SPATIAL SERVICE SCOPE OF CARBON NEUTRALITY AND ITS SIMULATION PREDICTION IN THE LOESS PLATEAU OF CHINA

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(Received 20th Dec 2023; accepted 25th Mar 2024)

Abstract. Quantifying carbon neutrality and its spatial range on the Loess Plateau of China is crucial for effective carbon planning. By utilizing advanced systems like the (Intelligent Urban Ecosystem Management System, IUEMS) and satellite data, we estimated carbon sequestration and emissions. Spatial carbon neutrality was determined, projecting distributions using the (Patch-generating Land Use Simulation Model, PLUS). Results show increasing carbon sequestration from 2000 to 2020, particularly in central and western regions. Topographical factors like altitude and slopes significantly influence sequestration. Carbon emissions are low overall, concentrated in urban areas on the northern slope, with an initial increase followed by a decline. The carbon neutrality service range from 2000 to 2050 spans 174-262.63 km, gradually expanding in space, albeit slightly decreasing after 2030.
Keywords: *carbon neutralization, carbon sink, carbon emissions, IUEMS model, the Loess Plateau*

Introduction

The "Dual Carbon Action" is a part of the international effort to combat climate change (Zhang and Liang, 2022). The European Union is the pioneer of "carbon neutrality" and has set a goal to achieve it by 2050 (Joos et al., 2001). During the 14th Five-Year Plan period, ecological civilization construction of China has entered a critical phase of transitioning from quantity-based to quality-based improvements, with a focus on carbon reduction as a strategic priority, promoting synergistic efficiency gains from pollution and carbon reduction, and facilitating a comprehensive green transformation of the economy and society for ecological and environmental quality enhancement. Given the current carbon emissions situation, realizing carbon neutrality is the primary research issue for China's carbon reduction strategy. The Chinese Academy of Sciences' consultation project on the "China Carbon Neutrality Framework Roadmap Research" divides the process of achieving carbon neutrality into emission reduction, carbon sequestration, and policy promotion. Carbon neutrality refers to the absorption of artificially emitted carbon dioxide (from fossil fuel use and land use), by human activities such as timber accumulation, soil organic carbon, and engineering sequestration, as well as natural processes such as ocean absorption, carbon burial in erosion-sedimentation processes, and carbon sequestration in alkaline soils (Sun et al., 2019). Thus, carbon emissions refer to the amount of carbon dioxide artificially emitted by human activities, including the use of fossil fuels and land use, as well as the amount of carbon absorbed by human activities such as timber accumulation, soil organic

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_22252240

carbon, engineering sequestration, and natural processes such as ocean absorption, carbon burial in erosion-sedimentation processes, and carbon sequestration in alkaline soils. The forest ecosystem has the highest proportion of carbon sinks among all ecosystem types. Therefore, quantitatively analyzing the carbon sequestration capacity of forest ecosystems and their role in carbon neutrality has both theoretical and practical significance.

The Loess Plateau is the largest forest-grassland hybrid ecosystem in western China. In recent years, with the implementation of China's policy of converting farmland back to forests and grasslands, the vegetation restoration rate on the Loess Plateau has accelerated significantly, leading to a marked increase in vegetation coverage. This has had a significant neutralizing effect on carbon emissions from surrounding cities. Therefore, the Loess Plateau forest-grassland hybrid ecosystem can be seen as a colossal carbon-absorbing server. In addition to absorbing carbon from the local area, this ecosystem can also fix the amount of carbon in the surrounding area. To address this issue, it is possible to calculate the spatial service range of carbon neutralization by considering the air diffusion characteristics of carbon dioxide. This approach can contribute to the formulation of China's carbon-neutral spatial planning policy and the achievement of its dual carbon goals.

At present, there are three main methods for estimating carbon sequestration: traditional forest carbon inventory methods, carbon sequestration models, and remote sensing carbon measurement methods. Regarding forest carbon inventory methods, there are several ways to estimate carbon storage, including satellite remote sensing data estimation, continuous function factor, growth equation and carbon storage biomass conversion and expansion factor, inventory, biomass, biological inventory, decomposition method (Fang et al., 2022), logarithmic average Divisia index (LMDI) method, sample plot census method, and regression model method (Wei et al., 2022). The commonly used carbon sequestration models include the CASA model (Wang et al., 2020), BIOME-BGC model (Hammond et al., 2021), INVEST model (Hwang et al., 2021), and forest stand biomass accumulation model (Schwartz, 2022). These models have been widely used in carbon sequestration quantification and ecosystem carbon sequestration service research, such as the spatial flow and pattern optimization of carbon sequestration services (Staffell et al., 2017), as well as the trade-off and synergistic relationship between carbon sequestration services and other ecosystem services (Xie et al., 2018, 2020). However, these carbon sequestration models often require a large number of relevant parameter adjustments, and their accuracy is greatly influenced by meteorological conditions. Although remote sensing carbon measurement methods have the advantage of being more expedient, intuitive, and accurate, their technical processes are still in the developmental stage, and their applications need to be further matured. Therefore, this study employed the carbon sequestration and oxygen release model in the International Union of Forest Research Organizations to calculate the carbon sink of the Loess Plateau. The model mainly utilizes the method of net ecosystem productivity estimation, which combines the conversion coefficient of biomass to carbon and the conversion coefficient of net ecosystem productivity and net primary productivity in different provinces and cities. Meanwhile, the ratio of CO_2 to carbon molecular weight is also taken into account. This approach considers the process principle of vegetation carbon sequestration and is characterized by its simplicity and convenience, making it highly applicable for calculating carbon sink of forest ecosystems.

