Carbon Emission Characteristics of Ecological Functional Area in National Functional Zoning and Sustainable Strategies for Regional Planning and Development: a Case Study of Ankang City, Shaanxi Province

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Abstract. Achieving carbon peaking and carbon neutrality objectives has emerged as a paramount endeavor in the contemporary urban and regional development agenda. This manuscript examines Ankang City in Shaanxi Province from a carbon emission standpoint, employing the city's domain as a foundational unit to delve into the correlation between carbon emissions and the emission efficiency within the nation's primary functional areas, specifically focusing on restricted development zones. It further investigates the impact of various factors such as urban construction scale, population magnitude, economic breadth, industrial configuration, and land utilization on carbon emissions. This study meticulously identifies the critical indices influencing carbon emissions. Through a detailed analysis of Ankang's carbon emission and carbon sequestration data, it is deduced that Ankang City manifests an overall carbon surplus. The findings indicate that the increment in carbon emissions and the efficiency thereof are intrinsically linked to the developmental and constructional dynamics of urban and rural areas, influenced by population density and economic advancement, displaying a year-on-year escalation alongside discernible spatial distribution patterns and characteristics. Consequently, this paper advocates strategic recommendations for fostering green and low-carbon development in Ankang City. The proposed strategic recommendations for Ankang City encompass several key actions. These actions include sustaining the overall stability of the ecosystem configuration, refining the spatial organization and intensive utilization of land, leveraging ecological benefits to bolster economic growth, constructing low-carbon urban and rural infrastructures, establishing a model for low-carbon living, and advancing the development of an intelligent carbon management framework.

Keywords: Carbon Emission, Low carbon, national main functional area planning, Sustainable development

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1 INTRODUCTION

On March 20, 2023, the Intergovernmental Panel on Climate Change (IPCC) unveiled its Sixth Assessment Report Synthesis Report, AR6 Synthesis Report: Climate Change 2023. Highlighting a concerning rise in global temperatures, now 1.1 degrees Celsius above pre-industrial levels due to fossil fuel combustion and unsustainable practices in energy and land use, the report underscores the acceleration of extreme weather events. Consequently, achieving Carbon Peaking and Carbon Neutrality has ascended as a critical goal in urban and regional planning.

China has introduced its inaugural comprehensive land development framework, delineating national territories into four principal functional zones: optimized, key, restricted, and prohibited development areas. Each zone is designated with specific roles, development trajectories, and governance guidelines. Within this schema, Ankang City in Shaanxi Province, positioned in the ecologically sensitive Qinba Mountains, is identified as a crucial ecological zone with development restrictions. Here, the juxtaposition of underdevelopment challenges and ecological riches offers a unique vantage point for harmonizing ecological preservation with socioeconomic advancement [1].

This study centers on Ankang, employing carbon emission dynamics as the lens to scrutinize the interplay between carbon output and the efficiency of emission management in zones facing developmental constraints. By examining factors such as urbanization scale, population dynamics, economic activities, industrial patterns, and land usage, pivotal drivers of carbon emissions are unearthed. Building on these insights, the paper advocates for strategic measures aimed at fostering a sustainable, green, and low-carbon trajectory for the region. This approach not only addresses the immediate challenges faced by Ankang but also contributes to the broader discourse on balancing developmental aspirations with environmental stewardship in restricted zones.

2 STUDY POPULATION AND DATA SOURCES

2.1 Overview of the Study Population

Ankang, designated as a prefecture-level city within Shaanxi Province, is strategically positioned in the province's southeast. It shares borders with Shiyan City in Hubei Province to the east, Chongqing City and Sichuan Province to the south, Hanzhong City to the west, and Xi'an City and Shangluo City to the north. The Han River, a significant tributary of the Yangtze River, traverses the city from east to west, covering an area of approximately 23,500 square kilometers. Situated at the confluence of the Guantian, Chengdu-Chongqing, and Jianghan economic zones, Ankang serves as a critical juncture between Sichuan, Hubei, and Chongqing, linking two major economic corridors: the Silk Road and the Yangtze River Economic Belt. This unique geographic positioning enables Ankang to absorb and disseminate the economic influence of Xi'an, Wuhan, Chongqing, and Chengdu, marking it as southern Shaanxi's sole first-tier logistics hub.

Furthermore, Ankang lies within a zone identified for its compounded challenges--namely, the Qinba Mountain region's concentrated contiguous areas of special difficulty and the pivotal South-to-North Water Diversion Middle Line Water Cultivation Zone. This juxtaposition of challenges and opportunities has sculpted the city's economic development landscape. Recent years have witnessed the local populace's shift from traditional, extractive practices towards a sustainable developmental paradigm, termed "the ecological economy, economic ecology." This transition underscores a commitment to high-quality, environmentally conscious growth, forging a path from reliance on natural resource exploitation to the establishment of a vibrant, green economy [2].

2.2 Data Sources

The dataset employed in this research encompasses five distinct categories: population, economic, land use, lighting, and carbon emission and sequestration data. Population metrics are derived from a comprehensive array of sources including the sixth (2010) and seventh (2020) national census bulletins, city and Shaanxi Province statistical yearbooks, district and county statistical reports, and the China Spatial Population Distribution in Kilometer Grids Dataset (Resource and Environmental Science Data Registration and Publishing System, 2020). Economic indicators are sourced from the National Social and Economic Development Bulletins of each district and county, along with the China GDP Spatial Distribution Kilometer Grid Dataset (Resource and Environmental Science Data Registration and Publishing System) [3]. Land use information is extracted from global 30m resolution surface cover data, based on Landsat TM imagery for the years 2010 and 2020. Illumination data are obtained from the NPP-VIIRS Night Light Remote Sensing Data spanning 2012 to 2020. Finally, carbon emissions and sequestration figures are collated from the China Carbon Emission Databases (CEADs) covering the period from 1997 to 2017. This diverse dataset forms the empirical foundation of the study, providing a robust basis for analyzing the interplay between urban development, environmental sustainability, and carbon dynamics.

