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Land-Use Optimization Based on Ecosystem Service Value: A Case Study of Urban Agglomeration around Poyang Lake, China

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Abstract: The optimal allocation of land use is a promising approach to achieving the sustainable use of land resources, to weigh ecological protection and economic development. The urban agglomeration around Poyang Lake is a crucial plate for implementing the spatial planning policy of the national urban agglomeration and supporting the development of the Yangtze River Economic Belt. Based on the ecosystem service value (ESV), we utilize the minimum cumulative resistance (MCR), the gray multi-objective planning (GMOP) and the future land-use simulation (FLUS) model to optimize the quantitative structure and spatial pattern of the land use in 2030. The present study designs four scenarios of baseline development (BD), ecological conservation (EC), economic priority (EP) and coordinated development (CD) to discuss how to optimize land-use allocation while considering ecological security and economic development. The result suggests that the land-use structure and spatial layout in the CD_scenario are relatively reasonable, and the overall eco-economic benefits and landscape pattern levels are better than those of the other three scenarios. Additionally, the ecological security and landscape pattern indices are optimized, landscape fragmentation decreases and aggregation degree increases. This study is instructive to promote the sustainable development of urban agglomeration and land spatial planning.

Keywords: land-use optimization; ecosystem service value; multi-scenario simulation; urban agglomeration

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1. Introduction

With the rapid development of urbanization and industrialization, the contradiction between land supply and demand is increasingly serious [1]. The over-exploitation, idle waste and unreasonable arrangement of land resources have a great negative impact on eco-environmental security, social and economic development [2,3]. From 1978 to 2020, China's urbanization rate increased from 17.9% to 63.89%. This upward trend is forecasted to remain in the coming decades [4]. Moreover, as the world's second-largest economy, China's economic growth is contributing to an increasing rate of global growth [5]. Population growth, economic development and urbanization continue to be accompanied by the phenomenon of urban sprawl. The continuous encroachment of construction land on cultivated land and ecological land and the occupation of ecological land by cultivated land have led to a serious imbalance in land-use structures [6,7]. The dramatic land-use changes have placed considerable pressure on sustainable development at the regional and national levels. With the background of national land spatial planning and the construction of ecological civilization, the optimal allocation of land use is a necessary measure to improve the intensive degree of land use and maintain the stability of the ecosystem. It is also the fundamental guarantee to realize the sustainable use of land resources [8].

The optimal allocation of land use refers to the rational and overall arrangement of all kinds of land use to promote the harmonious and coordinated development of society, economy and ecology, to achieve the optimization of various development goals [9,10]. Generally speaking, a reasonable land-use structure leads to a balance of ecological-economic benefits, which is a key concern for national and regional development [11,12]. Therefore, most scholars use the integrated evaluation of ecological and economic benefits as the reference goal of land-use optimization. While the evaluation methods regarding the economic benefits of land are relatively mature, the evaluation methods of ecological benefits have not been unified. Ecosystem services are the bridge between the natural environment and human well-being [13]. Monetizing ecosystem services to evaluate the ecological benefits of different land-use types has been a hot research topic in recent years [14]. It can visually express the functions and values of ecosystem services and is widely used in measuring comprehensive land-use benefits.

Currently, scholars have conducted studies on optimal land-use allocation at different regional scales, such as national [15], continental [16], urban [17], village [10] and watershed [18]. The research methods mainly involve two aspects: quantitative structure optimization and spatial layout optimization. Among them, the quantitative structure optimization method are mainly the gray model (GM) [19], multi-objective programming (MOP) model [20] and genetic algorithm (GA) [21]. Ecosystem service value [22], social-economic benefits [17] and the ecological green equivalent [23] are the dominant objectives or constraints. By adjusting the structure of different land-use types to achieve the balance of different benefits needs, the development goal is shifted from a single objective to a multi-objective balance and the top-down grasp of the overall regional policy regulations. The balance of economic and ecological aspects is achieved. However, it lacks the consideration of the optimal configuration of spatial patterns and cannot be reflected in space. With the shift from traditional mathematical models to intelligent geo-information processing technology, the bottom-up spatial optimization of land use is achieved. The spatial layout optimization method mainly uses the particle swarm optimization algorithm (PSO) [24], conversion of land use and its effects at small region extent (CLUE-S) model [25], cellular automata (CA) [26] and FLUS model [27]. Based on the spatial distribution of ecological sensitivity [28] and ecological security pattern [29], the land-use demand is input into the spatial model as an objective function to realize the spatial pattern under different development targets. The combination of mathematical and spatial models can simultaneously optimize the land-use structure and spatial layout. For example, Cheng et al. [30] optimized the spatial structure of mountain-abandoned-mine land reuse by combining system dynamics and the CLUE-S model. Ma et al. [31] combined an uncertain mathematical model with the FLUS model to solve the problem of the planning system with uncertainty of the land system and applied it to structural and spatial patterns. The coupled model balances macro policy effects and micro driving mechanisms, so it is widely used in the research of land-use optimization [32,33]. Among these methods, the GMOP model is dynamic linear programming that calculates the optimal structure under different benefit pursuits considering the uncertainty of the constraints, and also allows us to understand the developmental changes of the optimal structure. The FLUS model introduces a roulette-wheel selection based on the adaptive inertia mechanism on the basis of cellular automata, which improves the precision of simulating the spatial layout of land use.