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The aim of this study is to estimate carbon sequestration on the Loess Plateau in China using the carbon absorption and oxygen release model within the Intelligent Urban Ecosystem Management System (IUEMS). Carbon emissions in the region were simulated using nighttime lighting data to calculate carbon neutrality. Additionally, the Patch-generating Land Use Simulation Model (PLUS) was employed to forecast carbon neutrality on the Loess Plateau for 2030 and 2050. Furthermore, combining common gas diffusion coefficients with atmospheric CO_2 density, the spatial service range of the Loess Plateau's carbon sink was computed. The study outcomes aim to provide scientific grounds for the dynamic and spatial planning of carbon storage in carbon neutrality, offering decision-making support to relevant authorities in the Loess Plateau region of China.

Materials and Methods

Description of study area

The Loess Plateau, covering an area of approximately 640,000 square kilometers, is situated in the northern-central part of China and is one of China's four major plateaus (*Fig. 1*). The terrain of the Loess Plateau slopes down in a wave-like pattern from northwest to southeast, with higher elevations in the northwest and lower elevations in the southeast. In terms of climate, the Loess Plateau spans both the warm-temperate and temperate zones from south to north, and both the semi-humid and semi-arid regions from east to west. The eastern and southern regions belong to the semi-humid warm-temperate zone, the central region belongs to the semi-arid warm-temperate zone, and the western and northern regions belong to the semi-arid temperate zone. The climate of the Loess Plateau is influenced not only by latitude and longitude, but also by terrain, exhibiting typical characteristics of a continental monsoon climate. With the implementation of China's policy of returning farmland to forest, the vegetation coverage of the Loess Plateau has increased year by year, making it an important ecological conservation area in northern China.

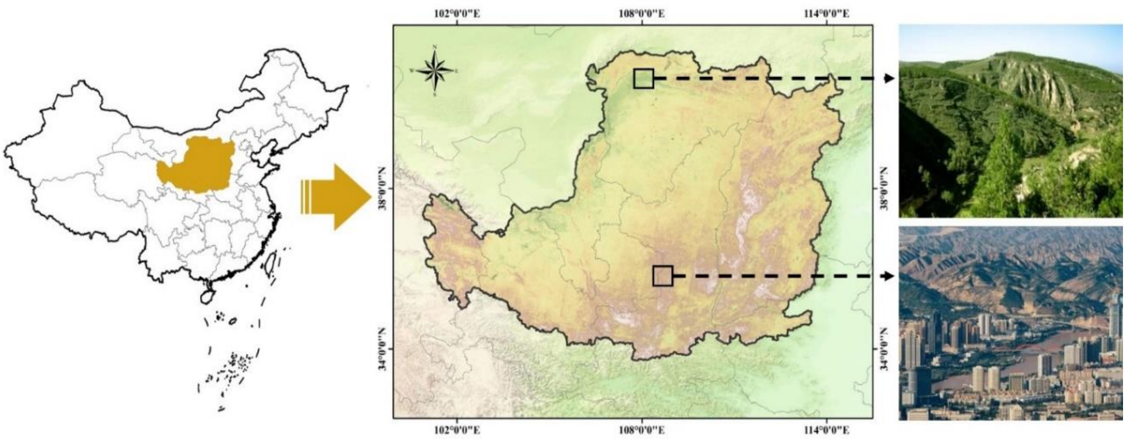

Figure 1. *Overview of the study area*

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Data and methods

Data sources

This study primarily utilized data that included NPP data, land use type surface coverage data, DMSP/OLS nighttime lighting data, as well as various energy statistical data. Among these, the NPP data for the Loess Plateau from 2000 to 2020 was sourced from NASA LAAADS (http://ladsweb.nascom.nasa.gov/data/search.html), with a resolution of 500 m. The annual NPP was obtained by summing all 8-day net photosynthesis (PSN) products (MOD17A2H) for a given year. The land-use data is sourced from the 2020 version of the 30 m global land-cover dataset released by the Ministry of Natural Resources to the public. The DMSP/OLS and NPP-VIIRS nighttime light data were obtained from the NGDC data center of the NOAA website (https://www.ngdc.noaa.gov/eog/download.html) updated on a monthly basis since April 1992, with a spatial resolution of 500 m. Additionally, other relevant information was included the "2020 China Carbon Price Survey Report" and so on.

IUEMS model

The carbon sequestration method used in the IEUMS model is based on the NPP principle, which posits that natural ecosystems absorb atmospheric CO_2 during photosynthesis to synthesize organic matter, fixating carbon in plants or soil, and releasing oxygen. Based on this principle, the carbon sequestration capacity is estimated using the net ecosystem productivity formula (*equation 1*).

$$Q_{\mathrm{CO}_2} = M_{\mathrm{CO}_2}/M_c \times NEP \tag{Eq.1}$$

In the equation, Q_{CO_2} represents the carbon sequestration capacity of terrestrial ecosystems, measured in units of t CO_2/a; M_{CO_2}/M_c is the molecular weight ratio of CO_2 to C, which is 44/12; NEP represents net ecosystem productivity, measured in units of t C/a. The calculation method for NEP is based on the conversion coefficients for NEP and NPP in each province and city and is obtained by calculating NPP (*equation 2*).

$$NEP = \propto \times M_c/M_{CHO} \times NPP \tag{Eq.2}$$

where "NEP" represents net ecosystem productivity (t C/a); α represents the conversion coefficient between NEP and NPP; "NPP" represents net primary productivity (t C/a). "M_c/M_{CHO}" is the molecular weight ratio of C to CHO.

Calculation and simulation of carbon emissions

This study simulates the carbon emissions of the Loess Plateau by establishing the correlation between night-time light data (DMSP/OLS and NPP-VIIRS images) and energy consumption carbon emissions (Sun et al., 2021). First, the night-time light data was preprocessed. Since the NPP/VIIRS data does not exhibit light saturation and overflow phenomena but contains occasional noise and outliers, Zhao's method was used to remove outliers (Zhao et al., 2019). Energy consumption carbon emissions were calculated and simulated based on the energy consumption statistics of ten cities in Shaanxi Province, and the carbon emission coefficients of various energy sources

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determined by the IPCC (2006) were used in the calculation formula as follows (*equation 3*):

$$CO_2 = \frac{44}{12} \times \sum_{i=1}^{9} K_i E_i \quad \text{(Eq.3)}$$

where the variable "i" denotes the type of energy; "K_i" represents the carbon dioxide emission coefficient (in 10,000 tons of carbon per 10,000 tons of standard coal) for the energy source "i"; and "E_i" denotes the consumption amount of energy source "i" in 10,000 tons of standard coal.

