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Evaluation of Low-Carbon Economic Efficiency under Industrial Clustering and Study of Regional Differences, Taking Xinjiang as an Example

Xiaoyu Ju [1,2,*], Xiaoli Zhou [2], Liangwei Zhang [2], Chun-Ai Ma [1] and Yue Zhang [2]

[1] School of Economics and Management, China University of Petroleum, Beijing 102249, China; mcaxjtu@163.com
[2] School of Business Administration, China University of Petroleum Beijing at Karamay, Karamay 834000, China; 2020016014@st.cupk.edu.cn (X.Z.); zlw799912525@gmail.com (L.Z.); 2022592110@cupk.edu.cn (Y.Z.)
* Correspondence: juxiaoyu@cupk.edu.cn

Abstract: As a major resource region, Xinjiang is both China's energy security base and an important hub connecting Asia and Europe. Following the country's call for carbon emission reduction, the Xinjiang government proposes to accelerate the construction of eight major industrial clusters in 2023. The concept of sustainable development is also reflected in the industrial clusters in areas such as new energy. In this study, we combined panel data from 14 regions and cities in Xinjiang from 2006 to 2020 and analyzed the synergy between the development of industrial clusters, carbon emissions, and economic growth using a coupling coordination degree model. Subsequently, we used the super-efficiency slack-based measure (SE-SBM) and Dagum's Gini coefficient to analyze the spatial disequilibrium of efficiency measures and efficiency cases. The results show the following: (1) Overall, the industrial clusters, carbon emissions, and economic growth in the 14 regions and cities of Xinjiang are not well coordinated. The best reported level has been medium coordination, but there exists a certain degree of correlation among the three. (2) Low-carbon economic efficiency under the influence of industrial clusters in the 14 regions and cities shows significant regional differences. The regions and cities with low-carbon economic efficiency greater than 0.8, which is significantly better than the other regions in terms of efficiency, are all located in northern Xinjiang. (3) During the study period, the overall regional difference in low-carbon economic efficiency under industrial clusters in Xinjiang decreased from 0.183 to 0.17. However, the regional differences were still large. The conclusions indicate that policies for industrial clusters in Xinjiang can promote industrial development, and there may be a correlation between them and the low-carbon economy. This will effectively contribute to local sustainable development. However, overall regional differences are significant, and the degree of coordination is low. Therefore, we suggest that the government can share the advantages of development by constructing cross-regional cooperation platforms. At the same time, the Xinjiang government should make full use of the rich local wind and solar energy resources and explore a low-carbon path toward transforming the traditional energy industry. It can also be seen that industrial clusters in Xinjiang can effectively promote local sustainable development.

Keywords: industrial clusters; low-carbon economy; coupling coordination degree; super-efficiency slack-based measure; Dagum's Gini coefficient

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1. Introduction

As the global economy recovers, global energy demand has rebounded significantly, leading to continuously increasing carbon emissions, and China is also facing the problem of high carbon emissions in the process of economic development. As a result of the Paris Agreement, many countries have made their own commitments to reduce greenhouse gas emissions. There is a need for every country around the world to explore a balanced path of development, both to reduce greenhouse gas emissions and promote economic development. Traditional development is mainly a high-consumption, high-growth consumption economic model, ignoring the carrying capacity of the environment. In 1980, the concept of sustainable development was put forward, which is defined as development that can meet contemporary economic development without jeopardizing future development and takes full account of carbon emissions and other pollution. With the continuous research on the concept of sustainable development in recent years, low-carbon sustainable development has now become the development goal of countries around the world. By the end of 2021, 136 countries proposed "zero carbon" or "carbon neutral" targets, and reducing carbon emissions has become a global issue. The Chinese government pointed out that, with the overall goal of "double carbon", reducing carbon emissions should be actively and steadily promoted. To reach the goal, the government must accelerate the manufacture of green, low-carbon products, promote a comprehensive green transformation of economic and social development, and build a modern society in which people coexist harmoniously with nature. As the world's largest developing country, China, in actively participating in global environmental governance, has proposed a "dual-carbon" goal, and the promotion of low-carbon sustainable development in cities is key to realizing that goal. Xinjiang, as China's largest provincial unit, is endowed with a large number of resources and has an important connecting role in the Central Asia region. At present, the eight main industrial clusters in Xinjiang focus on the region's own advantageous industries, including animal husbandry, oil and gas production, and textiles. However, because of the high carbon emissions produced by these industries, since General Secretary Xi Jinping put forward the Belt and Road Initiative in 2013, Xinjiang has been actively promoting the high-quality development of the core area of this initiative. In order to realize carbon peak and carbon neutrality goals, implementation must take place at the entity level. Overall, the promotion of low-carbon sustainable development in Xinjiang not only helps to break through the contradiction between local resources and the environment but also facilitates the formulation of measures suitable for local green and efficient development.

In addition, economic growth is accompanied by significant industrial clustering of the status quo [1]. According to a survey, the entire world's economic activities and output are now mainly concentrated in industrialized countries and regions. With continuous development, China's industries in the provincial capitals and the eastern part of the cluster are obvious. In recent years, the phenomenon of industrial clustering has become more obvious in China, and research shows that industrial clusters can accelerate the flow of resources in the reorganized space, thus promoting economic growth [2]. With the continuous promotion of Belt and Road (B&R), the importance of Xinjiang as the core area of the Silk Road Economic Belt has become more obvious in terms of the trend of carbon emissions and economic development under industrial clusters. This paper analyzes the data from 14 prefectural and municipal regions and cities of Xinjiang from 2006 to 2020. A map of the regions and cities is shown in Figure 1. Utilizing the role of industrial clusters in the process of low-carbon economic development helps to promote the low-carbon sustainable development of the city. Based on this, we investigated the coordination among industrial clusters, carbon emissions, and economic growth and measured low-carbon economic efficiency under the influence of industrial clusters. The aim of this research is to provide a decision-making basis for the two-pronged approach of reducing carbon emissions and stabilizing growth in the western region and actively exploring effective measures suitable for local low-carbon sustainable development.

First, Xinjiang, located in the western region, is China's agricultural and resource supply base, which mainly includes the primary and secondary industries. This paper analyzes the current situation of the relationship between carbon emissions and economic growth in Xinjiang based on an analysis of primary and secondary industry clusters, which helps us to scrutinize the development of the region's low-carbon economy in a more scientific manner and provides a useful basis for relevant policies and theoretical guidance.

Figure 1. Map of Xinjiang's 14 prefectures and cities.

Second, studying the coordination status of industrial clusters, carbon emission reduction, economic growth, and the efficiency of a low-carbon economy can lead to a feasible path for China's northwest region to control the growth of carbon emissions while fully utilizing the economic benefits of clustering.

2. Literature Review

2.1. Emissions and Economic Growth

Xinjiang, as the base of the Silk Road Economic Belt, has abundant resources, and an over-reliance on fossil energy is one of the main reasons for the increase in carbon emissions. The development of a low-carbon economy, i.e., carbon emission reduction along with steady economic growth, is necessary for future economic development [3]. In the context of advocating for a low-carbon economy, domestic and foreign scholars have studied the relationship between carbon emissions and economic growth; for example, Salman et al. concluded that carbon emissions and economic development have a certain degree of correlation [4]. The population size of economically developed regions is the main contributing factor to carbon emissions [5], while in economically less developed regions, economic output is the most important contributing factor [6]. Different regions have different degrees of economic development, and the factors that contribute to carbon emissions are also different. Nguyen et al. found that the key factors leading to increased carbon emissions are energy consumption and economic growth [7].

