International Core Journal of Engineering
ISSN: 2414-1895
Volume 12 Issue 2, 2026
DOI: 10.6919/ICJE.202602_12(2).0017

Spatio-Temporal Case Study of Carbon Emissions and Balance in a County of Shaanxi Province

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Abstract

Global warming has heightened concerns about carbon emissions, prompting China to implement the "Dual Carbon" strategy. As pivotal connectors between urban and rural areas, counties' carbon emissions research is essential for green, low-carbon development. this study investigates the spatiotemporal patterns of county-level carbon emissions from 2006 to 2021 using nighttime light data and carbon emission statistics. Standard deviation ellipse analysis reveals a steady southeastward shift of the emission center and a near doubling of emissions over the study period. Based on a "Production-Living-Ecological" spaces(PLES) land-use framework, the study evaluates 2021 emissions and applies the Ecological Support Coefficient (ESC) to analyze the spatial distribution of carbon balance. Results show that industry and tourism are the main emission sources, with major carbon sources in the east and sinks concentrated in the northeast. To meet "Dual Carbon" goals, counties should reduce emissions from key sectors and strengthen carbon sink protection to support low-carbon development.

Keywords

County-level Carbon Emissions; Nighttime Light Data; Spatial Pattern; "Production-Life-Ecological" Spaces.

1. Introduction

With the increasing trend of global warming, carbon emissions have become the focus of global attention [1,2]. In order to cope with climate change, China has committed to reach the peak of carbon emissions by 2030, strive to achieve carbon neutrality by 2060, and actively fulfill its international carbon emission reduction responsibility[3]. As a bridge and link between urban and rural areas, the rational allocation of land resources in counties has a direct impact on the overall development strategy of the country [4].In 2021, the Ministry of Housing and Urban-Rural Development, together with 14 other departments, issued the " Opinions on Strengthening the Green and Low-Carbon Construction of County Towns, " emphasizing the county as the carrier, promoting the concept of green and low-carbon, leading the high-quality development of the county, promoting the transformation of green production methods and lifestyles, and helping to achieve the " dual-carbon goal. " However, the current county is in the stage of rapid growth of carbon emissions, and it is expected that the realization of its carbon peak target may lag behind the overall national target by 5 to 10 years[5,6]. Therefore, the county will undoubtedly become the key to future carbon emission reduction work.

Currently, numerous scholars have conducted extensive research on county-level carbon emission accounting methods, spatial and temporal patterns, and carbon balance. In terms of carbon emission accounting, Howie Blue et al. [7] and Hengshuo Zhang et al. [8] employed the energy consumption measurement method to assess carbon emissions in counties of Zhejiang Province. However, this method is relatively simplistic and may not yield accurate carbon emission calculations. On the other hand, Juan Chen et al. [9] and Wang Shaojian et al. [10] utilized data from the China Carbon Accounting Database, offering a comprehensive perspective for future county-level carbon emission reduction efforts. Deng Wenping et al. [11] and Yahui Zhang et al. [12] used the carbon emission measurement method of land use type. This method can not only be directly measured by land type, but also be classified by land function. The method of calculating carbon emissions through the classification of PLES has a strong comprehensiveness and can evaluate regional carbon emissions more comprehensively. Accounting for carbon emissions helps to grasp the actual situation of carbon emissions in the county, and further exploration of the spatial and temporal patterns of carbon emissions in the county can provide insight into the distribution characteristics and trends of carbon emissions. In terms of the characteristics of the spatio-temporal pattern of carbon emissions, scholars at home and abroad mainly adopt the methods of Terre index, spatial autocorrelation, and standard deviation ellipse to reveal the spatial differentiation characteristics of carbon emissions in the study area. For example, Zhou Xuande et al. [13] quantitatively analyzed the overall differences in carbon emissions in Hubei Province using the Terrell index, and Ji Zhang et al. [14] and Zhao Wenting et al. [15] studied the counties using spatial autocorrelation. Zhang Zhiyang et al. [16] and Weiping Zhang et al. [17] used the standard deviation ellipse to explore the characteristics of the spatial pattern and spatial distribution of carbon emissions. The Terrell index is sensitive to extreme values and susceptible to individual high carbon emission factors. The local heterogeneity of spatial autocorrelation can lead to the global spatial autocorrelation analysis results not being accurate enough. The standard deviation ellipse, on the other hand, is suitable for revealing the degree of spatial aggregation and directionality of the data, which helps to understand whether the spatial distribution of the data exhibits a specific trend or directionality. The spatial and temporal characteristics reveal the spatial distribution and temporal change rules of carbon emissions, and further use the carbon ecological sustainability coefficient (ESC) to study the carbon balance partition. For instance, Wang Lirong et al. [18] used the carbon ecological sustainability coefficient to analyze the carbon emission network spatial correlation module of the county area of Gansu Province, the carbon neutralization division, and research on carbon balance partitioning is conducive to clarifying the key regions and key areas of carbon emission reduction. On the whole, the study of county carbon emissions is gradually improving. However, due to the fact that the socio-economic data at the county scale are often incomplete, most of the studies are limited to exploring county carbon emissions from the national and provincial perspectives, and lack in-depth studies on specific emission sources. This study aims to synthesize the advantages of multiple methods and adopt data on land use and nighttime lighting to make a refined assessment of county carbon emissions in order to reveal in depth the intrinsic mechanisms of carbon emissions and their spatial variability.

