# Research on Provincial Differences in Thermal Carbon Emission Reduction in China Based on Quadrant Method and Cluster Analysis

**Jiarui Huang, Ying He*, Zhirong Wang**
*College of Environmental Science and Safety Engineering, Tianjin University of Technology, Tianjin, China*
** Corresponding Author.*

**Abstract: As a major carbon emitter, China's thermal industry is developing rapidly. Due to the significant regional and development differences among provinces and cities in China, it is particularly important to classify provinces and formulate effective emission reduction strategies based on local conditions. This article measures the thermal carbon emissions of 30 provinces in China and selects five main factors to conduct regional classification analysis using the quadrant method and clustering method. The results show that: first, thermal carbon emissions in most provinces and cities are growing rapidly, but there are significant differences among provinces, with only Shanghai experiencing negative growth. Second, provinces and cities in the first quadrant of the quadrant method need to control all indicators, while those in the second and fourth quadrants need to control a single indicator. Third, the four categories of regions output by the cluster analysis have their own characteristics, and different countermeasures should be taken for different regions to reduce emissions. The research results can provide suitable suggestions for the formulation of thermal carbon emission reduction plans in different provinces in China, helping to achieve the "dual carbon target".**

**Keywords: Quadrant Method; Cluster Analysis; Thermal Industry; Carbon Peaking; Carbon Neutrality**

## 1. Introduction

Global climate change is an important issue in today's society and a shared responsibility that the global community needs to take [1]. Since modern times, irreversible climate warming caused by the increase in $CO_2$ concentration in the atmosphere due to industrialization is one of the major ecological issues facing humanity. China holds the distinction of being the world's foremost energy producer and, concurrently, the largest consumer of energy on a global scale [2]. China is currently the world's largest emitter of carbon dioxide, facing enormous pressure to reduce carbon dioxide emissions [3]. The current rapid development of the thermal industry has posed considerable obstacles to carbon emission reduction efforts in various provinces and cities. Therefore, conducting classified research on provinces and regions can help formulate emission reduction strategies suitable for specific geographical areas, at the same time, to contribute to China's dual-carbon goals and high-quality economic development [4, 5].

Based on data from *the China Statistical Yearbook*, *China Energy Statistical Yearbook*, and the International Energy Agency, This article studies the impact of different influencing factors on different provinces and cities, and conducts a classified discussion. Subsequently, based on the classification results, the article puts forth strategic countermeasures aimed at advancing the realization of the 'dual-carbon' goal.

Currently, there have been numerous articles that have conducted accounting of carbon emissions in different industries and employed various methods, including but not limited to clustering, scenario forecasting, model, and index analysis, to conduct in-depth research on carbon emissions across various industries. The goal is to identify suitable carbon reduction pathways and propose corresponding policies. However, there are few articles that apply classification methods to study the differences in carbon emissions from the thermal industry among different provinces and cities. Some studies have used the quadrant method to discuss urban carbon reduction paths and corresponding policies [6, 7], including research on agricultural emission reduction. There are also articles that apply cluster analysis to classify differences in industry carbon emission reduction among cities [8-10]. However, there are no articles that have used two classification methods to conduct a comparative analysis of the provincial differences in influencing factors of carbon emissions from China's thermal industry. Based on this, this article measures the increment and growth rate of thermal carbon emissions in 30 provinces over 2020, and uses the quadrant method and K-means cluster analysis for classification analysis based on the main influencing factors collected from the literature and consultations, ultimately providing corresponding recommendations.

## 2. Method

### 2.1 Carbon Emission Calculation Methods

In this article, the term "carbon emissions" refers specifically to carbon dioxide emissions. According to the Greenhouse Gas Inventory Guidelines issued by the Intergovernmental Panel on Climate Change (IPCC), carbon emissions are calculated using Equation (1):

$$C = \sum E_{\mathrm{i}} \times U_{\mathrm{i}} \tag{1}$$

In the equation, C refers to the carbon emissions from the thermal industry; Ei represents the consumption of the i-th type of energy in the thermal industry (physical quantity), which is obtained from the "China Energy Statistics Yearbook"; Ui refers to the carbon dioxide emission coefficient of the i-th type of energy.

