Clustering Analysis and Countermeasures of the Peak Carbon Dioxide Emissions Trend in Cities in Northeast China

Yunyan Peng [1], Hui Dong [2], Yongbo Sun [1]

[1] School of Economics, Heilongjiang University of Science and Technology, Harbin, Heilongjiang Province, China

[2] Changjiang Road Sales Department of China Merchants Securities Co., Ltd. in Harbin, Harbin, Heilongjiang Province, China

Keywords: City peak carbon dioxide emissions, K-means clustering algorithm, Tapio decoupling model, Clustering analysis, Peak carbon dioxide emissions trend

Abstract: With the advancement of China's "goal of peak carbon dioxide emissions and carbon neutrality", cities are areas with high energy consumption. Urban carbon emissions accounting and trend research have gradually become one of the hot spots of research. This paper selected the Tapio decoupling model and the K-means clustering algorithm, stared from both static and dynamic levels, and used SPSS software to conducted the clustering analysis of the peak carbon dioxide emissions trend of 34 sample cities in Northeast China. The results show that according to the trend of peak carbon dioxide emissions, cities in the Northeast region can be divided into three types: low-carbon potential cities, resource-dependent cities, and traditional industrial transformation cities. Except for provincial capitals, the average annual growth rate of carbon emissions in other cities has not changed significantly. Their economic growth is slow. The two kinds of city situations show weak negative decoupling and strong negative decoupling respectively, indicating that the development of carbon trends among cities is not balanced.

1. Introduction

In September 2020, China proposed to adopt more powerful policies and measures, strive to reach the peak of carbon dioxide emissions by 2030, and strive to achieve carbon neutrality by 2060. It has been an important task for economic development to accelerate the implementation of the national peak carbon dioxide emissions action plan. The industrial base in the Northeast is relatively large. Many cities have formed an industrial structure dominated by mining of mineral resources. Since the reform and opening up, with the transfer of the national economic construction center to the southern coastal cities, the economic development of the Northeast region has begun to highlight the disadvantages. In order to achieve the national carbon peak and carbon neutral mission goals, research on the peak carbon dioxide emissions trend of cities in cities of the Northeast region, and the problems of economic development need to be solved urgently.

  DOI: 10.25236/iiiece.2022.017

2. The Status Quo of Literature Research

In recent years, as the greenhouse effect has intensified and climate and environmental issues have become increasingly prominent, cities have become the main energy consumption areas. The exploration of urban carbon emissions has become one of the key areas of foreign research [1]. Zheng Haitao [2] selected China's urban per capita carbon emissions as a research sample. The results showed that with the continuous growth of consumption levels, the impact weight of per capita GDP on per capita carbon emissions gradually expanded, and the impact of urbanization on its impact decreased slightly. Liu Xingjian [3] analyzed the data of prefecture-level cities in China and found that under the same conditions, “shrinking” cities with population loss are less energy efficient than “growth” cities. Tang Kai (2021) conducted a study on the impact of China's pilot carbon trading market on carbon emission intensity and found that emissions trading rights have a significant effect on reducing carbon emissions in pilot cities. Gu Gaoxiang [4] studied the carbon emission reduction and climate economic impact of global low-carbon technology transfer by constructing a new comprehensive evaluation model CIECIA-TD. The results showed that technology transfer has a significant cooling and mitigation effect. Jiang Hanying et al. (2021) used the characteristics of carbon dioxide emissions and total carbon dioxide emissions in 36 typical large cities in China from 2005 to 2019 to construct a model for judging the peak of urban carbon dioxide emissions. Yu Xiang et al. (2020) used the Tapio decoupling model to examine the relationship between the economic growth of low-carbon pilot cities and changes in total carbon emissions. They classified low-carbon pilot cities and different types of low-carbon cities according to the elasticity coefficient of decoupling and made development suggestions. Dong Ying et al. (2020) used a systematic clustering method to comprehensively evaluate the carbon emission reduction capabilities of 14 cities and prefectures in Gansu Province based on the issue of carbon emissions and the possibility of emission reduction. The results show that the classification results are highly comprehensive and do not fully reflect regional continuity, that is, geographical location cannot be used to guide the classification of carbon emission reduction.

Through combing the literature, it is not difficult to find that foreign research on urban carbon emissions issues started earlier, with high research levels, and a wide range of coverage. This is closely related to foreign policies and regulations; while domestic related research is still in its infancy. At the same time, due to the different research perspectives of different scholars, the obvious differences in indicator selection methods, data sources and samples, research models, etc., a unified conclusion has not yet been reached. Secondly, for local areas, especially cities in the Northeast region, peak carbon dioxide emissions trend-related research has yet to be improved.