In this study, a county in Shaanxi Province was selected as the research object. The correlation analysis method between nighttime lighting data and carbon emissions was applied to analyze the spatial and temporal patterns and distribution laws of carbon emissions in the county from a macroscopic perspective. Based on this, this study combined with the specific classification of PLES, conducted an accurate quantitative assessment of the county 's carbon emissions in 2021, and further analyzed the spatial distribution characteristics of carbon balance from a small scale.This provides solid theoretical support and practical reference for local governments to formulate scientific and reasonable carbon emission management strategies.

2. Research Data and Methods

During the "13th Five-Year Plan" period, the continuous improvement of ecological environment quality in China is facing great pressure. Entering the " 14th Five-Year " stage, China has entered a new journey of building a modern socialist country in an all-round way [19]. This study analyzes the characteristics of county-level carbon emissions from 2006 to 2021 with a five-year cycle, and constructs a PLES system to accurately calculate carbon emissions in a specific year, and discusses the spatial distribution of carbon balance. In view of the availability of data, this study selected 2021 as the year of detailed calculation. The research framework is detailed in Fig. 1.

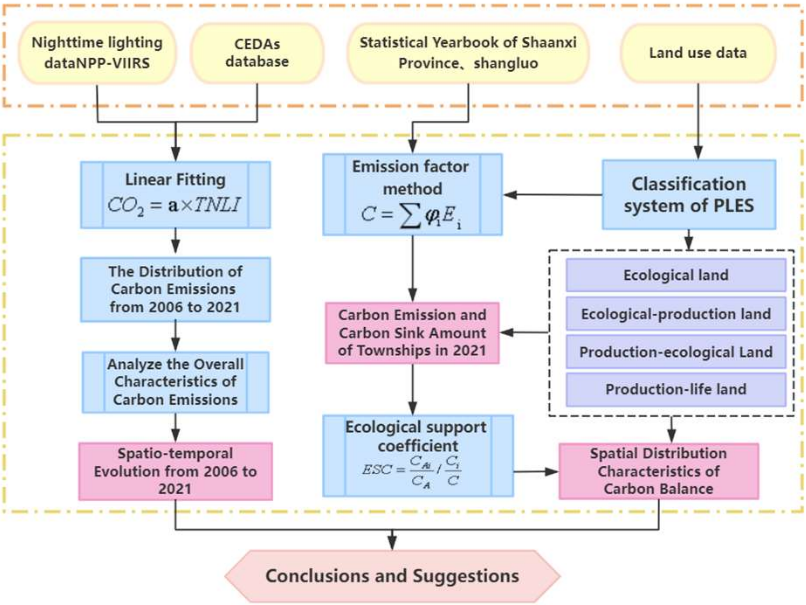

Fig. 1 Research framework diagram.

2.1 Study Area and Data Sources

2.1.1 Overview of the Study Area

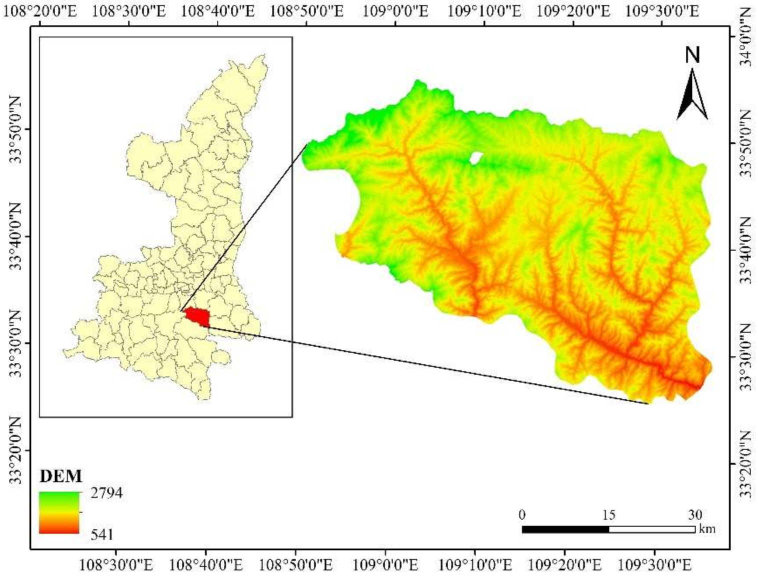

Fig. 2 Geographical positioning map of Study area.

China's development has entered a new era, and the rural revitalization strategy has been incorporated into the national development strategy [20], emphasizing its strategic importance in national development. The rural revitalization strategy encompasses not only economic development but also places a significant emphasis on the protection and enhancement of the ecological environment [21]. The study area of this paper is located in Shangluo City, Shaanxi Province, situated in the northwest of the city. As a practical and innovative base for the concept that "lucid waters and lush mountains are invaluable assets", the area boasts a thriving tourism industry, abundant natural resources, and unique ecosystems that provide vital ecological services. Consequently, an investigation into the region's carbon emission characteristics not only aids in understanding its ecological status but also enables a more precise identification and quantification of carbon emission sources, offering a foundation for the formulation of localized emission reduction strategies. The geographic location of this study area is indicated in Fig.2.

2.1.2 Data Sources

The county's carbon emissions from 2006 to 2017 were obtained from the CEDAs database (https://www.ceads.net/data/county/). The data related to the calculation of carbon emissions from PLES in 2021 were sourced from Statistical Yearbook of Shaanxi Province, the Shangluo Municipal Statistical Yearbook, and the County's 2021 Statistical Bulletin of National Economic and Social Development. Additional related data are presented in Table 1.

