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Analysis of the Synergistic Effect of Carbon Emission Intensity and High-Quality Economic Development: A Case Study of Central Plains Region

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Abstract: Due to the intensification of global climate change, the issue of carbon dioxide emissions has attracted widespread attention. Against this background, the Chinese government has responded positively to the challenge of climate change by proposing the environmental goal of "achieving carbon peaking by 2030 and carbon neutrality by 2060". The Central Plains region occupies a central position in China's economic map, and at the same time, as an important energy strategy implementation base of the country, it is of great significance for China's sound economic development and CO_2 emission control. This study evaluates the impacts of different factors on CO2 emission intensity and puts forward targeted recommendations based on the economic development perspective.

1. Introduction

1.1 Background and significance of the study

1.1.1 Background of the study

With the rapid development of the global economy, the issue of carbon emissions has gradually become the focus of attention of the international community, and in this era of the community of human destiny, the building of a community of human destiny has expanded from a Chinese initiative to an international consensus. As early as June 2013, the then Vice Premier Ma Kai attended the national energy conservation and emission reduction TV and telephone conference and pointed out that we should fully recognize the extreme importance and urgency of energy conservation and emission reduction, make greater determination, use more energy, take more powerful policies and measures, and fight the battle of energy conservation and emission reduction and the protracted war. Therefore facing the problem of carbon emissions means that we need to change the mode of economic development and jointly tackle this global challenge. In the face of these serious challenges, the international community has begun to actively explore ways to solve them, with a view to effectively controlling carbon emissions and realizing sustainable environmental protection while promoting economic development. In this context, the Central Plains region of China, as an important economic, agricultural and cultural center of the country, has assumed the important mission of promoting the high-quality development of the national economy.

1.1.2 Purpose of the study

As global climate change poses an increasingly serious challenge to socio-economic development, the realization of high-quality economic development and the reduction of carbon emissions have become mutually reinforcing twin goals. Especially in China, this goal not only reflects a response to domestic and international environmental pressures, but is also an inevitable choice for transformation and upgrading, and promoting sustainable development strategies. Although the relationship between high-quality urban economic development and carbon emission reduction has received increasing attention, existing research is still limited in revealing the specific mechanisms of action and spatial effects between the two. In view of this, this paper aims to explore the dynamic relationship between high-quality urban economic development and carbon emission intensity, and through the comprehensive use of spatial data analysis methods, it aims to reveal the spatial heterogeneity of the interaction between the two, and to provide a scientific basis for the formulation of regionally differentiated green development strategies.

2. Literature review, impact mechanisms and research innovations

2.1 Domestic and international research status

2.1.1 Status of domestic research

In China's academic research on the relationship between carbon emissions and high-quality economic development, a series of in-depth analyses and empirical tests have revealed the impacts of various aspects of energy consumption patterns, renewable energy applications, and carbon emissions trading mechanisms on economic development.

In his study, Yao Jun (2022) points out that there is a long-term equilibrium relationship between energy consumption, carbon emissions and economic growth, and that energy consumption has a significant impact on national economic development. This finding highlights the importance of energy consumption pattern change [1]. Following this, the study of Qi Shaozhou and Li Yang (2021), by analyzing the data of EU member states, found that in countries with a higher level of economic development, the growth of renewable energy consumption has a positive contributing effect on the high rate of national economic development [2]. On the contrary, in countries with a lower level of economic development, the consumption behavior of renewable energy may hinder the development of the national economy to a certain extent.

In the field of carbon emissions trading, Tang Yuejun and Lai Defu (2021) argued that the carbon emissions trading mechanism can internalize environmental costs and promote regional economic growth [3]. Gao Fengping's (2022) study shows that carbon trading can significantly improve the green total factor energy efficiency, especially in economically developed regions the effect is more significant [4].

In terms of the evaluation of high-quality economic development, studies by scholars such as Fan Qingquan (2020) and Shangguan Xuming (2020) emphasized the importance of green total factor productivity in measuring the level of high-quality economic development [5][6]. For his part, Shi Dai-min (2022) used the SBM method to measure production efficiency based on resource and environmental constraints, which provided a new perspective on the measurement of green total factor productivity (GTFP) [7].

These research results provide an important theoretical basis for understanding the relationship between carbon emission control, energy transition, and high-quality economic development, and are of great significance in guiding the formulation of effective environmental policies and promoting sustainable economic development.

