Pol. J. Environ. Stud. Vol. 31, No. 6 (2022), 5649-5660
DOI: *10.15244/pjoes/152145* ONLINE PUBLICATION DATE: 2022-10-12

Original Research

Analysis of Characteristics and Factors Influencing Urban Carbon Emissions Based on Decoupling Index and LMDI, Using Ordos City in Inner Mongolia as an Example

Jiaqi Fan, Riwa Hu, Yingga Wu, Ruiping Zhou*

College of Geographical Science, Inner Mongolia Normal University, Hohhot 010022, China

Received: 6 February 2022
Accepted: 15 July 2022

Abstract

Considering China's goal of achieving peak carbon emissions in 2030 and carbon neutrality in 2060, this paper analyzes carbon emissions, carbon emission intensity, the decoupling of carbon emissions and economic development, and associated influencing factors using data from Ordos City from 2009 to 2020. The methods employed are the IPCC carbon emission calculation method, Tapio decoupling model, and logarithmic average Dickens index decomposition. The results show the following: (1) During the study period, Ordos City carbon emissions showed an increasing trend, and the total carbon emissions increased from 5.634 billion tons in 2009 to 204.734 million tons in 2020, with an average annual growth rate of 13.77%. (2) The decoupling elasticity of Ordos City from 2009 to 2016 was 1.26, which is the expansion negative decoupling state. From 2016 to 2020, the decoupling elasticity was -3.2657, showing a strong negative decoupling state. (3) The increase in population and per capita GDP in Ordos are the main factors contributing to the increase of carbon emissions, and the main negative growth driver is the increase in energy intensity.

Keywords: urban carbon emissions, Tapio decoupling model, LMDI decomposition method, Ordos City

Introduction

Faced with increasingly prominent global climate problems, China is actively responding to the international call for carbon emissions reduction. Reducing carbon emissions and developing a low-carbon economy have become the inevitable choices used in China's economic and social low-carbon transformation and sustainable development strategy. In 2020, China put forward at the United Nations General Assembly that it will implement more powerful policies and measures toward the targets of peak carbon dioxide emissions by 2030 and carbon neutrality by 2060. These proposed targets add to the pressure on China to cut emissions. To effectively achieve the dual carbon targets, it is necessary to allocate the task of carbon emissions reduction to each city according to its economic development level and carbon emission status.

*e-mail: rpzhou@126.com

At present, domestic and foreign scholars of urban carbon emissions mainly focus on the calculation of large-scale carbon emissions [1, 2], prediction of carbon emissions [3, 4], and analysis of factors that influence carbon emissions [5-7]. Domestic scholars have relatively mature research on carbon emissions measurement and the influencing factors. The literature presents a comprehensive analysis of trends in carbon emissions, including spatial distribution patterns and influencing factors determined by measuring the overall carbon emissions in a study area [8, 9]. Measured carbon emission data are presented in a basic fashion in local statistical yearbooks [10]. In recent years, some scholars have also directly used carbon emissions data calculated by platforms [11]. However, whether the energy data released by statistical departments are used for calculation or platform acquisition, only data from national [12] or provincial [13] sources or some well-developed cities [14] are well measured, and most of the calculation models are based on the reference methods provided in the IPCC Guidelines for National Greenhouse Gas Inventories [15-16].

Researchers who seek to decompose the influencing factors of carbon emission change typically first use a decoupling state analysis to evaluate the decoupling relationship between carbon emissions and economic growth or human development in various regions [17]. There are two main types of decoupling models: OECD [18] and Tapio [17]. In practical applications, the Tapio decoupling model does not require the selection of a base period and is not affected by statistical dimension when it is used in a calculation, and its decoupling index system is more complete [19]. The Tapio decoupling model has been widely applied to evaluating the decoupling status of carbon emissions and economic indicators at the national [20], provincial [21-22], or industry [23] level. Second, to profoundly investigate the change mechanism of carbon emission growth, researchers employ the factor decomposition model [24], IPAT model [25], STRIPAT model [26], grey correlation analysis [27], or other methods. The Dsmt4 Log Mean Divisia Index method (LMDI) is widely applied by virtue of its many excellent properties [28-29]. Dsmt4 can not only remove residual items that cannot be explained, but also handles the zero-value problem in data. It also has a simple calculation process and intuitive decomposition results [30].

The carbon emissions of cities and towns have also been studied by a small number of researchers in recent years [31]. For example, Su Wangxin [32] analyzed the driving factors of carbon emissions in six representative cities in the typical urban agglomerations of China and found that economy and population have positive effects and energy intensity has negative effects on carbon emissions. In contrast, research on the measurement and influence of carbon emissions in western China has been limited to the provincial level [1] and the study of carbon emissions generated by a specific action [4]. In summary, research to date on the factors influencing carbon emissions in China remains concentrated at the national and provincial levels, and there is less literature examining the factors influencing total urban carbon emissions.

Ordos, located in the western region of China, is representative of a typical industrial city with high energy consumption and high carbon emissions [33]. With the vigorous development of coal resources, the GDP of Ordos increased from 216.1 billion yuan in 2009 to 353.4 billion yuan in 2020, and the population also increased from 1.88 million in 2009 to 2.16 million in 2020. In 2020, Ordos was still relying on secondary industry with high carbon emissions as its main economic source. Such industry accounts for 56.76% of the regional GDP. This paper analyzes the change in carbon emissions in Ordos City from 2009 to 2020, the decoupling relationship between carbon emissions and economic growth, and the factors influencing carbon emissions based on the LMDI model and the Tapio decoupling model. This study provides a theoretical basis for determining carbon emission reduction measures in resource-based cities in western China and emission reduction policies in Ordos City intended to achieve low-carbon economic and social development.