Utilizing the calibrated nocturnal light data to establish a correlation with the measured carbon emissions from energy consumption. By utilizing a boundary map of the cities in the Shaanxi province, the nocturnal light data was partitioned and analyzed to obtain six statistical values, including maximum, minimum, range, mean, standard deviation, and sum, for each of the ten cities. Linear regression was then performed between the energy consumption data and nocturnal light values for each city, and it was determined that the highest degree of correlation was achieved using the maximum nocturnal light value. The regression parameters for the best-fit equation are presented in *Table 1*. Using the well-correlated equations from *Table 1*, the carbon emissions from energy consumption for Loess Plateau in 2000, 2010, and 2020 were calculated. In the regression equation from *Table 1*, *x* represents the maximum nocturnal light value and y represents the energy consumption statistic.

Table 1. *Carbon emission simulation regression parameters*

Year	**Fitting formula**	**R^2**
2000	y=0.563x+5.698	0.802
2010	y=2.635x-566.32	0.95
2020	y=1.869x-569.35	0.85

The Plus model

The PLUS model is a patch-based land use change simulation model that utilizes a novel analytical strategy to better explore the causes of various types of land use change. At the same time, this model includes a new multi-class seed growth mechanism that can better simulate the changes at the patch level for multiple land use types. Coupled with a multi-objective optimization algorithm, the simulation results of this model can better support planning policies to achieve sustainable development (Wang et al., 2022). In this paper, the PLUS model's CARS (Carbon Accounting and Reporting System) module is mainly used to simulate future carbon neutrality. The simulation process adopts a CA (cellular automata) model based on multi-class random patch seeds, which is the CARS module of the PLUS model. This module combines random seed generation and threshold decrement mechanism, allowing the PLUS model to generate spatiotemporal dynamic simulation patches under the constraint of development probability. The mathematical principle of multi-class random seed generation is referenced in the literature (Quan, 2021).

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Calculation method of carbon fixation service scope

At ambient temperature and pressure, this article calculates the carbon sequestration service range of the Loess Plateau by combining gas diffusion coefficients with the density of CO_2 in the air, taking into account that gas diffusion coefficients represent the physical quantity of gas (or solid) diffusion. Diffusion coefficient refers to the amount of gas passing through a unit area in one second when the density difference between two parts of gas that are 1 cm (or each meter) apart is 1 g/cm^3 (or each meter), and the concentration gradient is one unit. It is defined as the diffusion coefficient of gas, with units of cm^2/s or m^2/s. Based on the gas diffusion coefficient (r), CO_2 density (ρ), and carbon sequestration amount (Tc), the carbon sequestration service range can be calculated using the following formula (*equation 4*):

$$\mathrm{Dis(m)} = \frac{Tc(kg/a)}{r(m^2/s)\times\rho(kg/m^3)} \quad \text{(Eq.4)}$$

According to the data, most gases have a diffusion coefficient of 10^{-4} to 10^{-5} m^2/s under normal temperature and pressure. The density of CO_2 in the air is 1.98 kg/m^3. Therefore, according to the formula for calculating the distance of carbon fixation, when r = 10^{-4} m^2/s, Dis = 0.162374 $\times$ Tc, and when r = 10^{-5} m^2/s, Dis = 1.62374 $\times$ Tc. Based on this, together with the carbon sequestration amount, the spatial distribution value of carbon sequestration services in the Loess Plateau can be obtained.

Results and analysis

Temporal and spatial distribution characteristics of carbon sequestration in the Loess Plateau

Using the IUEMS model and inputting NPP data and corresponding LUCC data for each year, we obtained the Loess Plateau carbon density spatial grid data for 2000, 2010, and 2020. Based on the carbon density data, we converted it into a fixed area per pixel and obtained the spatial distribution map of carbon sequestration on the Loess Plateau (*Fig. 2*). From *Fig. 2*, it can be seen that the maximum amount of carbon sequestration on the Loess Plateau has been increasing year by year. Through calculation, we found that the total amount of carbon sequestration on the Loess Plateau has also shown an upward trend, reaching 10.86 billion tons in 2000, 13.63 billion tons in 2010, and 14.33 billion tons in 2020. Spatially, regions with higher carbon sequestration are distributed in the central and western regions of the Loess Plateau, while the northern and southern regions have relatively lower carbon sequestration. By grading the classification statistics of carbon sequestration (*Fig. 3*), we can see that the area with a carbon sequestration greater than 5000 tons has been gradually increasing from 2000 to 2020, while the area with a carbon sequestration of 2000 to 5000 tons has been decreasing. This indicates that the area with high carbon sequestration on the Loess Plateau has been expanding continuously in the past 20 years and the productivity of forest vegetation quality has been increasing year by year.

According to the carbon sequestration rate in *Fig. 2*, the carbon sequestration rate was higher during 2000-2010, slowed down during 2010-2020, and relatively low over the 20-year period. Overall, the carbon sequestration rate in most regions of the Loess Plateau showed an increasing trend. The area with an upward trend in carbon

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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sequestration rate accounted for 96.7% during 2000-2010 and 96.2% during 2000-2020, indicating a steady increase in carbon sequestration rate over the past two decades. However, in the past decade, the area with a positive trend in carbon sequestration rate has slightly decreased to 80.14%, as revealed by the carbon sequestration rate classification in *Fig. 2*.