2.1.2 Current status of foreign research

Within the international academic field, research on the relationship between carbon emissions and high-quality economic development has made significant theoretical and empirical progress. In terms of carbon market research, Bergh and Savin (2021) and Yan et al. (2020) point out that a carbon emissions trading system as a property rights system can promote overall socio-economic development by incentivizing technological innovation in enterprises [8].Hu et al. (2020) and Zhang et al. (2020) use a synthetic control method to analyze the carbon trading policy emission reduction effects and found that carbon trading significantly suppressed regional carbon emissions [9][10].

An empirical analysis by Bai et al. (2023) showed that carbon emissions trading can positively affect carbon emission reduction efficiency through technological innovation and industrial restructuring [11]. This study highlights the important role of carbon market in environmental protection and economic development. In terms of evaluating the quality of economic growth, Jahanger (2020) argued that total factor productivity is an important driver of economic growth and can be used as an indicator of the quality of economic development [12]. At the same time, they also pointed out that total factor productivity fails to adequately take into account environmental factors, and therefore advocated the use of green total factor productivity to more accurately reflect the level of high-quality development of the economy.

Mlachila et al. (2023) constructed a high-quality composite development index from the growth base and social dimensions. Their study showed that high growth rates and socially friendly growth can reflect high-quality economic growth [13]. Together, these research results construct a diversified theoretical framework on the complex relationship between carbon emissions, environmental policies and economic development, which provides valuable theoretical support and practical experience for realizing the balance between economic growth and environmental sustainability on a global scale.

2.2 Definition of relevant concepts

2.2.1 Carbon intensity

In the current context of social and economic development, industrial production and day-to-day operational activities are generally dependent on the consumption of fossil fuels such as coal, oil and natural gas. This extensive use of fossil fuels not only drives economic growth, but also leads to a significant increase in energy consumption and emissions.

Against this background, carbon emission intensity has become an important indicator for measuring and assessing the impact of the greenhouse effect. Carbon emission intensity is usually defined as the amount of carbon dioxide emissions produced per unit of economic output or per capita within a specific time and space horizon. This indicator can effectively reflect the environmental impact caused by a region or country in the pursuit of economic growth, and is a key parameter for evaluating its environmental performance and sustainable development level.The measurement of carbon intensity is usually based on the statistics of the total CO2 emissions of a particular region or country, which need to be estimated from the energy consumption and its corresponding carbon emission factor. Subsequently, this total is compared to economic output (e.g. gross domestic product GDP) or the total population to derive the carbon dioxide emissions per unit of output or per capita, which is known as the carbon intensity.

2.2.2 High-quality economic development

Against the backdrop of the great economic structural changes in contemporary China, the concept of "high-quality economic development" has become a hot topic for research and practice. The core of high-quality economic development lies in the pursuit of a fundamental shift in the mode of economic growth, that is, a shift from an overreliance on quantitative expansion to a greater emphasis on improving quality and efficiency. This shift is reflected in a number of ways: first, the optimization and upgrading of the economic structure, second, the innovation-driven development model, third, the sustainability of the ecological environment, fourth, the general improvement of social well-being, and fifth, the deepening of openness to the outside world.

In order to realize high-quality economic development, it is necessary to adhere to the five development concepts: innovation, coordination, green, openness and sharing. Innovation is the first driving force to lead development, while coordination is an intrinsic requirement to maintain a balanced and comprehensive economic and social development. Green development emphasizes ecological environmental protection and the sustainable use of natural resources, while openness is the driving force behind the formation of a domestic and international double cycle. Shared development ultimately realizes a fair distribution of social wealth and a general improvement in people's living standards. Only by fully implementing these five development concepts can China's economy be pushed to realize a qualitative leap and comprehensive development.

2.3 Research Innovations

(1)Innovations in indicator empowerment

The relevant literature collected so far is insufficient in building a framework of evaluation criteria for measuring high-quality economic growth, the completeness of evaluation factors needs to be improved, and a large number of researchers still rely mainly on a single allocation tool in the process of weight allocation. This requires that evaluators have a deep understanding of the evaluation system and its inherent meaning in order to implement scientific and appropriate scoring and weighting. If not, the reliance on individual subjective weighting techniques may lead to significant bias in the results. In order to solve this problem, this paper assigns weights from the perspective of the five major development perspectives, and adopts entropy value method and other assigning methods when constructing the indicator system to comprehensively assign weights to the indicators, so as to eliminate the bias of assigning weights.

(2)Mechanisms to study innovation

This paper analyzes the relationship between carbon emission intensity and high-quality economic development from three different mechanisms. In the direct mechanism, it analyzes how high-quality economic development directly affects carbon emission intensity through "reducing increment" and "suppressing stock", and discusses specific technological paths and efficiency enhancement methods, such as information technology transformation and intelligent production. In the indirect mechanism, it explores how changes in industrial structure and ecological environment indirectly affect carbon emissions, and analyzes the role of scale efficiency and technological effects as well as industrial restructuring. The spatial mechanism of action, on the other hand, uses geographically weighted regression models to consider spatial differences between regions, providing a theoretical basis for regionally differentiated emission reduction strategies.