Among the theories regarding carbon emissions and economic growth, the low-carbon economy theory has attracted the most attention. The typical approaches in related research are the environmental Kuznets curve and the "decoupling" model [8]. Regarding the influence mechanism, Dong et al. noted that there is a stable equilibrium relationship between industrial structure upgrading, economic growth, and carbon emissions [9]. Liu et al. reported that there is a stable long-term relationship between carbon emissions, economic growth, and industrial structure [10]. Yu et al. sorted out the characteristics of industrial upgrading and transfer relative to carbon emissions and economic growth and analyzed the impact of industrial transfer on a low-carbon green economy [11]. Guo et al. examined the relationship between carbon emissions, economic growth, and urbanization and found that there is a constant cointegration relationship among the three [12]. Lv et al. measured the degree of coordination between carbon emissions, economic growth, and the ecological environment and analyzed the spatial correlation of the coupling results; they found that there is obvious spatial heterogeneity and a positive correlation with a downward trend [13]. In addition, scholars have analyzed the relationship between energy structure [14,15], population growth [16], technological progress [17], and other aspects of carbon emissions and economic growth.

2.2. Industrial Clustering

The concept of industrial clustering can be traced back to the 19th century when Marshall elaborated on the idea in his theory of economic externalities. The research on industrial clustering and economic development has now matured, with many studies showing that economic growth is often accompanied by industrial clustering. However, there are not many studies on the link between industrial clustering and carbon emissions.

Most of the research on industrial clustering has mainly focused on studying the economic effects of clusters through empirical analysis and analyzing the causes of the cluster phenomenon [18]. With the rise of green low-carbon theory, scholars began to pay attention to the externality of industrial clustering in terms of environmental carbon emissions [19,20]. On the whole, the current situation of environmental pollution in the world is getting more serious as rapid economic development and continuous industrial clustering are taking place. As far as China is concerned, carbon emissions are more serious in areas with obvious industrial clusters. However, many studies present different views: there are positive and negative environmental externalities caused by industrial clustering, and there is no clear and unified conclusion on the relationship between industrial clustering and low-carbon development [21].

In recent years, scholars have begun to study the relationship between industrial clustering and carbon emissions using different samples and methods, but the conclusions are mostly inconsistent. The current studies are broadly categorized into the following three views:

One view is that industrial clustering has an inhibitory effect on carbon emissions, and some scholars have found that industrial clustering can promote reduced carbon emissions and reduce environmental pollution. Scholars such as Newman [22] and Cheng [23], through empirical research, have indicated that industrial clustering can promote information spillover and technological innovation, thereby reducing pollution and improving the environment. Ren et al., based on samples of 61 cities in China's urban clusters, studied the relationship between industrial clustering and carbon emissions, and the results showed a clear opposite relationship between industrial clustering and carbon emissions intensity [24], indicating that increasing industrial clustering in China's cities can promote carbon emission reduction. Based on pollution emissions and import and export data of Chinese industrial enterprises from 2001 to 2010, Miming and others used the Tapio decoupling model to study the impact of industrial clustering on the decoupling of carbon exports of enterprises. The results showed that the development of industrial clusters helps enterprises to export carbon and realize the goal of reducing carbon emissions [25].

Another view is that industrial clustering will aggravate carbon emissions and other pollution. Ciccone et al. concluded that industrial clustering will lead to the over-clustering of enterprises, which will lead to depleted resources and increased natural pollution in the region [26]. There is also a view that there is a non-linear relationship between industrial clustering and carbon emissions [27]. Yang et al. showed that there is an inverted U-type relationship between industrial clustering and environmental pollution [28]. In addition, by reading the literature, it can be found that the impact of industrial clustering on carbon emissions depends, to a certain extent, on the type of industry [29].

In summary, most of the research on carbon emissions and economic growth by domestic and foreign scholars combines urbanization, energy structure, technological progress, and other factors, and there are fewer studies on industrial clusters and carbon emissions as well as economic growth. Compared with previous studies, the contribution of this paper is as follows: Xinjiang, as the core area of the Silk Road Economic Belt, is of great significance for the development of China as well as the Central Asian region, and its main economy comes from the primary and secondary industries. Based on this, the current Xinjiang government proposes the development of advantageous industrial clusters. Firstly, this paper analyzes the influence mechanism of industrial clusters, carbon emissions, and economic growth based on the data of Xinjiang to provide a reference for high-quality development. Secondly, this paper adopts the coupled coordination degree model to analyze the coordination level of advantageous industrial clusters (primary and secondary industries), carbon emissions, and economic growth in Xinjiang and measures low-carbon economic efficiency under industrial clusters by means of the super-efficient SBM model, and then further analyzes the regional heterogeneity of low-carbon economic efficiency.

3. Methods and Data

3.1. Methods

3.1.1. Methodology for Measuring Carbon Emissions and Industrial Clustering

Regarding the measurement of carbon emissions, we referred to the carbon emission method of the United Nations Intergovernmental Panel on Climate Change (IPCC). The emission factor method was used to estimate carbon emissions in Xinjiang [30], and the formula is as follows:

$$C_t = \sum AD_i \times EF_i \quad (1)$$

where C_t is the total carbon emissions of a city in Xinjiang in year t; ADi is the volume of activity that led to the emissions, such as consumption of oil and gas, net purchases of electricity and steam, etc.; and EF is the coefficient corresponding to the activity data. There are many methods to measure industrial clustering, such as location entropy, location Gini coefficient, Herfindahl index, industry cluster index, etc. Compared with other methods, location entropy is more reliable and accurate in reflecting the overall level of relevant industries in the region, and it can better reflect the level of regional clustering, so many scholars use this method to evaluate the degree of industrial clustering. For example, Qiu et al. used location entropy to measure the clustering effect of the new energy industry and evaluated and compared the clustering effect and development status of new energy industries in the EU through calculation and analysis [31]. Xinjiang is dominated by primary and secondary industries, so in this paper, we need to calculate the degree of primary and secondary industry clustering.

Location entropy was selected as an indicator of the degree of industrial clustering, and its calculation formula is:

$$Q = \frac{y/T}{g/G} \quad (2)$$

where y represents the GDP of the *n*th industry of a city or region; g represents the gross product of a city or region; T stands for the GDP of the *n*th industry in Xinjiang; and G represents Xinjiang's regional GDP. If $Q > 1$, it means that the clustering level of the *n*th industry in the region is higher than the average of Xinjiang as a whole, and the clustering effect is relatively obvious; if $Q < 1$, it means that the *n*th industry in the city or region lacks a significant industrial clustering effect.

3.1.2. Coupled Coordination Models

The coupling degree model, which is mainly used to determine the degree of association between two or more systems or elements [32], was combined with information from existing studies [33,34] to construct a coupling degree model of industrial clustering, carbon emissions, and economic growth in Xinjiang:

$$C = 4\left(XYZ_1Z_2\right)^{\frac{1}{4}} / (X + Y + Z_1 + Z_2) \quad (3)$$

In the formula, C is the coupling degree; X represents the situation of carbon emissions in Xinjiang, which is reflected by carbon emissions; Y represents economic growth, and GDP is used here as a measure; and Z_1 and Z_2 represent the location entropy of primary and secondary industry clusters, and the specific calculations are first standardized.

Based on Equation (3), the coupling coordination degree model is constructed with the following formula:

$$A = \sqrt{CT} \tag{4}$$

$$T = \alpha X + \beta Y + \chi Z_1 + \varepsilon Z_2 \tag{5}$$

In the formula, A is the degree of coupling coordination, and T is the comprehensive evaluation index of the overall level; the sum of the pending coefficients α and β is 1, which is used to reflect the contribution of each system to the whole. Based on previous research on the importance of carbon emissions and economic growth and industrial clusters, in this paper, we take the same value for each of the coefficients to be determined. The coupling degree of coordination A is in the range (0–1), and the larger A is, the better the coordination and development between the systems. The degree of coupling coordination is generally divided into 10 levels, as shown in Table 1.

