | 0.0314 | 0.2148 | 0.3607 | 0.3278 | 0.1782 | 0.1479 | 0.1398 | 0.3083 | 0.2820 | 0.7637 |
| 2011 | 0.4361 | 0.3021 | 0.2673 | 0.5263 | 0.0040 | 0.2663 | 0.2723 | 0.1877 | 0.1389 | 0.1424 | 0.1321 | 0.2668 | 0.1996 | 0.8260 |
| 2012 | 0.4324 | 0.4485 | 0.4068 | 0.5671 | 0.0099 | 0.2409 | 0.2902 | 0.1867 | 0.1522 | 0.1846 | 0.1891 | 0.2711 | 0.3165 | 0.7436 |
| 2013 | 0.3412 | 0.2894 | 0.2829 | 0.5852 | 0.0057 | 0.1845 | 0.2676 | 0.1356 | 0.1321 | 0.2438 | 0.1612 | 0.2543 | 0.3366 | 0.7765 |
| 2014 | 0.4070 | 0.2905 | 0.3404 | 0.5942 | 0.0000 | 0.1708 | 0.2893 | 0.1732 | 0.1227 | 0.3402 | 0.2107 | 0.2694 | 0.2874 | 0.8108 |
| 2015 | 0.3529 | 0.2450 | 0.2437 | 0.6352 | 0.0000 | 0.1795 | 0.2478 | 0.1199 | 0.1447 | 0.3854 | 0.1903 | 0.2366 | 0.1198 | 0.7410 |
| 2016 | 0.4164 | 0.3804 | 0.5096 | 0.6429 | 0.0049 | 0.2394 | 0.2767 | 0.1161 | 0.1032 | 0.4489 | 0.2770 | 0.3332 | 0.3023 | 0.6130 |
| 2017 | 0.3339 | 0.4104 | 0.6201 | 0.6222 | 0.0246 | 0.1979 | 0.4072 | 0.1405 | 0.1737 | 0.4720 | 0.2829 | 0.3366 | 0.3222 | 0.6799 |
| 2018 | 0.3231 | 0.3177 | 0.3493 | 0.4879 | 0.0367 | 0.2518 | 0.5732 | 0.2793 | 0.1109 | 0.2971 | 0.1607 | 0.3257 | 0.3074 | 0.4474 |

oil and gas resource-based cities in China. In terms of the resource consumption intensity, different oil and gas resource-based cities in China show an insignificant difference before 2016 and the difference gradually increases after 2017; in terms of environmental impact and treatment, the sub-system difference first increases and then decreases; in terms of economic development, the difference between different oil and gas resource-based cities in China is increasing; in terms of technological innovation and investment, although the difference between the cities is significant, the difference is decreasing. The difference between the oil and gas resource-based cities in China in environmental impact and treatment and technological innovation and investment is gradually decreasing, which verifies the overall increasing trend of the industrial green development levels of the oil and gas resource-based cities; the sub-system difference between the cities in resource consumption intensity and economic development is increasing, indicating that the resource consumption of some oil and gas resource-based cities still needs to be improved to enhance the overall economic strength of the cities. Since oil and gas resource-based cities are located throughout the eastern, central, and western regions of China, the advantages and disadvantages of each region are different in the context of prominent regional differences in China.

## Conclusions

The development of oil and gas resource-based cities is constrained by their economic structures and other factors, and most of the cities are in an extensive economic development mode, in which mode low energy consumption and pollution are achieved through industrial green development. In this study, the entropy weight-TOPSIS model was used to measure the industrial green development levels of 14 oil and gas resource-based cities from 2004 to 2018, and the overall system and sub-system nearness degrees of the industrial green development levels of the oil and gas resource-based cities and their rankings were analyzed. The following conclusions are drawn:

1. The industrial green development levels of the oil and gas resource-based cities are generally low, and the difference between the cities is significant. The nearness degrees of the industrial green development levels of the oil and gas resource-based cities in China range from 0.2 to 0.5, which is obviously low. Specifically, the industrial green development levels of Karamay, Dongying, Daqing, and Ordos are relatively high, while the industrial green development levels of Dazhou, Luzhou, Nanchong, and Tangshan are relatively low.

2. According to the variation trend of the industrial green development levels of the oil and gas resource-based cities, some cities show a similar variation trend over the 15 years while some cities fluctuate greatly in terms of the industrial green development level. For instance, Yulin, Yan'an, Ordos, and Nanyang show a rapid increase, while Dongying, Daqing, Nanchong, and Songyuan show a rapid decrease.

3. The four sub-systems of industrial green development level vary among different oil and gas resource-based cities in China. Specifically, the differences between different cities in resource consumption intensity and economic benefits and structure have been increasing in recent years, while the differences between different cities in environmental impact and treatment and technological innovation and investment have been decreasing in recent years.

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## Conflict of Interest

The authors declare no conflict of interest.

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