3. Data and scenarios

3.1 Data collection and pre-processing

The data involved in this paper are mainly from the China Statistical Yearbook 2009-2022, some of which are from the EPS data platform. Due to other reasons such as historical legacy and delayed data updating, some of the yearly indicators lack corresponding data, and this paper uses the index smoothing method to predict the data for preprocessing, or adopts the average value of the indicators in the two years before and after the indicator for preprocessing.

3.2 Data standardization

Because the original data obtained from the statistical yearbook are different from each other in terms of magnitude and order of magnitude, which may have a certain impact on the evaluation results, in order to eliminate this impact, this paper decides to standardize the data of each indicator by the method of polar deviation first, as follows:

(1)Raw data collation

Let there be a total of i cities (i=1, 2, ..., 8) and j evaluation indicators (j=1, 2, ..., 37), which are collated to form the original data matrix X, as shown in equation (1) below:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1j} \\ x_{21} & x_{22} & \cdots & x_{2j} \\ \vdots & \vdots & \ddots & \vdots \\ x_{i1} & x_{i2} & \cdots & x_{ij} \end{bmatrix} = [x_1, x_2, \dots, x_j] \quad (1)$$

Where x_j is the column vector data for all provinces under each year for the jth evaluation indicator.

(2)Data standardization based on the efficacy coefficient method

In the efficacy coefficient method, each assessment indicator is assigned a satisfactory value and a contraindicated value (usually representing the highest and lowest acceptable values for that indicator) for a given objective. In the actual process, the normalization method is used to eliminate the scale of the indicators in Table 4:

For positive indicators:

$$X_{ij} = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \times 0.5 + 0.5 \quad (2)$$

For reverse indicators:

$$X_{ij} = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} \times 0.5 + 0.5 \quad (3)$$

Where x_{ij} is the raw data obtained for the indicator, x_{ij} is the data obtained after normalization, city sample ordinal i=1, 2, ..., 8, indicator ordinal j=1, 2, ..., 37.

3.3 Measurement of carbon intensity

In order to deeply analyze the intensity of carbon dioxide emissions and its spatial distribution characteristics in the Central Plains region, the total amount of carbon dioxide emissions in the region should be calculated first. Considering the specific situation of the Central Plains region, this study chooses the carbon emission coefficient method to calculate carbon dioxide emissions.

According to the part on carbon emission intensity measurement in the article on the exploration of high-quality development evaluation index system, the carbon dioxide emission intensity can be calculated by the following formula (4):

$$Q=\sum_{i=1}^{n} E_i \times SC_i \times CF_i \tag{4}$$

Where i is the type of energy, E_i is the energy consumption of the ith energy source, SC_i is the standard coal conversion factor (kgce/kg) of the ith energy source, and CF_i is the carbon emission factor factor (t-C) of the ith energy source.

Given that the time span chosen in this study is from 2009 to 2022, the variation of carbon emission coefficients of each energy source in this period is small, so these coefficients can be approximated as constant values, and the energy consumption coefficients are shown in Table 1. Such an assumption simplifies the calculation process to a certain extent, and also ensures the reliability of the measurement results.

Table 1: Energy consumption coefficients

type of energy	**coals**	**coke**	**crude oil**	**diesel**	**gasoline**	**diesel fuel**	**fuel oil**	**petroleum**
CF_i	0.7143	0.9714	1.4286	1.4714	1.4714	1.4571	1.4286	1.3300
SC_i	1.9003	2.8604	3.0202	2.9251	3.0179	3.0959	3.1705	2.1622

3.4 Measurement of the level of high-quality economic development

3.4.1 Entropy weight method of empowerment

After eliminating the effect of the magnitude of the data set, we use the entropy weight method to objectively assign weights to the indicators. Firstly, the weight of each sample sign value is calculated by the constructed original matrix and establish the weight matrix see Eq:

$$p_{ij}=\frac{x_{ij}}{\sum_i^m x_{ij}} \tag{5}$$

Where x_{ij} is the post-standardized data.

Then the entropy value and information utility value are calculated:

$$e_j=-\frac{1}{\ln m}\sum_i^m p_{ij}\ln p_{ij} \tag{6}$$

Where $\frac{1}{\ln m}$ is a correction operation for the sample size, and the jth city under the ith indicator accounts for the share of that indicator $p_{ij}=\frac{x_{ij}}{\sum_{i=1}^{n} x_{ij}}$.