3 RESEARCH METHODOLOGY

3.1 Scope of the Study

This investigation delineates its focus within the territorial bounds of Ankang City, which comprises 10 county-level administrative divisions: Hanbin District, Xunyang, Shiquan, Hanyin, Ziyang, Langao, Baihe, Pingli, Zhenping, and Ningshan Counties, collectively spanning approximately 23,500 square kilometers. Utilizing these districts and counties as analytical units, the study employs a temporal framework to comprehensively examine the economic, environmental, spatial, cultural, and social dimensions of Ankang City. The objective is to elucidate the spatial distribution patterns of carbon emissions and sequestration within this urban expanse. Moreover, the research aims to elucidate strategies for low-carbon development within the confines of the country's restricted development zones, with Ankang City serving as a case study. This approach enables a nuanced understanding of how localized strategies can contribute to the broader goals of sustainable development and carbon neutrality in areas facing developmental constraints.

3.2 Methodological Path

In the domain of scientific inquiry, quantitative analysis serves as a pivotal methodology for enhancing the precision of our understanding concerning research subjects. It systematically unveils underlying laws, captures the essence, clarifies interrelationships, and forecasts developmental trends, thereby standing as the quintessential methodological approach in academic research for investigating the occurrence and rationale behind specific phenomena. The objective of this paper is to dissect the interplay between carbon emission intensity and variables such as population size, demographic composition, industrial framework, GDP, and land usage across district and county levels, employing quantitative data analysis to distill overarching principles and characteristics [4].

Initially, this study embarks on a detailed examination of the socio-economic evolution of the selected sample, adopting the lens of the intricate "society-economy-nature" ecosystem. It prioritizes critical economic and social information pertinent to urban and regional planning, including data on urban construction land, population demographics, and economic growth. This involves compiling, visualizing, and analyzing the current state of urban construction land coverage alongside the demographic, economic, and industrial structures of the counties (districts) under study. Such an approach facilitates a comprehensive exploration of how carbon emissions correlate with the aggregate and scale of economic activity and population at a macro level.

Subsequently, the research advances to quantify the total carbon emissions and sequestration, emissions attributable to the built environment of county-level administrative units, population-based emissions, sequestration by administrative areas, and the industrial mix within counties (districts). This phase aims to elucidate the association between carbon emission efficiency and factors such as spatial attributes, industrial composition, and population metrics, highlighting regional disparities in carbon emission efficiency across varying stages of development. By juxtaposing economic and social development indicators with carbon data, the study endeavors to map out and analyze the spatial distribution of carbon emissions and sinks within the city [5].

In conclusion, through rigorous statistical analysis of both the prevailing economic-social landscape and carbon emission-sequestration data, the research extrapolates patterns and distinct characteristics of carbon emissions within the study area. Drawing from these insights, it proposes recommendations for sustainable development, thereby contributing to the scholarly discourse on environmental stewardship and sustainable urban planning.

4 ECONOMIC DEVELOPMENT TRENDS IN ANKANG CITY

4.1 Characteristics of Urban Form Change in Ankang City

Employing Landsat satellite imagery from the United States, this study meticulously generated land use status maps for Ankang City for the years 2000, 2017, and 2022 through manual visual interpretation, as depicted in Figures 1 to 3. These maps reveal a distinct evolution in the urban fabric of Ankang City, with the Hanbin District—serving as the urban nucleus—underpinning a pronounced expansion pattern. This pattern is characterized by a radial growth of artificial structures from the core outward, marking a transition from the initial retraction of land usage in 2000 towards the establishment and subsequent widescale urban development post-2017. Such development has led to a continuous expansion of the construction land boundaries across various settlements within the city.

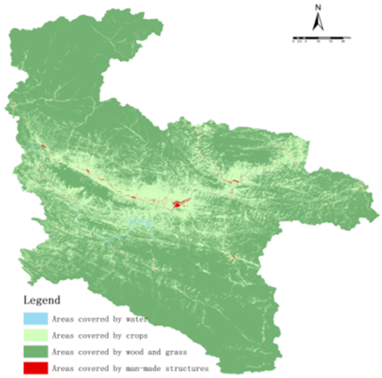

Fig. 1. Distribution of land use types, 2000.

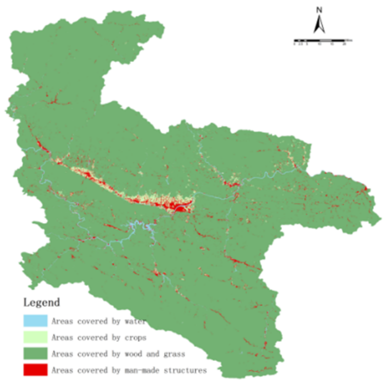

Fig. 2. Distribution of land use types, 2017.

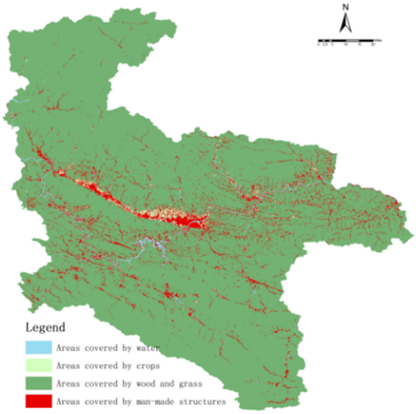

Fig. 3. Distribution of land use types, 2022.

