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Spatio-Temporal Relationship between Land Use Carbon Emissions and Ecosystem Service Value in Guanzhong, China

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Abstract: In the context of escalating global concerns for "carbon neutrality and peak carbon" and the urgent need for ecological conservation, deciphering the spatiotemporal interactions between carbon emissions and the ecosystem service value (ESV) in relation to land use changes becomes critically significant. Identifying areas to bolster ecosystem services and curtail carbon emissions, especially within the Guanzhong urban agglomeration, is crucial for advancing sustainable and low-carbon regional development. The study focuses on the urban agglomeration of Guanzhong, using land use and socio-economic data from three periods between 2010 and 2020. Methods such as grid analysis and bivariate spatial autocorrelation models are employed to explore the temporal and spatial evolution characteristics and interaction patterns of carbon emissions and ESV in relation to land use. The findings reveal: (1) during 2010–2020, the Guanzhong urban agglomeration experienced varied transitions in land use types, marked by a significant net decrease in arable land and net increases in grasslands and urban construction areas. (2) The ESV in the Guanzhong urban agglomeration witnessed a consistent rise, exhibiting a spatial distribution pattern with higher values in the southwest and lower in the northeast. Among the categorized ecosystem service functions, services related to hydrological and climate regulation stood out. (3) The Guanzhong urban agglomeration observed an average annual growth rate of 5.03% in carbon emissions due to land use, with a spatial trend that was higher in the center and tapered towards the periphery. Predominant carbon sources included arable lands and urban construction areas, while forests accounted for 94% of carbon sequestration. (4) A pronounced negative correlation between the ESV and carbon emissions was discerned in Guanzhong. Regions with a stronger correlation were primarily centered in Guanzhong, notably around Xi'an and Baoji. The results emphasize the pivotal role of the primary sector's qualitative development in harmonizing the ESV and carbon emission dynamics in the Guanzhong urban agglomeration. This research provides valuable insights for optimizing land resource management, aligned with the rural revitalization strategy, streamlining carbon dynamics, bolstering ESV, augmenting carbon sequestration efficiency, and guiding ecological spatial planning.

Keywords: land-use carbon emission; ecosystem service value; Guanzhong urban agglomeration; bivariate spatial autocorrelation

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1. Introduction

As global economic integration accelerates, China's economic achievements have garnered extensive international recognition. However, this rise has coincided with substantial energy consumption and associated carbon emissions, leading to discernible environmental degradation. According to the World Bank (2019), the combined carbon emissions of China, the United States, and the European Union account for more than half of the global total, with China exceeding the other two and becoming the world's largest contributor to carbon emissions [1]. In response, China has initiated a series of carbon-reduction measures, aligning its commitment to ecological conservation with economic growth and setting ambitious goals for carbon neutrality and peaking emissions.

Ecosystem services represent the environmental conditions and utilities that ecosystems form and maintain, which are essential for human survival and development. As a coupling bridge and bond between natural and social processes, ecosystem services provide new theoretical support for coupled human–environment system research. Conducting ecosystem service assessments can offer scientific foundations for territorial spatial planning, resource management, and optimization of ecosystem services [1,2]. The value of ecosystem services (ESV) focuses on ecological assets, signifying the sum of the final products and services provided by regional ecosystems to humanity and their value [3]. It serves as an economic perspective to evaluate the quality of the ecological environment.

Land use carbon emissions focus on the principles and pathways by which human activities, particularly land use/cover changes (LUCC), directly or indirectly affect carbon emissions. According to a statistical report released by the Global Carbon Project in 2016, the global cumulative carbon emissions from land use changes reached 145 billion metric tons between 1870 and 2015 [4]. China's carbon emissions have been rising annually, with the cumulative carbon emissions from land use changes between 1950 and 2005 amounting to 10.6 billion tons, representing 12% of the global land use change emissions during the same period [5]. Following China's announcement of its "dual carbon" goals in September 2020, a series of policies to address climate change were introduced. Notably, in the 2021 "Opinions of the CPC Central Committee and the State Council on Fully, Accurately, and Comprehensively Implementing the New Development Concept and Doing a Good Job in Peaking Carbon Dioxide Emissions and Achieving Carbon Neutrality", it was proposed to continuously consolidate and enhance the carbon sequestration capacity of ecosystems, highlighting the important correlation between ecosystems and carbon emissions. On the one hand, different land use types generate varying carbon emissions due to their distinct surface characteristics and functions. On the other hand, changes in land use affect the spatial distribution and extent of ecosystems, indirectly influencing the services and values they provide.

Land use/cover changes (LUCC) impact the functionality [6], type, structure, and ecological processes of ecosystems by altering regional biodiversity, resource allocation, landscape patterns, and management practices [7]. These changes affect the quality of the ecological environment and consequently influence the change in ecosystem service value (ESV) [7,8], while also significantly impacting carbon emissions. On one hand, LUCC directly affects the net carbon emissions by driving changes in the carbon source/sink structure, impacting the carbon cycle system and regional net carbon emissions. On the other hand, energy consumption in construction land indirectly influences regional carbon emissions. The consensus that LUCC and energy consumption are significant contributors to global warming and the carbon cycle highlights the importance of identifying the spatiotemporal heterogeneity and interactive relationships between ESV and carbon emissions driven by LUCC. Doing so aids in assessing the impact of human activities on the environment and formulating key strategies for promoting low-carbon land use, which is of great significance for achieving carbon peaking and carbon neutrality. On one hand, research examining the effects of LUCC on ESV spans multiple spatial scales [9], from national [10] to provincial [11] and municipal levels [12,13]. Various methodologies are employed for assessing ecosystem services, including value quantification, material quantification, and energy value assessments [14]. ESV calculations predominantly utilize unit-area value-equivalent factors [2] to standardize ecosystem service functions across diverse ecosystems. These standardized metrics are then integrated with the spatial distribution of ecosystem areas [15–17], facilitating more efficient and data-sparse evaluations [18,19]. Such methodologies allow ESV to not only compare a range of ecosystem services but also to integrate these assessments into national economic accounting systems [20]. This, in turn, aids in the calculation of ecological benefits and the development of compensation models across different regions and types of ecosystems [21,22]. On the other hand, a substantial corpus of work focuses on carbon emissions, examining the links between land-use changes and shifts in carbon sources and sinks. These studies also delve into the spatial heterogeneity of emissions and their driving factors [23,24], as well as correlations between carbon emissions and economic growth [25]. However, it is noteworthy that most existing studies are conducted at a macro-scale and often approach ESV and carbon emissions from isolated disciplinary viewpoints [26]. As a result, there remains a paucity of research investigating the interconnectedness between ESV and carbon emissions within a unified spatiotemporal framework.

Figure 1 demonstrates that Guanzhong is located in the central region of Shaanxi Province, China, positioned within the crucial ecological area of the Yellow River basin's middle reaches as part of the "National Key Project for Ecosystem Protection and Restoration". It also lies in the Qinling protected area, classified as a "Priority Region for Biodiversity Conservation" in China. Guanzhong plays a crucial role in ecological conservation within the country. The region is characterized by a multitude of ecologically sensitive and fragile areas, encompassing extensive territories with severe degrees of vulnerability. It represents a typical area affected by soil erosion at a national level. The ecosystem in the Guanzhong urban agglomeration integrates intensive resource utilization, ecological fragility, and significant importance for protection.

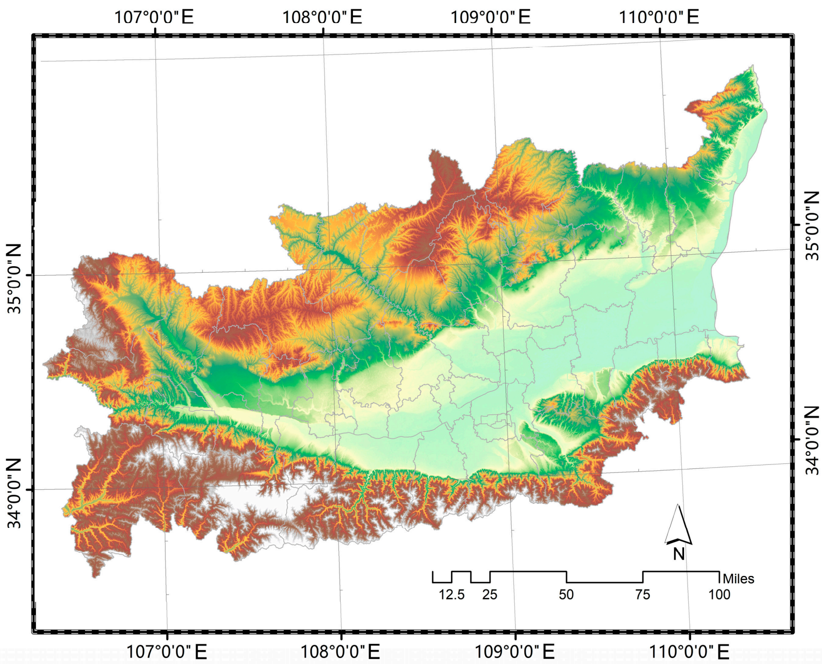

Figure 1. Map of the Guanzhong Research Area. Image source: Drawn by the author.