Table 1. Data Source

Data type	Data source
Administrative division data	National Geographic Information Public Service Platform (Tianditu)
Land use data	CLCD(China Land Cover Dataset)
Nighttime light data	The National Earth System Science Data Center (https://www.geodata.cn) global 500-meter resolution "NPP-VIIRS-like" nighttime light dataset

2.2 Classification of PLES and Measurement of Carbon Emissions

2.2.1 Classification System of PLES

The natural environment constitutes the foundation for human activities, and the land system exhibits a variety of functions due to the interplay of natural, economic, and social needs. China's PLES classification system emphasizes the roles of land in ecology, production, and life. Yu Li et al. [22] synthesized the criteria of the "Current Land Use Classification" to scientifically illustrate the current state and development trends of land use. The system helps policy makers balance land resource allocation by distinguishing ecological land , Ecological-production land, etc.

Table 2. "Production-life-ecological" space classification system

PLES classification system		Land use types
Item	Implication	
Ecological land	Human utilization is relatively limited, capable of directly or indirectly improving regional ecological environments.	Grassland
		Water land
Ecological-production land	Possesses dual functions of ecology and agricultural production, but the ecological function outweighs the production function.	Forest land
		Shrub land
Production-ecological land	The primary objective is to obtain agricultural products while simultaneously providing ecological functions.	Cultivated land
Production-life land	Wholly or partially covered by buildings or structures, used for production or living purposes other than agricultural production.	Impervious surface

2.2.2 Carbon Emission Measurement Methods

Carbon emission estimation encompasses various land use types. By quantifying the carbon emissions (sinks) associated with PLES, we analyze the disparities in carbon activities between village and town development. This reveals the connection between the spatial attributes of these three living spaces and carbon activities. “Ecological” and “ecological-production” land is dominated by carbon sinks, emphasizing its ability to absorb and store carbon ; “Production-ecological” and “Production-life” land is focused on the amount and source of carbon emissions, using the coefficient method to calculate. Carbon sinks and sources are determined using equations (1) and (2), respectively.

$$C_h=\sum(L_i\times\alpha_i) \tag{1}$$

where Ch represents the carbon sink; Li denotes the area classified by land use type for area i; and αi is the carbon emission factor for various land use types.

$$C_y=\sum\left(\varphi_i\times E_i\right) \tag{2}$$

Where: Cy is the carbon emission, tons; is the carbon emission coefficient; Ei is the consumption of each type.

Various types of carbon emission coefficients are selected as follows:

(1) Ecological land

Rural ecological land plays a key carbon sink role in ecosystem services, absorbing and storing carbon dioxide through processes such as vegetation, soil and water cycle. The carbon sink coefficient has different standards according to different land use types. Through the relevant literature, the carbon sink coefficient of grassland is 0.0021 C Kg / m2 * a [23], and the carbon sink coefficient of water body is 0.0257 C Kg / m2 * a [24].

(2) Ecological-production land

Ecological-production land mainly includes forest land (including forest and orchard), in which orchard has production function. Carbon emissions from orchards are far less than their carbon sinks, so this part of carbon emissions can be ignored. [25] The northern part of the study area belongs to the warm temperate climate, and the southeast belongs to the northern subtropical climate. The whole county is in the transition zone between subtropical and warm temperate climate. The carbon sink coefficient was selected as 0.0613 C Kg/m2*a [26].

(3) Production-ecological Land

Table 3. Agricultural carbon emission coefficient

Carbon source	Carbon source factor	units	Source
Fertilizer	895.6	C kg/t	Oak Ridge National Laboratory
Pesticide	493	C kg/t	Oak Ridge National Laboratory
Geomembrane	5180	C kg/t	Study on Agricultural Resources and Ecological Environment of Nanjing Agricultural University
Ploughing	312.6	C kg/km^2	College of Biology and Technology, China Agricultural University
Irrigation	2.66	C kg/km^2	CUI Yongfu, et al.[27]

Production ecological land mainly refers to cultivated land. Based on previous studies, this paper points out that carbon emissions from agricultural production are mainly caused by the consumption of agricultural materials, especially the use of pesticides, agricultural films and fertilizers, and tillage. These activities increase agricultural production, but also lead to greenhouse gas emissions. In order to accurately assess the carbon emissions of agricultural activities, this paper systematically sorts out and analyzes the relevant research results at home and abroad, and selects and determines the corresponding carbon emission coefficients of various agricultural activities.

(4) Production-life land

The land for living and production includes land for rural and urban living purposes, as well as land for production, transportation, culture and entertainment. The life and production functions of such land are intertwined and difficult to clearly distinguish. In this study, the two major areas of life and production land are mainly responsible for production functions : animal husbandry and industry. Meanwhile, the resource consumption of life land is mainly reflected in the direct and indirect consumption of villagers.

Production - Animal Husbandry

The carbon emission calculation of animal husbandry mainly includes the methane emission of intestinal tract and feces. The animal husbandry in this county mainly includes the breeding of cattle, sheep, pigs and poultry. Table 4 shows the relevant carbon emission coefficients.

Table 4. Carbon emission coefficient of animal husbandry

Carbon source	Carbon emission coefficients	units	Source
Intestinal canal			
Cattle	47	kg CH_4/head/year	IPCC
Pig	1	kg CH_4/head/year	IPCC
Sheep	5	kg CH_4/head/year	IPCC
Defecation			
Cattle	1.86	kg CH_4/head/year	Provincial CO_2 emission inventory
Pig	1.38	kg CH_4/head/year	Provincial CO_2 emission inventory
Sheep	0.32	kg CH_4/head/year	Provincial CO_2 emission inventory
Poultry	0.01	kg CH_4/head/year	Provincial CO_2 emission inventory

Production-Industry

The calculation of industrial carbon emissions usually uses the coefficient method, which is divided into the output value coefficient method and the energy consumption coefficient method. Currently, the energy consumption coefficient method is more commonly used, but the data acquisition in rural areas is difficult and easy to miss, which affects the accuracy of the results. Therefore, the output value coefficient method is more appropriate. Table 5 is the emission coefficient of related industries.