As demonstrated in Figure 4, the expanse covered by man-made structures in Ankang City has witnessed a significant transformation. In 2000, the area spanned merely 82.38 square kilometers, escalating to an expansive 1,403.95 square kilometers by 2022. Notably, between 2017 and 2022, the area experienced a staggering increase of 163.50% in artificial building coverage. This enlargement predominantly took place within the central urban districts and adjacent counties, with the areas around the Moon River and River Road observing the most substantial augmentations. A spatial autocorrelation analysis, employing the Anselin Local Moran's I method coupled with a 50 km distance threshold for clustering and outlier examination, was conducted. This analysis underscored a pronouncedly clustered, contiguous pattern of built-up land, extending laterally from east to west along the Moon River River Road axis, indicating a cohesive and concentrated urban development trajectory in Ankang City.

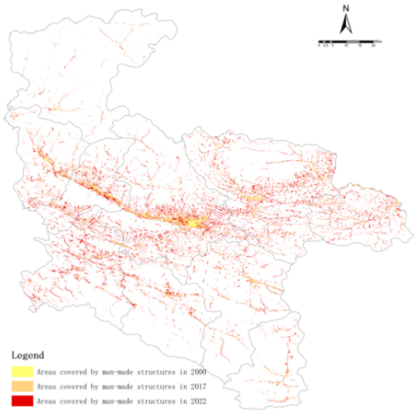

Fig. 4. Change in area covered by man-made buildings.

Figures 5 and 6 depict the significant alterations in agricultural and vegetative land covers within Ankang City, underpinned by the farmland-to-forest policy and various ecological conservation measures. The quantified data reveal a drastic reduction in the cropland area, plummeting from 5,063.88 square kilometers in 2000 to a mere 223.76 square kilometers by 2022, marking a reduction of approximately 95.58%. Conversely, the expanse of forest and grassland has witnessed a notable expansion, growing from 17,397.03 square kilometers in 2000 to 20,807.56 square kilometers in 2022, an increase of roughly 19.6%. This transformation in land cover underscores a pronounced shift in Ankang City's landscape dynamics, characterized by a decrease in agricultural land juxtaposed with an increase in forested and grassland areas, thereby reflecting the city's evolving urban and rural developmental footprint alongside its commitment to ecological conservation and sustainable land use practices.

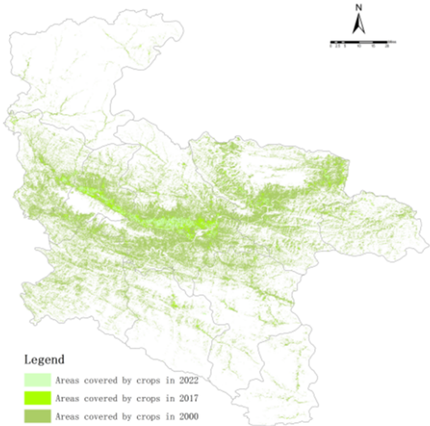

Fig. 5. Changes in the area covered by crops.

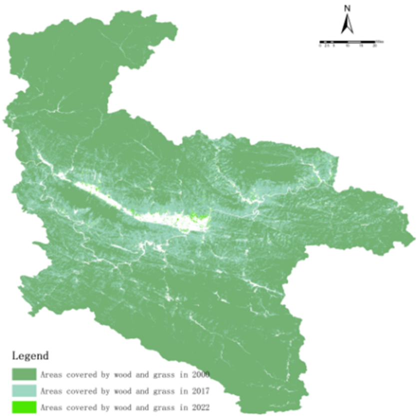

Fig. 6. Changes in the area covered by forest and grassland.

4.2 Characteristics of Population Change in Ankang City

Between 2000 and 2022, Ankang City experienced divergent trends in its resident population dynamics. Initially, the population evidenced a decline, decreasing by approximately 5.5% or 142,500 individuals, from an initial count of 2,613,900 in 2000 to 2,471,400 by 2022. Contrarily, a subsequent period reflected an upward trajectory, with an overall increment of 3.2% or 93,700 people, elevating the population from 2,924,300 in 2000 to 3,018,000 in 2022. The net decrease in the resident population, outweighing the increase in household numbers, typifies the demographic challenges faced by urban areas undergoing shrinkage. Figure 7 delineates the year-over-year fluctuations in the total resident population across Ankang City.

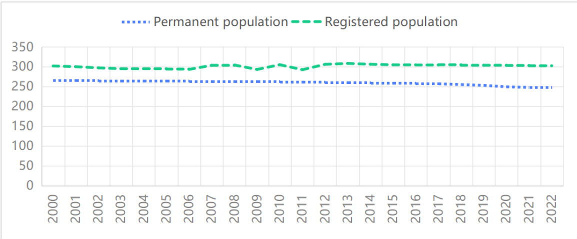

Fig. 7. Trends in population change over the years.

Detailed analysis of population alterations within each district and county of Ankang City reveals that growth was predominantly localized in the Hambin District—the urban center of Ankang--between the Fifth and Sixth National Census periods (2000 to 2010). During this interval, notable population increases were observed not only in Hambin District but also in Hanyin County, Xunyang City, Langao County, and Shiquan County. However, the period spanning the Sixth to the Seventh Census (2010 to 2020) marked a pivotal shift wherein only Hambin District witnessed a rise in its resident population, whereas all other county-level administrative units experienced reductions to varying extents. Figure 8 graphically represents these demographic shifts, offering a visual account of the population growth and decline across the respective county-level units within Ankang City, further elucidating the complex patterns of population dynamics over the two decades.

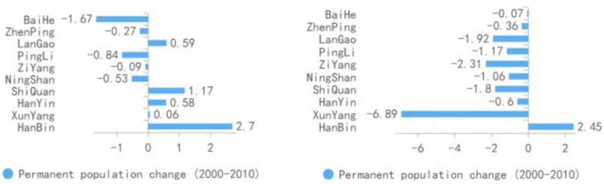

Fig. 8. Changes in population growth in county administrative units.