The Guanzhong Urban Agglomeration, as the core of the "Guanzhong Plain Urban Agglomeration" and the second-largest urban cluster in Western China, stands as both a distinct natural region and a comprehensive economic and geographical entity. According to the 2020 statistical data from the Shaanxi Provincial Bureau of Statistics, by the end of 2020, its population reached 25.8755 million, accounting for 65.42% of the total population of Shaanxi Province. Its Gross Domestic Product (GDP) amounted to 16,901.88 billion

CNY, which constituted 64.56% of the province's overall GDP. The total grain production was 7.3814 million tons, equating to 57.90% of the province's aggregate, exemplifying it as a typical urban cluster in the middle reaches of the Yellow River basin with evident "human-land" conflicts. The region's intricate geographical setting heightens the ecological environment's sensitivity, while unreasonable shifts in land use exacerbate the tension between development and ecological conservation. Furthermore, the Guanzhong urban agglomeration, characterized by frequent land use alterations and high carbon emissions, is a representative area in the middle reaches of the Yellow River basin. Owing to its vibrant socio-economic dynamics, extensive man-made land cover, and notable east–west disparities in ecological resources, it aptly demonstrates the complex relationship between carbon emissions and Ecosystem Service Valuation (ESV) in the context of land use changes.

To this end, the current study focuses on the Guanzhong urban agglomeration, employing county-level data for the decade from 2010 to 2020. Utilizing bivariate spatial autocorrelation analysis, the study examines the spatiotemporal variations of carbon emissions and ESV, influenced by land-use transitions. Such analysis has crucial implications for the sustainable development of geographical units within the Yellow River basin, particularly when guided by ecological conservation and carbon reduction goals.

2. Research Method and Data Sources

The research methodology adopted in this study is illustrated in Figure 2. Using land use vector data from 2010, 2015, and 2020, the study employs the ArcGIS spatial analysis tool to calculate the land transfer matrix based on LUCC, facilitating spatial visualization of land transfer scenarios. Furthermore, the study allocates land use types at the county level. The Ecosystem Service Value (ESV) is calculated using a per-area value equivalent factor method, which involves multiplying the land area by corresponding adjustment coefficients. Carbon emissions are determined by adding direct carbon emissions, calculated by multiplying land area by specific coefficients, to the indirect emissions generated from construction land. Lastly, the study conducts a correlation analysis to identify regions in the Guanzhong urban agglomeration with the potential for enhancing ecosystem services and carbon reduction.

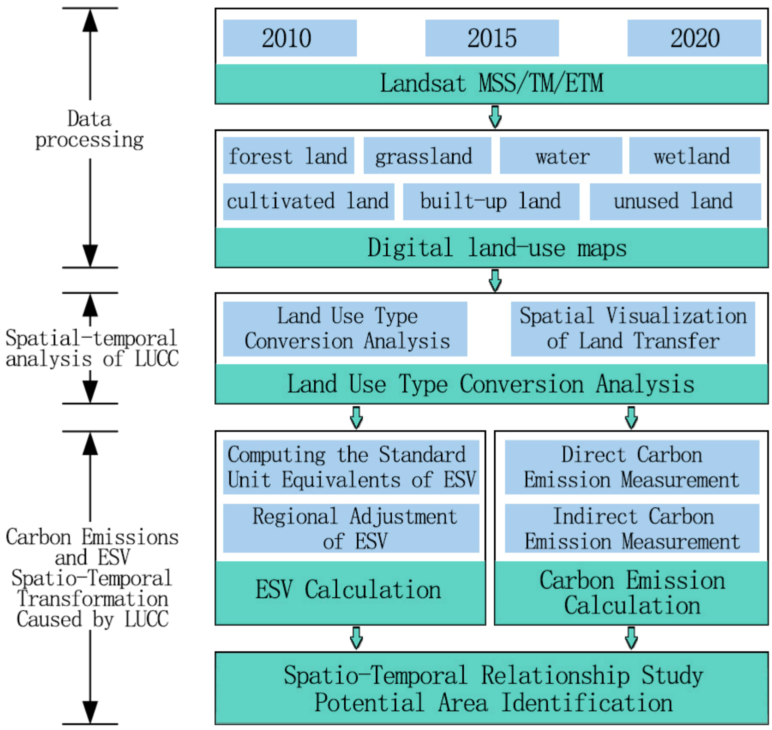

Figure 2. Research Methodology Flow Chart. Image source: Drawn by the author.

2.1. ESV Calculation and Adjustment

In this study, considering the compatibility between the ecosystem characteristics of the Guanzhong urban agglomeration and terrestrial ecosystem service functions, and referencing the research findings on ESV by Xie G D and colleagues, we established a per-unit area ESV equivalence accounting system for the Guanzhong urban agglomeration and made regional adjustments.

2.1.1. Computing the Standard Unit Equivalents of ESV

The standard unit ESV equivalent refers to the actual value that can be exchanged for the average annual yield of 1 ha of cultivated land. It can also be interpreted as the net profit generated by the food production of the unit area cultivated land ecosystem [17]. This net profit is 1/7 of the average grain price [27]. This equivalent is used as a reference to determine the equivalents for other ecosystem services. The calculation formula is as follows:

$$D = \frac{1}{7} \times \sum_{i=1}^{n} \left(\frac{P_i \times G_i}{S_i} \right) \quad (1)$$

where D represents the value of a standard equivalent ecosystem service in the Guanzhong urban agglomeration (CNY/ha); P_i denotes the unit price of the ith crop for the current year (CNY); G_i denotes the annual yield of the ith crop; S_i denotes the planting area of the ith crop.

2.1.2. Regional Adjustment of ESV

Given the challenges posed by regional and scale variations in ecosystem services, it is essential to revise calculations of the ESV equivalents in the Guanzhong urban agglomeration. This study adjusts these values by considering three factors: grain production yield from the Guanzhong urban agglomeration, socio-economic factors, and biomass factors.

- Revision Coefficient for Grain Production Factor

There exists a disparity in grain production levels between the Guanzhong urban agglomeration and the entire country. This study utilizes grain yield per unit area data from 2010, 2015, and 2020 to revise the ESV equivalent for the Guanzhong urban agglomeration. The calculation formula is as follows:

$$\lambda_1 = \frac{Q}{Q_0} \quad (2)$$

where λ_1 denotes the revision coefficient for grain production in the ESV equivalent of the Guanzhong urban agglomeration; Q, Q_0, respectively, denote the grain yield per unit area of cultivated land in the Guanzhong urban agglomeration and nationwide.

Referencing the grain yield per unit area data for both the Guanzhong urban agglomeration and the entire country from 2010, 2015, and 2020, the revision coefficient for grain production in the Guanzhong urban agglomeration was determined to be 0.74 for 2020, 0.72 for 2015, and 0.74 for 2010.

- Revision Coefficient for Socio-economic Factors

The socio-economic development level of the Guanzhong urban agglomeration differs from the national average. As the value of ecosystem services needs to take into account people's willingness and ability to pay, it is essential to incorporate this factor into the revision system. The calculation formula is as follows:

$$\lambda_2 = W_n \times R_n \quad (3)$$

$$W_n = \frac{W_s}{W_g} \quad (4)$$

$$W = \frac{2}{1 + e^{-m}} \quad (5)$$

$$m = \frac{1}{E_n} - 2.5 \tag{6}$$

$$E_n = E_{nr} \times (1 - P) + E_{nu} \times P \tag{7}$$

$$R_n = \frac{GDP_s}{GDP_g} \tag{8}$$

where λ_2 denotes the socio-economic revision coefficient for the ecosystem service value equivalent in the Guanzhong urban agglomeration; W_n denotes the willingness to pay; R_n denotes the ability to pay; W_s is the willingness-to-pay parameter for the Guanzhong urban agglomeration, while W_g is for the entire country. W denotes the willingness-to-pay parameter for W_n, m denotes the coefficient for the stage of social development, and e denotes the natural logarithm. E_n signifies the Engel coefficient (%) for the nth year, with E_{nr} and E_{nu}, respectively, denoting the Engel coefficients for rural and urban areas in the nth year. P denotes the urban population ratio (%). GDP_s and GDP_g correspond to the per capita GDP (CNY/person) of the Guanzhong urban agglomeration and the national scale, respectively.

Drawing upon the research findings of Su et al. [28], and using socio-economic development data from the Guanzhong urban agglomeration and the entire country for 2010, 2015, and 2020, it was computed that the socio-economic revision coefficient for Guanzhong was 0.92 for 2020, 0.94 for 2015, and 0.86 for 2010.

- Revision Coefficient for Biomass Factor

Due to China's vast size and the marked variations in climatic and hydrothermal conditions, there is a significant discrepancy in the quantity and quality of biomass throughout the country. The ESV (Ecosystem Service Value) is closely associated with the biomass levels of different regions. Thus, it is essential to incorporate this factor into the revision system. The calculation formula is as follows:

$$\lambda_3 = \frac{b_i}{B_i} \tag{9}$$

where λ_3 denotes the biomass revision coefficient for the ecosystem service value equivalent in the Guanzhong urban agglomeration, b_i denotes the biomass of the ith ecosystem category in Guanzhong, and B_i denotes the average biomass of the ith ecosystem category at the national level.

The revision coefficient for grassland biomass was determined to be 0.77, referencing the research results on China's grassland vegetation biomass by Pu, S.L. [29]. The revision coefficient for forest biomass was set at 1.32, based on the studies on China's forest vegetation biomass by Xu, W.y. [30]. For the cropland system biomass, the coefficient was established as 0.51, referring to the research findings by Xie, G.D. [3]. For other types of ecosystems, the analysis revealed minimal variations on a national scale; thus, no revisions were made.

- The calculation formula for the equivalent value of ecosystem services (ESV) in the Guanzhong urban agglomeration is as follows:

$$E_i = \lambda_1 \times \lambda_2 \times \lambda_3 \times E_0 \tag{10}$$

where E_i denotes the revised equivalent value of ecosystem services for the ith ecosystem type, while E_0 denotes the national average equivalent value of ecosystem services for the same ith ecosystem type.