Table 1. Criteria for classifying coupling coordination degree.

Interval of D-Values for Coupling Coordination	Level of Coordination	Degree of Coordination
(0.0~0.1)	1	Extreme disorder
[0.1~0.2)	2	Severe disorder
[0.2~0.3)	3	Moderate disorder
[0.3~0.4)	4	Mild disorder
[0.4~0.5)	5	On the verge of disorder
[0.5~0.6)	6	Reluctant coordination
[0.6~0.7)	7	Preliminary coordination
[0.7~0.8)	8	Intermediate coordination
[0.8~0.9)	9	Good coordination
[0.9~1.0)	10	Quality coordination

3.1.3. Super-Efficiency Slack-Based Measure (SE-SBM) Model

When measuring low-carbon economic efficiency, both desired and non-desired outputs should be taken into account. The super-efficiency SBM model combines the advantages of the DEA model and the SBM model, introduces slack variables, and deals with non-desired outputs in a more reasonable way. It can solve the shortcomings of efficiency assessment caused by the inability of the CCR and BBC models to measure all slack variables. The results of the model's efficiency measurement are independent of the units used to measure the input and output terms, while at the same time the efficiency value is monotonically decreasing. The SE-SBM model is as follows:

$$\begin{gathered} \min\rho = \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{S_i^-}{x_{ia}}}{1+\frac{1}{q_1+q_2}\left(\sum_{r=1}^{q_1}\frac{S_r^+}{y_{ra}}+\sum_{t=1}^{q_2}\frac{S_t^{b-}}{b_{ra}}\right)} \\ \text{s.t. } X\delta + s^- = x_a \\ Y\delta - s^+ = y_a \\ B\delta + s^{b-} = b_a \\ \delta, s^-, s^+, s^{b-} \geq 0 \end{gathered} \tag{6}$$

where ρ is the efficiency value of the evaluated unit DUM_a: the actual inputs, desired outputs, and non-desired outputs of DUM_a are x_a, y_a, and b_a, and their optimal target values are X, Y, and B. s^- is the slack of the inputs, s^+ is the slack of the desired outputs, and s^{b-} is the slack of the non-desired outputs. When the value of a decision unit is greater than or equal to 1, it is an effective decision unit; otherwise, there is a lack of efficiency.

In this part, the primary and secondary industry cluster location entropies are used as input indicators, GDP is selected as the desired output, and carbon emissions is selected as the non-desired output.

3.1.4. Dagum Gini Coefficient

Dagum divided the Gini coefficient into within-group Gini coefficient, between-group Gini coefficient, and hyperdensity differences. This method can better solve regional distribution and cross-cutting problems. In this paper, the Dagum Gini coefficient decomposition method is used to analyze different regional differences in Xinjiang.

The formula for calculating the overall Gini coefficient (overall regional differences) is as follows:

$$G = \frac{\sum_{j=1}^{k}\sum_{h=1}^{k}\sum_{i=1}^{n_j}\sum_{r=1}^{n_h}\left|y_{ji} - y_{hr}\right|}{2n^2\overline{Y}} \tag{7}$$

In the formula, n = 14, indicating the 14 regions and cities in Xinjiang; k = 3, indicating the 3 major regions in Xinjiang, with j and h being different regions; n_j and n_h are the number of regions and cities in regions j and h; y_{jr} and y_{hr} are the low-carbon economy efficiency (SE-SBM efficiency) of the regions and cities in regions j and h; and $\overline{Y}$ is the average of the low-carbon economy efficiency of all regions and cities. The total Gini coefficient is decomposed into 3 components: the degree of intra-regional contribution variance Gw, the degree of inter-regional variance contribution Gb, and the supervariable density Gini coefficient (Gt). The specific formulas are as follows:

$$Gw = \sum_{j=1}^{k} G_{jj}P_jS \tag{8}$$

$$Gb = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}\left(p_js_h + p_hs_j\right)D_{jh} \tag{9}$$

$$Gt = \sum_{j=2}^{k}\sum_{h=1}^{j-1} G_{jh}\left(p_js_h + p_hs_j\right)\left(1 - D_{jh}\right) \tag{10}$$

where $p_j = \frac{n_j}{n}$, $s_j = \frac{n_j\overline{Y}_j}{n\overline{Y}}$, $D_{jh} = \frac{d_{jh} - p_{jh}}{d_{jh} + p_{jh}}$, d_{jh} indicates the difference in low-carbon economy efficiency between the regions j and h, and p_{jh} is the hypervariance one matrix.

3.2. Data Sources

Because China first proposed the energy conservation and emission reduction target in the Eleventh Five-Year Plan in 2006, in this paper, we use the panel data of Xinjiang from 2006 to 2020. In order to maximize the continuity and uniformity of the data, the raw data required for carbon emission measurement in this paper, the value added of the primary and secondary industries, and the gross domestic product (GDP) of regions and cities were all derived from the official data published in the Statistical Yearbook of China, the Statistical Yearbook of Xinjiang, and other official data sources.

4. Results

4.1. Results of Primary and Secondary Industry Cluster Location Entropy

According to the operation of Equation (2), Figures 2–5 were obtained.

As shown in Figure 3, among the seven regions and cities in Northern Xinjiang, the degree of secondary industry clustering in Karamay remained near 1.9, which is a very high level in Xinjiang, in a leading position. The degree of concentration of the secondary industry in Changji Prefecture remained above 1 since 2012, which is higher than the average in Xinjiang as a whole, and the cluster effect is relatively obvious. The degree of industrial clustering in Altay fluctuated above and below 1 after 2012, and the degree of industrial clustering of the secondary industry in Urumqi, Tacheng, Bortala Mongol Autonomous Prefecture, and Ili Kazakh Autonomous was lower than 1, with a relatively disadvantageous clustering effect, and an increasing degree of secondary industry clustering in Bortala Mongol Autonomous Prefecture.

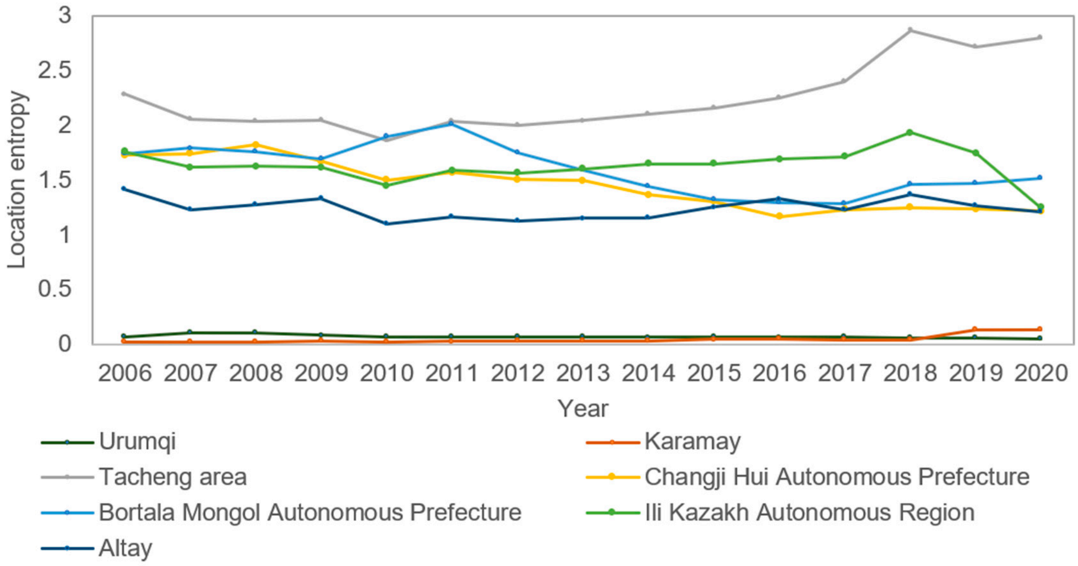

Figure 2. Level of primary industry clustering in various regions and cities in northern Xinjiang.