In this study, a multifaceted approach to population analysis in Ankang City is employed, incorporating variables such as land use type, nighttime light intensity, and settlement density. These elements are individually weighted, after which aggregate weights for administrative divisions at both district and county levels are computed. Subsequently, a raster-based spatial analysis technique is applied to examine the shifts in population distribution, yielding insights into the contemporary spatial patterns of habitation within the city. The findings delineate a pronounced urban configuration wherein the central urban zone acts as the nucleus, around which county-level administrative units are dispersed. Notably, the regions adjacent to the Moon River and River Road emerge as linearly concentrated residential areas, highlighting a distinctive pattern of population density. Figure 9 graphically represents these spatial demographics, showcasing the distribution of population across Ankang City and underscoring the primary areas of human settlement within its geographic confines.

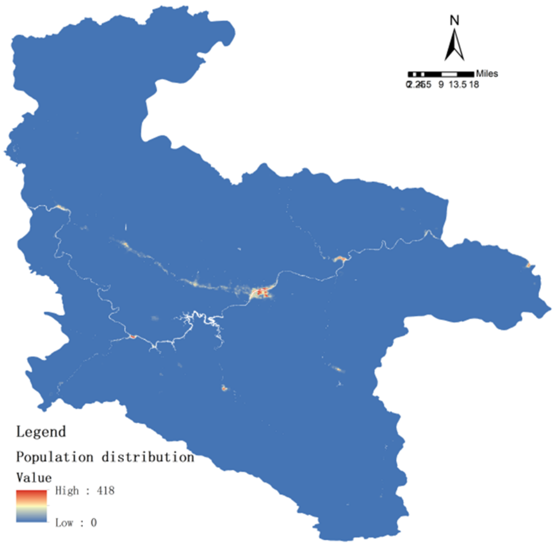

Fig. 9. Population distribution map (2020).

4.3 Characteristics of Economic Changes in Ankang

Nestled within the Qinba hinterland and constrained by its natural topography, Ankang City confronts distinct developmental challenges. This locale is designated as a critical ecological function area with development restrictions, positioned at the heart of the South-to-North Water Diversion Project's Water Cultivation Zone and encompassing the Qinba Mountains' contiguous regions marked by pronounced hardships. Its responsibilities extend beyond ecological conservation, encompassing the safeguarding of water clarity for the strategic Beijing-Tianjin axis, to addressing poverty alleviation and enhancing overall well-being. By the culmination of 2017, all ten counties and districts within the city were classified as impoverished, highlighting a persistent economic underdevelopment that has characterized Ankang's socio-economic landscape since the dawn of the 21st century.

Despite these challenges, Ankang City has experienced a gradual increase in both its Gross Domestic Product (GDP) and per capita GDP, signaling positive economic momentum. The primary sector has witnessed sustained growth, while the secondary and tertiary sectors have seen accelerated development, with the latter recently surpassing the former in total output value and emerging as the dominant force in the city's economic framework. Years of strategic development have culminated in the establishment of a diversified industrial structure within Ankang, featuring sectors such as clean energy, selenium-enriched food products, textiles and garments, new materials, equipment manufacturing, biomedicine, and niche markets including handicrafts and toy manufacturing.

Figures 10 through 12 elucidate the trajectory of Ankang City's economic evolution across three dimensions: annual GDP fluctuations, per capita GDP trends, and sector-specific GDP changes. These visualizations provide a comprehensive overview of the economic growth patterns within Ankang, underlining the city's gradual transition towards a more diversified and robust economic base amidst its geographical and ecological constraints.

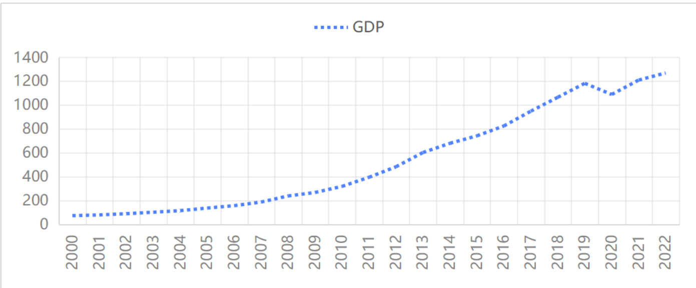

Fig. 10. Changes in GDP over the years.

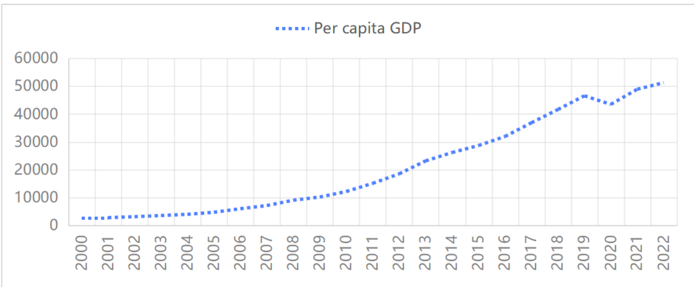

Fig. 11. Change in per capita GDP over the years.

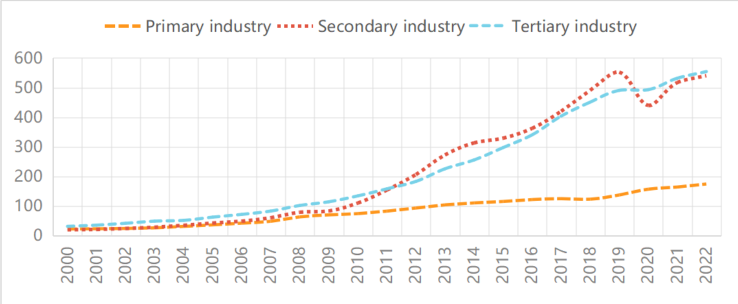

Fig. 12. Change in Industrial Output by Industry Sector over the Calendar Years.