3. Analysis on City Carbon Emissions in Northeast China Based on the Tapio Decoupling Model

Carbon emissions is an abbreviation for greenhouse gas emissions, because the main gas in greenhouse gases is carbon dioxide, so the term carbon is used instead. The results of urban carbon emissions accounting are generally presented in the form of emission inventories, which can more intuitively disclose the emissions of urban areas and sectors (industry), mainly including production mode, consumption mode and mixed mode.

3.1 Tapio Decoupling Model

This paper adopts the Tapio decoupling model based on the change of growth elasticity in the decoupling model, which combines two types of indicators, relative change and total change. It ensures the objectivity and accuracy of the decoupling relationship analysis to a certain extent. The formula for calculating the elastic coefficient value of the Tapio model is as follows:

$$e = \frac{\frac{\Delta CO_2}{CO_2}}{\frac{\Delta GDP}{GDP}} \quad \text{(Formula 1)}$$

Table 1 Tapio Decoupling Model

Status		$\frac{\Delta CO_2}{CO_2}$	$\frac{\Delta GDP}{GDP}$	e
	increase	< 0	> 0	e< 0
Decoupling	weaken	> 0	> 0	0 < e<0.8
	decline	< 0	< 0	e >1.2
	increase	> 0	< 0	e<0
Negative decoupling	weaken	< 0	< 0	0 < e< 0.8
	increase	> 0	> 0	e>1.2
Connection	increase	> 0	> 0	0.8 < e< 1.2
	decline	< 0	< 0	0.8 < e< 1.2

(data sources:City Statistical Yearbook, has been processed with Excel)

3.2 Analysis of Peak Carbon Dioxide Emissions in Cities in Northeast China Based on the Tapio Decoupling Model

Based on the Tapio decoupling model, this paper calculated the decoupling elasticity coefficients of 34 cities in the Northeast. It can be seen that the proportion of cities in the Northeast region whose carbon emissions and economic growth were decoupled from the recession from 2012 to 2017 was 8.82%, which was in a weak decoupling state. The proportion of cities was 17.65%, the proportion of cities in weak negative decoupling was 41.18%, the proportion of cities in strong decoupling state was 8.82%, and the proportion of cities in strong negative decoupling state was 23.53%. Among them, the economic growth of the five cities of Changchun, Suihua, Mudanjiang, Jiamusi, Heihe, and Harbin were weakly decoupled from carbon emissions, indicating that the economic growth of these five cities was greater than the growth rate of carbon emissions. The economic growth of 14 cities like Yingkou, Songyuan, and Siping were weakly negatively decoupled from carbon emissions. The economic growth and carbon emissions changed in the same direction, that is, the decline in economic growth was much faster than the decline in carbon emissions. The economic growth and carbon emissions of Liaoyuan, Baishan, and Baicheng were strongly decoupled, indicating that the direction of economic growth and carbon emissions of these three cities had changed, that is, with the continuous economic growth, carbon emissions had gradually decreased. The economic growth and carbon emissions of Qiqihar, Dalian, and Huludao were in a recessive decoupling state, indicating that the economic growth and carbon emissions of these three cities were in the same direction. When the economic growth rate showed negative growth (Dalian, Huludao), their carbon emissions was also in a negative direction and was greater than the economic growth rate. When the economic growth changed into a positive direction (Qiqihar), the economic growth rate was weaker than the carbon emission growth rate, that is, as the economic growth rate was lower than the carbon emission growth rate. 11 cities including Yichun, Shuangyashan, Hegang, Jixi, etc., showed a strong negative decoupling between economic growth and carbon emissions. The two changed in opposite directions, with economic growth declining year by year and carbon emissions increasing year by year.

4. Clustering Analysis of the Trend of City Peak Carbon Dioxide Emissions in Northeast China

4.1 Indicator Selection

This paper selected 10 indicators (6 static indicators and 4 dynamic indicators) to perform a clustering analysis on 34 cities in Northeast China. Among them, the static indicators are: population, per capita GDP, energy consumption intensity, industrial structure, and urbanization rate. The four dynamic indicators include the average annual growth rate of population, total GDP, urbanization rate and total carbon emissions, which are used to characterize the impact of key indicators on the trend of peak carbon dioxide emissions.