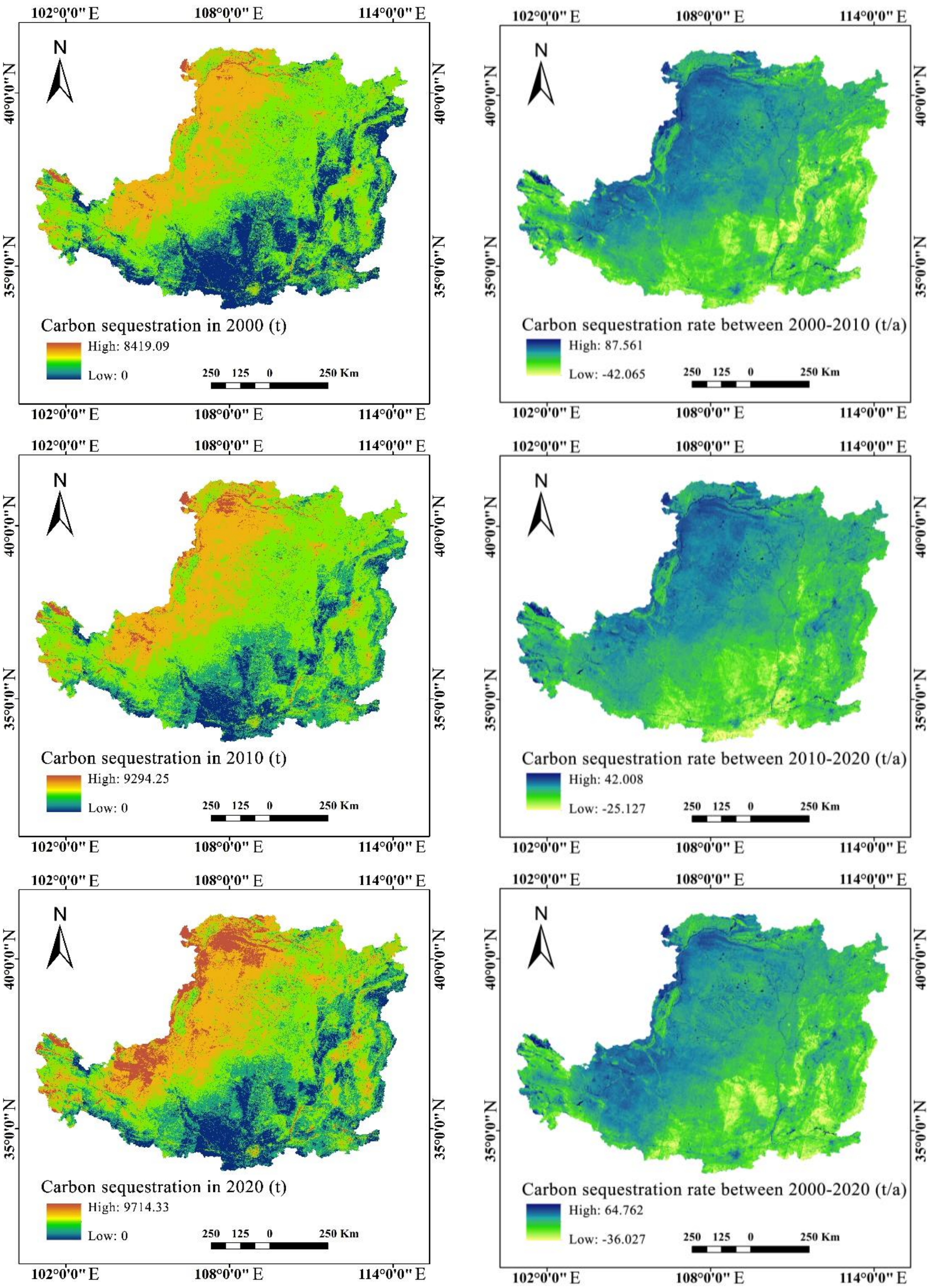

Figure 2. *Temporal and spatial distribution of carbon sequestration amount and rate in Loess Plateau*

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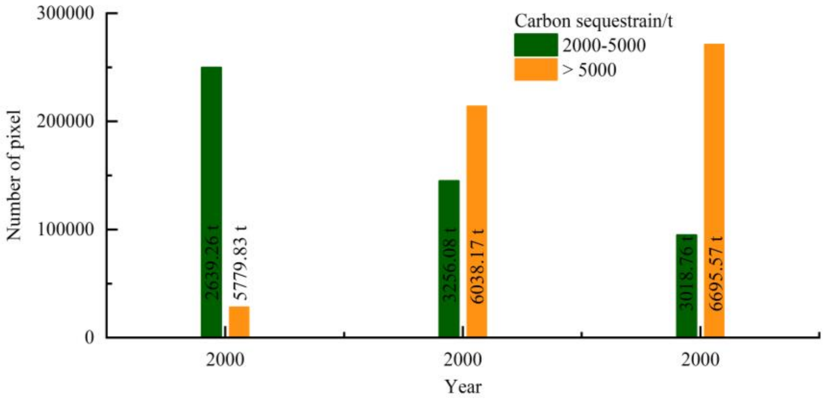

Figure 3. *The classification statistics of carbon sequestration*

By incorporating topographic factors, the relationship between carbon sequestration and elevation, slope, and aspect was analyzed. As shown in *Fig. 4*, the carbon sequestration on the Loess Plateau increases with elevation, reaching its peak at an altitude of over 1000 meters, and then declines. In terms of slope, carbon sequestration is highest on steep slopes, while it remains relatively high on semi-sunny and semi-shaded slopes (*Table 2*).