Table 5. Carbon emission coefficient of some industries

Carbon source	Carbon emission coefficients	units	Source
Tourism	1.33	t CO_2/(ten thousand yuan)	HE Yanqiu [28]
Steel industry	0.15	t CO_2/t	LI Shuaike[29]
Ferroalloy industry	0.28	t CO_2/t	LI Shuaike

Life

Carbon emissions in life mainly include direct consumption and indirect consumption. Direct consumption includes the use of various energy sources; indirect carbon emissions are mainly consumed by villagers in food, clothing, living, transportation, education, culture and entertainment, and health care. Table 6 presents the corresponding carbon emission coefficients.

Table 6. Carbon emission coefficient of domestic consumption

Consumption category	Carbon emission coefficients	units	Source
Food	0.095	kg C/yuan	TANG Wei[30]
Clothing	0.115	kg C/yuan	TANG Wei
Living and residential	0.168	kg C/yuan	ZHANG Mimi[31]
Transportation	0.193	kg C/yuan	TANG Wei
Education, Culture and Recreation	0.14	kg C/yuan	TANG Wei
Medical care	0.157	kg C/yuan	ZHANG Mimi
Energy consumption	0.67	t C/t standardized coal	National Development and Reform Commission

2.3 Characterization Methods for Spatial and Temporal Evolution

2.3.1 Fitting Nighttime Lighting to Carbon Emissions

Nighttime lighting data reveals the concentration and distribution of human activities, and quantitative analysis aids in assessing the intensity and type of these activities and their impact on energy consumption and carbon emissions. Combined with nighttime light data and carbon emissions, the main carbon emission sources can be identified. By processing the nighttime light data of ' NPP-VIIRS ', the continuous county nighttime light image is generated, corrected, projected and normalized. Then, a linear model of nighttime lighting and carbon emissions is established to explore the relationship between the two, and an equation is constructed to predict carbon emissions. The calculation formula is:

$$CO_2=a\times TNLI \tag{3}$$

Where CO2 represents carbon emissions, in tons; a is the fitting coefficient; and TNLI (Total Nighttime Light Intensity Index) indicates the sum of brightness values of image elements within the administrative unit.

In this paper, the error between the fitting amount and the specific calculation amount is 18.9 %, which shows that the prediction of carbon emissions by night light has high accuracy.

2.3.2 Standard Deviation Ellipse

Standard deviation ellipse analysis is used to quantify the spatial distribution characteristics and evolution of research objects. The center of the ellipse shows the location of the geographical elements, and the azimuth indicates the main distribution direction. The standard deviations of the long axis and the short axis represent the degree of dispersion of the elements in the main and secondary directions, respectively.

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2.4 Ecological Support Coefficient of Carbon Emissions

Ecological Support Coefficient of carbon emissions (ESC) reflects the carbon sink capacity of each region from an ecological perspective and measures the fairness of the ecological capacity contribution of each regional unit [32]. The calculation formula is:

$$ESC=\frac{C_{Ai}}{C_A}/\frac{C_i}{C} \tag{4}$$

Where ESC represents the ecological carrying capacity coefficient for carbon emissions, CAi signifies the carbon absorption of each township, and CA denotes the total carbon absorption of the county. Ci represents the carbon emission of each township, and C represents the total carbon emission of the county. If ESC > 1, it shows that the contribution of township carbon sinks exceeds carbon emissions, with additional carbon emission quotas and high ecological carrying capacity, which is beneficial to the ecology of other regions and promotes regional sustainable development. Conversely, If ESC < 1, it indicates that the carbon emissions in the region are unbalanced, the ecological carrying capacity is weak, and the carbon compensation rate is low, which may cause environmental problems and affect the surrounding ecological stability.

3. Results and Analysis

3.1 Fitting Analysis of Night Lighting and Carbon Emission

After processing the nighttime light data, the total nighttime light value of the county is obtained. Combined with the total value of nighttime lights and the carbon emissions in the database, a linear estimation model of carbon emissions is constructed. The results of the linear fitting are shown in Fig. 3:

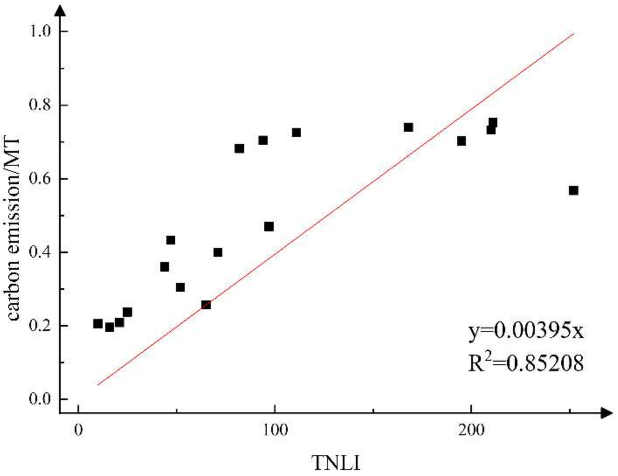

Fig. 3 The result of linear fitting between carbon emission and light.