2.2. Carbon Emission Quantification

In order to facilitate the correlation analysis between carbon emissions and the results of ESV calculations, this study adopts the method of land use carbon emissions estimation. The emissions are categorized into two types: direct and indirect carbon emissions.

(1) For cultivated land, forest land, grassland, water bodies, and unused land, direct carbon emissions are calculated. The calculation formula is as follows:

$$E_Z = \sum e_i = \sum S_i \times \delta_i \tag{11}$$

where E_Z denotes the direct carbon emissions; e_i denotes the carbon emissions from each type of land use; S_i denotes the area of the ith type of land use; and δ_i is the carbon emission coefficient for the ith type of land use. The carbon emission coefficients for each type of land use refer to the data given in Table 1.

Table 1. Statistical Table of Land Use Carbon Emission Coefficients.

Land Use Type	Carbon Emission Coefficient (t/ha)	Land Use Type	Carbon Emission Coefficient (t/ha)	Land Use Type	Carbon Emission Coefficient (t/ha)
Cultivated Land	0.422	Grassland	−0.022	Wetland	−0.253
Forest land	−0.644	Water	−0.253	Unused Land	−0.005

Data Sources: The carbon emission coefficients for different land types are referenced from the research findings of Li Ying, Fang Jingyun, Duan Xiaonan, Lai Li, and others.

(2) For built-up land, indirect carbon emissions are calculated. The calculation formula is as follows:

$$E_J = GDP_{2,3} \times H \times K \tag{12}$$

where E_J denotes the indirect carbon emissions; $GDP_{2,3}$ denotes the annual output value of the secondary and tertiary industries; H stands for the energy consumption per unit GDP, and the coefficient K refers to the conversion factor for standard coal carbon per unit (the value of K is derived using the calculation method of the National Bureau of Statistics for converting to standard coal carbon per unit: saving 1 kg of standard coal equates to reducing 2.493 kg of "carbon dioxide", which corresponds to a reduction of 0.68 kg of "carbon". Hence, 0.68 is selected as the standard coal conversion coefficient for this research).

(3) The calculation formula for total carbon emissions from land use is as follows:

$$E = E_Z + E_J \tag{13}$$

where E denotes the total carbon emissions.

2.3. Data Sources

The data involved in this study include both geospatial data and statistical data such as population, economy, and grain yield. The derivation of these data is detailed as follows: ① the 30 m DEM data for the Guanzhong urban agglomeration were sourced from the geospatial data cloud platform; ② vector data delineating the boundaries of the county-level administrative regions in Guanzhong were obtained from the Shaanxi Province Geographic Information Public Service Platform; ③ land use data for the years 2010, 2015, and 2020 were sourced from the National Geographic Information Resources Catalog Service System; ④ statistical data related to population, economy, and grain yield were sourced from the "National Statistical Yearbook", the "Shaanxi Province Statistical Yearbook", and the websites of statistical bureaus for relevant prefecture-level cities.

3. Result Analysis

3.1. Land Use Type Conversion Analysis

Utilizing ArcGIS spatial analysis tools, land-use data from Guanzhong for the years 2010 and 2020 were overlaid. Subsequent calculations for land-use transition matrices were conducted using Excel. The results were spatially visualized (Figure 3) to analyze the relationships and magnitudes of land-use type conversions.

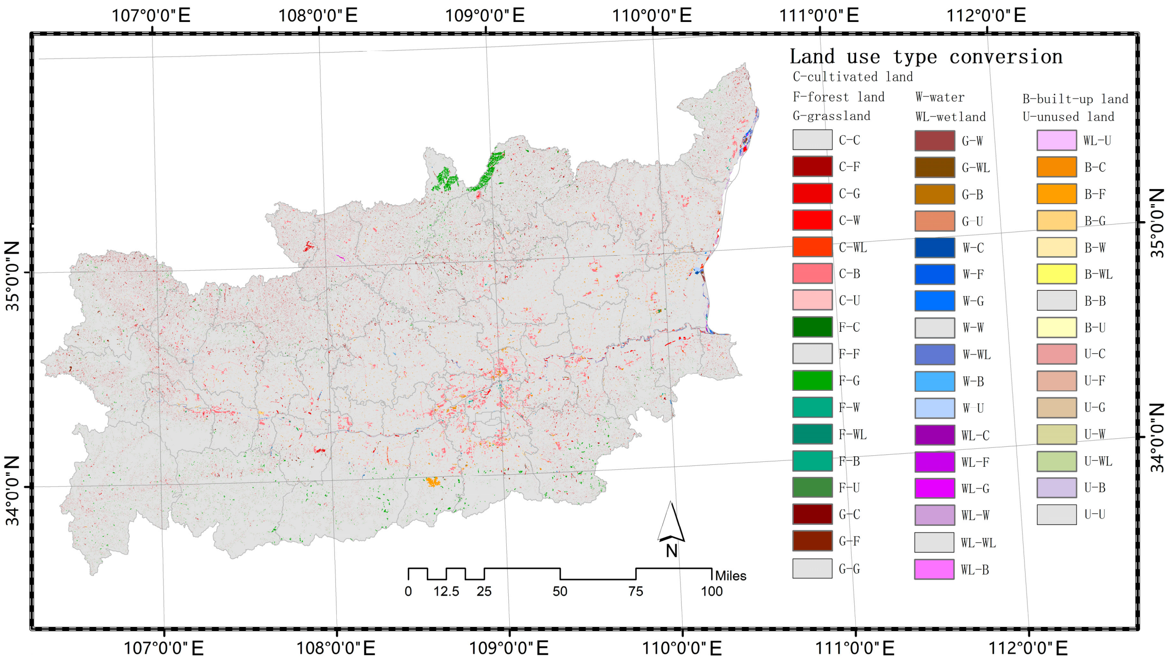

Figure 3. Land Use Conversion Map of the Guanzhong urban agglomeration during 2010–2020. Image source: Drawn by the author.

Figure 4 delineates the land-use transition matrix for the Guanzhong urban agglomeration, revealing a total land transition area of 5161.25 km^2 between 2010 and 2020. Of note, cultivated and forest lands are primarily giving way to other types of land use. In contrast, transition volumes for built-up land are markedly high, whereas those for water, wetland, and unused lands remain relatively low. Over this decade, cultivated land experienced a net reduction of 697.47 km^2, largely transitioning to grassland and urban areas. Conversely, net additions of 387.47 km^2 in grassland were chiefly due to conversions from cultivated and forest lands. Similarly, built-up land saw a net increase of 377.91 km^2, mainly originating from cultivated land conversions. Forest land observed a net loss of 168.41 km^2, while water areas, wetlands, and unused lands saw net gains of 30.29 km^2, 46.00 km^2, and 24.21 km^2, respectively.

In the Guanzhong urban agglomeration, where cultivated land constitutes over 40% of the total area, urban expansion, notably around Xi'an, has led to ongoing loss of peripheral agricultural lands. Policy imperatives complicate this landscape. While agricultural policies advocate for maintaining arable land to ensure food security, ecological initiatives encourage the conversion of erosion-prone or low-yield cultivated land into forests and grasslands. Such diverse policy drivers result in complex land-use transformations. Thus, Guanzhong exhibits a dynamic equilibrium among natural ecological, agricultural, and urban lands, with urban expansion particularly exerting pressure on suburban cultivated areas.

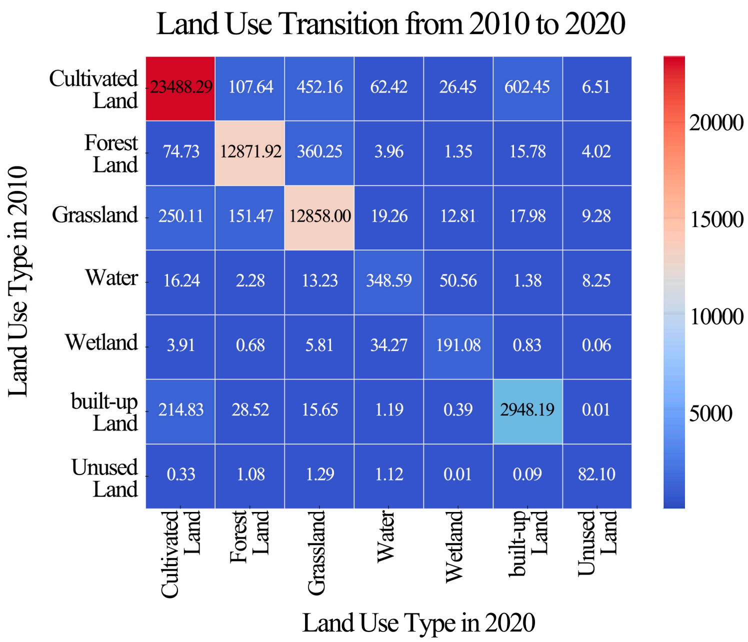

Figure 4. Land Use Type Transition Heatmap of the Guanzhong urban agglomeration during 2010–2020. Image source: Drawn by the author.

3.2. ESV Calculation Results Analysis

Leveraging data from the National Resources and Environmental Database and accounting for the unique land characteristics of the Guanzhong urban agglomeration, this study classifies land use into six primary categories: Cultivated Land, Grassland, Forest Land, Water, Wetland, and Unused Land. For the purpose of Ecosystem Service Value (ESV) computation, both built-up and unused lands are aggregated under a singular resource type. Building upon Xie G.D.'s "National Per Unit Area ESV Equivalence Table [3]", ecosystem services are categorized into four principal types: provisioning, regulating, supporting, and cultural services, which are further divided into 11 secondary types. Value equivalencies across these service types were subsequently established for each of the six land-use categories.

