Proceedings of the 4th International Conference on Materials Chemistry and Environmental Engineering
DOI: 10.54254/2755-2721/61/20240931

Spatiotemporal evolutions and reasons of land-use carbon emissions in counties, Shaanxi Province, China

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Abstract. Global warming caused by factors such as the expansion of construction land poses a major threat to the sustainable development of China. As an important component of China's low-carbon development strategy, there is a relative lack of analysis of the spatial and temporal evolution of land-use carbon emissions and the influencing factors at county-level. In this study, we employed Emission-Factor Approach to estimate carbon emissions from land use in 107 counties, Shaanxi province, China. Our findings revealed construction land were the primary contributors to carbon emissions, showing a substantial increase from 2000 to 2020. There was positive spatial autocorrelation in carbon emissions among counties, forming distinct aggregation patterns around the City of Xi'an and both the southern and northern regions of Shaanxi. By utilizing the Spatial Durbin Error Model (SDEM), demographic factors emerged as key drivers of carbon emissions, indicating the significance of addressing population concentration to curb emissions. Furthermore, promoting coordinated development and adjusting the economic structure in different counties can mitigate both population concentration and carbon emissions. Emphasizing industrial development and investments can also effectively suppress carbon emissions. Additionally, managing transportation-related emissions can be achieved by enhancing public transportation services and regulating private car usage.

Keywords: Land use, carbon emission, SDEM, county-level

1. Introduction

Global temperatures are expected to rise by at least 1.5 °C in the mid-21st century due to carbon emissions from human activities, posing a significant threat to human survival and environmental sustainability [1]. China is the world's largest energy consumer and carbon emitter, whose urban carbon emissions account for 85% [2]. Chinese government has announced its commitment to reach peak carbon emissions by 2030 and achieve carbon neutrality by 2060 during the seventy-fifth session of the United Nations General Assembly [3]. Optimizing land use structure plays a pivotal role in achieving regional carbon emission control [4]. China's "Ten Peak Carbon Actions" includes Peak Carbon Actions for Urban and Rural Construction, Green and Low-Carbon Actions for Transportation, Consolidation and Enhancement of Carbon Sinking Capability, and Orderly Peak Carbon Actions for Various Regions are closely related to the carbon emissions from land use [5]. To provide decision-making support and promote carbon emission control, it' s important to measure, analyze the spatial and temporal evolution, and analyze the influencing factors of carbon emissions from land use. The scale of studies on carbon emissions varies. At present, the related research mainly focuses on the national, provincial and municipal levels [6]. Counties play an important role in the implementation of China's low-carbon development strategy, with their carbon emissions accounting for more than 50% of the total national carbon emissions, and their carbon intensity per unit of GDP being about 20% higher than the national average [7]. Compared with provinces and cities, county carbon emissions are affected by economic scale and industrial structure, showing greater complexity and diversity [8]. However, there is still a gap in understanding the influencing factors of county land use carbon emissions. In this study, in order to effectively curb carbon emissions, the emission factor method is utilized to take Shaanxi Province as the experimental base, and the total amount of carbon emissions and changes in the past ten years are derived from the estimation of carbon emissions, the reasons for raising carbon emissions are derived, and prospective suggestions are put forward.

2. Materials and methods

2.1. Study area

Shaanxi Province is located in northwest China, spanning from 105°29'E to 111°15'E longitude and 31°42’N to 39°35'N latitude, strategically connecting the eastern and central regions of China. The administrative district covers an expansive area of 205,624.3 square kilometers and is characterized by the North Mountain and Qinling Mountains, dividing the province into three distinct natural regions: the Loess Plateau Region in the north, the Guanzhong Plain, and the Qinba Mountain Region in the south. Shaanxi Province comprises 107 county-level divisions.

2.2. Data collection and processing

Table 1. Description of potential influencing factors.