### 2.2 Cluster Analysis Method

This article employs a normalization formula to standardize the data processing in order to avoid excessive deviation in clustering results caused by the dimension of indicator data. The normalization formula is shown in Equation (2) below.

$$\mu'_i = \frac{\mu_i - \overline{\mu}}{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(\mu_i - \overline{\mu})^2}} \tag{2}$$

### 2.3 Quadrant Analysis Method

In this article, the quadrant method is used for analysis with four indicators, and the average of the selected indicators is used to classify the 30 provinces into four regions.

## 3. Results and Discussion

This article calculates the increment of thermal carbon emissions and the growth rate of thermal carbon emissions in China's provinces from 2005 to 2020, and selects five driving factors to conduct classification discussions using quadrant analysis and cluster analysis. The results show that thermal carbon emissions in most provinces have grown rapidly over the past 15 years, with significant differences in development among provinces. Only Shanghai has experienced negative growth in thermal carbon emissions. Compared to the quadrant method, the K-Means clustering analysis produced the same four types of regions. However, there is a concentration of provinces in two of these categories, making the quadrant method appear more scientific and comprehensive. The quadrant method is also better able to propose targeted and regional policy recommendations. Finally, this article provides corresponding policy recommendations for the six types of regions, hoping to provide support for future research. The inadequacy of this article lies in not establishing a model or setting scenarios to predict future changes in thermal carbon emissions at the provincial level. Future research will incorporate scenario settings to simulate the impact of thermal changes on overall carbon emissions.

The numbers in the following figures correspond to the following provinces and regions: 1-Beijing, 2-Tianjin, 3-Hebei, 4-Shanxi, 5-Inner Mongolia, 6-Liaoning, 7-Jilin, 8-Heilongjiang, 9-Shanghai, 10-Jiangsu, 11-Zhejiang, 12-Anhui, 13-Fujian, 14-Jiangxi, 15-Shandong, 16-Henan, 17-Hubei, 18-Hunan, 19-Guangdong, 20-Guangxi, 21-Hainan, 22-Chongqing, 23-Sichuan, 24-Guizhou, 25-Yunnan, 26-Shaanxi, 27-Gansu, 28-Qinghai, 29-Ningxia, 30-Xin.

### 3.1 Thermal Carbon Emissions of Provinces

According to the carbon emission calculation method, the carbon emissions of China's thermal power industry from 2005 to 2020 in various provinces are calculated using the data in the regional energy balance table from the "China Energy Statistics Yearbook," as shown in Figures 1, 2 and 3 below.

From the perspective of carbon emissions, Shandong Province topped the list of carbon emissions from the thermal power industry in 30 provinces in 2020, reaching 175,423,100 tons, far exceeding Liaoning Province, which was in second place with 101,504,900 tons of carbon emissions. Shandong's emissions were approximately 1.7 times that of Liaoning. There were five provinces with carbon emissions exceeding 80 million tons, including Shandong, Liaoning, Inner Mongolia Autonomous Region, Jiangsu, and Heilongjiang. Guizhou Province had the lowest carbon emissions from the thermal power industry in 2020, with 1,008,900