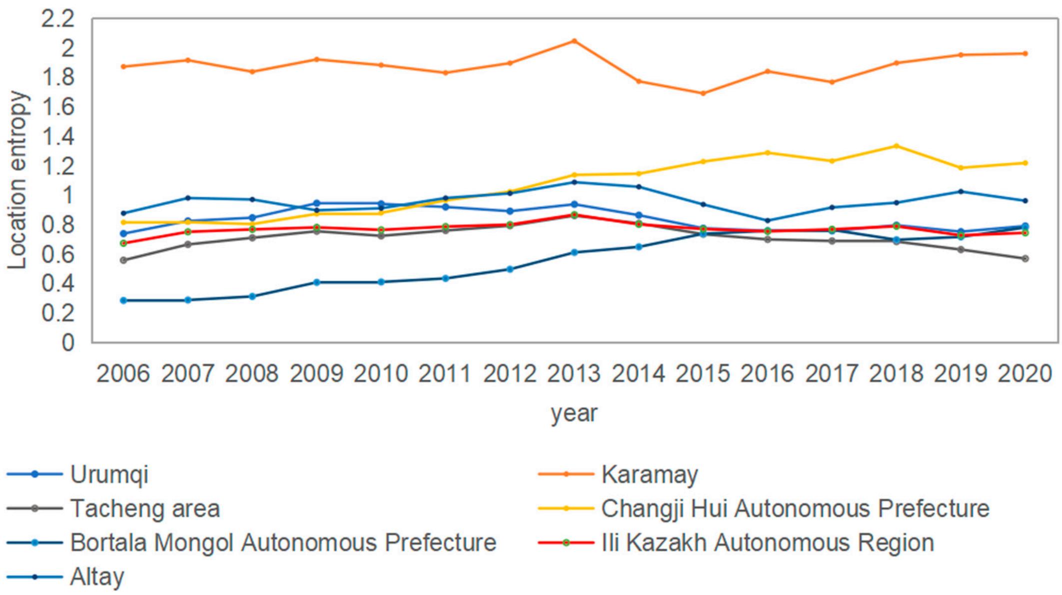

Figure 3. Level of secondary industry clustering in various regions and cities in northern Xinjiang.

Combined with the primary industry cluster in Figure 2, it can be seen that there are few primary industry clusters in Urumqi and Karamay; these two regions have mainly developed the secondary industry, and the secondary sector is huge. Secondary industry clustering in Urumqi has been hovering around 0.8, which does not exceed the average of the whole territory, but in Urumqi, as the capital city of the province, the tertiary industry based on the support of the secondary industry is well developed and the GDP is the highest, so there is still a lot of room for secondary industry clustering. The degree of primary industry clustering in the remaining regions and cities in Northern Xinjiang is significantly higher than the average in Xinjiang as a whole, and the clustering effect is obvious; however, the degree of primary industry clustering in the remaining regions and cities, except for Tacheng, shows an overall decreasing trend, and secondary industry clustering as a whole fluctuates between 0.7 and 1. Among them, the secondary industry gradually showed a relatively obvious degree of clustering in Changji Prefecture and gradually rose from low clustering in Bortala Mongol Autonomous Prefecture.

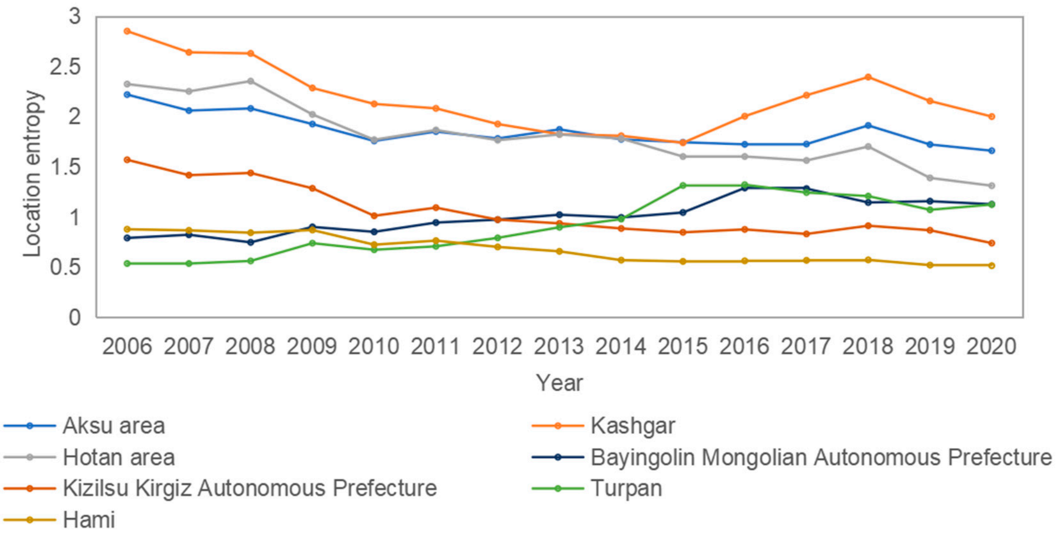

Figure 4. Level of primary industry clustering in various regions and cities in southern and eastern Xinjiang.

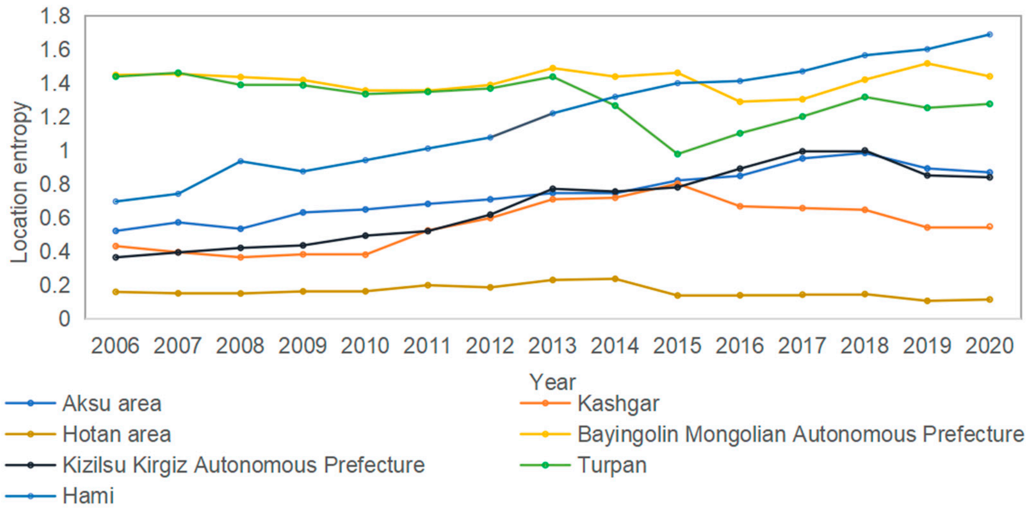

Figure 5. Level of secondary industry clustering in various regions and cities in southern and eastern Xinjiang.