Material and Methods

Study Area

Ordos City is located in the southwestern part of China's Inner Mongolia Autonomous Region. It is located within the geographical coordinates 37°37'-40°53'N and 106°27'-11°27'E, and its total area is about 86,700 km^2. The annual average temperature is 5.5-8.7ºC. Westerly and northwesterly winds prevail throughout the year, with an annual average wind speed of 3.6 m/s and a maximum wind speed of 22 m/s. Ordos City is rich in mineral resources, with more than 50 kinds of minerals. It has proven coal reserves that account for about 1/6 of the country's reserves, covering a wide distribution area. It is one of the 14 largest coal production bases in China, and such coal resources are important for promoting urban economic development [34]. In 2019, the GDP was 353.36 billion yuan, and the resident population reached 2.0876 million. In recent years, as the City of Ordos experienced rapid economic development due to its abundant resources, especially coal, the environmental impact of large-scale resource exploitation has become increasingly evident [35].

Data Sources

The time span of the data in this paper is 2009 to 2020. The original data for population, urbanization rate, GDP, energy consumption, and industrial structure are derived from Statistical Bulletin of National Economic and Social Development of Ordos

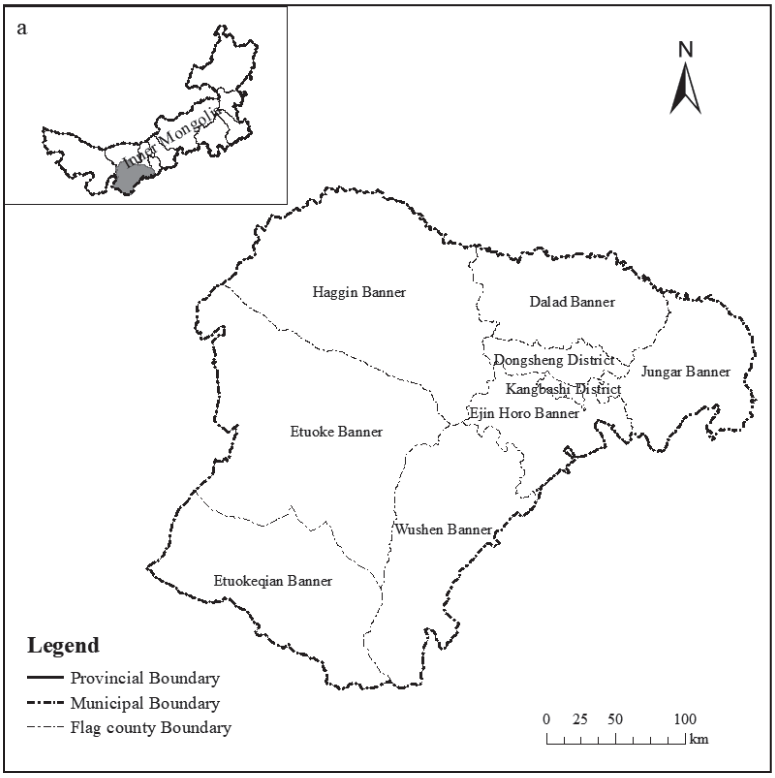

Fig. 1. Map of Ordos City.

and Statistical Yearbook of Ordos. Carbon emissions are calculated based on consumption of coal, oil, and natural gas and their respective carbon emission factors. The basic consumption data come from the Statistical Yearbook of Ordos and the Statistical Yearbook of China's Regional Economy from 2009 to 2020. Carbon emission intensity is calculated from the ratio of fossil energy consumption to total GDP value in tons per 10,000 yuan.

Carbon Emission Accounting Method

To date, China has not yet directly published carbon emission data for each province and city. For the study area of this paper, as a typical industrial city, the main carbon emissions come from industrial activity, urban energy consumption, urban residential activity, and transportation. According to the method of Ding et al. [36] and combined with the characteristics of industrial carbon emissions in the research area, industrial production and consumption indicators are selected as the industrial carbon emissions. A city's electricity consumption can be used to estimate the carbon emissions from the burning of fuels used for power generation. Urban residential energy consumption is mainly from natural gas and produces heat, so natural gas emissions and heat emissions are selected to determine urban residential carbon emissions. The main energy consumption from urban transportation is liquified petroleum gas, so the carbon emissions of liquefied petroleum gas are measured.

The reference method provided in the IPCC Guidelines for National Greenhouse Gas Inventories [35] can directly estimate carbon emissions by using the product of various types of energy consumption in cities and their carbon emission factors, calculated by the following equation:

$$C_{it} = \sum_{i=1}^{n} En_{it} \times \varepsilon_i \quad (1)$$

where C is carbon emissions (ten thousand tons); ε is the energy carbon emission coefficient; En is the energy consumption, calculated in ten thousand tons of standard coal; i is the energy type; and t represents time.

Using the above calculation as the basis of carbon emissions from Ordos City, the analysis selects a total of 13 main energy source types, such as raw coal, clean coal, and coke. The various energy sources are converted into standard coal reference coefficients and carbon emission coefficients, as shown in Table 1.

Tapio Decoupling Index Model

Decoupling theory is used first to measure the relationship between environmental pollution and economic growth and then gradually applied to study the relationship between carbon emissions and economic growth [35]. Based on the elaboration of the decoupling index by Tapio [17], this paper establishes a decoupling analysis model between carbon emission

Table 1. Reference coefficient of standard coal and carbon emission coefficient of various energy sources.

Energy types	Standard coal coefficient t/t	Carbon emission coefficient tC/t
Raw coal (t)	0.7143	0.7559
Washed coal (t)	0.9	0.7559
Hard coke (t)	0.9714	0.855
Other coking products (t)	1.3	0.6449
Coke oven gas (ten thousand m^3)	6.143	0.3548
Natural gas (ten thousand m^3)	12.143	0.4483
Gasoline (t)	1.4714	0.5538
Kerosene (t)	1.4714	0.5714
Diesel oil (t)	1.4571	0.5921
Natural gas (t)	1.4286	0.6185
Liquefied petroleum gas (t)	1.7143	0.5042
Heat (million KJ)	0.0341	0.2772
Electric power (million KW.h)	1.229	0.68

change and economic aggregate growth. The equation is as follows:

$$D_{C,Y}=\frac{\Delta C'}{\Delta Y'}=\frac{C_t-C_{t-1}/C_{t-1}}{Y_t-Y_{t-1}/Y_{t-1}} \quad (2)$$

where $D_{C,\ Y}$ is the elasticity coefficient of carbon emission change relative to GDP growth, ΔC' is the change rate of carbon emissions; ΔY' represents the economic growth rate; $C_t–C_{t-1}$ represents the difference in carbon emissions between year t and year (t-1); and represents the difference between the GDP for year t and year (t-1). The definition of decoupling of carbon emissions from economic growth and the meaning of each decoupling state are shown in Fig. 2 [37].