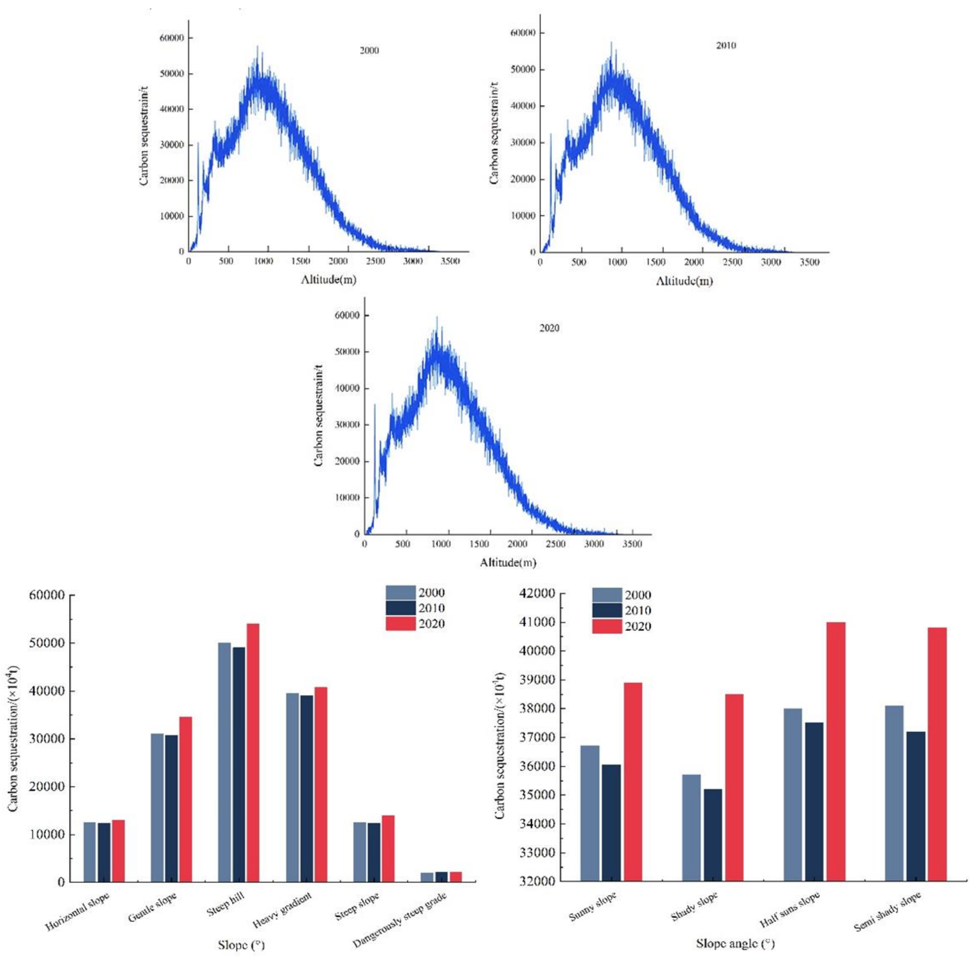

Figure 4. *Carbon sequestration characteristics under different terrain conditions*

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Table 2. *Classification standard of slope and aspect*

	Slope/(°)						Aspect/(°)			
	Horizontal slope	**Gentle slope**	**Steep hill**	**Heavy gradient**	**Steep slope**	**Dangerously steep grade**	**Sunny slope**	**Shady slope**	**Half suns slope**	**Semi shady slope**
Classification	0-5	6-15	16-25	26-35	36-45	>=46	135-225	315-45	90-135, 225-270	45-90, 270-315

Temporal and spatial distribution of carbon emissions in the Loess Plateau

In this study, a fitted model between nighttime light data and energy consumption data was established to obtain the spatial distribution map of carbon emissions in the Loess Plateau in 2000, 2010, and 2020, as shown in *Fig. 5*.

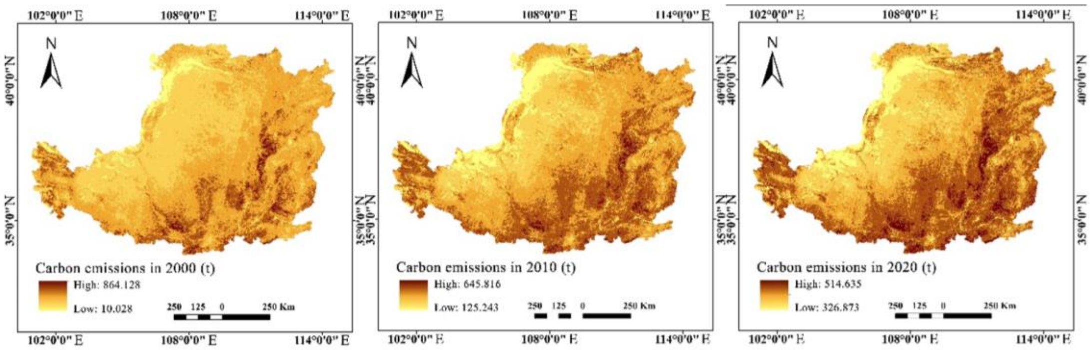

Figure 5. *Temporal and spatial distribution of carbon emission in Loess Plateau*

The *Fig. 5* shows that the carbon emissions in the Loess Plateau are all positive values. Among the three time periods, the lowest value of carbon emissions is 10.028 t, and the trend of low carbon emissions is increasing year by year, while the high carbon emissions are decreasing year by year. In terms of spatial distribution, as the Loess Plateau is mainly covered by forests, the overall carbon emissions are relatively low. The low emissions in each year basically account for 90% of the total area, while the areas with relatively high carbon emissions are mainly concentrated in urban agglomerations on the southern region.

Spatial distribution and future simulation of carbon neutrality in the loess plateau

Based on quantified values for carbon sequestration and carbon emissions, the static carbon neutrality of the Loess Plateau can be obtained by subtracting carbon emissions from carbon sequestration. A carbon neutral spatial classification map (*Fig. 6*) can be generated by classifying it accordingly. From the spatiotemporal classification map of carbon sequestration in the Loess Plateau, it can be observed that the regions with a high degree of carbon neutrality are mainly distributed in the central and western regions, while the regions with negative values of carbon neutrality are mainly located in some urban areas on the northern slope, with a very small area. Based on the calculation of the static carbon neutrality of the Loess Plateau, it is found that in 2000, the carbon produced by the Loess Plateau could provide a carbon absorption capacity of 102.78 x 10^4 t after offsetting the carbon emissions in the region, which increased to

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118.78 x 10^4 t in 2010, and 134.63 x 10^4 t in 2020. Overall, the carbon fixation capacity of the Loess Plateau is showing an increasing trend year by year. Therefore, from the results, the Loess Plateau can be viewed as a large carbon sink, providing a carbon sequestration service that absorbs a large amount of carbon released by human activities in the surrounding areas.