Finally, the weights are defined:

$$w_j=\frac{d_j}{\sum_{j=1}^{n} d_j} \tag{7}$$

Where the information entropy redundancy is $d_j = 1 - e_j$.

3.4.2 Linear integrated evaluation method

In order to eliminate the impact on the results of this paper due to the excessive weighting of one indicator, a linear comprehensive evaluation method is used to measure the level of high-quality economic development of city clusters in the Central Plains region on the basis of the entropy method of weighting.

Firstly, the development level of the first-level indicators is calculated:

$$y_p = \sum_{j=1}^{k} w_j \cdot x_{ij} \tag{8}$$

Where *wj* is the weight value corresponding to the *j*th secondary indicator and x_{ij} is the *i*th value of the *j*th secondary indicator. The second-level indicators in the same first-level indicators constitute a system, and the development level of the first-level indicators can be calculated from equation (9) after processing the data by the above method, where *p* denotes the indicator ordinal number.

The comprehensive development level of high-quality development is then calculated:

$$y = \sum_{p=1}^{k} w_p \cdot y_p \tag{9}$$

where *y* denotes the comprehensive development level of high-quality development and *wp* denotes the weight of the *p*th level indicator.

4. Model building

4.1 Overview of the study area

Table 2: City boundaries of city clusters in the Central Plains region

area	cities under the jurisdiction of	number of individual
Hebei	Shijiazhuang, Tangshan, Qinhuangdao, Handan, Xingtai, Baoding, Zhangjiakou, Chengde, Cangzhou, Langfang, Hengshui	11
Shanxi	Taiyuan, Datong, Yangquan, Changzhi, Jincheng, Shuozhou, Jinzhong, Yuncheng, Xinzhou, Linfen, Luliang	11
Jiangsu	Nanjing, Wuxi, Changzhou, Suzhou, Nantong, Yancheng, Yangzhou, Zhenjiang, Taizhou, Xuzhou, Lianyungang, Huaian, Suqian	13
Anhui	Hefei, Wuhu, Maanshan, Tongling, Anqing, Chuzhou, Chizhou, Xuancheng, Bengbu, Huainan, Huaibei, Huangshan, Buyang, Suzhou, Lu'an, Bozhou	16
Shandong	Jinan, Qingdao, Zibo, Zaozhuang, Dongying, Yantai, Rizhao, Weihai, Linyi, Dezhou, Liaocheng, Binzhou, Heze, Xuzhou, Weifang, Jining	16
Henan	Zhengzhou, Zhumadian, Sanmenxia, Kaifeng, Luoyang, Pingdingshan, Anyang, Hebi, Xinxiang, Jiaozuo, Puyang, Xuchang, Luohe, Shangqiu, Xinyang, Zhoukou	17
Hubei	Wuhan, Xiaogan, Huangshi, Shiyan, Yichang, Xiangyang, Ezhou, Jingmen, Jingzhou, Huanggang, Xianning, Suizhou,	13
Shaanxi	Xi'an, Xianyang, Baoji, Hanzhong, Weinan, Shangluo, Yan'an, Tongchuan, Yulin, Ankang	10

The eight provinces included in the Central Plains region-Hebei, Shanxi, Jiangsu, Anhui, Shandong, Henan, Hubei, and Shaanxi-are significantly different in terms of natural resources and economic structure, and the city boundaries of the urban agglomerations in the Central Plains region are shown in Table 2.The geographic location, climatic conditions, and Geographical location, climatic conditions, and hydrological characteristics directly or indirectly influence the carbon emission patterns and the choice of paths for high-quality development in the region, which is an important reference for the formulation of relevant policies and measures to promote sustainable development.

4.2 Current status analysis of carbon intensity

4.2.1 General overview of carbon intensity

Against the backdrop of today's rapid economic development, the Central Plains region faces the dual challenges of energy consumption and environmental pollution. Although some progress has been made in recent years in the area of new and clean energy, the region's energy consumption is still largely dependent on coal, owing to the limitations of its resource endowment and the immature level of development of new technologies. This has led to the fact that although the rate of carbon dioxide emissions has slowed down, its total amount still remains high.