5 REGIONAL CARBON EMISSION CHARACTERISTICS

5.1 Characterization of Total Carbon Sources and Sinks

Drawing upon the data derived from the China Emissions Accounts and Datasets (CEADs), this study quantitatively assessed the carbon emissions and sequestration within the county-level administrative units of Ankang City over a decade, spanning from 2008 to 2017. The cumulative carbon emissions recorded for Ankang City throughout this period approximated 56.70 Megatonnes (Mt). Conversely, the total carbon dioxide sequestered—attributable to initiatives such as reforestation, vegetation restoration, and urban greening efforts—was significantly higher, amounting to approximately 499.67 Mt. This sequestration volume represents an overwhelming 881.25% of the total emissions, indicating a substantial carbon surplus within the metropolitan area. Figure 13 visually encapsulates the evolution of both carbon emissions and carbon sequestration in Ankang City from 2000 to 2017, illustrating the city's effective transition towards ecological sustainability and its significant contribution to mitigating atmospheric carbon dioxide levels.

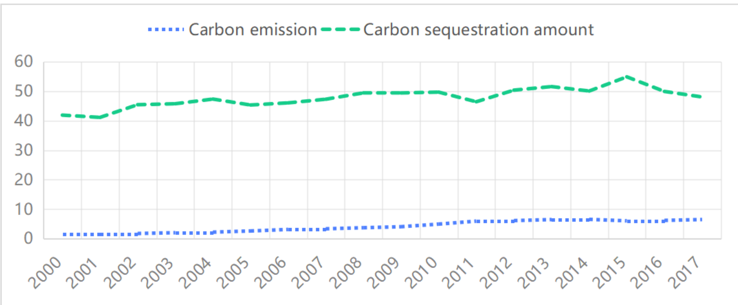

Fig. 13. Change in carbon emissions over the years.

5.2 Characteristics of the Spatial Distribution of Carbon Emissions

During a decade-long analysis segmented by county-level administrative divisions within Ankang City, the distribution of carbon emissions and sequestration data reveals distinct patterns. The Hanbin District, encompassing the city's urban core, emerged as the leading emitter of carbon, closely followed by Xunyang City, recognized for its industrial prominence. Significantly, Hanbin District not only features the most extensive footprint of artificial structures within Ankang but also boasts the highest population, the most comprehensive industrial network, the greatest GDP, and the largest expanses dedicated to crop cultivation. In stark contrast, Zhenping County, despite hosting the largest population and economic output, registers the lowest carbon emissions, estimated at approximately 1.08 Megatonnes (Mt), attributable to its minimal coverage by man-made edifices.

Further quantitative analyses highlight disparities in carbon emissions relative to the development intensity of land, with Ziyang County experiencing the highest emissions per unit area of developed land (inclusive of buildings and agricultural fields) at roughly 0.08 Mt/km², whereas Baihe County records the lowest at about 0.03 Mt/km². In terms of per capita emissions, Shiquan County records the highest levels at approximately 0.3 Mt per million inhabitants, contrasting with Baihe County, which demonstrates the lowest per capita emissions, notably around 0.08 Mt per million individuals. These findings illuminate the variegated carbon footprint across Ankang's administrative landscape, underscoring the intricate relationship between urban development, agricultural practices, and carbon emissions within the region.

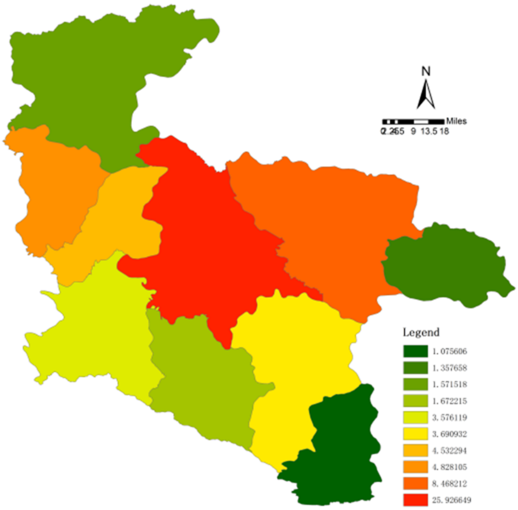

Fig. 14. Carbon emissions from county-level administrative units (2017).

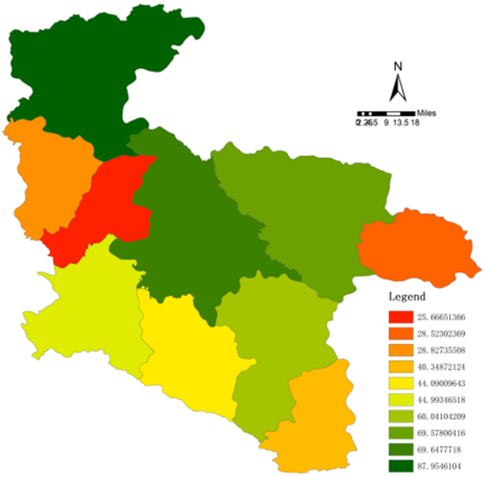

Fig. 15. Carbon sequestration by county-level administrative units (2017).

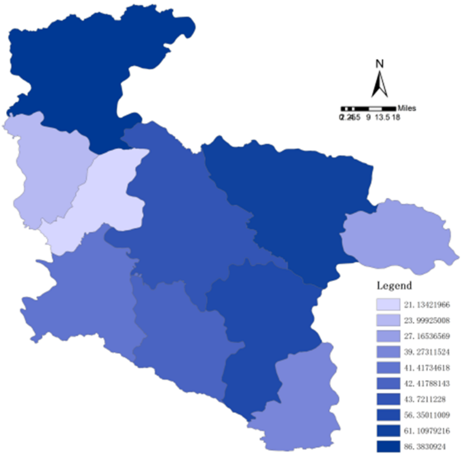

Fig. 16. Carbon sinks of county-level administrative units (2017).