Methods of Analysis of Influencing Factors

This work employs the LMDI model [38] to obtain the various factors that affect the index through its decomposition [39]. Specifically, the LMDI model is used to decompose the effects of the $\sum_{i=1}^{n} p\times g\times m\times e\times f_i$ factors on the changes in carbon emissions in Ordos City. The specific decomposition model is as follows:

$$C=\sum_{i=1}^{n} C_i=\sum_{i=1}^{n} p\times\frac{G}{p}\times\frac{E}{G}\times\frac{E_i}{E}\times\frac{C_i}{E_i}=\sum_{i=1}^{n} p\times g\times m\times e\times f_i \quad (3)$$

where C is the total carbon emissions of Ordos City, i represents the different energy types, p indicates

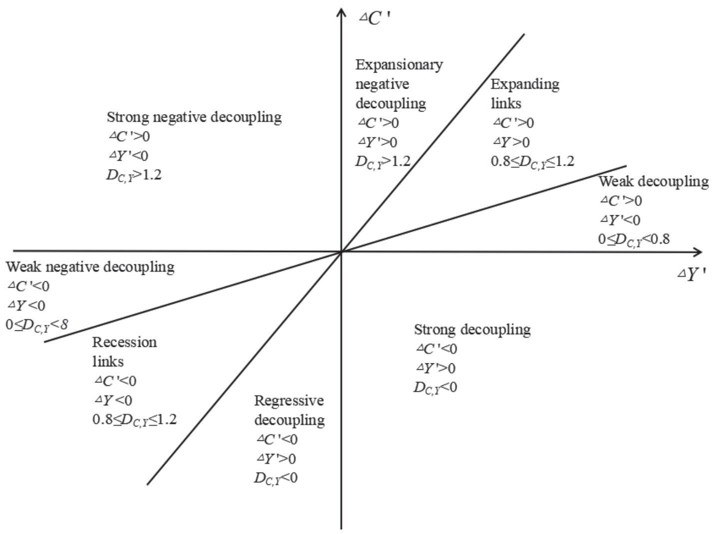

Fig. 2. The decoupling of carbon emissions from economic growth.

Table 2. Definition of each decoupling indicator.

Decoupling States		Decoupling indicator definition
Negative decoupling	Expansionary negative decoupling	Carbon emissions and economic growth rates are both positive and the growth rate of the former is higher than that of the latter, which is a less ideal state.
	Strong negative decoupling	The growth rate of carbon emissions is positive and the economic growth rate is negative, which is the last ideal state.
	Weak negative decoupling	Carbon emissions and economic growth rates are both negative, with the former falling faster than the latter, which is far from ideal.
Positive decoupling	Weak decoupling	Carbon emissions and economic growth rates are both positive. The growth rate of the former is less than that of the latter, which is a relatively ideal state.
	Strong decoupling	The carbon emissions growth rate is negative and the economic growth rate is positive, which is the optimal state.
	Regressive decoupling	Both carbon emission and economic growth rates are negative, and the former decreases faster than the latter.
Links	Expanding links	Carbon emissions and economic growth rates are both positive, with similar growth rates.
	Recession links	Carbon emissions and economic growth rates are both negative, and they are falling at the same rate.

population, G is the GDP, Ei represents the consumption of the i-th energy, and Ci is the carbon emissions produced by the i-th energy. After decomposition, the equation is obtained in which g = G/p, representing per capita GDP; m = E/G, representing energy intensity; e = E_i/E, representing energy consumption structure; and fi = C_i/E_i, representing the carbon emission coefficient.

Using the above LMDI decomposition model shows that the changes in carbon emissions can be decomposed into five influencing factors. The growth in carbon emissions, ΔC, is defined as a combined effect and is decomposed into five components: the population effect, ΔC_p; the GDP per capita effect, ΔC_g; the energy intensity effect, ΔC_m; the energy consumption structure effect, ΔC_e; and the carbon emission factor effect, ΔC_f. Because the carbon emission coefficient of a certain energy is constant, ΔC_f is assumed to be 0 and is excluded in the equation. The equation for the final carbon emission comprehensive effect is the following:

$$\Delta C = \Delta C_p + \Delta C_g + \Delta C_m + \Delta C_e + \Delta C_f \tag{4}$$

The equation for the effect of each factor is as follows:

$$\Delta C_p = \sum_{i=1}^{n} \frac{C_i^t - C_i^{t-1}}{\ln C_i^t - \ln C_i^{t-1}} \ln\left[\frac{p(t)}{p(t-1)}\right] \tag{5}$$

$$\Delta C_g = \sum_{i=1}^{n} \frac{C_i^t - C_i^{t-1}}{\ln C_i^t - \ln C_i^{t-1}} \ln\left[\frac{g(t)}{g(t-1)}\right] \tag{6}$$

$$\Delta C_m = \sum_{i=1}^{n} \frac{C_i^t - C_i^{t-1}}{\ln C_i^t - \ln C_i^{t-1}} \ln\left[\frac{m(t)}{m(t-1)}\right] \tag{7}$$

$$\Delta C_e = \sum_{i=1}^{n} \frac{C_i^t - C_i^{t-1}}{\ln C_i^t - \ln C_i^{t-1}} \ln\left[\frac{e(t)}{e(t-1)}\right] \tag{8}$$

In Eq. (5) for ΔC_p, the right-hand side term $\ln\left[\frac{P(t)}{P(t-1)}\right]$ represents the logarithmic proportion of the population size in year t compared to the population size in the base year. The denominator represents the logarithmic difference between the carbon emissions in year t compared to the carbon emissions in the base year. The numerator represents the difference between the carbon emissions in year t and the carbon emissions in the base year. The entire equation represents carbon emissions from population-level effects relative to total carbon emissions from the base year to year t. The same applies to ΔC_g, ΔC_m, and ΔC_e. To further clarify the contribution rate of each factor, β, they are defined in the form of an index:

$$\beta_p = \frac{\Delta C_p}{\Delta C} \quad \beta_g = \frac{\Delta C_g}{\Delta C} \quad \beta_m = \frac{\Delta C_m}{\Delta C} \quad \beta_e = \frac{\Delta C_e}{\Delta C}$$
$$\beta_p + \beta_g + \beta_m + \beta_e = 1 \tag{9}$$