Spatial diseconomies due to multiple ethnicities and geography create a gap between northern and southern Xinjiang. Most of the areas in southern Xinjiang are dominated by primary industries such as cotton. The level of primary industry clustering in Aksu, Kashgar, and Hotan has been greater than 1 for 15 years, but overall, the clustering is decreasing every year. The level of primary industry concentration has been decreasing from greater than 1 to less than 1 year by year in Kizilsu and gradually changing from less than 1 to greater than 1 in Bayingolin Mongolian Autonomous Prefecture. The level of primary industry clustering in Turpan in eastern Xinjiang has increased from significantly lower than the average in Xinjiang to a relatively obvious level, while the level in Hami has not increased. The level of primary industry clustering in Turpan at the eastern border has been increasing, from significantly lower than the average of the whole border to relatively obvious clustering. The level of primary industry clustering in Hami has been insignificant and shows a decreasing trend on the whole.

As shown in Figure 5, among the five regions and cities in southern Xinjiang, the level of secondary industry clustering in Bayingolin Mongolian Autonomous Prefecture is always greater than 1, which is higher than the average in Xinjiang as a whole, and the clustering effect is obvious. During 2006 to 2020, the level of secondary industry clustering in Aksu, Kashgar, and Kizilsu was less than 1, but on the whole, they all show an upward trend, and the level increased. The level of secondary industry clustering in the Hotan region obviously lagged behind that of other regions and cities. In eastern Xinjiang, the level of secondary industry clustering in Turpan has always been greater than 1, with an obvious clustering effect, while the level in Hami shows an upward trend, with the level of secondary industry clustering exceeding 1 in 2011, and since then it has been on an upward trend.

Generally speaking, both southern and northern Xinjiang, as a whole, have seen increasing levels of secondary industry clustering; at the same time, for the primary industry, the significant degree of clustering in prefectures and cities was adjusted to be reduced based on the guarantee of significance. However, Bayingolin Mongolian Autonomous Prefecture and eastern Xinjiang have different trends for primary and secondary industrial clustering than the other regions and cities. Specifically, this prefecture mainly includes petrochemical, agricultural, and sideline product processing; textile and garment industries; and petrochemical and other secondary industries, and these industries, as the mainstay of the region, have always had a high degree of clustering. In addition, during the 12th and 13th Five-Year Plan periods, the region's strong development in establishing an agricultural supply chain based on the advantages of local resources led to an increased concentration of primary industries. Turpan and Hami are both prominent in the petrochemical industry due to the existence of the Tuha oil field, new energy enterprises are growing at a fast pace, and the clustering effect of industrial parks is obvious. On the whole, the development of Turpan's secondary industry clustering is faster, while Hami is also making rapid progress. In order to achieve agricultural quality and efficiency for Turpan's wine and other primary industries in the 13th Five-Year Plan period, a grape industry supply chain was formed, and the local government is planning to vigorously develop eco-agriculture and constantly improve the related industrial cluster. However, the primary industry clustering effect has not been obvious in Hami.

Usually, almost all cities are developed through the secondary industry. The primary industry cannot have good results without the modern transformation of industrialization in the secondary industry. At the same time, the development of the secondary industry attracts a lot of foreigners, increasing the demand for services and other aspects of the tertiary industry to promote the development of the tertiary industry.

4.2. Analysis of Coupled Coordination Results

The analysis of coupled coordination included 15 years of data on industrial cluster location entropy, carbon emissions, and economic growth in 14 regions and cities in Xinjiang from 2006 to 2020, and the results are shown in Tables 2 and 3.

From the perspective of Xinjiang, the overall coupling coordination degree showed a steady increase from 2006 to 2013. The overall fluctuation declined from 2013 to 2019, but the average value of coupling coordination was maintained above 0.5, which is at or above the barely coordinated level, and the value began to rise after 2019. From the perspective of regional coordination, in 2013 and before, in northern, southern, and eastern Xinjiang, the coupling coordination degree showed an upward trend, reaching intermediate coordination status in 2013. The average coupling coordination degree of the three regions during 2013–2019 showed a fluctuating downward trend, and mostly, they were at the level of barely coordinated. The average value for eastern Xinjiang is significantly higher compared to the other regions, and the overall value for southern Xinjiang is the lowest; after 2019, the mean values for northern and eastern Xinjiang increased and returned to the previous coordination level. Overall, the state of change of the mean value of coupling coordination degree is better in northern and eastern Xinjiang than in southern Xinjiang. Most of the regions and cities in Xinjiang are at the level of barely dysfunctional and primary coordination, which needs to be further developed.

Table 2. Results of coupling coordination from 2006 to 2013.

Area	Year	2006	2007	2008	2009	2010	2011	2012	2013
Northern	Urumqi	0.273	0.618	0.691	0.717	0.710	0.741	0.696	0.717
	Karamay	0.290	0.470	0.516	0.450	0.491	0.572	0.611	0.668
	Tacheng	0.284	0.511	0.584	0.615	0.435	0.662	0.669	0.707
	Changji	0.357	0.406	0.415	0.585	0.597	0.700	0.725	0.776
	Bortala	0.298	0.390	0.417	0.500	0.385	0.443	0.746	0.775
	Ili	0.304	0.581	0.653	0.679	0.646	0.740	0.755	0.817
	Altay	0.458	0.605	0.665	0.620	0.485	0.627	0.601	0.679
	$\overline{X}$	0.323	0.512	0.563	0.595	0.536	0.641	0.686	0.734
Southern	Aksu	0.315	0.494	0.462	0.581	0.548	0.640	0.637	0.708
	Kashgar	0.446	0.456	0.386	0.466	0.393	0.607	0.613	0.596
	Hotan	0.500	0.558	0.606	0.628	0.615	0.720	0.702	0.763
	Bayingol	0.396	0.555	0.440	0.624	0.582	0.679	0.740	0.836
	Kizilsu	0.315	0.446	0.512	0.532	0.531	0.595	0.627	0.664
	$\overline{X}$	0.394	0.502	0.481	0.566	0.534	0.648	0.664	0.713
Eastern	Turpan	0.314	0.424	0.543	0.539	0.601	0.671	0.728	0.789
	Hami	0.315	0.455	0.608	0.581	0.599	0.682	0.687	0.713
	$\overline{X}$	0.315	0.440	0.576	0.560	0.600	0.677	0.708	0.751
Total	$\overline{X}$	0.348	0.498	0.536	0.580	0.544	0.649	0.681	0.729

Table 3. Coupling coordination results from 2014 to 2020.

Area	Year	2014	2015	2016	2017	2018	2019	2020
Northern	Urumqi	0.639	0.579	0.511	0.528	0.506	0.307	0.428
	Karamay	0.569	0.346	0.541	0.495	0.536	0.539	0.715
	Tacheng	0.646	0.635	0.587	0.431	0.512	0.547	0.617
	Changji	0.752	0.749	0.581	0.404	0.550	0.523	0.533
	Bortala	0.738	0.648	0.578	0.516	0.758	0.743	0.729
	Ili	0.798	0.772	0.550	0.654	0.610	0.680	0.720
	Altay	0.677	0.680	0.643	0.639	0.705	0.669	0.703
	Mean	0.688	0.630	0.570	0.524	0.597	0.573	0.635
Southern	Aksu	0.660	0.652	0.571	0.632	0.550	0.531	0.742
	Kashi	0.566	0.498	0.643	0.693	0.531	0.625	0.725
	Hotan	0.762	0.552	0.546	0.560	0.567	0.329	0.227
	Bayingol	0.785	0.805	0.461	0.497	0.405	0.514	0.506
	Kizilsu	0.629	0.559	0.407	0.472	0.617	0.557	0.360
	$\overline{X}$	0.680	0.613	0.526	0.571	0.523	0.511	0.512
Eastern	Turpan	0.764	0.457	0.704	0.788	0.757	0.558	0.666
	Hami	0.664	0.659	0.650	0.646	0.638	0.522	0.557
	$\overline{X}$	0.714	0.558	0.677	0.717	0.698	0.540	0.612
Total	$\overline{X}$	0.689	0.614	0.570	0.568	0.585	0.546	0.588