Situated amidst the rugged terrain of the mountains, Ningshan County distinguishes itself by leading in carbon sequestration within Ankang City, capturing approximately 87.95 megatonnes (Mt), whereas Shiquan County records the minimal carbon absorption, tallying around 25.67 Mt. An analysis on a per unit land area basis reveals that Zhenping County achieves the apex of carbon sequestration efficiency, with about 0.03 Mt/km^2, contrasted starkly against Shiquan County, which exhibits the lowest rate of approximately 0.02 Mt/km^2. In terms of net carbon surplus over the decade under review, Ningxia County stands out with an estimated surplus of 86.38 Mt, marking the highest across the region, while Shiquan County manifests the lowest surplus, calculated at about 21.13 Mt.

Figures 14 to 16 are illustrative of the comparative analysis across each county-level administrative unit within Ankang City, delineating variances in carbon emissions, sequestration, and net carbon sinks respectively. Furthermore, Figures 17 and 18 provide a detailed exposition on the disparity in carbon emissions attributed to each county-level unit, evaluated against the backdrop of artificially developed terrain and per capita considerations. Complementarily, Figure 19 offers insight into the carbon sequestration efficacy per unit area across the county-level administrative units, underscoring the intricate interplay between geographical positioning, land use practices, and carbon cycle dynamics within Ankang City.

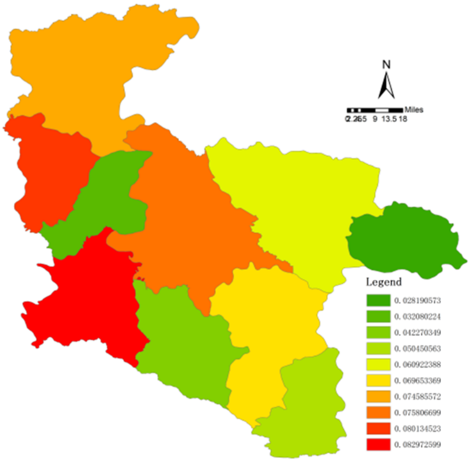

Fig. 17. Carbon Emissions from Artificial Development (Artificial Buildings and Crops) Area per Unit of County-level Administrative Units (2017).

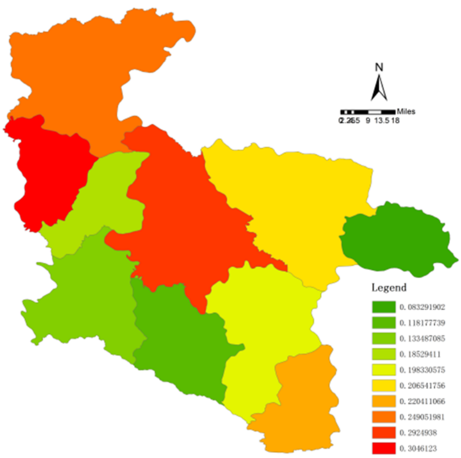

Fig. 18. Carbon emissions per capita in county-level administrative units (2017).

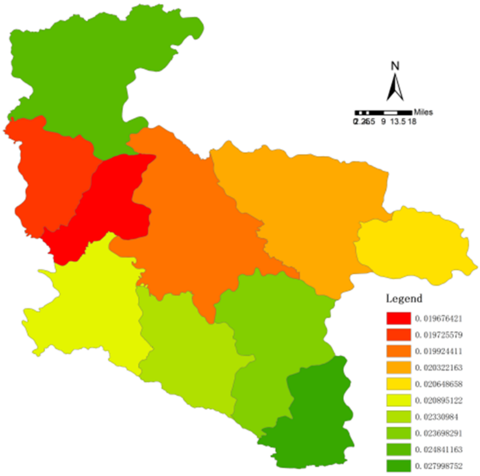

Fig. 19. Carbon Sequestration by Artificial Development (Artificial Buildings and Crops) Area per Unit of County-level Administrative Units (2017).

5.3 Regional Carbon Emission Impact Factors

Carbon Emission Efficiency and Spatial Correlation.

The efficiency of carbon emissions within Ankang City is intrinsically linked to its urban and rural spatial configuration, demonstrating a significant correlation between the two. An analysis reveals a gradient of decreasing carbon emission efficiency extending from the urban core to the city's periphery. This spatial variance is underscored by remote sensing data on land use, which indicates a concentration of constructed land, heightened population density, and complex urban dynamics in the central areas. These central zones are characterized by denser utilities, a more extensive road network, and a broader spectrum of infrastructure and urban services, all contributing positively to the area's carbon emission efficiency.

Further, a correlation analysis elucidates a direct relationship between the carbon emissions per unit of Gross Domestic Product (GDP) and the extent of land designated for artificial structures and agricultural use. This finding suggests that carbon emission efficiency is directly proportional to the degree of human-induced land development. Figure 20 provides a visual representation of this relationship, mapping the interplay between carbon emission efficiency and the extent of anthropogenic development across each county-level administrative division within Ankang City. This analysis serves to highlight the complex interdependencies between urban form, land use patterns, and their collective impact on carbon emission dynamics.

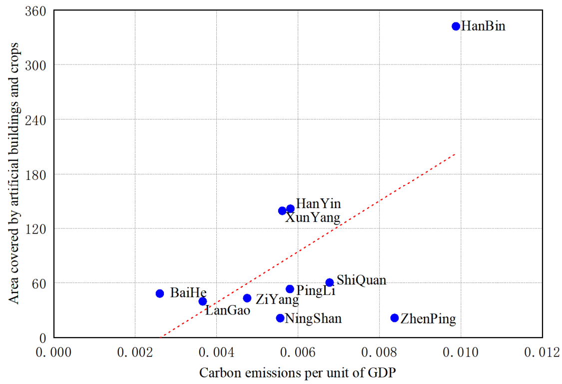

Fig. 20. Correlation analysis of carbon emissions per unit of GDP with the area covered by man-made buildings and agricultural crops Figure.