Results and Analysis

Analysis of the Change in Carbon Emission and Carbon Emission Intensity

Combined with the above calculation method for carbon emissions, the carbon emissions of Ordos City are obtained using the main energy consumption of industrial enterprises above a designated size. Changes in carbon emissions and intensity for 2009 to 2020 are shown in Fig. 3 below. The carbon emissions from Ordos City were 5.634 billion tons in 2009 to 204.734 million tons in 2020, with an average annual growth rate of 13.77%. In these 10 years, the overall carbon emissions in Ordos showed an increasing trend, which can be roughly divided into three stages. In the first stage (2009-2012), there was accelerated growth in carbon emissions, and they increased from 56.341,600 tons in 2009 to 99.755,300 tons in 2012, an annual growth rate of 20.98%. In the second stage (2013-2016), the carbon emissions showed a stable fluctuation trend, and the carbon emissions exceeded 10 million tons in 2013. During this period, carbon emissions increased from 109.8582 million tons in 2013 to 126.3672 million tons in 2016, with an average annual growth rate of 4.48%. In the third stage (2017-2020), the carbon emissions again increased at a uniform rate and stabilized, increasing from 144.7493 million tons in 2017, to 203.8123 million tons in 2019, to 204.734 million tons in 2020, with an annual growth rate of 12.25%.

To further reflect the carbon emissions situation of Ordos City, carbon emissions data are introduced that are obtained by dividing the fossil energy consumption by the total value of GDP. A statistical analysis shows that the carbon emissions intensity of Ordos City increased with the increase in carbon emissions, and its value also rose from 2.61 tons per 10,000 yuan in 2009 to 5.79 tons per 10,000 yuan in 2020. According to the growth trend, the carbon emissions intensity increased slightly in 2009–2016, and the carbon emissions intensity fluctuated from 2.5 to 3 tons per million yuan in 2010–2016, with little change. The significant change in carbon emissions intensity began to appear after 2017, and the growth rate in carbon emissions intensity reached 41.26% from 2016 to 2017. From 2017 to 2020, the carbon emissions intensity of Ordos City increased significantly, to 5.79 tons per 10,000 yuan in 2020.

Decoupling Analysis of Carbon Emissions and Economic Growth

To further analyze the relationship between carbon emissions and economic growth in Ordos City, the changes in carbon emissions and total industrial output value are calculated. Equation (2) and Figure 2 are used to develop the decoupling relationship table between 2009 and 2019 (Table 3).

From Table 3, it can be seen that carbon emissions and economic growth are in the state indicated by expansion negative decoupling during the study period. During this period, weak decoupling alternates with strong negative decoupling. The expansion negative decoupling persists for four years, the weak decoupling for three years, the strong negative decoupling for two years, and the expansion for one year. From the point of view of the decoupling elastic coefficient, the absolute value of the elastic coefficient shows an increasing trend; that is, the deviation between them is increasing. From the results of the decoupling elasticity, it can be seen that the decoupling state of economic growth and carbon emissions in Ordos City from 2009 to 2020 can be divided into two main stages. From 2009 to 2016, the state of weak decoupling and expansion of negative decoupling were dominant, indicating that carbon emissions were also increasing with economic growth. The overall decoupling elasticity of this stage is higher than that of 2016-2020, and the decoupling elasticity is 1.26. In 2016-2020, there was a strong negative decoupling state, indicating a negative state and economic downturn, but carbon emissions increased and the decoupling elasticity of this stage was -3.657. The maximum decoupling elasticity also appeared

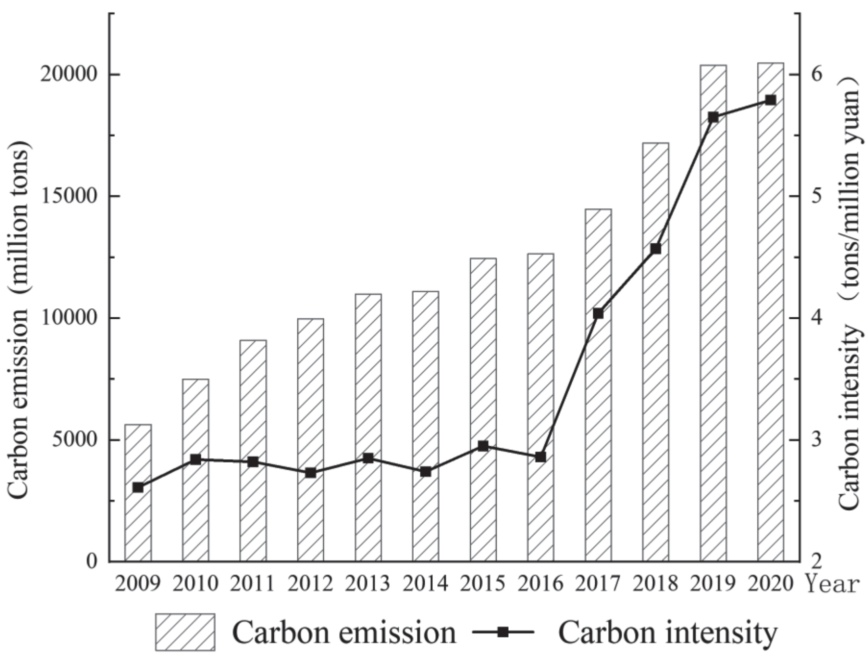

Fig. 3. Change trend of carbon emissions and carbon emissions intensity in Ordos City from 2009 to 2020.

Table 3. Table of decoupling relationship of Ordos City from 2009 to 2020.