The research focuses on the temporal and spatial changes of county-level carbon emissions from 2006 to 2021, because the CEDAs database is only updated to 2017. By fitting the carbon emission data with the nighttime light data, the missing carbon emissions from 2018 to 2021 are predicted.The high goodness of fit (R2 = 0.85208) of the fitting equation verified the prediction accuracy and supplemented the missing data.

3.2 Analysis of Spatio-temporal Pattern Evolution

ArcGIS software is used to integrate nighttime light data and carbon emission data to describe the distribution of carbon emissions from 2006 to 2021 in the county area.In view of the fact that nighttime light-intensive areas are mostly concentrated in towns and their adjacent watersheds, by extracting carbon emission information from these areas, we can construct a more detailed and detailed view of carbon emission characteristics and obtain the detailed distribution of carbon emissions in the county.

From 2006 to 2021, the county 's carbon emissions continued to grow, increasing by about twice. According to the results of Fig. 4, in 2006, the carbon emissions of Qianyou Street were significantly higher than other areas in all townships. However, by 2011, the geographical distribution pattern of carbon emissions has changed significantly. The carbon emissions of Xialiang Town and Xiaoling Town have increased significantly compared with 2006, jumped to the forefront of the county, and became one of the fastest growing areas of carbon emissions in the county at that time. By 2016, the geographical distribution pattern of county-level carbon emissions is still mainly concentrated in the three regions of Qianyou Street, Xialiang Town and Xiaoling Town. By 2021, the high-carbon emission areas in the whole basin will be less but the distribution of carbon emissions will be wider.

The geographical distribution of carbon emissions has a great relationship with local economic development. In 2006, the main economic activities and energy consumption were concentrated in the county (Qianyou Street) ; By 2011, Xialiang and Xiaoling towns in the county focused on the vigorous development of the steel industry and non-ferrous metal material bases. By strengthening the construction of industrial parks and actively expanding the scale of industrial economy, the economic activities of these two towns significantly promoted the rapid growth of carbon emissions in a short period of time. In 2016, the county is committed to promoting the expansion and upgrading of industrial concentration areas, accelerating the pace of construction of modern industrial parks, and strengthening the construction of park service platforms to promote further economic development. In 2021, due to the development of rural economy, the overall carbon emissions still show an upward trend, but it can be clearly observed that the geographical distribution of carbon emissions is more uniform, which reflects the equalization trend of economic development in different regions of the county.

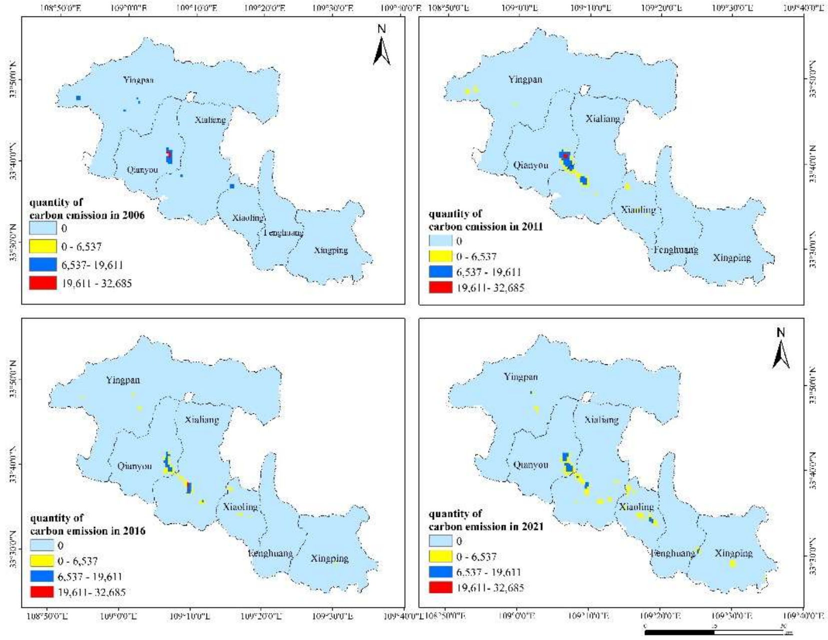

Fig. 4 Spatial distribution of carbon emissions from 2006 to 2021.

Through the standard deviation ellipse method and the center of gravity migration model, the spatial distribution and center of gravity change of carbon emissions in the study area can be clearly found.The results(Fig.5) show that the spatial distribution of carbon emissions is different from northwest to southeast, and the center of gravity continues to move southeast. This trend is related to the development of the industrial zone in the southeast and the adjustment of energy structure. In particular, as the main industrial center of Xiaoling Town, the focus of carbon emissions has shifted to the town.

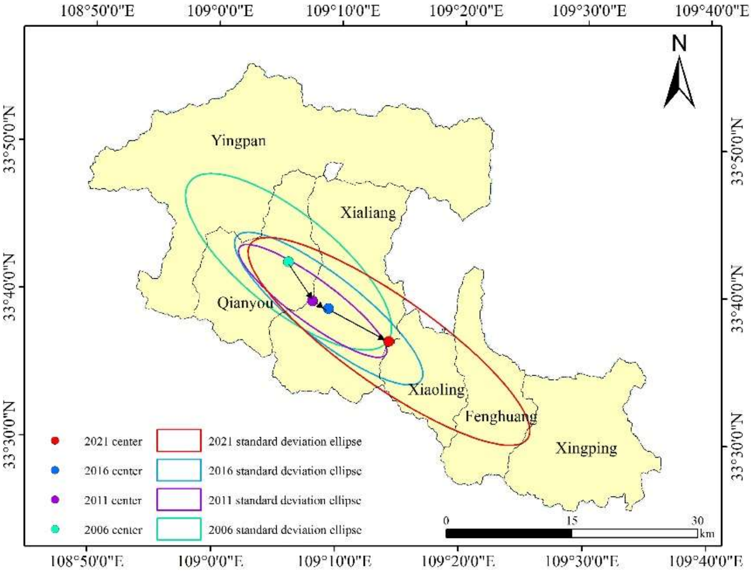

Fig. 5 Carbon emission standard deviation ellipse from 2006 to 2021.