As shown in Fig. 1, the carbon emission intensity and annual growth rate of the Central Plains region exhibit a certain degree of volatility. From the figure, it is obvious that in the time series from 2009 to 2022, the carbon emission intensity has experienced a trend of rising, then stabilizing and rising again. Specifically, the carbon emission intensity declines between 2009 and 2011, and then rises gradually until 2014, indicating that carbon dioxide emissions in the Central Plains region continue to grow during this period.After 2014, the growth rate begins to fluctuate and stabilize, which may reflect the effect of the implementation of low-carbon economic policies in the region, the promotion of new energy sources, and the gradual deepening of the sustainable development strategy.

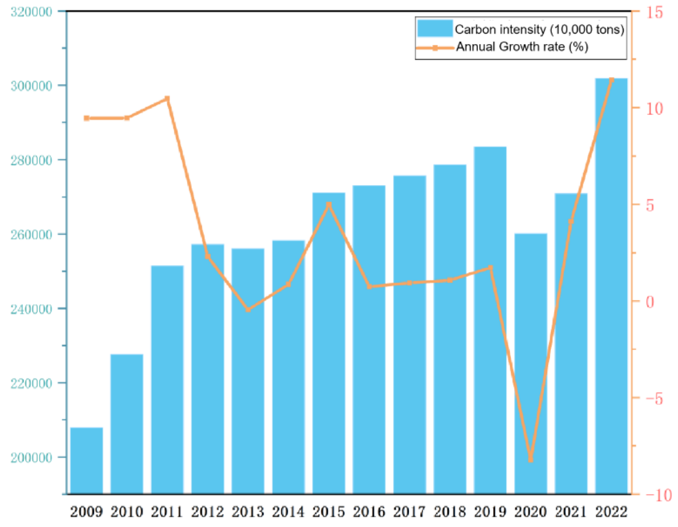

Figure 1: Overall change of carbon emission intensity in the urban agglomeration of the Central Plains region

The Central Plains has achieved some success in promoting a low-carbon economy and sustainable development, but the volatility of carbon emission intensity and the pickup in growth trends in recent years also suggest the need for more determined and sustained efforts to reduce emissions in the future. In particular, in the application of new energy technologies and the optimization of the energy structure, deeper reforms and greater investment are still needed to ensure a sustained decline in carbon emission intensity, so as to achieve synergistic progress in regional economic development and environmental sustainability.

4.2.2 Regional profiles of carbon intensity

Between 2009 and 2022, at the city level (Table 3, some year values are not shown due to space limitation), the provinces in the Central Plains region show different average annual growth rates in carbon emission intensity, revealing the complex relationship between carbon emissions and economic development in the region. From the data, it can be seen that Shanxi and Shaanxi provinces, with annual average growth rates of 16.16% and 15.92%, respectively, are at the top of the growth rate, while Henan Province shows a negative growth rate of -2.42%, which may reflect the effective implementation of emission reduction measures in the province. Meanwhile, Hebei, Jiangsu, Anhui, and Shandong provinces all show positive annual average growth rates, but at different rates, reflecting the balance between economic development and carbon emission control in these provinces.

In the ranking of mean carbon emission intensity, the mean carbon emission intensity of urban agglomerations is shown in Fig. 2, with Shandong province ranking first with 59,362.96, showing its high emission level during this period, while Hubei province has the lowest mean emission value of 16,312.87, which is ranked last. These data may indicate that cities or provinces with higher economic aggregates also have relatively higher carbon emissions, while regions with lower economic aggregates have relatively lower carbon emissions, which is in line with general experience and logical judgment.

Table 3: Measurement of Carbon Emission Intensity in Urban Agglomerations

area	**2010**	**2013**	**2016**	**2019**	**2022**	**average annual growth rate (%)**	**average value**	**league table**
Hebei	37187	42640	42005	41477	43001	4	41262	3
Shanxi	33213	39581	46273	54744	60349	16	46832	2
Jiangsu	30506	36546	38244	36529	40019	7	36369	4
Anhui	15319	18259	18619	19963	20495	8	18531	7
Shandong	49613	52311	62659	64838	67395	8	59363	1
Henan	29583	29333	27521	24266	26487	-2	27438	5
Hubei	16884	16094	14940	16587	17060	1	16313	8
Shaanxi	15329	21281	22854	25043	27021	16	22306	6