Carbon Emission Efficiency and Population Correlation.

The efficiency of carbon emissions within the Ankang City area is significantly influenced by demographic factors, with a discernible positive correlation existing between carbon emission efficiency and the spatial distribution of the urban and rural populace. This relationship indicates that county-level administrative units with higher population densities tend to exhibit greater efficiencies in carbon emissions. Such a pattern suggests that areas with more concentrated populations are potentially more effective in managing carbon outputs relative to their population size. Figure 21 graphically depicts this association, presenting a detailed analysis of the relationship between carbon emission efficiency and the density of permanent residents across the various county-level administrative divisions within Ankang City. This visual representation underscores the pivotal role of population distribution in determining the effectiveness of carbon management practices across different regions.

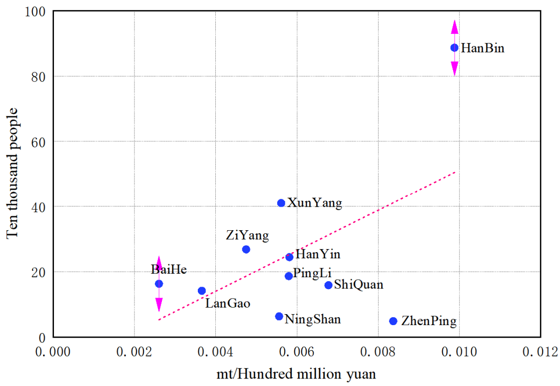

Fig. 21. Correlation analysis between carbon emissions per unit of GDP and population size.

Carbon Emission Efficiency and Economic Relevance.

The efficiency of carbon emissions in Ankang City exhibits a nuanced relationship with its economic dynamics and the composition of its industrial sectors. An analysis reveals that annual increments in carbon emissions align directly with the growth in Gross Domestic Product (GDP), suggesting that economic expansion is inherently linked with increases in both industrial activity and associated emissions. Concurrently, an intriguing inverse relationship is observed between carbon emissions per unit of GDP and the prevalence of the secondary industrial sector. Specifically, a higher concentration of secondary industries correlates with diminished carbon emission efficiency, underscoring the environmental cost of traditional manufacturing and industrial activities.

This pattern highlights the critical importance of industrial restructuring towards sectors with lower carbon footprints as a strategic approach to enhancing Ankang City's carbon emission efficiency. By transitioning towards a more diversified and environmentally sustainable industrial composition, Ankang can mitigate the environmental impacts of its economic development. Figure 22 provides a visual elucidation of this relationship, charting the correlation between carbon emission efficiency and the proportion of the secondary sector across the city's county-level administrative divisions. This representation serves to emphasize the pivotal role that industrial optimization plays in the broader context of achieving carbon efficiency and environmental sustainability within urban development paradigms.

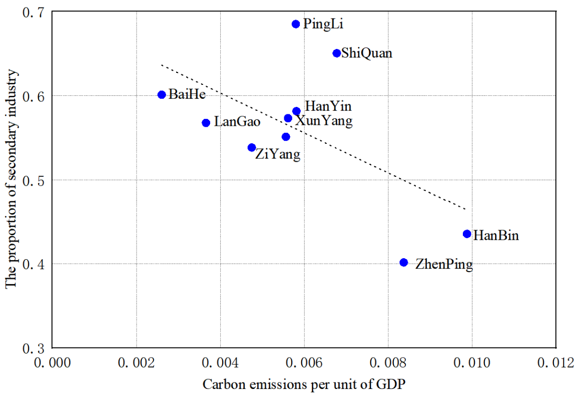

Fig. 22. Correlation analysis between carbon emissions per unit of GDP and the share of secondary industry.

6 SUMMARY AND RECOMMENDATIONS

6.1 Conclusion

Regularities and Characteristics of Carbon Emission.

Ankang City is characterized as a region with a carbon surplus, where the rate of carbon emissions remains below the natural environment's absorption capacity, a testament to the region's rich natural assets and effective carbon management strategies. This analysis delves into the spatial distribution of carbon emissions across the city's administrative divisions, highlighting distinct patterns in carbon output and sequestration [6].

Within Ankang, county-level administrative units such as Hanbin District, Xunyang City, Shiquan County, and Hanyin County emerge as the principal contributors to carbon emissions. These areas, notable for their advanced industrial development, host a greater density of industries and sewage-discharging entities compared to their counterparts, coupled with expansive built-up and agricultural lands. Conversely, the counties nestled within the Qinling and Dabashan Mountains, including Ningshan, Baihe, Zhenping, and Ziyang, exhibit minimal industrial activity and lower GDP figures. These mountainous regions, constrained by their geographical makeup, offer limited opportunities for industrial and settlement expansion, necessitating the establishment of enclave economic parks within the Hanbin District to mitigate land scarcity.

A closer examination reveals that Ziyang County, Shiquan County, Hanbin District, and Ningshan County register the highest carbon emissions per unit of constructed area. Similarly, Shiquan County, Hanbin District, Ningshan County, and Zhenping County exhibit elevated carbon emissions per capita, indicating that the energy-intensive industrial activities within these districts contribute significantly to their carbon footprint. Notably, Ziyang County, despite leading in emissions per constructed area, ranks lower in per capita emissions, reflecting its reliance on the selenium-enriched tea industry, which occupies extensive land but engages a smaller population segment. Zhenping County's scenario contrasts sharply, with high per capita emissions but low emissions per constructed area, underscoring the lack of industrial development and the challenges posed by its limited flat land, resulting in emissions predominantly originating from scattered residential areas [7].

This comprehensive analysis sheds light on the intricate dynamics of carbon emissions within Ankang, illustrating how industrial development, geographical constraints, and land use patterns collectively influence the region's carbon emissions profile.

Regularities and Characteristics of Carbon Sequestration.