3.3 The Calculation Results of Carbon Emissions of PLES Classification System

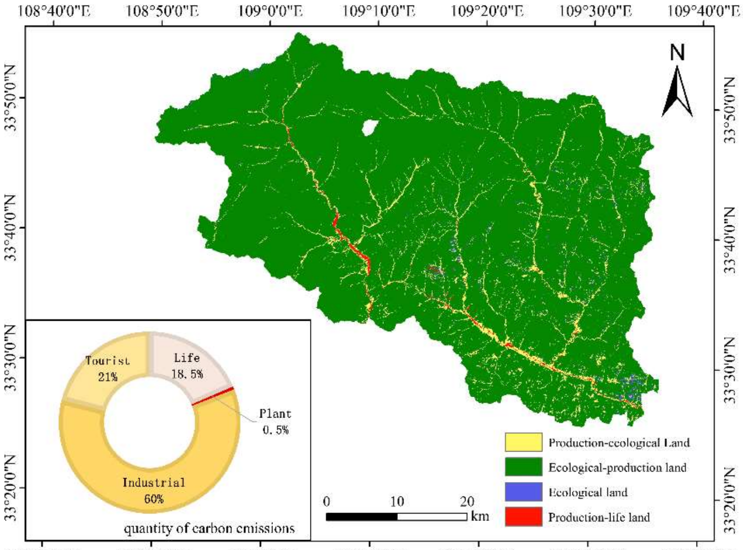

Fig. 6 Spatial distribution of "ecological, living, and industrial" land.

Studying the spatial evolution mechanism of long time series is helpful to reveal the temporal dynamic law of county carbon emissions. Accurate assessment of carbon emissions in a specific year can identify emission hotspots during this period and provide scientific support for formulating targeted emission reduction strategies. Based on the classification system of PLES, this study calculates the total amount of carbon emissions in the county by calculating the area of various types of land in the county and its use and production data, and calculating the total amount of carbon emissions in the county by the coefficient method. Fig. 6 shows the distribution of PLES classification system and the proportion of various carbon emissions in this study area in 2021.The county 's net carbon emissions in 2021 are accurately calculated to be 870,877.63 tons, and the carbon sink is

3,409.92 tons. Among them, the carbon emission of planting industry is 4,590 tons, accounting for only about 0.05 % of the total carbon emission of the county; the proportion of residents ' life carbon emissions is as high as 18.5%. The main sources of carbon emissions in the county are the secondary industry and the tertiary industry (especially tourism), which account for about 80 % of the county 's total carbon emissions.

Fig.7 shows the proportion of carbon emissions in the PLES classification system of each township. Xingping Town has the best performance in carbon absorption of ecological land, and the level of other towns is comparable. Yingpan Town is leading in carbon absorption of ecological-production land, and its carbon absorption accounts for 35 % of the county, benefiting from abundant forest resources. In terms of carbon emissions, Xingping Town has the highest carbon emissions from cultivated land, accounting for 20 % of the county. Life-production land is the main source of carbon emissions, including animal husbandry, industry and daily life consumption. Xiaoling Town, Qianyou Street, Xingping Town and Xialiang Town account for a large proportion of carbon emissions from living and production land. The differences in carbon emissions among townships are directly related to the local industrial structure and land use patterns. These findings provide an important reference for county-level carbon emission management and land use planning.

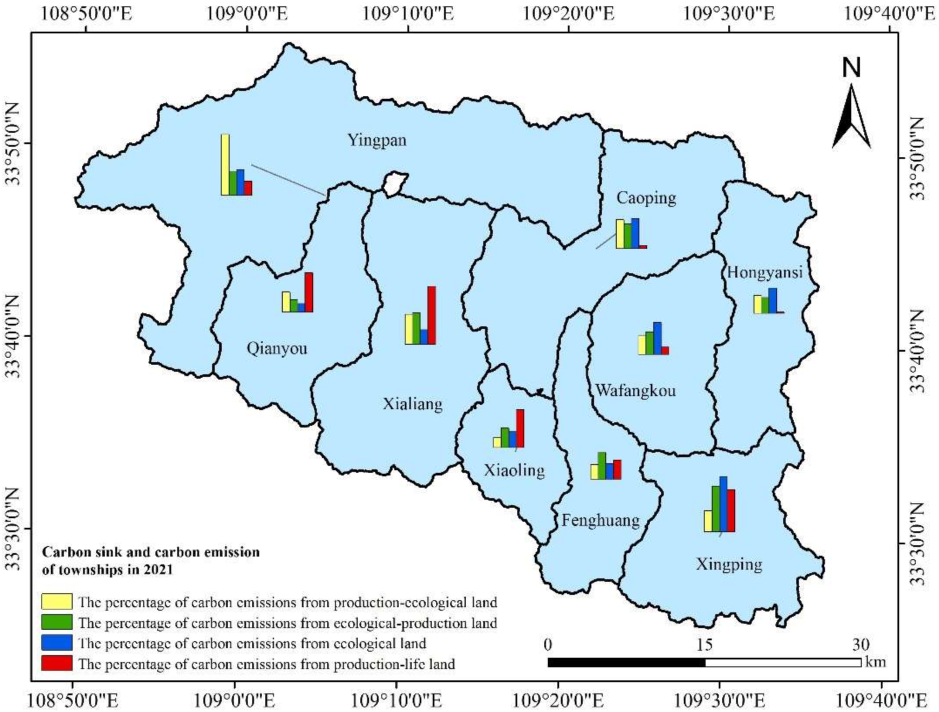

Fig. 7 Carbon emission of "ecological, living, and industrial" lands in each township.