Year	Decoupling States			
	ΔC'	ΔY'	D_{CY}	Decoupling
2009-2010	+	+	1.680	Expansionary negative decoupling
2010-2011	+	+	1.039	Expanding links
2011-2012	+	+	0.714	Weak decoupling
2012-2013	+	+	1.828	Expansionary negative decoupling
2013-2014	+	+	0.040	Weak decoupling
2014-2015	+	+	2.799	Expansionary negative decoupling
2015-2016	+	+	0.397	Weak decoupling
2016-2017	+	–	-0.734	Strong negative decoupling
2017-2018	+	+	3.553	Expansionary negative decoupling
2018-2019	+	–	-4.466	Strong negative decoupling
2009-2016	+	+	1.26	Expansionary negative decoupling
2016-2020	+	–	-3.657	Strong negative decoupling

during this period, with a decoupling elasticity of 3.553 in 2017-2018, showing an expanded negative decoupling state.

Analysis on Influencing Factors of Carbon Emissions

Results of the above analysis show that, in the past ten years in Ordos City, carbon emissions and economic growth overall showed "expansion negative decoupling" and "weak decoupling" alternating fluctuations. To further analyze the factors affecting carbon emissions in the study area, the LMDI model was used to decompose the carbon emissions in Ordos City, and the effects of population, per capital GDP, energy intensity, and energy consumption structure on carbon emissions were obtained from 2010 to 2020. The specific decomposition of the year-by-year effect is shown in Figure 4, where a positive value indicates promotion of the growth of carbon emissions, and a negative value indicates inhibition of carbon emissions. The population and per capital GDP of Ordos city from 2010 to 2016 are the main factors leading to the increase of carbon emissions, while the main driving factor of negative growth is energy intensity. The energy consumption structure has a small inhibiting effect. The annual effect of each influencing factor is shown as a percentage histogram in Figure 5. The figure shows that the effect intensity of energy consumption is the lowest, and the per capital GDP is mainly positive and shows a decreasing trend. The cumulative contribution rate of the decomposition is shown in Table 4. Population contributes the most to carbon emissions in Ordos city, reaching 75.06%. Contribution rates of other factors are per capital GDP, 16.22%; energy intensity, 41.05%; and energy consumption structure, 0.10%.

Population growth is an important factor that causes an increase in carbon emissions in Ordos City. As can be seen from Fig. 4, the impact of population on carbon emissions from 2010 to 2020 has always been positive, but its effect is steadily decreasing. The impact of population on carbon emissions decreased significantly after 2012, because the growth rate in the permanent population in Ordos slowed down after 2012 [40]. Subject to the family planning policy [41], China's natural population growth rate at this stage declined steadily, and the natural population growth rate decreased from 10.55% in 1995 to 4.95% in 2012. After 2012, the population growth rate in Ordos City decreased to less than 1%, and it was 0.44% in 2019. This result is related to the gradual and conscious implementation of late marriage, late childbearing, and low births and eugenics, and the results of government regulation are more remarkable [42].

The per capital GDP has a positive effect on the growth of carbon emissions, except in 2017, 2019, and 2020, and its effect is the largest of the four influencing factors in each year. The level of economic development in Ordos City has continuously improved from 2009 to 2016, and the per capita GDP decreased significantly in 2017. Correspondingly, carbon emissions had a negative effect on carbon reduction in that year. In the following two years, with the implementation of the national supply-side structural reform, the economic situation of Ordos recovered, but the growth rate has been slow, and in 2019, there was a decline again [43].

Energy intensity is an important indicator of the energy saving effect, reflecting the ability of sustainable development. The calculation shows that, during 2009-2020, the energy consumption intensity is a strong influencing factor after economic development, and its cumulative effect reaches 10981.41, which

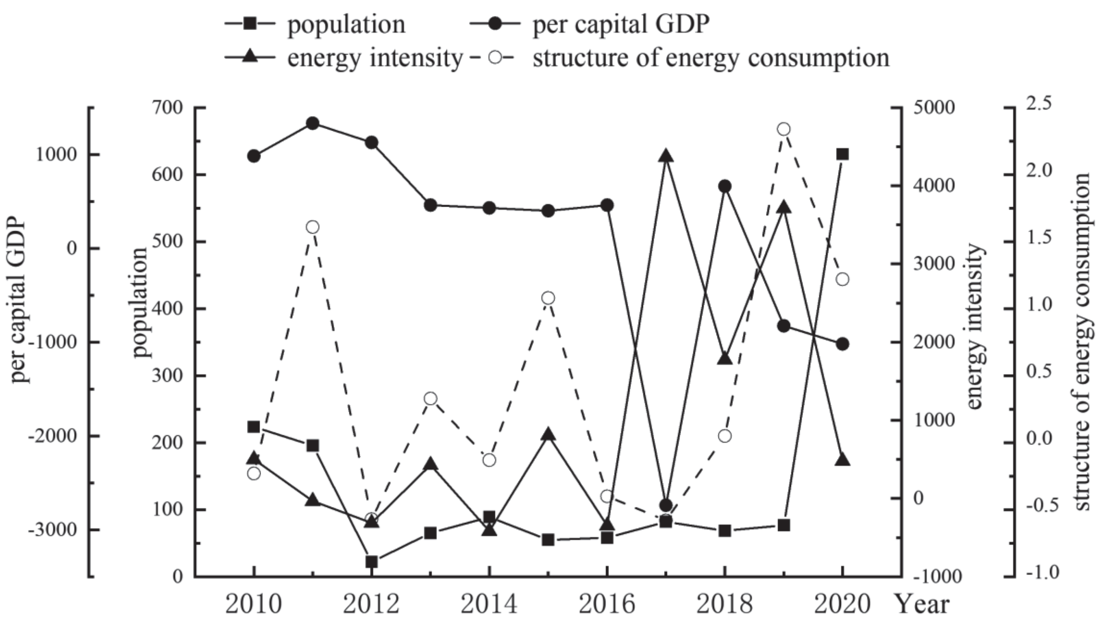

Fig. 4. Year-by-year effect change in carbon emission factor decomposition in Ordos City.