Analyzing the coupling coordination degree of the 14 regions and cities, we find that the best state in these areas is basically medium coordination, and overall, the state of coupling coordination is average. We also find that there is a large interaction between industrial clustering, economic growth, and carbon emissions. Specifically, during the first stage, from 2006 to 2013, the coupling and coordination degree of industrial clustering, carbon emissions, and economic growth in all cities and towns in Xinjiang basically showed an upward trend. Between 2014 and 2019, Xinjiang vigorously supported the development of the secondary industry, which inevitably caused a large amount of carbon emissions and relaxed the clustering of advantageous industries to a certain extent, and the coupling and coordination of industrial clustering, economic growth, and carbon emissions began to decline significantly. After 2019, Xinjiang began to develop in many ways and paid more attention to the clustering of various advantageous industries while reducing pollution and carbon emissions. As a result, the coupling coordination degree of all three factors started to pick up in the main production areas of the dominant industries throughout most of Xinjiang.

4.3. Analysis of SBM Efficiency Measurement Results

In this paper, primary and secondary industry cluster location entropies are used as input variables, and the input and output indicators of the 14 regions and cities in Xinjiang are solved by the SE-SBM model to obtain the low-carbon economic efficiency under the influence of industrial clustering from 2006 to 2020. The results are shown in Tables 4 and 5.

Table 4. SBM calculation results (northern Xinjiang).

Year	Urumqi	Karamay	Tacheng	Changji	Bortala	Ili	Altay
2006	1.000	0.501	0.393	0.415	0.895	0.737	1.000
2007	0.692	0.507	0.389	0.430	0.643	0.767	1.000
2008	0.699	0.528	0.444	0.472	0.237	0.781	0.863
2009	0.737	0.684	0.419	0.472	0.213	0.775	0.686
2010	0.789	0.597	0.492	0.556	0.220	0.907	0.936
2011	0.919	0.703	0.506	0.588	0.234	1.032	0.833
2012	0.793	0.764	0.536	0.608	0.545	0.915	1.000
2013	0.766	0.794	0.511	0.611	0.592	1.017	0.785
2014	0.750	0.792	0.490	0.701	0.623	0.981	0.769
2015	0.901	0.840	0.518	0.754	0.624	1.012	0.729
2016	0.986	0.825	0.488	0.637	0.591	0.679	0.707
2017	0.971	0.860	0.477	0.620	0.571	0.739	0.736
2018	0.891	0.903	0.469	0.659	0.563	0.725	0.716
2019	1.036	1.000	0.496	0.683	0.500	1.136	0.767
2020	1.080	1.109	0.494	0.703	0.475	1.000	0.771

Table 5. SBM calculation results (southern and eastern Xinjiang).

Year	Aksu	Kashi	Hotan	Bayingol	Kizilsu	Turpan	Hami
2006	0.444	0.403	0.620	0.654	1.000	1.000	0.496
2007	0.505	0.419	0.510	0.638	1.000	0.688	0.471
2008	0.523	0.459	0.800	0.696	0.716	0.698	0.376
2009	0.529	0.451	0.617	0.570	0.956	0.471	0.356
2010	0.557	0.480	0.606	0.675	1.000	0.534	0.526
2011	0.588	0.435	1.000	0.707	0.924	0.543	0.563
2012	0.640	0.547	0.772	0.689	1.000	0.528	0.621
2013	0.636	0.493	0.638	0.649	0.483	0.494	0.641
2014	0.658	0.486	0.660	0.654	0.615	0.497	0.718
2015	0.671	0.467	0.655	0.615	0.692	0.369	0.700
2016	0.484	0.475	0.624	0.512	0.347	0.377	0.634
2017	0.521	0.471	0.694	0.536	0.379	0.422	0.630
2018	0.504	0.469	0.675	0.537	0.465	0.363	0.594
2019	0.569	0.580	0.710	0.512	0.615	0.435	0.586
2020	0.598	0.614	0.820	0.502	0.876	0.419	0.529

As can be seen from Tables 4 and 5, some of the regions and cities in Xinjiang achieved a better state of efficiency over the past 15 years, but this state is unstable, which may be related to the local geographic environment and government policies, and more efforts are needed to maintain and improve the efficiency. Sorting the mean values of low-carbon economic efficiency of the 14 regions and cities (see Figure 6), we find that during the study period, there were obvious differences in low-carbon economic efficiency. According to the mean values, the 14 regions and cities are roughly divided into three categories: The first category is inefficient regions and cities. As can be seen in the figure, of the six regions and cities with an average low-carbon economic efficiency of 0.4–0.6 during 2006–2020, only Tacheng and Bortala Mongol Autonomous Prefecture are located in northern Xinjiang. Combined with Table 4, we find that the low-carbon economic efficiency of these regions and cities did not reach 1 in the 15-year period, and their carbon emission problems were relatively serious. The second category is regions and cities with medium low-carbon economic efficiency, with average values ranging from 0.6 to 0.8, including Bayingolin Mongolian Autonomous Prefecture, Changji, Karamay, Kizilsu, and Hotan, of which Changji and Karamay are located in northern Xinjiang. Combined with Table 5, we find that the low-carbon economic efficiency of Hotan and Kizilsu sometimes exceeded 1 over the 15 years, with large fluctuations. In general, these four regions and cities are bottlenecks for carbon emission reduction and economic development in Xinjiang. The third category is regions and cities with medium-high efficiency, with a mean value greater than 0.8, including Altay, Urumqi, and Ili. These are all located in northern Xinjiang, and all of them had years with efficiency greater than 1, which means they have great potential for carbon emission reduction, and it will be easy to achieve results.

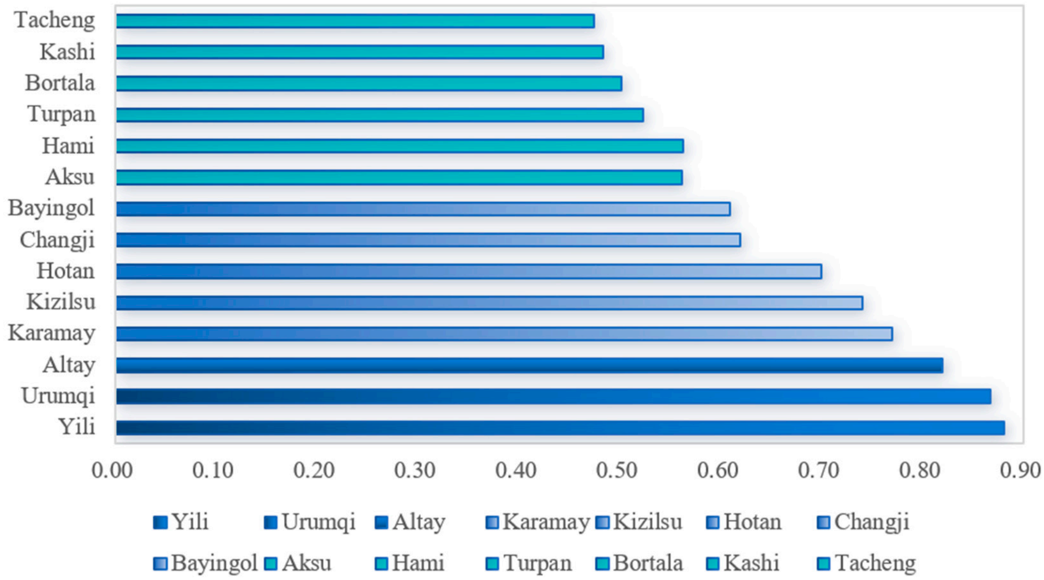

Figure 6. Average efficiency of regions and cities from 2006 to 2020.