Dimension	Coding	Description of Factor
Economy	x_1	GDP (billion US dollar)
	x_2	GDP per capita (million US dollar)
	x_3	Growth rate of energy consumption per unit of GDP (%)
	x_4	Per capita consumption (million US dollar)
Industry	x_5	Enterprise added value (billion US dollar)
	x_6	Total comprehensive energy consumption of enterprises (million tons of standard coal)
Investment	x_7	Growth rate of social fixed asset investment (%)
	x_8	R&D expenditure (million US dollar)
	x_9	R&D expenditure intensity (%)
Demographics	x_{10}	Population (million)
	x_{11}	Urban population (million)
	x_{12}	Urbanization rate (%)
Traffic	x_{13}	Car ownership (million units)
	x_{14}	Number of buses per 10,000 people (units)

1. Enterprise refers to the industrial legal person enterprise whose annual main business income is 2,769,546 US dollar or more.
2. In order to make the data substituted into the model conform to normal distribution, we processed the original data of GDP per capita, enterprise added value, urban population, urbanization rate, and car ownership by taking the logarithm base 10, and the corresponding x_2, x_5, x_{11}, x_{12}, and x_{13} are obtained.

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Table 2. Land use carbon emission factors (Unit: kg·m-2·a-1).

Land Use Type	Parameter Value
Arable land	0.4595
Forest land	-0.06125
Grassland	-0.0021
Wetlands	-0.0112
Waters	-0.0253
Unused land	-0.0005

1. kgce is the energy of 1 kg of standard coal. The calorific value of standard coal per kilogram is 29,307 kilojoules (7,000 kcal).
2. $t{\cdot}t^{-1}$ means ton of energy/ton of standard coal.

Table 3. Energy standard carbon conversion factor and carbon emission conversion factor.

Energy Type	Standard Carbon Conversion Factor	Unit	Carbon Emission Factor	Unit
Coal	0.7413	$kgce{\cdot}kg^{-1}$	0.7559	$t{\cdot}t^{-1}$
Coke	0.9714	$kgce{\cdot}kg^{-1}$	0.8550	$t{\cdot}t^{-1}$
Crude oil	1.4286	$kgce{\cdot}kg^{-1}$	0.59	$t{\cdot}t^{-1}$
Fuel oil	1.4286	$kgce{\cdot}kg^{-1}$	0.62	$t{\cdot}t^{-1}$
Gasoline	1.4714	$kgce{\cdot}kg^{-1}$	0.59	$t{\cdot}t^{-1}$
Kerosene	1.4714	$kgce{\cdot}kg^{-1}$	0.57	$t{\cdot}t^{-1}$
Diesel	1.4571	$kgce{\cdot}kg^{-1}$	0.59	$t{\cdot}t^{-1}$
Natural gas	1.2143	$kgce{\cdot}m^{-3}$	0.4483	$t{\cdot}t^{-1}$
Electricity	0.404	kgce·kW·h	0.7985	$tCO_2{\cdot}MWh^{-1}$

Land use data of Shaanxi Province were obtained from GlobeLand30 with a resolution of 30 meters. The used land types was processed by ArcGIS 10.5 (ESRI, Redland CA) to obtain land use data of each county. The influencing factors were shown in Table 1. Data of energy consumption in Shaanxi Province were obtained from the China Energy Statistical Yearbook. Social and economic development for each county were collected from the China Energy Statistical Yearbook, China County Statistical Yearbook, and the websites of the statistical bureaus of each county and city. The carbon emission coefficients of various land use types were shown in Table 2. The energy sources were selected in Table3.

2.3. Carbon emission calculation

Carbon emissions from land use sources encompass both non-construction land and construction land. Non-construction land carbon emissions (absorptions) include carbon emissions (absorption) from arable land, forestland, grassland, wetland, water, and unused land, which typically exhibit relatively stable changes in carbon emissions. The Emission-Factor Approach, proposed by IPCC, already widely used in areas like carbon emissions estimation. This study adopted the Emission-Factor Approach and performed calculations using Microsoft Excel 2016. The Emission-Factor Approach for non-construction land is presented in (1).

$$Nk = \sum e_i = \sum T_i \times ai \quad (1)$$

where, Nk represents the total carbon emission (kg) from non-construction land in county k, where k takes values from 1 to 107; the variable ei denotes the carbon emission generated by six different land use types (i=1,2,3,4,5,6) respectively; Ti represents the area of land use type i (km2), and αi denotes the carbon emission (absorption) coefficient associated with each land use type; Positive values of αi indicate carbon emission, while negative values indicate carbon absorption (Table 2).