3.4 Analysis of Spatial Pattern of Carbon Balance

The economic development level and industrial structure of different townships are different. As shown in Fig. 8, the townships with large carbon emissions in the county mainly include Xiaoling Town, Qianyou Street, Xingping Town and Xialiang Town. This is mainly due to the high level of urbanization in these areas and the concentration of industrial industries in the county. In contrast, Yingpan Town is dominated by tourism and agriculture. Among them, Niubeiliang National Forest Park is a key area for ecological protection. Its dense forest vegetation effectively absorbs a large amount of carbon dioxide, which greatly alleviates the town 's carbon emission problem and highlights its significant carbon sink capacity.

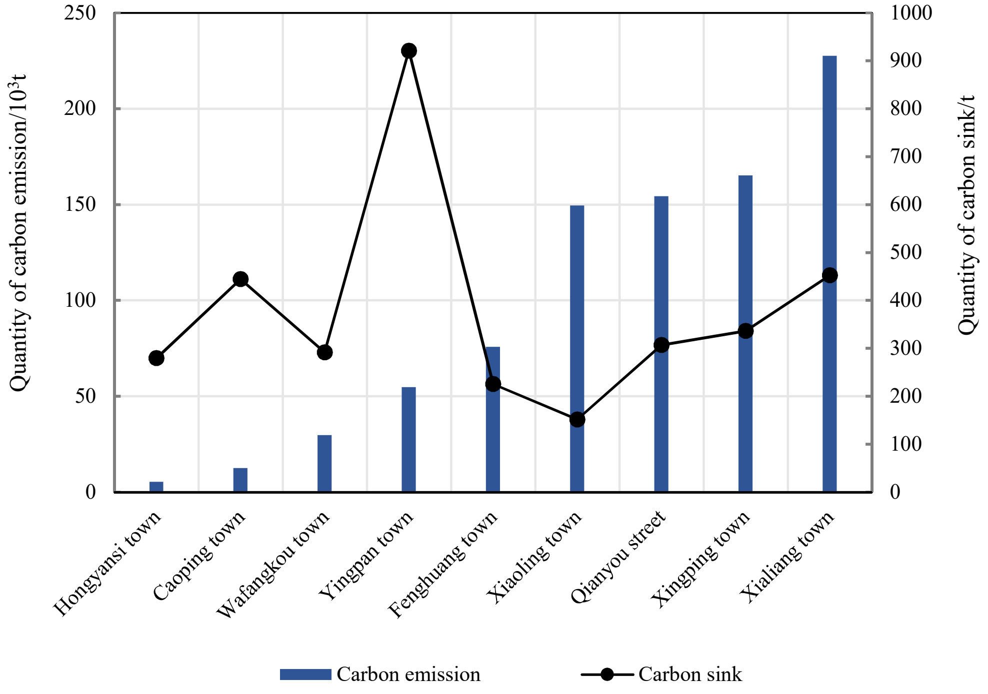

Fig. 8 Carbon emissions and carbon sinks by township.

Fig. 9 reveals the significant differences in the spatial distribution of carbon ecological carrying coefficient in the county, showing a lower distribution pattern in the southwest and a higher distribution pattern in the northeast. With the acceleration of urbanization, the ecological carrying capacity of the basin has been unable to fully offset the increase of carbon emissions, which constitutes a potential threat to the current environmental quality.

Specifically, the ESC of Xiaoling Town is the smallest, less than 0.5, which reveals that the carrying capacity of its ecological environment is the weakest. The ESC of four townships is in the range of 0.5 to 1, indicating that their carbon compensation capacity needs to be improved. The ESC of Yingpan Town and Wafangkou Town is in the range of greater than 1 but less than 5, indicating that the carbon absorption capacity of these two towns exceeds carbon emissions and has a certain carbon sink surplus, which has played a positive external effect on maintaining the ecological balance of other towns in the county. The coefficients of Caoping Town and Hongyansi Town are far more than 5, and their prominent feature is the strong carbon sink function, which contributes significantly to the ecological balance of the whole county. Among them, Yingpan Town has the largest area and the largest amount of carbon sinks. However, due to the high carbon emissions caused by the operation of scenic spots in the town, its carbon sink capacity is slightly less than that of Caoping Town and Hongyansi Town, but it still maintains a certain ecological carrying level. In view of the low ecological carrying coefficient areas such as Xiaoling Town, we should strengthen ecological restoration, improve vegetation coverage, enhance soil conservation and water conservation capacity, so as to gradually improve its ecological carrying capacity. Encourage and support the development of low-carbon, environmentally friendly and efficient green industries in villages and towns. For villages and towns with coefficients in the range of 0.5 to 1, the construction of carbon compensation mechanism should be strengthened, and local residents and enterprises should be encouraged to actively participate in ecological protection activities and enhance regional carbon compensation capacity through afforestation and ecological compensation.