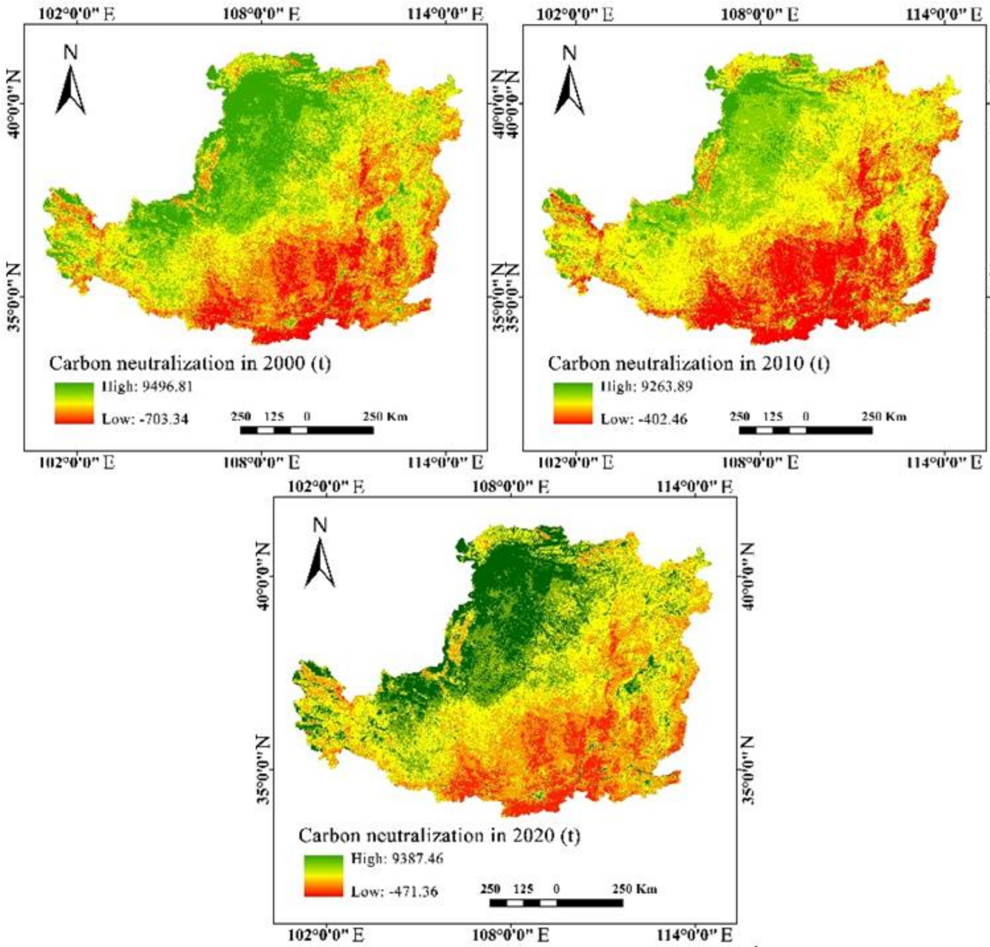

Figure 6. *Temporal and spatial variation of carbon sink in Loess Plateau*

Based on the carbon neutrality results from 2000, 2010, and 2020, the PLUS model was used to simulate carbon neutrality for 2030 and 2050, taking into account factors such as altitude, slope, aspect, distance to residential areas, GDP, and population. The simulation results can be seen in *Fig. 7*, which shows that the highest and lowest carbon neutrality values will continue to rise in the future, with total amounts of 149.07×10^4 t and 161.74×10^4 t respectively by 2030 and 2050. These represent increases of 14.44×10^4 t and 27.11×10^4 t respectively over 2020. In 2030, areas with carbon neutrality levels above 5000 t account for 51.88% of the total area, while in 2050 this percentage increases to 92.57%. These results indicate that the future carbon neutrality of the Loess Plateau still has significant potential for growth, which is of great importance for achieving carbon neutrality in the future.

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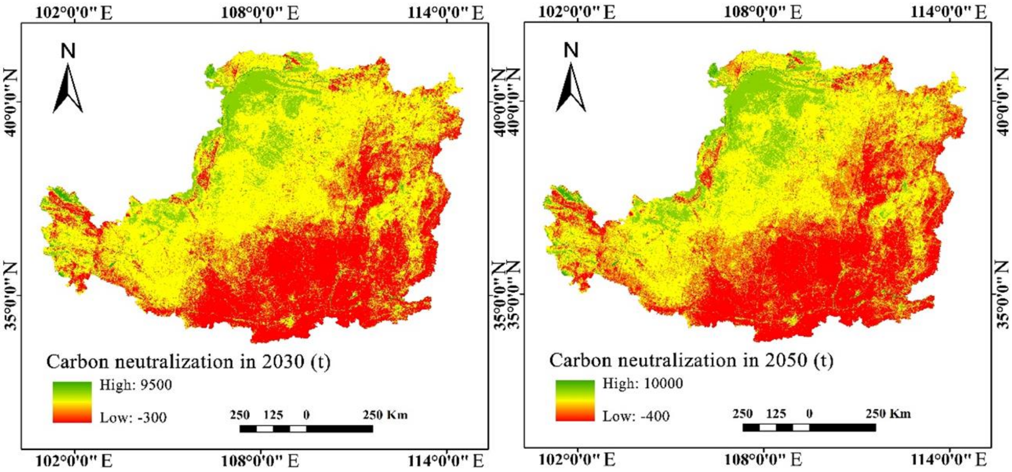

Figure 7. *The simulation results of carbon neutralization in 2030 and 2050*

Spatial service scope of carbon neutrality in the Loess Plateau

According to the diffusion coefficient of gas under normal temperature and pressure and the concentration of CO_2 in the air, the service range of the carbon sink in the Loess Plateau can be calculated. Based on the calculation results, the service range in 2000 was 174 km around the Loess Plateau, in 2010 it was 196.1 km, and in 2020 it was 218.64 km around the Loess Plateau.