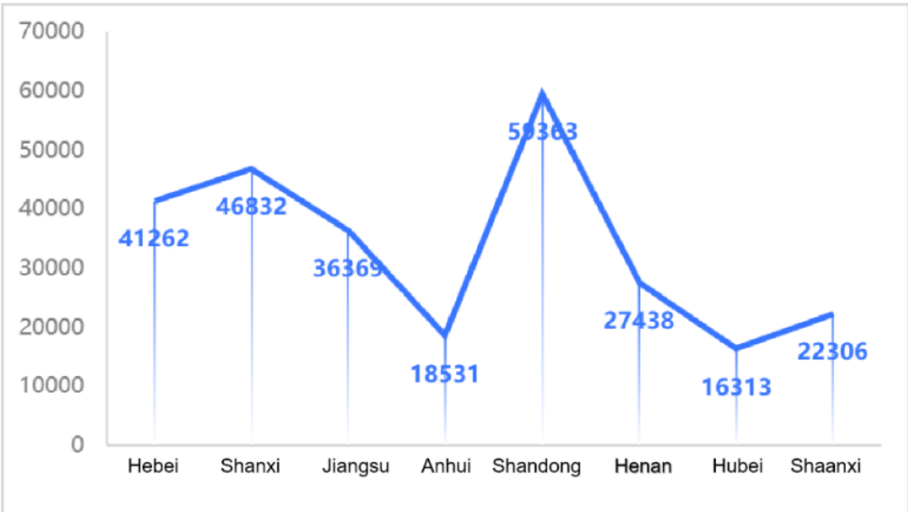

Figure 2: Average carbon emission intensity of urban agglomerations

4.3 Measurement of the level of high-quality economic development

4.3.1 Construction of the indicator system

In the process of constructing the indicator system, this paper, based on the research of scholars Gao Fengping [4] and Shi Daimin [7], constructs the evaluation indicator system for high-quality economic development based on the five development concepts of innovation, coordination, green, openness, and sharing, with the aim of ensuring that the evaluation system can comprehensively reflect the multifaceted requirements and intrinsic qualities of economic development in terms of the comprehensiveness and scientificity of these two dimensions. These five concepts represent the core content of high-quality economic development, covering a wide range of areas from technological innovation to social justice, and from environmental protection to international cooperation, providing a solid theoretical foundation and practical guide for the construction of the indicator system.

In view of the unique economic and social background and development needs of the Central Plains region, the selection of indicators in these five dimensions for the evaluation of high-quality development has significant rationality and adaptability. As an important economic region in China, the main challenges facing the Central Plains include, but are not limited to, industrial restructuring, ecological environmental protection, and unbalanced regional development. The evaluation index system guided by the five concepts of innovation, coordination, greenness, openness and sharing, as shown in Table 4, can not only comprehensively capture the multidimensional characteristics of the economic development of the Central Plains region, but also provide a scientific analytical framework and empirical support for the region to solve the existing problems and grasp the development opportunities.

Table 4: Evaluation index system for high-quality economic development of city clusters in the central plains region

dimension dimension	item level	indicator layer	information entropy e	information utility valued	weights (%)
innovations	Innovation Environment	Number of schools (number)	0.894	0.106	1.33
		Average number of students in higher education (persons)	0.773	0.227	2.848
	Innovation Inputs	Education expenses (ten thousand yuan)	0.819	0.181	2.267
		Business income (ten thousand yuan)	0.839	0.161	2.02
	Innovation Output	Number of new product development projects (item)	0.735	0.265	3.319
		Number of Patent Application Acceptance (pieces)	0.605	0.395	4.954
		Technology market turnover (ten thousand yuan)	0.785	0.215	2.691
Coordination	Industrial Coordination	Value added of primary industry (billion yuan)	0.875	0.125	1.563
		Value added of secondary industry (billion yuan)	0.729	0.271	3.395
		Value added of tertiary industry (billion yuan)	0.74	0.26	3.262
	Urban-rural coordination	Comparison of Urban and Rural Consumption Levels (Rural	0.914	0.086	1.072

		Residents=1)			
		Urban and rural community affairs (billion yuan)	0.701	0.299	3.748
		RMB savings deposits of urban and rural residents (year-end balance) (billion yuan)	0.748	0.252	3.157
Green	Environmental Protection	Greening coverage rate of built-up areas (%)	0.804	0.196	2.451
		Total afforestation area (ha)	0.823	0.177	2.212
	Energy Consumption	Per capita water resources (m3/person)	0.746	0.254	3.187
		Total water consumption (billion cubic meters)	0.841	0.159	1.989
		Harmless treatment rate of domestic garbage (%)	0.804	0.196	2.453
	Environmental Pollution	Amount of chemical fertilizer applied (million tons)	0.909	0.091	1.143
		Population using natural gas (million people)	0.841	0.159	1.997
		Sulfur dioxide emissions (tons)	0.873	0.127	1.589
		Electricity consumption (billion kilowatt hours)	0.816	0.184	2.305
Openness	Opening to the outside world	Number of foreign-invested enterprises (number)	0.739	0.261	3.272
		Import and export (million dollars)	0.399	0.601	7.528
		Receiving inbound overnight visitors (million)	0.694	0.306	3.836
	Openness to Domestic	Total investment (USD billion)	0.476	0.524	6.563
		Total passenger traffic (10,000 people)	0.867	0.133	1.673
		Total cargo volume (tons)	0.812	0.188	2.358
Sharing	Education Service	Number of graduates (persons)	0.886	0.114	1.424
		General higher education (number of teachers = 1)	0.895	0.105	1.319
		Average number of students in higher education (persons)	0.773	0.227	2.848
		Public libraries (number)	0.874	0.126	1.577
	Healthcare	Number of hospital beds (10,000)	0.77	0.23	2.878
		Licensed physicians (persons)	0.825	0.175	2.191
	Income Distribution	Per capita disposable income of residents (yuan)	0.715	0.285	3.572
		GDP per capita (yuan)	0.809	0.191	2.395
		Unemployment rate (%)	0.871	0.129	1.616