Economic valuation in this research was obtained through analyzing price and yield data for two key agricultural crops: wheat and maize. The resultant economic values per hectare for Cultivated Land ecosystems in the Guanzhong urban agglomeration were ascertained to be CNY 1137.08 in 2010, CNY 1438.89 in 2015, and CNY 1605.92 in 2020. By integrating variables from agricultural production, socio-economic factors, and biomass metrics, the study recalibrated the value equivalencies for various ecosystems. Findings reveal that the total ESV for the Guanzhong urban agglomeration escalated to CNY 427.68 billion in 2010, CNY 570.72 billion in 2015, and CNY 650.70 billion in 2020. Figure 5 delineates the overall ESV and its growth rate across 54 districts and counties in Guanzhong between 2010 and 2020, offering an insightful perspective on the spatiotemporal dynamics of ESV over the course of a decade.

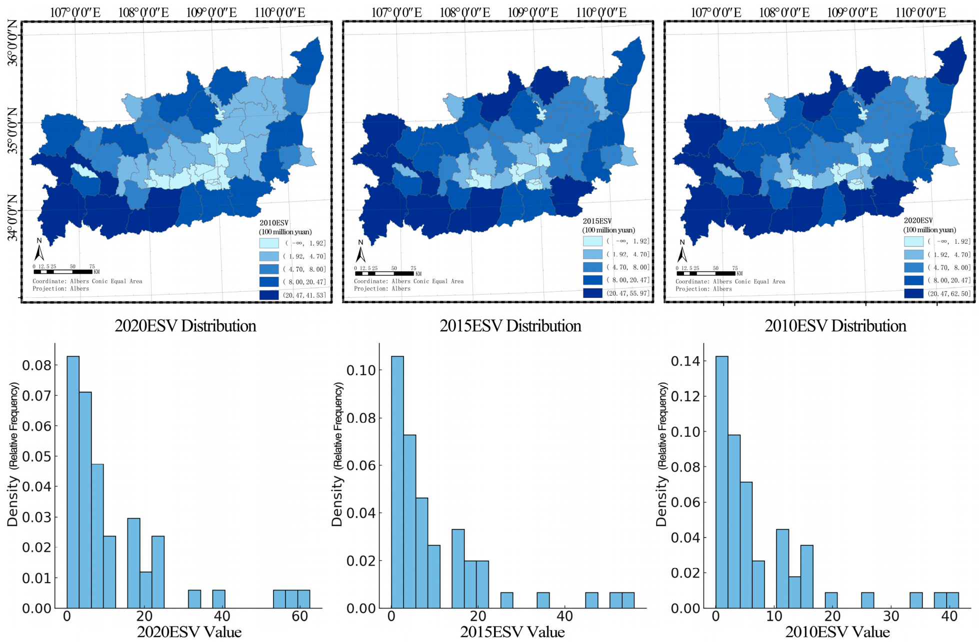

Figure 5. Distribution Map and Trends of ESV Levels in the Guanzhong urban agglomeration during 2010–2020. Image source: Drawn by the author.

3.3. *Spatial-Temporal Evolution Characteristics of ESV*

(1) Spatial Distribution Characteristics of ESV

Figure 5 illustrates a spatial distribution of Ecosystem Service Value (ESV) in the Guanzhong urban agglomerationa, revealing higher ESV concentrations in the southwest as opposed to the central region. A subsequent analysis of comparative ESV across individual districts and counties, as detailed in Figure 6, indicates that from 2010 to 2020, Taibai, Feng County, Zhouzhi County, Chencang District, and Long County consistently emerged as the top contributors to ESV growth, with respective rates of 9.65%, 8.91%, 8.16%, 5.89%, and 4.87%. These districts and counties collectively occupy approximately 24% of Guanzhong's total land area, encompass eight national nature reserves, and contribute to more than 37% of the region's overall ESV.

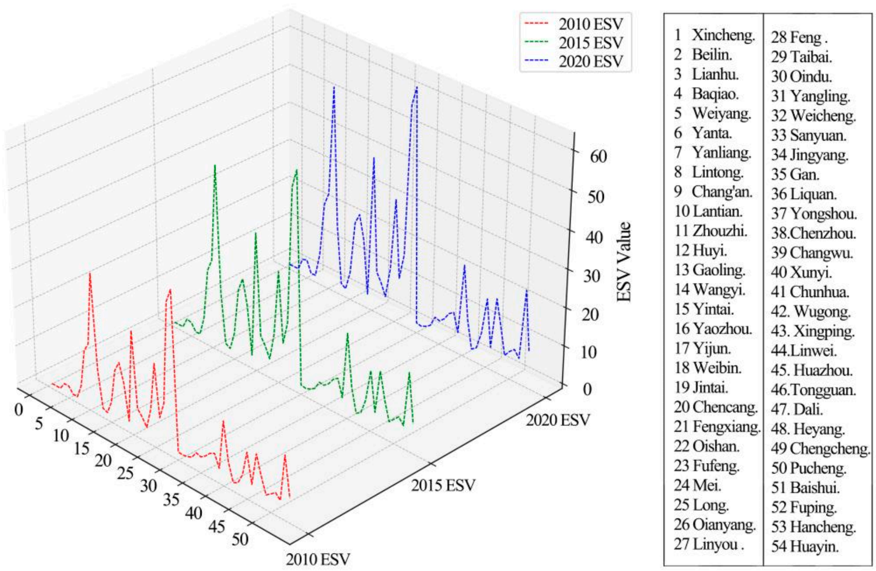

Figure 6. ESV Comparison Chart of Districts and Counties in the Guanzhong urban agglomeration. Image source: Drawn by the author.

(2) ESV Variation Characteristics of Land Use Types

Table 2 reveals a relatively minor fluctuation in ESV contribution rates among different land-use types in the Guanzhong urban agglomeration between 2010 and 2020. Forest land consistently held the highest ESV contribution rate, closely followed by grasslands. Together, these two ecosystems contributed to roughly 80% of the total ESV in the region. As depicted in Figure 7, the annual growth rate for Guanzhong's overall ESV stood at 4.28%. The yearly ESV growth rates for individual ecosystems were ranked as follows, in descending order: water > unused land > wetlands > grassland > forest land > cultivated land. Notably, significant net conversions of land from forests and cultivated areas over the decade served as limiting factors, inhibiting rapid ESV growth.

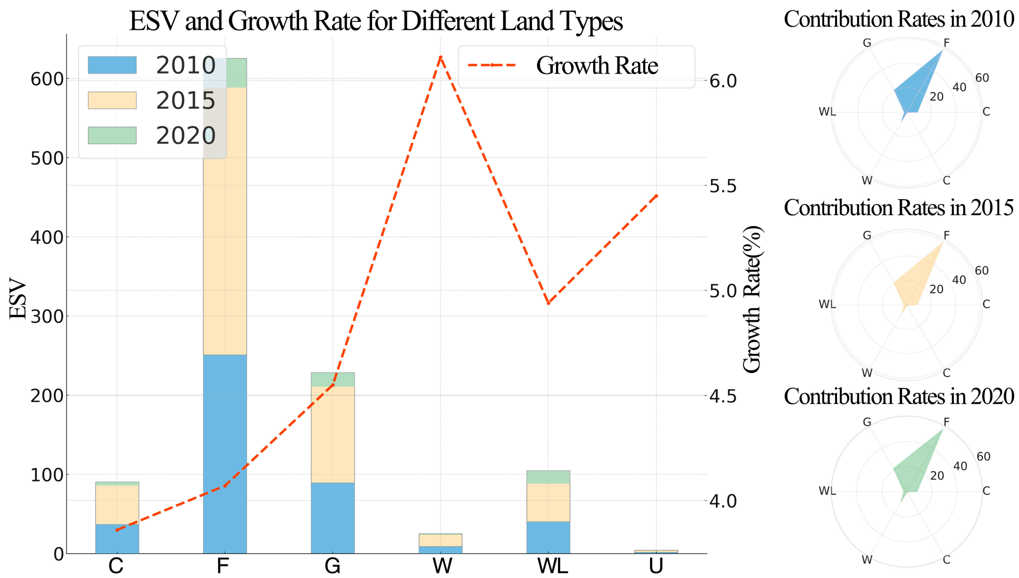

Figure 7. Comparison of ESV Growth and Contribution Rates for Various Land Uses in the Guanzhong urban agglomeration. Image source: Drawn by the author.

Table 2. Summary Table of ESV for Ecosystems in the Guanzhong urban agglomeration during 2010–2020.

Ecosystem	2010		2015		2020		ESV Increase (Billion CNY)		Annual Growth Rate of EVS (%)
	ESV (Billion CNY)	ESV Contribution Rate (%)	ESV (Billion CNY)	ESV Contribution Rate (%)	ESV (Billion CNY)	ESV Contribution Rate (%)	2010–2015	2015–2020	
Cultivated Land	36.86	8.62	48.71	8.53	53.68	8.25	11.85	4.97	3.86
Forest land	250.91	58.67	337.18	59.08	374.40	57.54	86.26	37.23	4.07
Grassland	89.36	20.89	120.73	21.15	139.12	21.38	31.37	18.39	4.55
Water	8.90	2.08	14.30	2.51	16.08	2.47	5.39	1.78	6.11
Wetland	40.03	9.36	47.58	8.34	64.69	9.94	7.55	17.11	4.94
Unused Land	1.61	0.38	2.23	0.39	2.73	0.42	0.62	0.50	5.45
total amount	427.68	100.00	570.72	100.00	650.70	100.00	143.04	79.98	4.28

Table source: Created by the author.