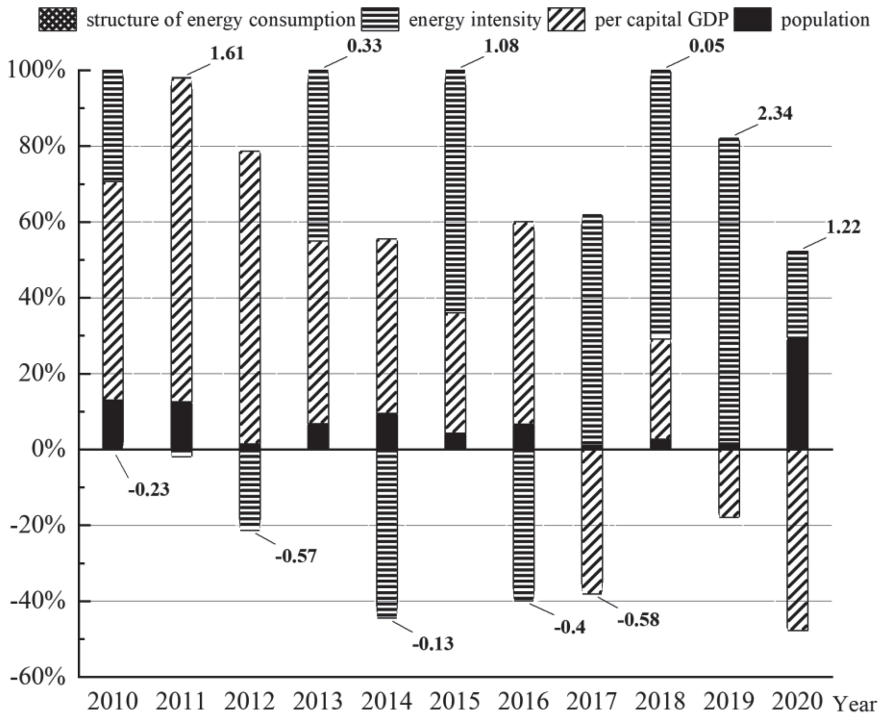

Fig. 5. Histogram of annual effect of carbon emission factor decomposition in Ordos City.
Note: The values marked in the figure show the effect of energy consumption structure on carbon emissions in each year.

is the highest among the four influencing factors. In Table 4, the annual contribution rate of the energy intensity factor is the highest in each year. The absolute value of its contribution rate reaches 501.33% in 2020, and its decomposition effect is 4370.65 in 2017, indicating that the energy use efficiency in 2017 is the lowest in the study period. This has had a restraining effect on carbon emissions reduction. The cumulative effect of the energy consumption structure accounts for the smallest proportion of the total effect of carbon emissions change, resulting in a smaller inhibitory effect. Five-year negative and five-year positive effects are observed during the study period. From a year-by-year perspective, the absolute value of the energy consumption structure effect shows an increasing trend, with an increase to 2.34 in 2019. Also, the cumulative

Table 4. Factor decomposition annual contribution rate.

Year	Population	Per capital gross domestic product	Energy intensity	Energy consumption structure
2010	13.07%	57.55%	29.39%	-0.01%
2011	13.05%	88.89%	-2.05%	0.11%
2012	2.63%	134.48%	-37.04%	-0.07%
2013	6.84%	48.19%	44.94%	0.03%
2014	85.99%	415.68%	-401.54%	-0.13%
2015	4.34%	31.69%	63.88%	0.09%
2016	33.49%	265.13%	-198.39%	-0.23%
2017	4.79%	-159.78%	255.02%	-0.03%
2018	2.73%	26.39%	70.87%	0.00%
2019	2.59%	-27.82%	125.15%	0.08%
2020	656.19%	-1058.80%	501.33%	1.27%
Grand total	75.06%	-16.22%	41.05%	0.10%

effect of energy consumption structure reaches 4.75 by 2020, and the energy consumption structure has a trend of carbon increase.

Discussion and Recommendations

Based on the energy consumption of Ordos City, this paper calculates carbon emissions using the IPCC calculation method and analyzes the relationship between carbon emissions and economic development status on the basis of the Tapio decoupling analysis using the LMDI model.

In previous research on carbon emissions, from the perspective of data accessibility and convenient measurement, most scholars [12, 13] conducted their investigations at the provincial and national levels but ignored the importance of urban carbon emissions in the process of emissions reduction. As a resource-based city, the main source of carbon emissions in Ordos is different from other cities, as it is not limited to the living carbon emission consumption of urban residents. The carbon emission generated by coal resource development is the main source of urban carbon emissions in Ordos city.

Therefore, in the process of selecting the energy emission index of the carbon emissions calculation, this paper draws on the selection of carbon emission measurement indexes from many scholars [35], fully considers the industrial carbon emission index, and constructs a carbon emission measurement standard suitable for resource-based cities. The economy in the process of urban development is an important criterion, and mineral resources are the main source of the economy in Ordos City. Its ecological and rapid development of social and economic contradictions are thus increasingly apparent, and the Tapio decoupling analysis provides an accurate analysis of the relationship between economy and carbon emissions to provide theoretical support. To more accurately reflect the influencing factors of Ordos carbon emissions, the Tapio decoupling analysis using the LMDI model was used to reconfirm the relationship between the economy and carbon emissions, while it was also used to analyze other factors affecting urban carbon emissions, thus providing the basis for future emissions reduction policies.

According to data calculation, from the perspective of carbon emission characteristics, the carbon emission of Ordos city gradually increased from 2009 to 2020, with an average annual growth rate of 13.77%. Compared with the change trend of carbon emission of Ordos City from 2000 to 2011 studied by QI T. in 2013 [33], the average annual growth rate was lower. This is also related to the current situation of developing low-carbon energy and renewable energy in the study area in recent years. From the perspective of decoupling, the decoupling index showed a downward trend, which is similar to the findings of other scholars [44]. From the perspective of influencing factors, the energy intensity has an inhibitory effect on the increase of carbon emissions, and per capital GDP plays a major role in promoting it. This conclusion is also consistent with the results of carbon emission influencing factors in Inner Mongolia studied by Gong Fang [1]. The change in energy consumption structure has no obvious effect on the increase of carbon emissions in Ordos City, which is consistent with the influence factors in carbon emissions in Chinese provinces studied by Liu Xianzhao in 2016 [36].

In addition to the four effects selected in this paper, factors such as carbon sinks, industrial intensification degree, and technical level will also affect the change in carbon emissions to a certain extent. Research into the carbon emissions of resource-based cities in western China needs to be further deepened. Future research should include additional data collection and collation.