The analysis of carbon sequestration across Ankang City reveals that Zhenping County, Ningshan County, and Pingli County exhibit the highest rates of carbon sequestration per unit area, attributable primarily to the extensive forest coverage within these jurisdictions. Conversely, Hanbin District, Hanyin County, and Shiquan County, characterized by their relatively flat terrains, register the lowest levels of carbon sequestration. This delineation of carbon sequestration capacity closely aligns with the spatial distribution of forested lands across Ankang City, underscoring the integral role of forest ecosystems in carbon absorption processes within the region. Such insights highlight the crucial interplay between topography, vegetative cover, and carbon sequestration dynamics, emphasizing the significance of preserving and expanding forested areas as a strategic approach to enhancing the carbon sink potential of Ankang City.

Regularities and Characteristics of Carbon Emission Efficiency.

In the analysis of carbon emission efficiency across Ankang City, it emerges that Hanbin District, Zhenping County, and Shiquan County exhibit the lowest levels of efficiency in this regard, whereas Baihe County, Langao County, and Ziyang County demonstrate the highest efficiency in carbon emissions. The study identifies a correlation between carbon emission efficiency and several factors including the intensity of urban development and construction, population density, and notably, the proportion of the secondary industry. However, this correlation is characterized by its modest strength and the presence of outliers, highlighting the intricate dynamics and nuanced patterns that define carbon emission efficiency within the region.

A significant observation is that the correlation between carbon emission efficiency and the prevalence of the secondary industry stands out as the most pronounced. Administrative units with a lesser engagement in secondary industries tend to exhibit reduced carbon emission efficiency, whereas those with a more substantial involvement in such industries show enhanced efficiency. This pattern suggests that the secondary sector in Ankang maintains a relatively higher efficiency in carbon emissions. This scenario can be attributed to Ankang's strategic regulation of high-pollution enterprises and its commitment to fostering green industries within its developmental agenda. Through deliberate planning and environmental stewardship, Ankang City has successfully optimized its industrial landscape to mitigate carbon emissions, emphasizing the adoption of sustainable practices and technologies across its economic sectors.

In conclusion, the varying levels of carbon emission efficiency across Ankang City underscore the complex interrelation between industrial activity, urban development, and environmental management strategies. The predominant influence of the secondary industry on carbon emission efficiency reflects Ankang's proactive approach to balancing economic growth with ecological preservation, marking a significant step towards achieving sustainability in industrial development [8].

6.2 Recommendations for Enhancing Carbon Surplus and Sustainable Development in Ankang

While Ankang's status as a carbon surplus region is commendable, it does not signify the apex of low-carbon development. It is imperative for Ankang to intensify efforts in scientific and technological innovation, propelled by strategic policy initiatives aimed at fostering green production and elevating environmental consciousness among businesses and the citizenry. By doing so, Ankang can further refine its carbon emissions structure towards a sustainable model, a move that not only aids in diminishing carbon footprints and safeguarding the environment but also propels local economic vitality.

Conservation and Stabilization of the Ecological Pattern.

The preservation of Ankang's ecological integrity necessitates maintaining and bolstering the resilience of its ecosystem. This involves safeguarding areas with compromised or vulnerable ecological conditions through targeted protection and restoration efforts and prioritizing biodiversity conservation. Essential to this strategy is relinquishing overutilized ecological spaces to prevent resource depletion and ecological degradation. Special focus should be placed on enhancing the carbon sequestration capabilities of regions like Ningshan County and Zhenping County, while also improving the ecological health of areas with significant carbon emissions and developmental pressures, including Hanbin District and Xunyang County [9].

Optimization of Land Use and Spatial Planning.
Ankang's governance and planning bodies must collaboratively refine the city's spatial and functional zoning to promote land use efficiency within urban confines. This entails a meticulous spatial arrangement and infrastructural optimization to augment the efficacy of urban systems and facilitate the transition to a greener and low-carbon cityscape, emphasizing the judicious allocation of land resources and fostering a symbiotic relationship between urban development and environmental sustainability.

Leveraging Ecological Assets for Economic Advancement.
To harmonize economic growth with carbon management objectives, Ankang must leverage its ecological assets and carbon surplus to stimulate economic diversification and resilience. This includes championing low-carbon industrial sectors such as renewable energy, sustainable agriculture, and eco-tourism, thereby facilitating a structural economic transformation towards industries with minimized carbon footprints. Moreover, adopting ecological compensation mechanisms can incentivize environmental stewardship, complemented by a shift towards renewable energy sources to meet the city's carbon neutrality ambitions.

Promoting Low-Carbon Urban and Agricultural Practices.
Ankang should champion the development of low-carbon urban areas, parks, and communities, alongside advocating for sustainable agricultural practices. This includes the green retrofitting of public and residential buildings, fostering organic urban renewal, and implementing innovative agricultural techniques that minimize greenhouse gas emissions, thus contributing to a comprehensive low-carbon lifestyle across urban and rural settings.

Establishment of Low-Carbon Living Prototypes.
By cultivating a municipal culture rooted in carbon consciousness, Ankang can set benchmarks for low-carbon living that integrate energy-efficient transportation, sustainable urban mobility, and community engagement in carbon reduction activities. These initiatives should be supported by policy frameworks that encourage energy conservation and carbon emission mitigation at both individual and community levels.

Development of an Intelligent Carbon Management Framework.
Ankang's strategic response to climate change necessitates the implementation of a sophisticated carbon management infrastructure, capable of monitoring, assessing, and

optimizing the city's carbon footprint. This includes the formulation of local climate action policies, the establishment of carbon trading and neutralization schemes, and the integration of green finance principles to support the city's low-carbon transition.

In summation, these recommendations provide a roadmap for Ankang to reinforce its ecological sustainability while navigating the complexities of economic development and carbon management. By adopting these strategies, Ankang can aspire to not only maintain its carbon surplus status but also set a precedent for sustainable urban development [10].

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