Upon examining the interrelated patterns and dynamics of ESV changes across different ecosystems, it became evident that ESV variability is influenced not only by alterations in land-use types, grain yield, and grain prices but also significantly correlates with the combined effects of willingness to pay and payment capability, factors indicative of the socio-economic conditions in the Guanzhong urban agglomeration. Strong forest cover plays a crucial role in ESV ranking assessments across various counties and districts. For instance, in Taibai County—which holds the highest ESV—three national nature reserves exist: Huang Baiyuan National Nature Reserve, Tai Bai Mountain National Nature Reserve, and Tai Bai Xi Shui He Rare Aquatic Life National Nature Reserve. The county's forest ecosystem alone accounts for an exceptional ESV contribution rate of 87.84%.

(3) ESV Variation Characteristics of Service Functions

Table 3 reveals a steady increase in the Ecosystem Service Value (ESV) of the Guanzhong ecosystem over a decade. Notably, the contribution rates for various secondary service functions have maintained a consistent ranking: hydrological regulation, followed by climate regulation, soil conservation, biodiversity, gas regulation, environmental purification, aesthetic landscapes, raw material production, food production, water resource provision, and nutrient cycling maintenance.

Table 3. Summary Table of the Value of Ecosystem Service Functions in the Guanzhong urban agglomeration during 2010–2020.

Service Function Type		2010 (Billion CNY)	2015 (Billion CNY)	2020 (Billion CNY)	Annual Growth Rate of EVS (%)
Provisioning Services	Food Production	13.11	17.32	19.51	4.07
	Raw Material Production	13.86	18.67	20.7	4.07
	Water Resource Provision	8.56	11.34	13.42	4.61
Regulating Services	Gas Regulation	40.11	54.07	60.39	4.21
	Climate Regulation	101.24	135.79	152.32	4.14
	Environmental Purification	32.66	43.93	49.78	4.28
	Hydrological Regulation	104.58	136.33	162.2	4.48
Supporting Services	Soil Conservation	50.63	68.44	76.31	4.21
	Nutrient Cycling Maintenance	4.24	5.76	6.4	4.21
	Biodiversity	40.42	54.42	61.77	4.34
Cultural Services	Aesthetic Landscapes	18.27	24.67	27.91	4.34

Table source: Created by the author.

Aligned with land-use transition analysis, the data underscore a strong correlation between ESV growth and shifts in land use types. Hydrological regulation emerges as the leading contributor, accounting for 24.37% of the ESV. This leadership is attributable to successful soil and water conservation initiatives, as well as ecological restoration in the Qinling Mountains and adjacent areas. These efforts have led to a significant expansion of forest and water body areas, thereby markedly enhancing local vegetation coverage. Consequently, the ecosystem's aptitude for intercepting, absorbing, and storing precipitation, along with regulating runoff and mitigating droughts and floods, has been fortified. In contrast, reductions in cultivated land area have precipitated a consistent decline in ESV contribution rates for food and raw material production services. The nutrient cycling maintenance function posts the lowest contribution rate at 0.97%. This minimal contribution is closely tied to the limited diversification of tree species and a homogenous ecosystem resulting from previous soil and water conservation efforts. Recommendations include optimizing planting structures, improving soil nutrient cycling functions, and advancing agricultural structural adjustments. Among primary categories, cultural services exhibit the lowest contribution rate at 4.27%, suggesting underutilization of Guanzhong's inherent resource advantages. Future endeavors should focus on establishing ecological science education bases, ecological cultural exhibition centers, and folklore experience parks to bolster the region's cultural service value.

3.4. Carbon Emission Calculation Results Analysis

According to the data from the "China Statistical Yearbook 2022", the study calculated the GDP energy consumption for the years 2010, 2015, and 2020 as 0.88, 0.72, and 0.55 (104 CNY/ton of standard coal), respectively. Utilizing the standard coal conversion coefficient method provided by the National Bureau of Statistics, a conversion factor of 0.68 (ton/ton of standard coal) was adopted for this research to represent the standard coal equivalent. Through the application of Equations (11)–(13), total carbon emissions attributable to land use in the Guanzhong urban agglomeration were determined to be 34.33 million tons for 2010, 52.08 million tons for 2015, and 55.85 million tons for 2020.

Figure 8 delineates the spatiotemporal variations in carbon emissions across the Guanzhong urban agglomeration from 2010 to 2020. This graphical representation enhances the intuitive understanding of the dynamic trends in carbon emissions within the area, facilitating more effective analyses of their spatiotemporal evolution.

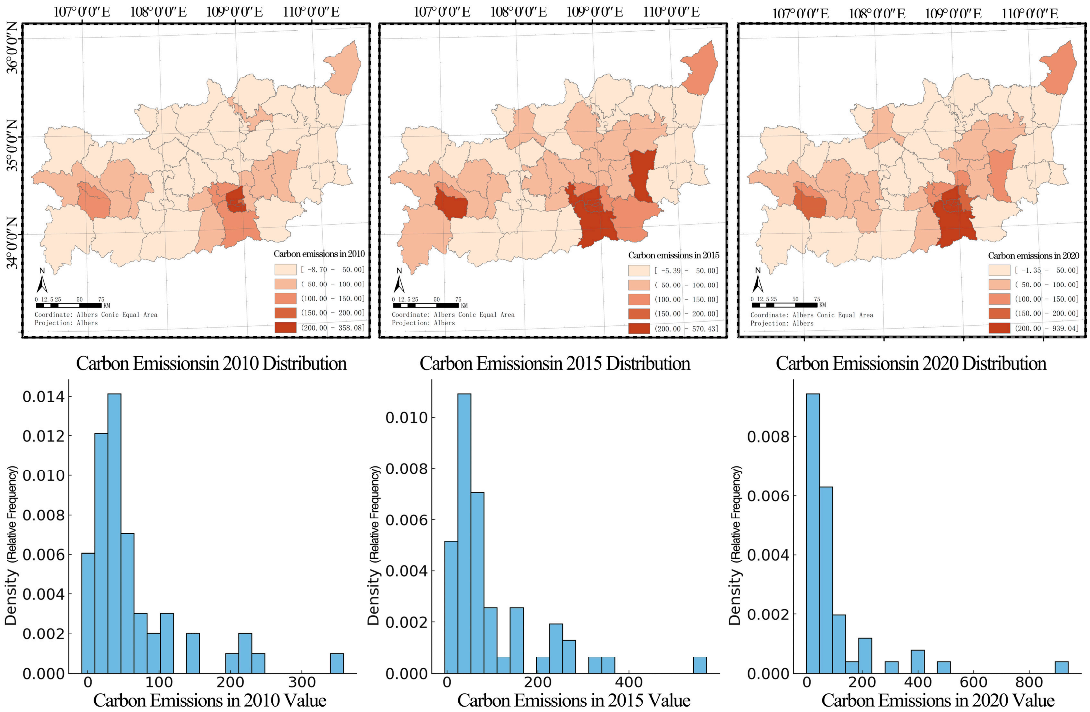

Figure 8. Distribution Map and Trends of Carbon Emission Levels in the Guanzhong urban agglomeration during 2010–2020. Image source: Drawn by the author.

3.5. Spatial-Temporal Evolution Characteristics Analysis of Carbon Emission

Figure 8 reveals that higher levels of carbon emissions in the Guanzhong urban agglomeration are predominantly localized in the central regions, particularly around Xi'an City, as well as in key urban sectors of prefecture-level cities like Weibin and Linwei districts. Carbon emissions in these high-emitting locales exhibit a pattern of initial increase, followed by a decline, revealing a distinct spatiotemporal evolution. Figure 9 shows that over a decade, carbon emissions in the six primary urban districts of Xi'an City, along with Chang'an and Linwei districts, have surpassed 500,000 tons, marking them as the most significant contributors to the rise in carbon emissions within the Guanzhong urban agglomeration. In contrast, areas such as Feng, Jingyang, Yintai, and Huayin City have experienced a decline in emissions. The remaining counties and districts have seen modest emission increases, with those situated along the Wei River experiencing marginally higher growth rates compared to those in the Qinling Mountains and the Loess Plateau hilly regions.

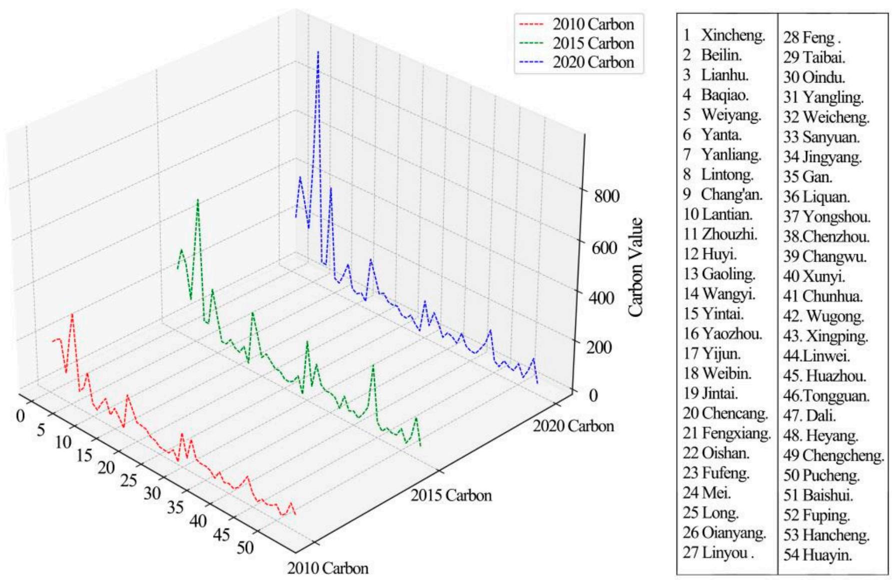

Figure 9. Carbon Emission Comparison Chart of Districts and Counties in the Guanzhong urban agglomeration. Image source: Drawn by the author.