In summary, typical cities like Ordos City, which rely on resources to support their economy, will contribute large increases in carbon emissions in the process of massive energy consumption. Through the analysis of influencing factors, it is seen that Ordos City should pay attention to the influence of per capita GDP, population, and energy consumption structure. From the perspective of economic development, Ordos City should develop carbon reduction strategies, avoid the dependence of economic development on single resources, and promote the diversification of the urban economic structure. For example, policies can strengthen the introduction of high-quality talent to ensure a steady development of enterprises in the city and promote the development of the whole region. Ordos City should establish and improve its system, promote a low-carbon economy, and take a road of green and sustainable economic development. This study provides examples for the analysis of the influencing factors of urban carbon emissions, addresses the gap in these data in Inner Mongolia, and provides a theoretical basis for Ordos City to achieve "peak carbon" and "carbon neutrality" as soon as possible.

Conclusions

During the study period, the carbon emissions from Ordos city showed an increasing trend, and the total carbon emissions increased from 5.634 billion tons in 2009 to 204.734 million tons in 2020. Thus, the average annual growth rate was 13.77%. With the growth in carbon emissions, carbon emission intensity also increased from 2.61 tons per 10,000 yuan in 2009 to 5.79 tons per 10,000 yuan in 2020. However, the growth rate of carbon emissions slowed down in 2020.

The elastic coefficient of carbon emissions in Ordos City is divided into two stages. First, the decoupling elasticity from 2009 to 2016 is 1.26, which is an expanded negative decoupling state. At this stage, the elastic coefficient decreased from 1.680 to 0.397, and the decoupling state gradually deteriorated. Second, the decoupling elasticity from 2016 to 2020 was -3.2657, showing a strong negative decoupling state. The decoupling state of the study area at this stage was worse than that of 2009-2016, indicating that the decoupling state of carbon emissions and economic growth in Ordos City showed a downward trend. The carbon emission growth rate was positive, while the economic growth rate was negative, which was the least ideal state. In the future, the carbon emissions of Ordos City still has an increasing trend, and the correlation between carbon emissions and the economy gradually weakens.

A comprehensive analysis of the factors influencing carbon emissions shows that per capita GDP has a positive effect on the increase in carbon emissions. The four influencing factors are the highest, and the cumulative effect will reach 1,281.98 by 2020. The population has a positive effect on carbon emissions, with the population contribution rate minimizing to only 2.59% by 2019 and 656.19% by 2020. The energy consumption structure has a negative but not obvious effect on the increase in carbon emissions, which peaked at 2.34 in 2019. The energy intensity effect showed a negative effect on the carbon emissions in Ordos City, and in 2014, the negative effect was the strongest, at -401.54%, while there was a 501.33% positive effect in 2020.

Acknowledgments

This research was financially supported by the sub-project of Inner Mongolia Autonomous Region major scientific and technological program of Research on Soil Quality Evolution and Control Mechanism of Coal Resource Exploitation in Windstorm Area [zdzx2018058], and the Inner Mongolia Natural Science Foundation Program of Study on the Influence Mechanism of Wind Power Station on Vegetation in Grassland Area of Northern China [2018MS04009].

Conflicts of Interest

The authors declare no conflict of interest.

References

1. GONG F., WANG F. Empirical study on carbon emissions in Inner Mongolia based on LMDI decomposition model. Journal of Arid Land Resources and Environment. **27** (2), 37, **2013**.
2. CHUN U., CHOI J., YUN J I. Urbanization effect on the observed change in mean monthly temperatures between 1951-1980 and 1971-2000 in Korea. Climatic Change. **66** (1), 127, **2004**.
3. GUAN M.J., YUAN Y.H., RAN M.X., WANG Z. Influencing factors and peak forecast of energy carbon emission in Shanxi based on STIRPAT model. China Coal. **47** (9), 48, **2021**.
4. HU Z., GONG X., LIU H. Prediction of household consumption carbon emission in western cities Based on BP model: Case of Xi'an city. Journal of Arid Land Resources and Environment. **34** (7), 83, **2020**.
5. LANTZ V., FENG Q. Assessing income, population, and technology impacts on CO_2, emissions in Canada: Where's the EKC?. Ecological Economics. **57** (2), 229, **2006**.
6. SHAO M., HAO Q., YAM G.H. Analysis of carbon emission influence factors of energy consumption in Shandong Province. Science and Management. **39** (4), 64, **2019**.
7. SONG X., JIA J.S., CHEN C.D. Spatio-temporal characteristics or decoupling relation and its driving factors of the carbon emission from energy consumption in underdeveloped Jiangxi Province. Journal of Ecology. **40** (20), 7451, **2020**.