4.3.2 Results of indicator measurement

Based on the evaluation index system for high-quality development of the city cluster economy in the Central Plains region proposed in Table 4 above, the evaluation indexes of the eight provinces in the Central Plains region for the period of 2009-2022 are calculated through the entropy assignment method, and then the comprehensive development level of high-quality development is calculated through the linear comprehensive evaluation method, and the high-quality development level of the city cluster economy in the Central Plains region as shown in the following table is shown in Table 5, and the trend of the high-quality development level of the city cluster economy in the Central Plains region is shown in Figure 3. Development level trend is shown in Fig. 3, and due to space limitation, this paper shows every other year as a representative from 2009.

Table 5: Level of high-quality economic development of urban agglomerations in the central China region

area	2009	2011	2013	2015	2017	2019	2021	average
Hebei	0.0186	0.0197	0.0181	0.0183	0.0196	0.0191	0.0203	0.0191
Shanxi	0.0169	0.0275	0.0277	0.0183	0.0151	0.0092	0.0043	0.0170
Jiangsu	0.0755	0.0755	0.0733	0.0741	0.0727	0.0748	0.0621	0.0726
Anhui	0.0157	0.0180	0.0248	0.0268	0.0250	0.0260	0.0274	0.0234
Shandong	0.0482	0.0454	0.0459	0.0478	0.0475	0.0477	0.0429	0.0465
Henan	0.0226	0.0228	0.0231	0.0356	0.0374	0.0437	0.0401	0.0322
Hubei	0.0201	0.0194	0.0256	0.0265	0.0284	0.0301	0.0297	0.0257
Shaanxi	0.0154	0.0178	0.0221	0.0226	0.0222	0.0145	0.0102	0.0178

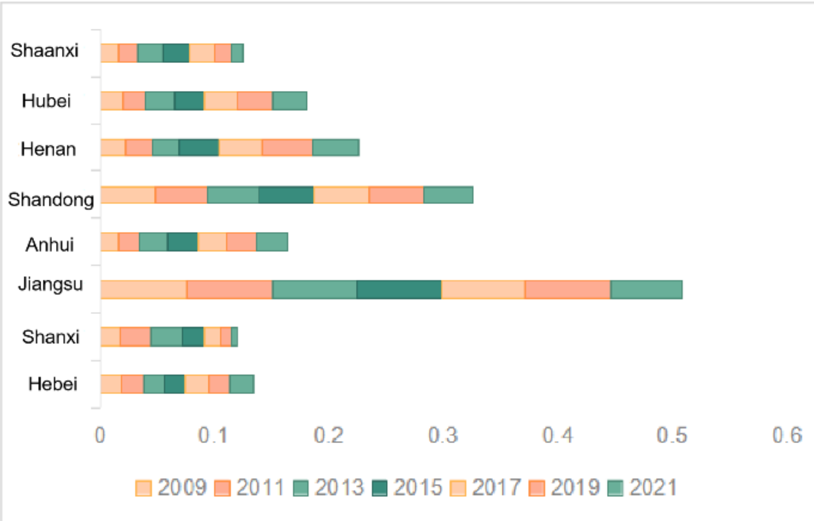

Figure 3: Trends in the level of high-quality economic development of city clusters in the central China region