Table 4 reveals a consistent increase in carbon emissions from land use within the Guanzhong urban agglomeration from 2010 to 2020, exhibiting an average annual growth rate of 4.99%. This upward trajectory closely aligns with the overall trend in carbon sources, albeit with a modest decline in carbon sequestration levels. A significant disparity exists between carbon sources and sinks in the region. Forests emerge as the primary contributors to carbon sequestration, accounting for over 94% of the total sequestered carbon over the period. Conversely, urban production and construction activities serve as the predominant sources of carbon emissions. To align with the strategic objectives of achieving "carbon peak and carbon neutrality", the region should curb the expansion of built-up areas, advocate for shifts in industrial and energy sectors, actively pursue renewable energy alternatives, and expand high carbon sequestration lands, such as forests, to bolster regional carbon sequestration capabilities.

Table 4. Summary Table of Carbon Emissions in the Guanzhong urban agglomeration during 2010–2020.

Year	Direct Carbon Emissions (10^4 tonnes)						Indirect Carbon Emissions (10^4 tonnes)	Total Carbon Emission (10^4 tonnes)	Carbon Source (10^4 tonnes)	Carbon Sink (10^4 tonnes)	Carbon Emission Intensity (tonne/ha)
	Cultivated Land	Forest Land	Grassland	Water	Wetland	Unused Land					
2020	101.49	−84.78	−3.02	−1.19	−0.72	−0.19	5573.89	5585.49	5675.37	−89.89	10.09
2015	104.27	−85.74	−2.93	−0.98	−0.71	−0.17	5195.21	5208.95	5299.49	−90.54	9.40
2010	104.43	−85.87	−2.93	−1.11	−0.60	−0.16	3419.63	3433.39	3524.07	−90.67	6.20

Table source: Created by the author.

3.6. Correlation Analysis

(1) Bivariate Spatial Autocorrelation Analysis.

Analyzing the calculation results of the ESV and carbon emissions of the Guanzhong urban agglomeration, it is observed that the central area of the Guanzhong urban agglomeration, with the six districts of Xi'an as its core, has a high level of carbon emissions and a lower ESV. In contrast, the situation in the southwest region of Guanzhong is the opposite. This study will employ the bivariate spatial autocorrelation model to further analyze the spatial association and correlation between ESV and carbon emissions. From the bivariate global autocorrelation analysis for Guanzhong in the years 2010, 2015, and 2020, the Moran's I indices were determined to be −0.177, −0.166, and −0.172, respectively (Figure 10). The *p*-values are 0.03, 0.05, and 0.02, respectively. This indicates that at a 95% confidence level, there is a pronounced negative spatial correlation between the carbon emissions and ESV of the various counties and districts in the Guanzhong urban agglomeration.

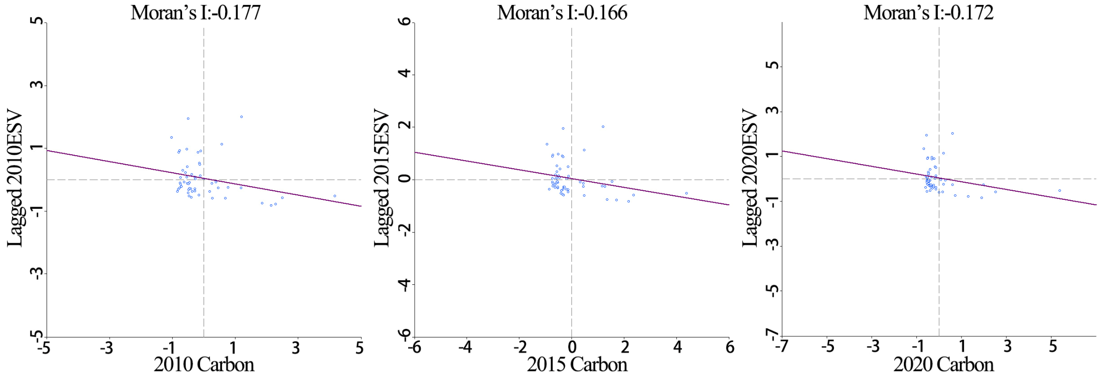

Figure 10. Moran's Scatterplot of Carbon Emissions and ESV in the Guanzhong urban agglomeration during 2010–2020. Image source: Drawn by the author.

The application of local bivariate Moran's I provides insights into the spatial clustering relationships between carbon emissions and ESV within the county-level administrative units of Guanzhong. Figure 11 illustrates a marked concentration of significant correlations in central Guanzhong, anchored by Xi'an, and in its southwestern region. The clustering patterns can be categorized as follows: (1) the high–high cluster region is situated in Weibin District, a central urban area of Baoji City. Ranking first in annual gross production value among Baoji's 12 county-level units, Weibin District's intense economic activity contributes to elevated carbon emissions. Its southern border consists of the Qinling Mountains, while the Wei River traverses the north, offering abundant vegetation and water resources that elevate the ESV and establish Weibin as a key carbon sink in Guanzhong. (2) The low–low cluster region is found in Liquan County, characterized by a less developed industrial sector and consequently lower carbon emissions. Limited vegetation coverage similarly leads to a diminished ESV. Over the past decade, minor fluctuations have been observed in the Weicheng and Gaoling Districts, with variations in industrial vitality and GDP accounting for the changes in carbon emissions. (3) The low–high cluster region is located in the Qinling Mountains in southwestern Guanzhong. Modest increases in forested land and enhanced landscape continuity have effectively augmented the area's ESV, designating it as an essential carbon sink within the region. (4) The high–low cluster region mainly encompasses the six urban districts of Xi'an. This area, representing Guanzhong's highest population density, experiences frequent construction activities. The primary land-use transition involves the conversion of cultivated land to built-up land, resulting in increased construction patch aggregation. Concomitant decreases in forested and grassland areas have been observed. Notably, unauthorized construction activities in the northern foothills of the Qinling Mountains have led to forest patch fragmentation, impairing forest ecosystem corridors. Such land-use changes not only inhibit ESV growth but also compromise the efficiency of carbon absorption and sequestration. Amidst socio-economic development, ecological resources are increasingly constrained, leading to sustained high carbon emissions and declining ESV.

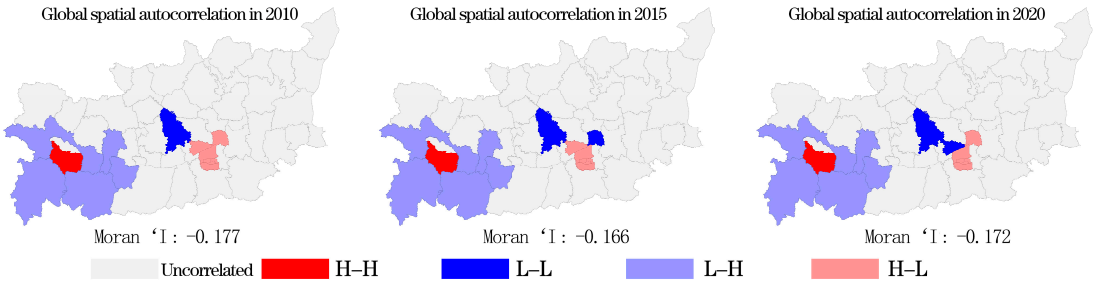

Figure 11. LISA Cluster Graph of Carbon Emissions and ESV in the Guanzhong urban agglomeration during 2010–2020. Image source: Drawn by the author.

(2) Multivariate Correlation Analysis for Comprehensive Insights

The ESV and carbon emissions of the Guanzhong urban agglomeration are influenced by a multitude of factors, including socio-economic aspects. To delve deeply into the dominant elements for precise energy-saving and emission-reduction initiatives, this study, drawing upon relevant research findings and emphasizing data's scientific nature, precision, and accessibility, selected 12 statistical datasets from 2020 for various counties in Guanzhong. These datasets encompass the Ecosystem Service Value (ESV); Primary Sector Gross Domestic Product (PSGDP); Secondary Sector Gross Domestic Product (SSGDP); Tertiary Sector Gross Domestic Product (TSGDP); Gross Domestic Product from Agriculture, Forestry, Livestock, and Fisheries (AFLFGDP); Total Gross Domestic Product (GDP); Total Population (TP); Per Capita Gross Domestic Product (PCGDP); Population Density (PD); County Land Area (CLA); Land Reclamation Rate (LRR); and Total Carbon Emissions (TCE). An in-depth correlation analysis was conducted on these datasets, and the computed results were visually represented using a diagonal correlation coefficient matrix.

Figure 12 reveals a strong positive relationship between Ecosystem Service Value (ESV) and both land area and carbon sequestration capacity. ESV exhibits a negative correlation with various socio-economic factors. Specifically, the Gross Domestic Product (GDP) of the primary sector, the GDP from agriculture, forestry, livestock, and fisheries, and the per capita GDP show a relatively weaker negative association. Total carbon emissions demonstrate a strong positive correlation with the GDPs of the secondary and tertiary sectors, as well as with overall GDP and other population–economic indicators. In contrast, a negative relationship is evident with the GDP of the primary sector, the GDP from agriculture, forestry, livestock, and fisheries, and county land area. An in-depth analysis suggests that the development of the primary sector in the Guanzhong urban agglomeration is pivotal for striking a balance between ESV and carbon emissions. Rural regions, which predominantly host primary industries and play a crucial role in carbon sequestration, face the challenge of reconciling economic growth with carbon emission concerns. The extent to which these dual objectives are harmoniously managed will directly influence rural farmers' willingness to adopt energy-saving and emission-reducing measures and to elevate their green agricultural production techniques. Such endeavors are instrumental in energizing and driving rural revitalization.