4.2 Static Indicator Clustering Analysis

This paper used SPSS software to do k-means clustering analysis on cities in the Northeast. As shown in Table 2, the current peak carbon dioxide emissions trend of cities in the three provinces were divided into three categories. Among them, the first category was more special, with only three cities including Harbin, Shenyang and Changchun, all of which are provincial capitals. The second category included Qiqihar, Suihua, Anshan, Chaoyang, Jilin and Dalian. The third category included 25 cities, such as Jixi, Hegang, Shuangyashan, Daqing, Qitaihe, Fushun, Fuxin and Panjin. According to Table 3, it is not difficult to find that the static indicator data of the first type of cities were mostly better than the other two groups, with large population, developed economy, low energy consumption and high urbanization level, so they were classified as low-carbon potential cities. The second type of cities were in the middle of population, per capita GDP, energy intensity and other indicators at the end of the year, while the urbanization level and per capita carbon emissions were low. They should be cities with traditional industrial transformation. The third category of urban indicators was worse than the other two groups, especially the year-end population and per capita GDP. Energy intensity and per capita carbon emissions remained high, so it was classified as a resource-dependent city.

Table 2 Fast Clustering Analysis Output Results: the Number of Cases in Each Cluster

The Number of Cases in Each Cluster		
CLUSTER	1	3.000
	2	6.000
	3	25.000
valid		34.000
deficiency		.000

Table 3 Fast Clustering Crosstab

	Case cluster number		
	1	2	3
	average	mean	mean
Population at the end of the year (10,000 people) 2017	813.47	458.66	198.04
GDP per capita (ten thousand yuan) 2017	7.1137	4.5767	4.0868
Industrial structure(%)2017	38.58	33.34	36.47
Energy intensity(%)2017	4.28	8.52	9.94
The level of urbanization(%)2017	62.44	44.63	55.37
Carbon emissions per capita (tons) 2017	8.42	7.41	9.61

4.3 Dynamic Indicator Clustering Analysis

As shown in Table 4, the current peak carbon dioxide emissions trend of cities in the three provinces were divided into three categories. Among them, the first category included 7 cities: Harbin, Qiqihar, Jiamusi, Mudanjiang, Heihe, Suihua, and Changchun. The second category included 15 cities including Jixi, Shuangyashan, Yichun, Shenyang, Dalian, and Jilin. The third category includes 12 cities like Daqing, Hegang, Qitaihe, Fushun, Anshan and Fuxin. According to the results in Table 5, under the clustering analysis of dynamic indicators, the first type of cities had rapid economic growth and relatively slow growth of carbon emissions, and the two were weakly decoupled. The second type of cities' economic growth and carbon emissions growth were both slow negative growths. The economic growth and carbon emission growth of the third type were the same as the second type. The negative growth was slow, but the difference was that the economic growth decline rate was significantly faster than the carbon emissions decline rate, and the two showed a weak negative decoupling state. Based on dynamic indicators, the first type of cities was classified as low-carbon potential cities, the second type of cities was classified as traditional industrial transformation cities, and the third type was classified as resource-dependent cities, which were consistent with the types of cities classified under static indicators. Resource-dependent cities has lost a large amount of effective domestic labor and cannot effectively attract talents from abroad. The population aging has intensified, which has led to slower economic development in Northeast China and has begun to fall into a vicious circle. The increase in the urbanization rate is because with the continuous development of the economy, the population will continue to gather in big cities, so the increase in the urbanization rate is an inevitable result.

Table 4 Output Results Of the Fast Clustering Analysis: the Number of Cases in Each Cluster

The Number of Cases in Each Cluster		
cluster	1	7.000
	2	15.000
	3	12.000
valid		34.000
deficiency		.000

Table 5 Fast Clustering Crosstab

	Case cluster number		
	1	2	3
	mean	mean	mean
Population growth rate (%)(2012-2017)	-1.03	-.64	-.83
Urbanization rate growth(%)(2012-2017)	1.16	1.79	1.42
GDP growth rate(%)(2012-2017)	6.04	-1.30	-5.87
Average annual growth rate of carbon emissions(%)(2012-2017)	1.99	-.16	-.53

4.4 Comprehensive Indicator Clustering Analysis

As shown in Table 6, the current peak carbon dioxide emissions trend of cities in the three provinces were divided into three categories, which were the same as the city types and the number of cities classified under the static indicators. Among them, the first category was the capital cities of the Northeast region. The second category was Qiqihar, Suihua, Anshan, Chaoyang, Jilin, and Dalian. The third category was the same as above. According to the results in Table 7, it is not difficult to find that under the clustering analysis of comprehensive indicators, the GDP growth rate and carbon emission growth rate values had been effectively aggregated, the standard deviation was smaller, and the accuracy was higher. There are such reasons: First, the weight of the static indicator data was relatively large, and the k-value clustering analysis method was easily affected by extreme values and outliers. Second, when the clustering index was reduced, there might be a fitting on a certain index, resulting in the deviation of the clustering results.