8. LIU X.Z., GAO C.C., ZHANG Y. Spatial dependence of China's provincial carbon emissions from energy consumption and its spatial regression analysis. Journal of Arid Land Resources and Environment. **30** (10), 1, **2016**.
9. YU J., DA Y.B., OU Y.B. Analysis of carbon emission changes in China's transportation industry based on LMDI decomposition method.China Journal of Highway and Transport. **28** (10), 116, **2015**.
10. DUAN L.F., LU P.Y., PU Y.Y. The decoupling effect and driving mechanism of carbon emissions in typical city groups.Environmental Science & Technology. **44** (11), 55, **2021**.
11. Umal Ali Amal Tikali. Spatial-temporal variation and influencing factors of carbon emission in ecological urban agglomeration around Poyang Lake from 2000 to 2018. Ecological economy. **37** (6), 51, **2021**.
12. GUO H.D., QIAO W.Z., LIU J.R. Dynamic feedback analysis of influencing factors of existing building energy-saving renovation market based on system dynamics in China. Sustainability. **11** (1), 273, **2019**.
13. ZHANG W., ZHANG J.S., ZOU S.H. Study on energy consumption carbon emission factor decomposition based on LMDI in Shaanxi Province.Arid land resources and environment. **27** (9), 27, **2013**.
14. TANG S., FU J.W., WU J.L. Analysis on influencing factors of carbon emission in typical Chinese cities. Statistical observation. **23**, 59, **2021**.
15. DING F., ZHANG G.Y.,LIU D. Environmental regulation, industrial agglomeration and urban carbon intensity: An empirical analysis based on panel data of 282 prefecture-level cities in China.Journal of China University of Geosciences (Social Science Edition). **20** (3), **2020**.
16. United Nations Human Settlements Program.Global Human Settlements Report 2011: Cities and Climate Change.United Nations Human Settlements Program Paper. **2011**.
17. TAPIO P. Towards a theory of decoupling: degrees of decopling in the EU and the case of road traffic in Finaland between 1970 and 2001. Transport Policy, **12** (2), 137, **2005**.
18. Organization for Economic Co-operation and Development. Indicators to Measure Decoupling of Environmental Pressures from Economic Growth. Paris:OECD, **2002**.
19. FENG B., WANG X.Q. Research on carbon decoupling effect and influence factors of provincial construction industry in China. China Population, Resources and Environment. **25** (4), 28, **2015**.
20. WU Y., ZHU Q.W., ZHU B.Z. Decoupling analysis of world economic growth and CO_2 emissions:a study comparing developed and developing countries.Journal of Cleaner Production. **190**, 94, **2018**.
21. GAO C.C., GE H.Q., LU Y.Y. Decoupling of provincial energy-related CO_2 emissions from economic growth in China and its convergence from 1995 to 2017.Journal of Cleaner Production. **297**, 126627. **2021**.
22. WANG M., FENG X.Z., AN Q. Study on green and low-carbon development strategy of Qinghai Province based on decoupling index and LMDI.Advances in climate change research. **17** (5), 598, **2021**.
23. WANG X.L., WEI Y.W., SHAO Q.L. Decomposing the decoupling of CO_2 emissions and economic growth in China's iron and steel industry. Resources, Conservation and Recycling. **152**, 104509. **2020**.
24. QUAN C.G., CHENG X.J., YU S.S. Analysis on the influencing factors of carbon emissions in China's logistics industry based on LMDI method. Science of Total Environment. **734**, 138473, **2020**.
25. SONG X.H., ZHANG Y.F., WANG Y.M. Analysis of impacts of demographic factors on carbon emissions based on the IPAT model. Research of Environmental Sciences. **25** (1), 109, **2012**.
26. HANG R., WANG Z., DING G.Q. Analysis of influencing factors and trend prediction of energy consumption carbon emissions in Jiangsu Province based on STIRPAT model. Geographical research. **35** (4), **2016**.
27. LI J., ZHOU H. Correlation analysis of carbon emission intensity and industrial structure in China. China Population, Resources and Environment. **22** (1), 7, **2012**.
28. CHONG C.H., TAN W.X., TING Z.J. The driving factors of energy-related CO_2 emission growth in Malaysia:the LMDI decomposition method based on energy allocation analysis. Renewable and Sustainable Energy Reviews. **115**, 109356, 2**019**.
29. WANG L.Y., CHEN X.P., PANG J.X. Energy consumption carbon emission factor decomposition and scenario analysis based on LMDI:A case study of Lanzhou city. Ecological economy. **35** (9), 38, **2019**.
30. ANG B.W. Decomposition analysis for policy making in energy:Which is the preferred Method.Energy Policy. **32** (9), 1131, **2004**.
31. SUN Q., WANG P., CAI G.T. Evaluation model of total energy Consumption index based on LMDI.Ecological economy. **35** (6), 98, **2019**.
32. SU W.X., SUN R.H. Driving factors of carbon emissions from urbanization of typical Urban agglomerations in China.Acta ecological sinica. **38** (6), 1975, **2018**.
33. QI T., ZHANG M. Empirical analysis of carbon emission change in Inner Mongolia – Taking Ordos as an example. Northern Economy. **16** (8), 52, **2013**.
34. SONG L.L., BAI Z.K. A case study on Ordos city: ecological risk assessment and prediction in coal city. Resources and Industries. **19** (5), 15, **2017**.
35. LIU X.Q., PEI T., ZHOU C.H. A systems dynamic model of a coal-based city with multiple adaptive scenarios: A case study of Ordos. China Science: Earth Sciences. **48** (2), 243, **2018**.
36. LIU X.Z., GAO C.C., SONG Y. Temporal-spatial carbon emission patterns caused by fossil energy consumption at the city level in Hunan Province, China and the factors driving their composition. Journal of Ecology. **37** (7), 2476, **2017**.
37. DING F., ZHANG G.Y., LIU D. Environmental regulation, industrial agglomeration and urban carbon intensity: An empirical analysis based on panel data of 282 prefecture-level cities in China. Journal of China University of Geosciences (Social Science Edition). **20** (3), **2020**.
38. WANG J., LI Z.G., GU J.J. Decoupling analysis between energy consumption and economic growth in BRICS countries: Based on Tapio decoupling and LMDI model analysis. World Regional Studies. **30** (3), 501, **2021**.
39. WANG L.Y., CHEN X.P., PANG J.X. Decomposition and scenario analysis of carbon emission from energy consumption based on LMDI method: Taking Lanzhou as an Example. Ecological Economy. **35** (9), 39, **2019**.
40. LI W.T., SONG N.Z., SHEN Y.C. Application of mathematical model in carbon emissions measurement and prediction. Environmental Science and Management. **45** (12), 41, **2020**.
41. CHEN K., CHAI Y.Y., LI K. Effects of population and GDP on land use or cover in resource-based cities: A case

study of Ordos city, Inner Mongolia.Resource development and marketing. **36** (11), 1197, **2020**.
42. LI T., ZHENG Y.X. The population development process since the founding of new China and the population thought and practice history of the Communist Party of China. Ningxia Social Sciences. (01), 134, **2022**.
43. YUAN H.Y., LI F.Q. The "dual carbon" target affects the mechanism and coping strategies of supply-side structural reform. Theoretical discussion. (01), 140, **2022**.
44. LAI W.T., WANG Y., HUANG Y.M., LUO J., CHEN H.Y. The decomposition of industrial carbon emission drivers in Fujian province and its decoupling relationship from economic growth.Chinese Journal of Applied Ecology, Oct. **31** (10), 3529, **2020**.