Balanced ecological–economic development is essential to maintain sustainable land-resource use. However, in terms of the research content, apart from combining the quantitative structure and spatial layout of land use, the research that incorporates ecological security into simulation optimization is relatively weak. It is also rare to integrate ecological–economic values and landscape pattern characteristics under multiple types of constraints, such as policy planning and accessibility, for which is difficult to meet the realistic needs of socio-economic development in a new stage of ecological civilization construction. Urban agglomerations are the strategic core areas of national economic development and vital growth poles for the country's high-quality development, which has extremely high requirements for ecological environment and economic stability [34]. The land-use structure under different development orientations has a significant influence on the ecological civilization construction and social-economic development of urban agglomeration [35]. Nevertheless, the studies focusing on land-use optimization in urban agglomerations are not common. Therefore, taking ecological conservation into account in land-use simulation and optimization is crucial for urban planning and ecological management of large-scale areas.

In view of this, this paper takes the urban agglomeration around Poyang Lake, one of the urban agglomerations in the middle reaches of the Yangtze River, as the study area. We coupled the minimum cumulative resistance (MCR) model, the gray multi-objective planning (GMOP) model and the future land-use simulation (FLUS) model to simulate and optimize the land-use structure and spatial patterns. Based on the spatial and temporal evolution characteristics of ecosystem service values, we delineated the core ecological protection zone and compared the differences in land-use structure, spatial layout and ecological–economic effects before and after optimization under the four scenarios (baseline development, BD; ecological conservation, EC; economic priority, EP and coordinated development, CD), to explore the optimal land-use decision making in the study area. Meanwhile, it provides a reference for regional land-resource management and ecological practice.

2. Materials and Methods

2.1. Study Area

The ecological urban agglomeration around Poyang Lake is a key urban agglomeration in Jiangxi Province according to the *Development Plan of Urban agglomeration in the middle reaches of the Yangtze River* (Figure 1). The area of this region is 9.23×10^4 km^2, including all the administrative areas of Nanchang, Jiujiang, Jingdezhen, Shangrao, Yingtan, Yichun, Xinyu, Pingxiang prefecture-level cities, and the municipal districts of Fuzhou, Dongxiang County, Jinxi County and Chongren County, Xingan County and Xiajiang County of Ji'an City.

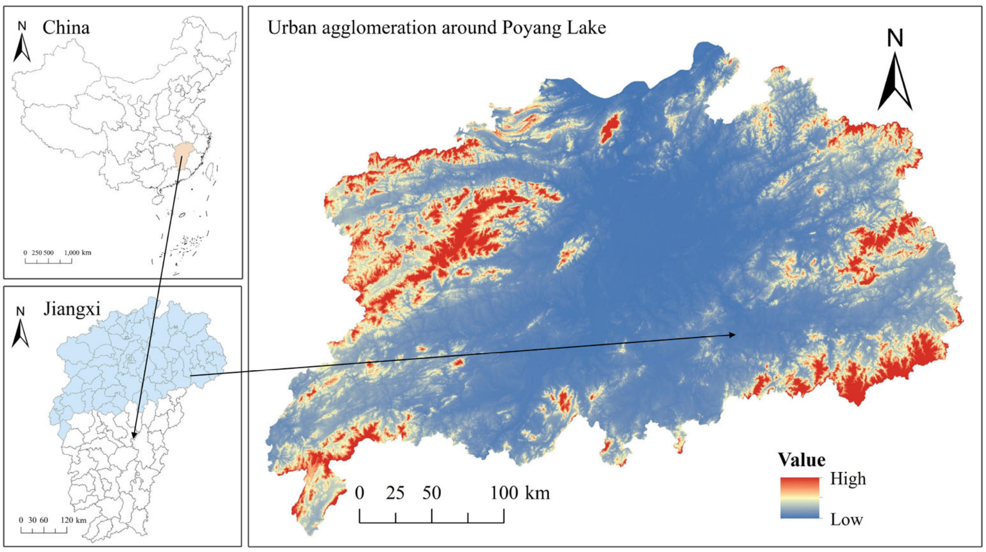

Figure 1. DEM and location of the study area.