Table 6 Output Results Of the Fast Clustering Analysis: the Number of Cases in Each Cluster

The Number of Cases in Each Cluster		
cluster	1	3.000
	2	6.000
	3	25.000
valid		34.000
deficiency		.000

Table 7 Fast Clustering Crosstab

	Case cluster number		
	1	2	3
	mean	mean	mean
Population at the end of the year (10,000 people) 2017	813.47	458.66	198.04
GDP per capita (ten thousand yuan) 2017	7.1137	4.5767	4.0868
Industrial structure(%)2017	38.58	33.34	36.47
Energy intensity(%)2017	4.28	8.52	9.94
The level of urbanization(%)(2017)	62.44	44.63	55.37
Carbon emissions per capita (tons)(2017)	8.42	7.41	9.61
Population growth rate (%)(2012-2017)	-.23	-.65	-.89
Urbanization rate growth(%)(2012-2017)	2.24	2.04	1.32
GDP growth rate(%)(2012-2017)	3.93	-1.04	-2.12
Average annual growth rate of carbon emissions(%)(2012-2017)	1.60	-.04	.02

5. Countermeasures and Suggestions

Based on the characteristics of peak trend classification, urban economic development stage, and resource endowment, the design of the peak carbon dioxide emissions action plan for cities in the Northeast should be consistent with the urban conditions in northeast China. It can be roughly started from the following aspects. First, for cities with low-carbon potential, reasonable plans should be made to establish a low-carbon industrial system, encourage the development of innovative green financial markets, and further promote energy conservation in key areas such as construction and transportation. Second, for cities in the transition period of traditional industries, it is necessary to accelerate the transformation of industrial structures, vigorously eliminate outdated production capacity, strictly control high-energy-consuming industries, establish a sound regulatory mechanism, and promote the transformation and upgrading of these high-energy-consuming industries as soon as possible. Third, for resource-dependent cities, it is essential to improve the efficiency of resource use while vigorously introducing new energy to complete the adjustment of energy structure as soon as possible. It is also vital to actively develop new industries, build new service markets, gradually shift the industrial focus, weaken the dependence on mineral resources. What's more, those cities should also actively develop their own tourism resources, accelerate the promotion of modern service industry. Fourth, the governments should increase the introduction of talents, and provide policy support for low-carbon industries and new industries. They should accelerate the implementation of the green financial market, improve its related mechanisms, and promote the development of the market's low-carbon economy. Besides, they also need to improve the efficiency of market energy allocation, and improve the efficiency of the market's energy allocation. Moreover, for emission reduction technologies, they should provide policy and financial support, financial subsidies, and tax reductions, etc.

6. Research Deficiencies and Prospects

This paper conducted the clustering analysis of urban carbon emissions in cities in Northeast China. Due to time and data constraints, the studied period is only until 2017. Secondly, there were estimation phenomena in the process of data collection and summarization, which might lead to deviations in research conclusions. The next stage of research will focus on whether there is a correlation between indicators and whether they are linear or non-linear relationships.

Acknowledgment

This paper is funded by the National Social Science Fund Project (13BJY059) and the 2020 Basic Research Fund Project of Heilongjiang Provincial Undergraduate Universities (70229).

References

[1] HaroldoV,Ribeiro,DiegoRybski,Jürgen P,Kropp. Effects of changing population or density on urban carbon dioxide emissions [J].Nature Communications, 10 (01), pp.86-99, 2019.

[2] Haitao Zheng, Jie Hu, Shanshan Wang. Examining the influencing factors of CO_2 emissions at city level via panel quantile regression: evidence from 102 Chinese cities [J]. Applied Economics, 51 (34/36), pp.3906-3919, 2019.

[3] Xingjian Liu, Mingshu Wang, Wei Qiang, et.al. Urban form, shrinking cities and residential carbon emissions: Evidence from Chinese city-regions [J]. Applied Energy. 261 (01), pp. 114409.1-114409.12, 2020

[4] Gaoxiang Gu, Zheng Wang, Leying Wu. Carbon emission reductions under global low-carbon technology transfer and its policy mix with R&D improvement [J]. Energy, 216 (03), pp.321-327, 2021.