Simulations were conducted to determine the carbon neutralization service range for the years 2030 and 2050. The results showed that the service range is 242.05 km and 262.63 km, respectively. This indicates that the carbon neutralization service range of the Loess Plateau is gradually expanding, with the greatest increase occurring between 2020 and 2030. After 2030, the degree of expansion of this service range is expected to decrease.

Discussion

Estimation of carbon sequestration and carbon emissions based on IUEMS and night light data

The goal of carbon neutrality is a proactive measure and a shared pursuit in the face of the climate crisis (Zou et al., 2021). The main path of China to achieving carbon neutrality in the short term is through energy transformation. However, this process faces uncertainties in terms of safety, economic viability, disruptive and unpredictable technological advancements, as well as the potential for encountering many new key technologies after transformation. In addition to energy transformation, regional carbon sequestration spatial planning and maintaining and improving carbon sequestration capacity are also important ways to promote carbon neutrality (*Fig. 8*).

Accurate accounting methods for carbon sequestration and carbon emissions are still major issues that need to be addressed in order to achieve carbon neutrality. This study used the IU-EMS system to measure the carbon sequestration capacity of the Loess Plateau, which is simpler and more convenient for unified management and accounting compared to other carbon sequestration calculation methods.

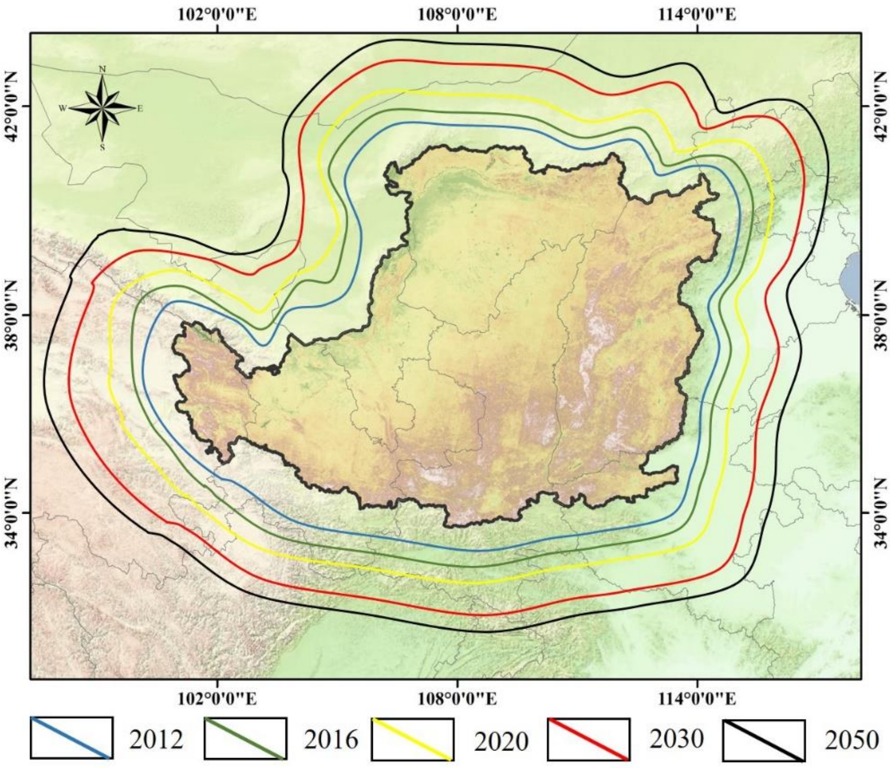

Figure 8. *Diffusion range of carbon neutralization space services in the Loess Plateau*

As for carbon emissions calculation, there are currently other methods including carbon emission coefficient method (Li et al., 2019), IPCC reference method (Sun et al., 2017), and China's carbon emission accounting database (CEADs). However, these methods have some errors and limited accuracy. Therefore, combining multiple methods, this paper uses the fitting relationship between night-time light data and energy statistical data to simulate and spatialize carbon emissions (*Fig. 9*). This method is suitable for spatial simulation of carbon emissions on a large and medium scale and is currently widely used. By combining night-time light data and energy data, the results are more realistic.

Space equalization of carbon neutralization based on the research of carbon fixation service scope

Currently, research on carbon sequestration services is focused on the calculation of carbon quantities and their economic value, with little consideration given to their spatial service range. By combining the principles of forest vegetation carbon sequestration, which involves the conversion of CO_2 and water into biomass and the release of oxygen, it is clear that forests can absorb a large amount of CO_2. This phenomenon is known as the carbon sequestration effect of forests. CO_2 absorbed by forests is converted and diffused through the air, and this study used gas diffusion coefficients and CO_2 density under normal temperature and pressure conditions, in conjunction with the carbon sink capacity of the Loess Plateau, to determine the theoretical spatial service range of the carbon sink in the Loess Plateau. However, in practice, diffusion coefficients are not constant and are affected by changes in

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DOI: http://dx.doi.org/10.15666/aeer/2203_22252240

temperature and pressure during the adsorption and diffusion processes (Liu et al., 2022). Moreover, CO_2 is subject to complex weather-related influences during these processes. Therefore, it is important to consider temperature, pressure, and other parameters in future studies to determine the carbon neutrality service range under different seasonal and weather conditions. In conclusion, achieving carbon neutrality is not only about meeting the overall target but also about ensuring spatial balance. For instance, China's Three-North Shelterbelt not only neutralizes domestic carbon emissions but also absorbs and neutralizes foreign carbon emissions, thus highlighting the significance of carbon neutrality and spatial balance research in avoiding the problem of uneven carbon neutrality distribution.