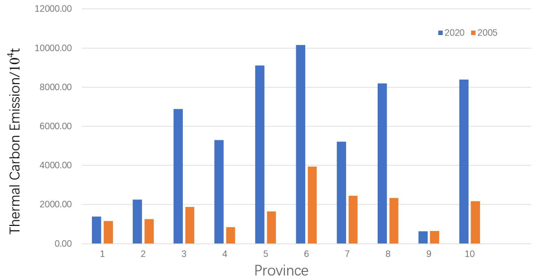


**Figure 1. Thermal Carbon Emissions of the Top 10 Provinces Including Beijing, Tianjin, and Hebei in 2020 and 2005**

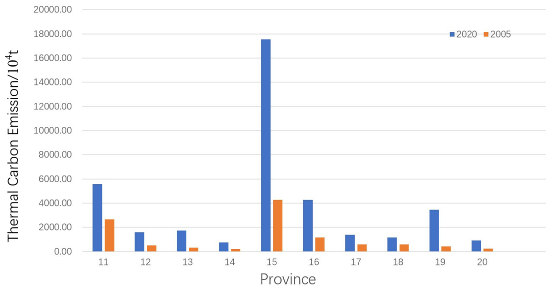


**Figure 2. Thermal Carbon Emissions of the Middle 10 Provinces Including Zhejiang, Anhui, and Fujian in 2020 and 2005**

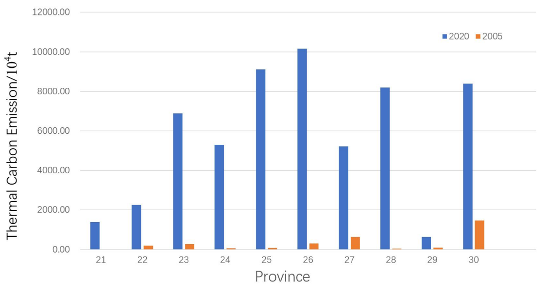


**Figure 3. Thermal Carbon Emissions of the Last 10 Provinces Including Xin, Ningxia, and Qinghai in 2020 and 2005**

tons. Six provinces and municipalities, including Guizhou, Yunnan, Hainan, Qinghai, Chongqing, Shanghai, Jiangxi, and Guangxi Zhuang Autonomous Region, had thermal power industry carbon emissions of less than 10 million tons. There were significant differences in carbon emissions from the thermal power industry among different regions, with Shandong Province, which had the highest carbon emissions in 2020, emitting 173.8 times more than Guizhou Province, which had the lowest.

From the perspective of analyzing the increment of carbon emissions over the past 15 years, it has been found that only four provinces and cities have increments of less than 3 million tons, including Beijing, Shanghai, Guizhou, and Yunnan. Among them, Shanghai is the only province or city among the 30 that has reduced its thermal carbon emissions. Shandong Province alone has an increment of carbon emissions over the past 15 years equivalent to the sum of the increments of the last eighteen provinces and cities, amounting to 132.7577 million tons. The increments of carbon emissions in Shandong, Inner Mongolia, Jiangsu, Liaoning, Heilongjiang, Xin, and Hebei exceed 50 million tons.

### 3.2. Cluster Analysis Results

In this chapter, SPSS statistical software was used to select four indicators for China's provinces in 2020: the average GDP growth rate over the past three years, household heating intensity, thermal energy proportion, and industrial proportion. The K-Means cluster analysis method was then applied to categorize China's provinces into groups.

SPSS software was employed to conduct a K-means cluster analysis on the four standardized values of 30 provinces in 2020. The results yielded four regional categories, which are presented in Table 1.

Among these four categories of regions, Category I consists of three provinces with average development speed, low heating intensity, average thermal energy proportion, and low secondary industry proportion; Category II comprises nineteen provinces with high development speed, low heating intensity, average thermal energy proportion, and high secondary industry proportion; Category III consists of two provinces with high development speed, low heating intensity, low thermal energy proportion, and average secondary industry proportion; and Category IV comprises six provinces with average development speed, high heating intensity, high thermal energy proportion, and high secondary industry proportion.

### 3.3 Quadrant Analysis Results

As can be seen in Figure 4, eight provinces and cities, including Beijing, Shanghai, Jiangsu, and Zhejiang, are regions with high growth rates and high per capita GDP. Seven provinces and cities, including Heilongjiang, Jilin, and Liaoning, are regions with relatively low growth rates and low per capita GDP. Tianjin, Shandong, and Inner Mongolia belong to regions with high per capita GDP but low growth rates. The remaining eleven provinces are regions with high growth rates but low per capita GDP.

In Figure 5, it can be observed that most southern provinces and cities are concentrated in the third quadrant, characterized by low heat consumption intensity and low industrial heat consumption intensity, with only Beijing located in the fourth quadrant, exhibiting low industrial heat consumption and average overall heat consumption intensity. Provinces and cities such as Ningxia, Xin, Heilongjiang, Liaoning, and Jilin are characterized by high industrial heat consumption and high residential heat consumption.