Overall, the efficiency status of the 14 regions and cities and towns shows significant regional differences. Most of the cities and regions in northern Xinjiang were leaders in efficiency, which is closely related to the development of the region. Combined with the results of Section 4.1, it is found that a higher level of industrial clustering and a better economic base can better support carbon emission reduction. The analysis shows the measured low-carbon economy efficiency under the influence of industrial clustering in Xinjiang, although none of them are too optimistic. However, there is a certain positive relationship between efficiency and the degree of industrial clustering. The development of a low-carbon economy in Xinjiang is still at the preliminary stage, with the use of a relatively rough method and low resource utilization, and attention should be paid to grasping the effects of industrial clustering on carbon emissions and the economy.

4.4. Analysis of Regional Differences in Low-Carbon Economic Efficiency in Xinjiang

In order to further measure regional differences in the efficiency of a low-carbon economy under the influence of industrial clustering in Xinjiang and its law, the Dagum's Gini coefficient is used to decompose the efficiency of SE-SBM, and the results of the measurements are visualized in Figure 7.

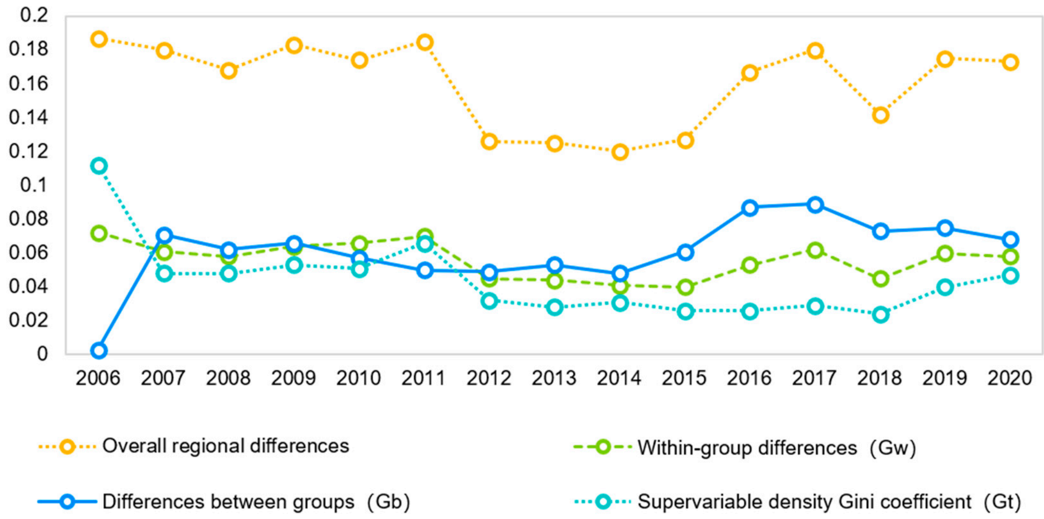

Figure 7. Change trend of overall regional differences and differences between parts.

It can be seen that the overall regional differences in the efficiency of Xinjiang's low-carbon economy range from 0.12 to 0.19. From the time dimension, the cut-off points for overall regional differences in low-carbon economy efficiency are 2011 and 2016, and these differences in 2006–2011 and 2016–2020 fluctuate slightly above and below 0.18 and basically fluctuate around 0.12 in 2012–2015. Taken together, the overall regional differences in low-carbon economic efficiency in Xinjiang are at a relatively stable level, and since the decline in 2012, during the 12th Five-Year Plan period, they have remained at a lower level. The evolution of overall regional differences in the three periods is relatively flat, but the non-homogeneity of low-carbon economic efficiency generally improved. From Figure 7, it can be seen that intra-regional difference Gw and inter-regional difference Gb are the main reasons for the overall regional differences. Gw is more stable, and Gb shows significant fluctuations and increased during the sample period; Gt is the lowest, which indicates that the low-carbon economic efficiency in eastern, southern, and northern Xinjiang is less affected by the crossover.

The following can be seen in Figure 8: (1) Overall, although the intra-regional differences fluctuate considerably, the intra-regional differences show a decreasing trend compared to the previous years, with the largest intra-regional differences in northern Xinjiang and the smallest in eastern Xinjiang, and the decreasing trend is more obvious. (2) The intra-regional differences in Xinjiang's low-carbon economic efficiency show that it is higher in northern Xinjiang than southern Xinjiang and higher in southern Xinjiang than eastern Xinjiang. The climate conditions and industries in eastern Xinjiang have great commonality and correlation, and, to a large extent, clustering of industries such as wind energy and agriculture has been achieved, but the primary industry clustering of the two regions is average. Northern Xinjiang is dominated by the primary and secondary industries, and although the overall development is better than that of southern Xinjiang, the development of the region is mainly based on the core of Urumqi and radiates to the surrounding areas. Technology, location, and other factors have a great impact on industrial clustering and local development, with obvious differences between regions. Southern Xinjiang is vast and sparsely populated, the links between regions are not strong, and due to the location, technology and other aspects are impacted by the large differences, so although the primary industry is the main industry, the differences between regions are also large. Combined with the relevant policies, it can be seen that Xinjiang has been optimizing and reasonably clustering industries in recent years under the support of policies, and the local government has paid more attention to the coordinated and synchronous development of a low-carbon economy in each region.

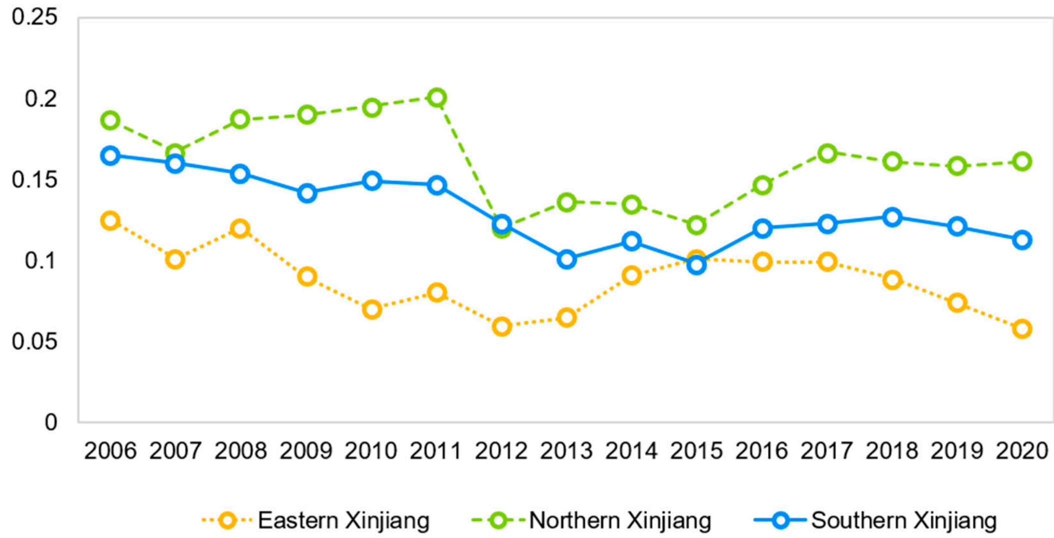

Figure 8. Variation trend of within-group differences (Gw).