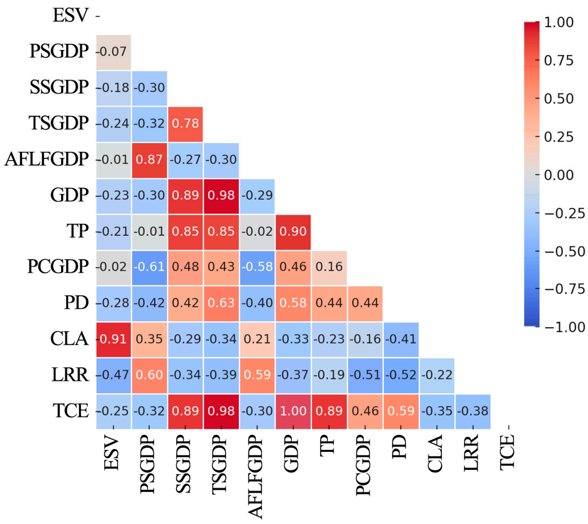

Figure 12. Multivariate Diagonal Correlation Coefficient Matrix for 2020.

4. Discussion

(1) Rural Revitalization Guides Industrial Structure Adjustment for Enhanced ESV and Carbon Sequestration Efficiency.

In the context of the "dual carbon" strategy, China faces the intricate challenge of balancing economic benefits with carbon reduction efforts. To maximize land resource utilization and augment the ESV while enhancing carbon sequestration efficiency, strategic planning surrounding ecological spaces has become crucial. While most existing studies on ESV and carbon emissions take distinct systemic approaches and largely concentrate on broader scales like national [15], provincial [16], and city levels [17,18], this paper narrows its focus from the conventional "city" scale to the more detailed "county" scale. It investigates the spatial heterogeneity of ESV and carbon emissions in the Guanzhong urban agglomeration, factoring in land-use changes and multivariate interactions. Additionally, the study pinpoints areas within the Guanzhong urban agglomeration that present opportunities for elevating ecosystem services and minimizing carbon emissions, thereby providing policymakers with insights to formulate forward-thinking and practical strategies.

Research reveals that in the Guanzhong urban agglomeration, the growth of the primary sector exerts a minimal influence on ESV but is potent in suppressing carbon emission increases. Given that rural areas predominantly support the primary sector, they play an instrumental role in striking a balance between ecological preservation and carbon emission reduction. External catalysts that blend rural revitalization with ESV enhancement encompass "dual carbon" goals, rights to natural ecological capital, ecological rejuvenation, and policies related to carbon sink trading. Numerous cities have pioneered ways to actualize the value of ecological capital. Notable examples include Lishui in Zhejiang with its "Ecological Capital Value Realization Mechanism Pilot [31]", Nanping in Fujian's "Forest Ecological Bank [32]", and Chongqing's initiative to "Expand the Ecological Function of Land Tickets [33]", all contributing to the rural revitalization blueprint. To foster ESV enhancement and elevate carbon sequestration efficacy in the Guanzhong urban agglomeration, there is a pressing need to embrace rural revitalization blueprints. This encompasses streamlining the rural industrial framework, tailoring the entry protocol for secondary and tertiary industries in rural sectors, championing high-caliber growth via carbon-conscious agricultural modalities, and ushering in avant-garde agricultural technologies to diminish the energy footprint of farming machinery. This paradigm paves the way for carbon-efficient, large-scale agricultural undertakings. A synergy between industrial endeavors and ecological prerogatives, expedited by the genesis of multi-tiered carbon trading marketplaces, can facilitate the metamorphosis of carbon sink assets into tangible economic yields. By galvanizing market appetency for eco-products via carbon quota modulation and instating compensation plus profit-sharing mechanisms, a harmonious progression of rural rejuvenation, ESV amplification, and carbon cutback can be achieved. It is imperative for governmental entities across the spectrum to embark on initiatives such as reforestation, rural habitat beautification, and combating soil erosion. Concurrently, it is essential to introduce benchmarks like carbon emission quotas, forestation rates, water purity metrics, and salubrious air standards. Integrating carbon quotas with eco-product compensation strategies can mesh governmental stewardship with market requisites, ensuring a consistent ESV upsurge.

(2) Innovative Land Management Strategies to Optimize Guanzhong's Carbon Source and Sink Patterns.

Based on the calculation results of land use carbon emissions and ESV (Ecosystem Service Value) from 2010 to 2020, it is found that different land use types have different potentials for ecological value enhancement. The study suggests that changes in land management methods can influence the ecological efficiency and resource distribution of ecosystems, thereby promoting ecological process changes and the enhancement of ecological value. In the northern part of Guanzhong, Tongchuan City, a large amount of idle and abandoned construction land or abandoned mines can be restored to arable land or forest land. Developing them into tourist attractions can enhance the ecosystem service value. In the central part of Guanzhong, the Weihe River Basin can organize the transfer of water resource asset property rights, market-oriented operations, and development. In the western part of Guanzhong, Baoji City has abundant grassland resources, but the returns from individual investments are relatively low. They are mostly used as auxiliary ecological products for national parks, realizing ecological value through tourism revenue from tickets and peripheral products. In the Qinba Mountain area, a large amount of forest resources is usually centralized for trading, transferring the forest management rights to ecological banks, and realizing assetization of natural resources and the cashing of ecosystem service value through timber management, under-forest economy, forest health preservation, and the carbon sink trading policy [34]. The optimization of land management methods not only improves ecological efficiency and increases regional ESV but also regulates the balance of the carbon cycle system, reduces carbon source emissions, and thus affects the carbon source and carbon sink patterns in the Guanzhong urban agglomeration.

In light of the findings, this study strongly recommends that the government intensify efforts to improve energy utilization rates and adjust regional energy structures. In areas surrounding Xi'an, where urbanization rates are higher, it is advocated to employ unconventional energy sources in place of conventional ones [35], promoting a cleaner energy matrix. In contrast, rural areas with lower urbanization rates should prioritize ecological conservation and curtail the loss of arable lands. Leveraging the distinct administrative and geographical advantages of the Guanzhong urban agglomeration, there is an urgency to accelerate the collaborative development of its urban clusters. Implementing joint ecological conservation measures can pave the way for a unified regional market and management mechanism that serves as both a model and a catalyst. Driven by synergistic and win–win collaborations, it is imperative to expedite the adjustments in regional economic and energy configurations. Only then can the integrated objectives of ecological preservation, economic progression, and energy conservation and emission reduction in the Guanzhong urban agglomeration be realized.

(3) Limitations and Future Enhancements

This study investigates and illustrates the spatiotemporal evolution of land use carbon emissions and Ecosystem Service Value (ESV) from 2010 to 2020 in the urban agglomeration of Guanzhong at a county scale, along with their spatial correlation. The current framework for assessing carbon emissions and ESV can be seen as a universal tool, requiring only minor modifications according to the specific conditions of different regions. For instance, the regional adjustment of ESV should incorporate grain production statistics, socio-economic data, and biomass statistics to enhance the precision of the calculated results for the study subject. However, it should be noted that the research has certain limitations.

Firstly, when calculating land-use carbon emissions, this study adopted carbon emission coefficients for various land types based on the research findings of Li Ying, Fang Jingyun, Duan Xiaonan, Lai Li, and others, as well as official documents like the China Energy Statistical Yearbook. These coefficients might not be entirely applicable to the study area. In the future, it would be prudent to either construct a scientifically sound carbon emission coefficient calculation model tailored to the region or make regional adjustments. Secondly, while this study uses county-level administrative areas as the research units, ecological and geographical processes come with intricate scale effects. Different scales prioritize different aspects of carbon emissions accounting, making it essential to delve deeper into the relationship between carbon emissions and ESV from various perspectives in the future. Lastly, due to data constraints, the study's carbon emissions calculations for urban construction land did not account for residential living emissions, resulting in an underestimation. However, this does not impact the spatiotemporal analysis of land-use carbon emissions. Future research should seek more comprehensive and accurate data sources to enhance the scientific rigor and precision of the study.

5. Conclusions

Influenced by urbanization and policies promoting the reversion of farmland to forest or grassland, the Guanzhong urban agglomeration experienced varied degrees of land use transitions between 2010 and 2020. A notable net decrease in arable land, totaling 697.47 km^2, was observed, whereas grasslands and urban construction lands saw the most substantial net increases.

The Ecosystem Service Value (ESV) in the Guanzhong urban agglomeration demonstrated a spatiotemporal evolution, characterized by higher values in the southwest and lower values in the northeast, accompanied by an annual increment in value. The scale of changes in ESV is closely linked with shifts in land use types, grain production, grain prices, and variations in the willingness and capacity to pay, reflecting the socio-economic status of Shaanxi Province.

Carbon emissions in the Guanzhong urban agglomeration displayed a distinct pattern of being elevated centrally and diminishing towards the periphery, with an ascending trend observed annually. Forest lands emerged as the primary source of carbon sequestration, accounting for over 94% of the total, while the principal contributors to carbon emissions were arable lands and urban construction areas.

There is a significant negative correlation between ESV and carbon emissions in Guanzhong urban agglomeration with stronger correlations are mainly concentrated in central Guanzhong, centered around Xi'an, and the southwestern part, centered around Baoji. High-quality rural development is key to balancing the relationship between ESV and carbon emissions in the Guanzhong urban agglomeration.