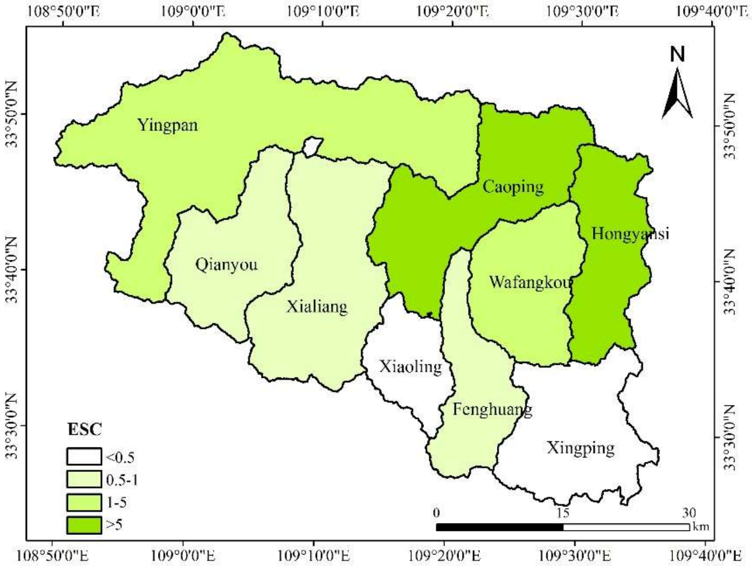

Fig. 9 Spatial distribution of ecological carrying coefficient of carbon emission.

4. Conclusion and Recommendations

4.1 Conclusion

In this paper, a county in Shangluo City, Shaanxi Province is taken as the research object. Firstly, the NPP-VIIRS nighttime light data and CEADs database are fitted to verify their correlation, and the fitting equation is obtained and the carbon emission status from 2006 to 2021 is obtained according to the equation. Then the county 's carbon emissions in 2021 are calculated in detail through the PLES classification system and statistical data. According to the ecological support coefficient of carbon emissions, the spatial distribution characteristics of carbon balance are obtained.

(1) From 2006 to 2021, the county 's carbon emissions showed a significant upward trend, and the growth rate was about doubled. The carbon emission center shows a continuous and stable trend of moving southeastward. This trend is closely related to the acceleration of industrialization and urbanization in the southeastern part of the county. With the development of the economy, the industrial production and residents ' living activities in the region have increased, resulting in an increase in energy consumption and carbon emissions.

(2) The net carbon emission of the county in 2021 is 870,877.63 tons, and the carbon sink is 3,409.92 tons. The county 's industry and tourism are the main sources of carbon emissions, which is similar to the conclusion of Zheng Quanyi et al. on carbon emissions in Quanzhou County.Industrial is the main source of emissions both at the county level and at the township level. Xiaoling Town, Qianyou Street, Xingping Town and Xialiang Town are the main carbon source areas in the county. Yingpan Town and Caoping Town are the main carbon sink areas.

(3) In 2021, the spatial distribution characteristics of the carbon balance of the PLES classification system are high in the east and low in the west. The towns with strong carbon sink function are mainly distributed in the northeast. At the same time, it is worth noting that although the towns in the northwest have outstanding performance in carbon sink function, their carbon emissions are also relatively high, which indicates that these areas need to seek a better balance between economic development and environmental protection. The carbon compensation capacity of villages and towns along the river basin direction is relatively weak, and it is necessary to strengthen the construction of carbon sinks to achieve sustainable development.

4.2 Suggestions

(1) It is worth noting that although the number of high-carbon emission areas will decrease in 2021, the upward trend of total carbon emissions shows that the overall carbon emission control of the county is still facing challenges. Therefore, the future development strategy needs to pay more

attention to sustainable development, through scientific and technological innovation and industrial upgrading, to achieve a win-win situation between economic growth and environmental protection. Construction land is the main carbon source, and its high carbon emission coefficient means that its area increase will lead to more carbon emissions. In the future, it is necessary to reasonably control the expansion intensity of construction land, improve the utilization efficiency of construction land, and effectively control the carbon emission intensity.

(2) The overall planning of county spatial planning is of great strategic significance for the realization of total carbon emission control. In the planning, it is necessary to coordinate the production, life and ecological space, especially the industrial and residential space layout. At the same time, the protection and construction of ecological space should be strengthened. In view of the reduction of carbon emissions in the industrial sector, the land use layout should be adjusted, the energy structure should be optimized, and the use of renewable energy should be increased. Tourism, as another major source of carbon emissions in the county, also needs to take corresponding carbon reduction measures : First, strengthen the construction of public transport in the scenic area, promote the use of electric vehicles and hydrogen energy vehicles, and optimize traffic routes ; secondly, the scientific and rational development of natural landscape resources ; finally, guiding tourists to adopt low-carbon ecological behavior helps to cultivate tourists ' low-carbon awareness, thus promoting the reduction of carbon emissions.

Abbreviations:

“Production-Living-Ecological” spaces(PLES)

Ecological Support Coefficient (ESC)

Declarations:

Consent for Participation and Publication:

Not applicable.

Availability of Data and Materials

The data that support the findings of this study are openly available in Mendeley Data at https://data.mendeley.com/datasets/9sfj8v8jyc/1, reference number 10.17632/9sfj8v8jyc.1.

Competing Interests

The authors declare they have no competing interests.

Acknowledgments

Funding:

This paper has no funding support.

The authors gratefully acknowledge the institutions and researchers who provided the statistical data, energy consumption data, and nighttime light datasets used in this study. Their data support and related research contributions made this work possible.

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