As can be seen from Figure 9, the inter-regional differences in low-carbon economic efficiency under the influence of industrial clustering in Xinjiang during the sample period show a fluctuating upward trend, in which the inter-regional differences between eastern and southern Xinjiang have basically been at the lowest level, indicating that the gap between these two areas is the smallest and that overall, the inter-regional differences between eastern and northern Xinjiang and between northern and southern Xinjiang are larger. It is possible that development in terms of infrastructure, technology, etc., is better in northern Xinjiang than in southern and eastern Xinjiang, and the radiation effect of the provincial capital of Urumqi is obvious, which prompts the neighboring cities to respond and implement the relevant policies issued by the government in a timely and rapid manner, and there is a good foundation for industrial clustering. In addition, the high-tech industry in northern Xinjiang has formed a certain scale of clustering and has certain geographical advantages. Eastern Xinjiang is greatly affected by the environmental factors of its location, and the efficiency of resource utilization is not as good as that in northern Xinjiang.

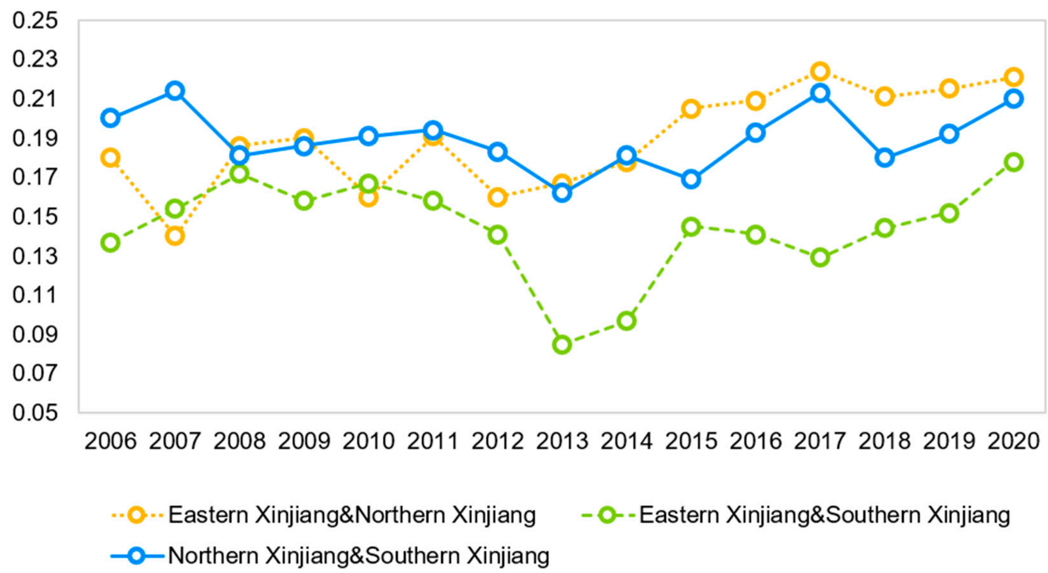

Figure 9. Variation trend of differences between groups (Gb).

5. Discussion and Conclusions

Currently, studies on industrial clustering, carbon emissions, and economic growth are mainly two or two-oriented, and there are fewer studies on the relationship between the three. Xinjiang, as the core area of the Silk Road Economic Belt, is very important for the development of China as well as Central Asia. As a city developing due to high energy consumption in China, a green and low-carbon economy is extremely important in Xinjiang. This paper integrates the concept of sustainable development and investigates the relationship between industrial agglomeration, carbon emissions, and economic growth in Xinjiang. The results of the study are mainly as follows.

First of all, the government work report of Xinjiang Uygur Autonomous Region in 2023 proposes to build “eight industrial clusters”. These industries basically represent the primary and secondary industries in Xinjiang. Combined with the empirical results, it can be found that in southern and northern Xinjiang, almost all of the primary industries in the regions and cities are highly clustered; at the same time, on the whole, the level of secondary industry clustering is constantly increasing, and for the regions and cities where there is a significant degree of primary industry clustering, they are all adjusted to reduce it based on the guarantee of a significant degree of clustering.

Secondly, Deleeuw et al. argue that industrial clusters are accompanied by significant economic activity, a situation that is not conducive to environmental quality [35]. Li et al. show that industrial agglomeration promotes economic growth but leads to greater pressure to reduce carbon emissions [36]. We find that the best level of coupling coordination is basically medium coordination, and overall, the level is general. This corroborates, to a certain extent, the existing studies, but we found the interaction between industrial clustering, economic growth, and carbon emissions is large. This supports the current findings to some extent. According to Shi et al., there is some evidence linking industrial clusters to economic growth [37], and the majority of studies examining the relationship between industrial clusters and economic growth and carbon emissions from the perspective of each industry found some correlation [38,39].This paper has a small sample size due to the fact that it is only based on Xinjiang, which makes it insufficiently applicable to developed regions. However, for cities with similar development situations, the research results have some applicability.

Third, in the study by Sun et al., it was found that the level of low-carbon economic development in Xinjiang is backward and regionally uneven, which coincides with the findings of this paper [40]. Our research shows that the regional non-equilibrium of low-carbon economic efficiency in Xinjiang regions and cities is obvious, and northern Xinjiang is significantly better than southern and eastern Xinjiang. And the overall regional differences in low-carbon economic efficiency under industrial clustering in Xinjiang during the study period were reduced, but the spatial non-equilibrium was still large, and the development was unbalanced.

Yuan et al. found, through empirical research, that China is still in the stage of increasing carbon emissions and the economy simultaneously [41]. A low-carbon economy has become a guiding concept that must be followed in the process of sustainable development, so the research in this paper fully integrated the key points of the concept of low-carbon sustainable development—economic growth, carbon emissions, and industrial clustering. Research shows that the low-carbon economy under industrial clustering in Xinjiang is less efficient, proving that Xinjiang is lagging behind in the development of a low-carbon economy. Thus, the choice of emission reduction methods should be made very carefully so that it can effectively promote the low-carbon sustainable development of Xinjiang regions.

6. Suggestion

As the core area of the Silk Road Economic Belt, Xinjiang plays an important role in opening up to the outside world and promoting the development of the western part of the country, so the following suggestions are made based on the above Discussion and Conclusions:

First, accelerate the building of a modern industrial system with eight industries clustered together with high-tech and new technologies. The primary industry in Xinjiang, as a whole, is at a high level of clustering, but industrial manufacturing in the secondary industry has developed substantially and is scattered, resulting in a lot of carbon emission pollution that could have been avoided. Thus, it is important to speed up the process of promoting the creation of secondary industry clusters while actively encouraging the combination of industrial clustering with low-carbon technological innovation and linkage, thereby enhancing low-carbon sustainable development in Xinjiang.

Second, the government should actively introduce relevant guiding policies to promote a complete system of low-carbon economic parks [42]. Xinjiang is a vast area and has a good advantage in terms of land area for the clustering of various upstream and downstream industries. The autonomous regional government should actively strengthen the relevant policy guidance and coordinate multiple departments to increase the conversion rate of industrial clustering, improve the service system, innovate the institutional system, and build competitive low-carbon industrial parks.

Third, construct a mechanism for coordinated regional development within Xinjiang. The low-carbon economic efficiency of regions and cities in Xinjiang shows a general upward trend, but there is an obvious problem of uncoordinated regional development. On the whole, the low-carbon economic efficiency in southern Xinjiang is relatively lagging behind, and the overall situation in northern Xinjiang is better. Therefore, the implementation of emission reduction measures and the stabilization of growth in different regions should take full account of regional differences and be adapted to local conditions, and appropriate and sufficient policy guidance should be formulated and financial support provided. The construction of cross-regional cooperation platforms through the government should be encouraged with democratic cooperation methods constituting regional coordination mechanisms according to the actual situation to carry out talent projects and optimize resources for multi-level cooperation and exchange, thereby enhancing its positive effect on low-carbon sustainable development.

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