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References

1. Gao, P.; Yue, S.J.; Chen, H.T. Carbon emission efficiency of China's industry sectors: From the perspective of embodied carbon emissions. *J. Clean. Prod.* **2021**, *10*, 283. [CrossRef]
2. Costanza, R.; D'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J.; et al. The value of the world's ecosystem services and natural capital. *Nature* **1997**, *387*, 253–260. [CrossRef]
3. Xie, G.D.; Zhang, C.X.; Zhang, L.M.; Chen, W.H.; Li, S.M. Improvement of ecosystem services value method based on unit value equivalence factor. *J. Nat. Resour.* **2015**, *30*, 1243–1254. (In Chinese) [CrossRef]
4. Xie, G.D. Ecosystem Carbon Sink Capacity in China and Its Improvement Approach. *Environ. Prot.* **2023**, *51*, 12–16. [CrossRef]
5. Bamminger, C.; Poll, C.; Marhan, S. Offsetting global warminginduced elevated greenhouse gas emissions from an arable soil by biochar application. *Glob. Chang. Biol.* **2018**, *24*, e318–e334. [CrossRef] [PubMed]
6. He, Q.; Tan, S.; Xie, P.; Liu, Y.; Li, J. Re-assessing vegetation carbon storage and emissions from land use change in china using surface area. *Chin. Geogr. Sci.* **2019**, *29*, 601–613. [CrossRef]
7. Tolessa, T.; Senbeta, F.; Kidane, M. The impact of land use/land cover change on ecosystem services in the central highlands of Ethiopia. *Ecosyst. Serv.* **2017**, *23*, 47–54. [CrossRef]
8. Liu, M.; Fan, J.; Wang, Y.; Hu, C. Study on ecosystem service value (ESV) spatial transfer in the central plains urban agglomeration in the yellow river basin, China. *Int. J. Environ. Res. Public Health* **2021**, *18*, 9751. [CrossRef] [PubMed]
9. Arowolo, A.; Deng, X.Z.; Olatunji, O.A.; Obayelu, A.E. Assessing changes in the value of ecosystem services in response to land-use/land-cover dynamics in Nigeria. *Sci. Total Environ.* **2018**, *636*, 597–609. [CrossRef]
10. Heli, S.; Jyri, M.; Turo, H.; Kaisu, A. Participatory multi-criteria decision analysis in valuing peatland ecosystem services—Trade-offs related to peat extraction vs. pristine peatlands in Southern Finland. *Ecol. Econ.* **2019**, *162*, 17–28.
11. Schenau, S.; van Berkel, J.; Bogaart, P.; Blom, C.; Driessen, C.; de Jongh, L.; de Jong, R.; Horlings, E.; Mosterd, R.; Hein, L.; et al. Valuing ecosystem services and ecosystem assets for the Netherlands. *One Ecosyst.* **2022**, *7*, e84624. [CrossRef]
12. Zhang, K.; Liu, T.; Feng, R.; Zhang, Z.; Liu, K. Coupling coordination relationship and driving mechanism between urbanization and ecosystem service value in large regions: A case study of urban agglomeration in yellow river basin, China. *Int. J. Environ. Res. Public Health* **2021**, *18*, 7836. [CrossRef]
13. Yu, H.; Yang, J.; Sun, D.; Li, T.; Liu, Y. Spatial responses of ecosystem service value during the development of urban agglomerations. *Land* **2022**, *11*, 165. [CrossRef]
14. Li, Z.; Sun, Z.; Tian, Y.; Zhong, J.; Yang, W. Impact of land Use/Cover change on yangtze river delta urban agglomeration ecosystem services value: Temporal-spatial patterns and Cold/Hot spots ecosystem services value change brought by urbanization. *Int. J. Environ. Res. Public Health* **2019**, *16*, 123. [CrossRef] [PubMed]
15. Wang, W.C.; Liu, X.J.; Wu, Y.Z.; Chen, R.B.; Wang, S.Z. Dynamic Assessment and Change Analysis of Ecosystem Service Value Based on Physical Assessment Method in Cili County, China. *Forests* **2023**, *14*, 869. [CrossRef]
16. Chen, W.; Zeng, J.; Zhong, M.; Pan, S. Coupling analysis of ecosystem services value and economic development in the yangtze river economic belt: A case study in Hunan province, China. *Remote Sens.* **2021**, *13*, 1552. [CrossRef]
17. Xie, G.D.; Zhang, C.X.; Zhang, C.S.; Xiao, Y.; Lu, C.X. The value of ecosystem services in China. *Resour. Sci.* **2015**, *37*, 1740–1746.
18. Huang, T.; Huang, W.; Wang, K.; Li, Y.; Li, Z.; Yang, Y.A. Ecosystem service value estimation of paddy field ecosystems based on multi-source remote sensing data. *Sustainability* **2022**, *14*, 9466. [CrossRef]
19. Wang, W.; Guo, H.; Chuai, X.; Dai, C.; Lai, L.; Zhang, M. The impact of land use change on the temporospatial variations of ecosystems services value in China and an optimized land use solution. *Environ. Sci. Policy* **2014**, *12*, 62–72. [CrossRef]
20. Costanza, R.; de Groot, R.; Sutton, P.; van der Ploeg, S.; Anderson, S.J.; Kubiszewski, I.; Farber, S.; Turner, R.K. Changes in the global value of ecosystem services. *Glob. Environ. Chang.* **2014**, *26*, 152–158. [CrossRef]
21. Cao, Y.N.; Kong, L.Q.; Zhang, L.F.; Ouyang, Z.Y. The balance between economic development and ecosystem service value in the process of land urbanization: A case study of China's land urbanization from 2000 to 2015. *Land Use Policy* **2022**, *108*, 105536. [CrossRef]
22. Guo, S.; Hu, Z.; Ma, H.; Xu, D.; He, R. Spatial and temporal variations in the ecological efficiency and ecosystem service value of agricultural land in China. *Agriculture* **2022**, *12*, 803. [CrossRef]
23. Lu, Z.; Feng, Q.; Xie, J.; Yin, Z.; Zhu, M.; Xu, M. The reallocation of water and ecosystem service values in arid ecosystems with the implementation of an ecological water diversion project. *Appl. Water Sci.* **2023**, *13*, 93. [CrossRef]
24. Yang, F.; He, F.; Li, S.; Li, M.; Wu, P. A new estimation of carbon emissions from land use and land cover change in China over the past 300 years. *Sci. Total Environ.* **2023**, *863*, 160963. [CrossRef]
25. Zhu, E.; Deng, J.; Zhou, M.; Gan, M.; Jiang, R.; Wang, K.; Shahtahmassebi, A. Carbon emissions induced by land-use and land-cover change from 1970 to 2010 in Zhejiang, China. *Sci. Total Environ.* **2019**, *646*, 930–939. [CrossRef] [PubMed]

26. Cai, C.; Fan, M.; Yao, J.; Zhou, L.; Wang, Y.; Liang, X.; Liu, Z.; Chen, S. Spatial-temporal characteristics of carbon emissions corrected by socio-economic driving factors under land use changes in Sichuan Province, southwestern China. *Ecol. Inform.* **2023**, *77*, 102164. [CrossRef]
27. Meng, Q.; Zheng, Y.; Liu, Q.; Li, B.; Wei, H. Analysis of spatiotemporal variation and influencing factors of land-use carbon emissions in nine provinces of the yellow river basin based on the LMDI model. *Land* **2023**, *12*, 437. [CrossRef]
28. Xie, G.D.; Xiao, Y.; Zhen, L.; Lu, C. Research on ecological service value of grain production in China. *Chin. J. Ecol. Agric.* **2005**, *3*, 10–13.
29. Su, K.; Wei, D.Z.; Lin, W.X. Evaluation of ecosystem services value and its implications for policy making in China: A case study of Fujian province. *Ecol. Indic.* **2020**, *108*, e105752. [CrossRef]
30. Piao, S.L.; Fang, J.Y.; He, J.S.; Xiao, Y. Spatial Distribution of Grassland Biomass in China. *Acta Phytoecol. Sin.* **2004**, *28*, 491–498.
31. Xu, W.Y.; Jin, X.B.; Yang, X.H.; Wang, Z.Q.; Liu, J.; Wang, D.; Shan, W.; Zhou, Y.K. The Estimation of Forest Vegetation Biomass in China in Spatial Grid. *J. Nat. Resour.* **2018**, *33*, 1725–1741. [CrossRef]
32. Yao, J.C.; Zhu, J.; Jiang, H.; Li, X. Research on the path of urban-rural integration in ecological areas based on the realization of the value of ecological products. *J. Nat. Resour.* **2023**, *38*, 2169–2183. [CrossRef]
33. Zhang, L.B.; Cheng, L.; Xiang, W.J.; Hao, Z.C.; Yang, B.Y.; Liang, T. The Development History, Operation Mode and Improvement Suggestions of China's "Forest Ecological Bank"—A Case Study of Nanping City, Fujian Province. *Environ. Prot.* **2023**, *51*. [CrossRef]
34. Zhang, Y. Green Finance as a Catalyst for Realizing the Value of Rural Ecological Products: An Analytical Pathway. *Environ. Prot.* **2023**, *51*. [CrossRef]
35. Xie, X.S.; Chen, S.Z.; Zhao, R. The practical logic of ecological product value realization: A study of grounded theory based on 87 typical cases in the field of natural resources. *J. Nat. Resour.* **2023**, *38*, 2504–2522. [CrossRef]