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The carbon emission from the construction land primarily generated from the indirect estimation of energy consumption in industrial production and mining, transportation, and residential areas during the land use process. The total consumption of various types of energy in Shaanxi Province, as given in the China Energy Statistics Yearbook, was converted into standard coal equivalent in the Emission-Factor Approach. County-level energy consumption data were indirectly measured using the ratio of county GDP to provincial GDP. The estimation formula for the construction land is shown in (2).

$$Ek = \sum Cj \times \beta j \times \delta j \quad (2)$$

where, Ek represents the carbon emission from the construction land in county k; Cj represents the consumption of energy j, with j ranging from 1 to 9; βj denotes the standard coal conversion factor of energy j, while δj represents the carbon emission factor of energy j (Table 3).

The total land use carbon emissions E is calculated by (3).

$$E = Nk + Ek \quad (3)$$

3. Results and Discussion

3.1. The temporal evolution of carbon emission with land use changes

The structure of carbon emission and absorption based on land use for all counties of Shaanxi Province from 2000 to 2020 is shown in Table 5. From 2000 to 2020, carbon emission in Shaanxi Province grew rapidly, but the growth rate tended to slow down. From 2000 to 2010, carbon emissions increased from 36.99 million tons to 129.54 million tons. In 2010 to 2020, carbon emissions increased from 129.54 million tons to 220.34 million tons. The change of carbon absorption was not obvious in the two periods, which could not match the growth of carbon emissions.

The construction land was the most significant carbon source, contributing to 92.05% to 98.70% of the total carbon emissions in both 2000-2010 and 2010-2020 periods, with its carbon emission impact being further strengthened. Simultaneously, the carbon emission role of arable land had weakened significantly, experiencing a rapid decline of 5.72% from 2000 to 2010, attributed to the rapid urbanization in Shaanxi Province during that period.

Regarding the carbon absorption structure, forestland accounted for the largest proportion (over 98%), followed by grassland, contributing to approximately 1.6%. Since 1999, the national project of returning arable land to forest (grass) has been implemented in Shaanxi Province, leading to a gradual increase in the carbon absorption role of forests during both study periods. The project of returning arable land to forest (grass) resulted in an increase of 12,410 km2 of forest over 20 years. However, the impact on carbon absorption was not substantial due to simultaneous urban expansion.

3.2. The temporal evolution of carbon emission with land use changes Analysis of spatial evolution of carbon emission with land use changes

3.2.1. Global spatial autocorrelation features. Based on the results of the global autocorrelation analysis of land use carbon emissions for all counties in Shaanxi Province from 2000 to 2020, it was observed that the Moran's I values of carbon emissions in 2000, 2010, and 2020, as well as the amount of carbon emission changes in the two periods, were all positive.

4. Conclusion

This study estimated the land use carbon emissions of 107 counties in Shaanxi Province in 2000, 2010, and 2020, and analyzed the spatial and temporal differences and influencing factors. The main conclusions are as follows. Based on the findings, the study puts forth several recommendations aimed at enhancing regional carbon management in Shaanxi Province. First, coordinate regional industries development. It is vital to enhance the radiation strength of counties located in the regional economic centers. This can be facilitated through the strategic transfer of high-energy-consuming industries from counties in the HH pattern to counties in the LL pattern, coupled with technological upgrading within retained high-energy-consuming industries. Improve the efficiency of energy use is also support this goal by reducing the rate of growth of energy consumption per unit of GDP, and balancing distribution of land-use carbon emissions and carbon sequestration in the region. Second, develop public transportation. It is essential to improve the county and inter-county public transportation system, ensuring that it effectively meets the daily travel needs of residents while encouraging eco-friendly and sustainable travel choices. By reducing the reliance on automobile ownership, this initiative can help mitigate carbon emissions from land use in both the county and neighboring areas. Third, it is imperative to implement more constrict measures for curbing the uncontrolled spread of construction land, focusing on intensive and compact development.

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