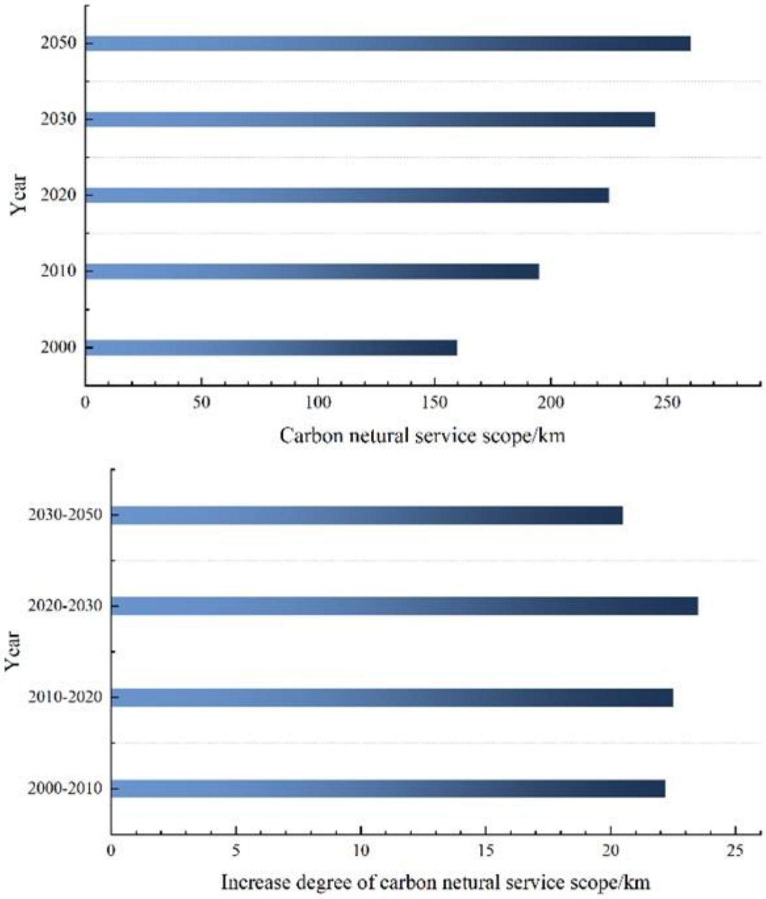

Figure 9. *Carbon neutral service range and change degree in the Loess Plateau*

The research findings juxtaposed with those of other regions in China as well as across the globe

The study indicates an upward trend in carbon sequestration on the Loess Plateau, which may differ from trends in other regions of China. For instance, the eastern regions of China typically exhibit higher levels of industrialization and urbanization, potentially resulting in higher carbon dioxide emissions, whereas western regions may prioritize natural ecosystems, thus possessing stronger carbon sequestration capabilities. Consequently, compared to the eastern regions, the Loess Plateau may have greater carbon neutrality potential. In comparison to other regions worldwide, the Loess Plateau

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may exhibit distinct trends in carbon emissions and sequestration. Certain developed countries may have already implemented emission reduction policies and made progress in enhancing carbon sequestration capacities. However, some developing countries or regions may still face challenges related to increasing carbon emissions and inadequate carbon sequestration capabilities.

The Loess Plateau, as one of China's crucial ecological functional zones, holds significant importance in achieving carbon neutrality goals, not only for China but also for the global carbon neutrality agenda. The findings of this study can serve as a valuable reference for global carbon neutrality strategies, particularly for carbon management and neutralization planning in ecologically vulnerable regions akin to the Loess Plateau.

Conclusion

This study employed the IUEMS model to obtain the spatial distribution of carbon sequestration on the Loess Plateau. Using nighttime light data, the carbon emissions of the study area were determined, and the difference between carbon sequestration and emissions was calculated as carbon neutrality. Due to the significantly higher amount of carbon sequestration than carbon emissions on the Loess Plateau, it can be regarded as a large carbon sink. The PLUS model was used to simulate and predict carbon emissions for the Loess Plateau in 2030 and 2050. Finally, the spatial service range of the carbon sink on the Loess Plateau was calculated based on the gas diffusion coefficient at normal temperature and pressure and the concentration of CO_2 in the air. The following conclusions were drawn: (1) The total amount of carbon sequestration on the Loess Plateau ranges from 10.86 to 14.33 billion tons and shows an increasing trend year by year. The carbon sequestration rate in over 80% of the area is gradually increasing, and topographical factors such as altitude over 1,000 meters, slopes, and half-sunny and half-shady slopes have a significant impact on carbon sequestration on the Loess Plateau. (2) The overall carbon emissions on the Loess Plateau are relatively small and show a spatial distribution with low values gradually increasing and high values gradually decreasing, reflecting to some extent the impact of continuous adjustment of production capacity structure on carbon emissions in the region. (3) Over 90% of the Loess Plateau has achieved carbon neutrality, and this trend is increasing year by year. The carbon neutrality will also continue to increase in the future. (4) The carbon neutral service range from 2000 to 2050 is expanding year by year and involves surrounding provinces and cities of Shaanxi. (5) In studying the carbon sequestration service range, factors such as weather and climate that affect CO_2 diffusion and absorption should be considered, and research on carbon neutrality spatial balance deserves attention.

Funding. This study is financially supported by Inner scientific research project of Shaanxi Land Engineering Construction Group (DJNY2024-40, DJNY2024-41, DJNY-YB-2023-38, DJNY-YB-2023-48, DJTD 2022-1), the Natural Science Basic Research Plan in Shaanxi Province of China (2024JC-YBQN-0329), and key Research and Development Program of Shaanxi (Program No. 2024SF-YBXM-565).

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http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2203_22252240

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http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
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