Analyzing from the perspective of time dimension, this paper calculates the evaluation results of the level of high-quality economic development from 2009 to 2022 according to the data of the evaluation index system of high-quality economic development of eight provinces in the Central Plains region, as shown in Table 6, and the trend of the development level is shown in Fig. 4. The average value of high-quality economic development from 2009 to 2022 is 0.03073, the minimum value is 0.0275 in 2010, and the maximum value is 0.0328 in 2021, with a standard deviation of 0.00178. The maximum value is 0.0328 in 2021, and the standard deviation is 0.00178. It can be seen that the level of high-quality development of the economy of the city cluster in the Central Plains region is constantly improving, with an annual growth of 19.3% from 2010 to 2021. Although the high-quality development of the economy of the city cluster in the Central Plains region has a certain degree of volatility, but the overall upward trend, as shown in Figure 1, the growth of the high-quality development of the economy of the city cluster in the Central Plains region during the period of 2009-2022 can be divided into 2 stages, with a clear upward trend in the period of 2009-2015, and the period of 2015-2022 is in a stable stage, and the fastest growth is in 2013, with a year-on-year growth of 10.9%.

Table 6: High-quality development level of the overall economy of the city cluster in the central region

particular year	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
Overall level of development	0.0279	0.0275	0.0283	0.0284	0.0315	0.0315	0.0317
particular year	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Overall level of development	0.0310	0.0317	0.0321	0.0323	0.0318	0.0328	0.0318

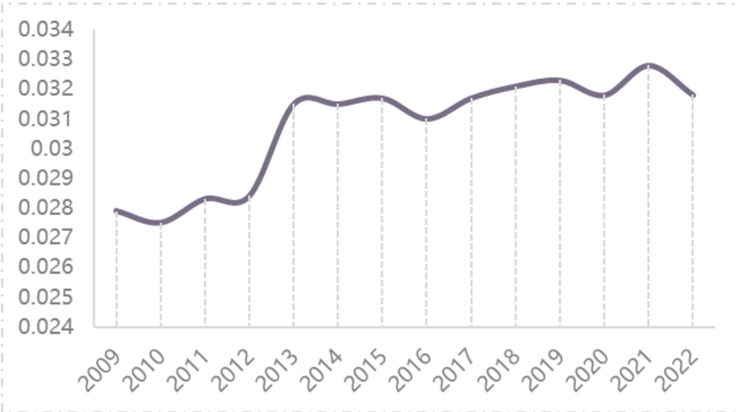

Figure 4: Trends in development levels

To study the absolute difference and relative difference of the sample, this paper introduces the values of standard deviation and coefficient of variation to reflect, in order to further analyze the changes of the level of high-quality economic development of the city cluster in the Central Plains region in each year, the standard deviation and coefficient of variation are calculated based on the value of the development level in each year and make the trend graph, as shown in Figure 5. Generally speaking, the standard deviation of the high-quality economic development level of the city cluster in the Central Plains region from 2009 to 2022 shows a stable trend, which indicates that the absolute difference of the high-quality economic development of the city cluster in the Central Plains region does not show a significant trend of change, i.e., the level of the economic degree of the development of the city cluster in the Central Plains region is basically the same. From the perspective of the coefficient of variation, the absolute difference in the level of high-quality economic development of the city cluster in the Central Plains region as a whole shows an overall trend of rising and then stabilizing, with an upward phase in 2009-2015 and remaining stable in 2015-2022. Overall, the positive development level of city clusters in the Central Plains region is basically consistent.

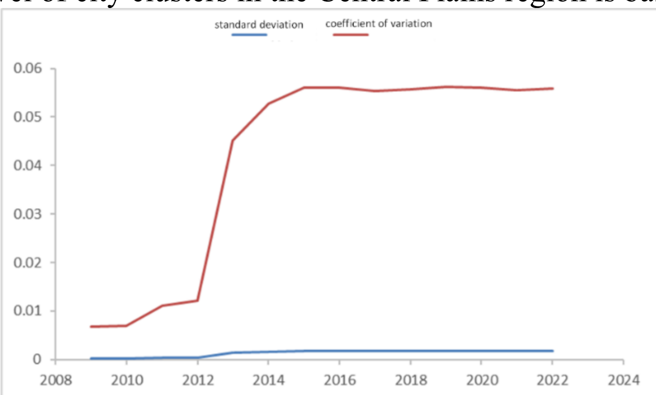

Figure 5: Standard deviation and coefficient of variation of the level of high-quality economic development of city clusters in the central China region

The above findings show that the level of high-quality economic development in the urban agglomerations of the Central Plains region has been increasing, and the number of regions with a better level of high-quality economic development has been growing.

5. Conclusions

The research results show that:

(1) The high-quality economic development of the city cluster in the Central Plains region shows regional non-equilibrium, with a distribution pattern of high in the southeast and low in the northwest.

(2) The carbon emission intensity of the city cluster in the Central Plains region shows significant spatial aggregation, reflecting the close correlation between economic development and carbon emission among regions.

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