As can be seen from Figures 4 and 5, compared to clustering analysis, the quadrant method is more intuitive. It represents data points that are close to each other within a single quadrant, allowing for a clear identification of similar regions. However, in clustering analysis, the second category is overly concentrated, with approximately two-thirds of the provinces classified into the same category, which is not conducive to formulating targeted strategies for different regions.

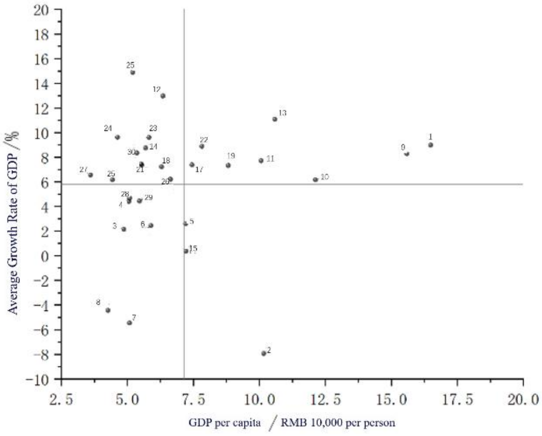


**Figure 4. Per capita GDP and Average GDP Growth Rate over the Past Three Years in Various Provinces of China**

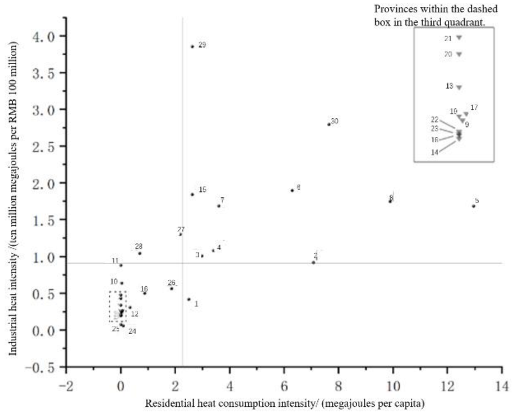


**Figure 5. Residential Heat Intensity and Industrial Heat Intensity in Various Provinces of China**

**Table 1. Classification of Cluster Analysis Results for 30 Provinces in China**

| Category | Provinces Included | Number of Categories |
|---|---|---|
| I | Beijing, Shanghai, Hainan | 3 |
| II | Jiangsu, Hunan, Zhejiang, Hubei, Anhui, Guangdong, Fujian, Jiangxi, Chongqing, Sichuan, Guangxi, Hebei, Shanxi, Shandong, Henan, Shaanxi, Gansu, Qinghai, Ningxia | 19 |
| III | Guizhou, Yunnan | 2 |
| IV | Tianjin, Jilin, Heilongjiang, Inner Mongolia, Liaoning, Xin | 6 |

### 4. Suggestions

(1) Establish development goals and avoid uncontrolled growth in carbon emissions due to rapid development. Specific to each province, strategies will vary based on actual conditions. Provinces such as Beijing, Shanghai, Jiangsu, and Zhejiang should strive to decouple economic growth from carbon emissions. On the other hand, less developed provinces like Heilongjiang, Liaoning, and Jilin should avoid blindly pursuing economic growth, which may lead to overheating of the economy and rapid growth in carbon emissions.

(2) Optimize the thermal intensity for industrial and residential use. Since there is a strong regional characteristic in residential heating, we only provide suggestions for northen provinces and cities. For example, Beijing is a province with excellent control over residential heating intensity, and other

provinces can learn from Beijing's heating experience. In provinces and cities with similar or even lower latitudes, such as Ningxia and Jilin, where the residential heating intensity is relatively high, various measures need to be taken to reduce carbon emissions from residential heating, including but not limited to improving the efficiency of pipeline heating, installing household metering devices, and so on. Meanwhile, provinces and cities with high thermal intensity for industrial use, such as Ningxia, Xin, Heilongjiang, and Liaoning, need to reduce the amount of heat consumed by the secondary industry and control its proportion. Efforts should be made to promote the development of characteristic industries, including the primary and tertiary industries.

## 5. Conclusion

Based on the comparison between the clustering method and the quadrant method discussed in this article, it can be found that the quadrant method is simpler, easier to operate, and has the advantage of intuitive results.

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