From the implementation plan of the 14th five-year plan for the development of urban agglomeration in the middle reaches of the Yangtze River and the planning of ecological urban agglomeration around Poyang Lake (2015–2030), it is clear that the urban agglomeration around Poyang Lake is an essential carrier to promote the development of the Yangtze River economic belt and occupies an essential place in the economic and social development patterns in China. The study area is dominated by a mountainous and hilly topography, with high forest coverage, numerous rivers and lakes and the Poyang Lake, the largest freshwater lake in China, which is rich in ecological resources and has a high ecosystem service value. It is a typical Mountain–River–Forest–Farmland–Lake–

Grass System. However, regional development has long focused on economic benefits at the expense of land ecological benefits, leading to increased conflicts between people and land. From 2011 to 2020, the regional GDP rapidly increased from CNY 915.655 billion to CNY 1945.990 billion, the population increased from 30.410 million to 30.726 million and the urbanization rate increased from 47.49% to 63.03%. The continuous socio-economic development has led to drastic changes in the land-use structure. During this period, cultivated land and forest land decreased by 5.21×10^4 hm^2 and 5.09×10^4 hm^2, respectively, while construction land increased by 9.76×10^4 hm^2. Therefore, scientific and rational land-use planning is urgently needed to promote regional ecological security, economic development and the sustainable use of land resources.

2.2. Data Sources

The data of this study include land-use data, distance accessibility data, natural environment data and socio-economic data (Table 1). Based on the land-use classification system and the purpose of the study, land was divided into cultivated land, forest land, grassland, water area, construction land and unused land, among which construction land was divided into urban land, rural residential land and other construction land. Furthermore, this study combined the concept of ecological land with the research achievements on the division of eco-land, taking forest land, grassland and water as ecological land, and cultivated land and construction land as economic land [36]. Following a series of operations, such as Euclidean distance, cropping, masking and reclassification in ArcGIS, all data were unified as raster data with a resolution of 200 m × 200 m and the same number of rows and columns under the same projection coordinate system.

Table 1. Key data and sources.

Category	Data Name	Year	Data Attributes	Data Source
Land-use data	Land-use data	2010, 2015, 2020	Grid	Remote sensing image processing (http://www.gscloud.cn) (accessed on 23 October 2020)
Distance accessibility data	The rural settlement, river, city center, road network	2015	Shapefile	Extracted from land-use data
Natural environment data	DEM, NDVI	2015	Grid	Geospatial Data Cloud platform (http://www.gscloud.cn) (accessed on 23 October 2020)
	Slope, aspect		Grid	Extracted from DEM
	Soil type, temperature, precipitation	2015	Grid	Resource and Environment Science and Data Center (https://www.resdc.cn) (accessed on 1 January 2020)
Socio-economic data	Population, GDP, grain-crop planted area and yield, food prices	2011–2020	Text	National agricultural product cost–income data compilation, Jiangxi statistical yearbook, statistical yearbook and statistical bulletin of cities and counties around Poyang Lake urban agglomeration
	Population density, GDP	2015	Grid	Resource and Environment Science and Data Center (https://www.resdc.cn) (accessed on 1 January 2020)

2.3. Methods

The research is divided into five parts: (1) estimation of ecosystem service value (ESV); (2) delineation of ecological protection functional areas based on the MCR model; (3) land-use structure optimization based on the GMOP model; (4) land-use spatial optimization based on FLUS model and (5) analysis of land-use optimization results (Figure 2).

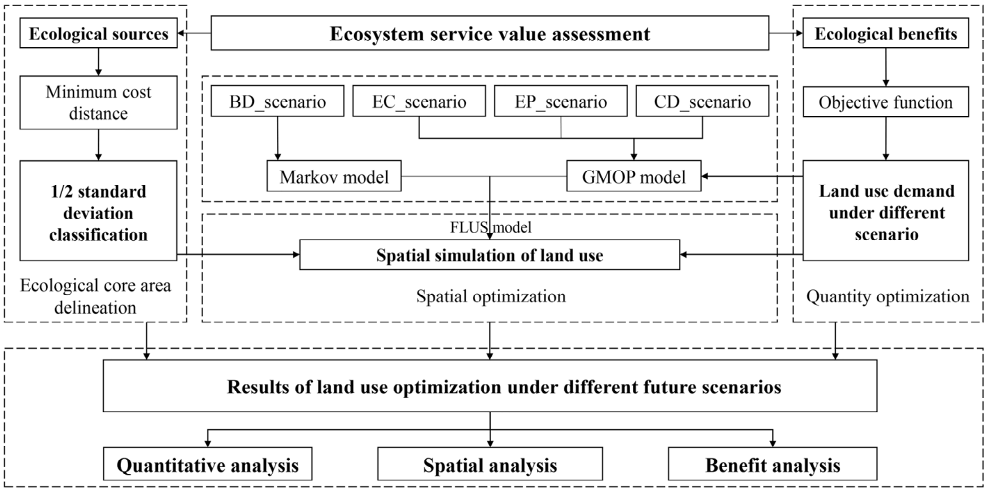

Figure 2. Flowchart of the methods.

2.3.1. ESV Assessment

The equivalent factor method was first proposed by Costanza et al. [37] for the monetary expression of ecosystem services. Xie et al. [38] modified the method locally and developed an ESV equivalent factor table suitable for China's ecological status, which has been widely used [39]. We revised the ESV coefficients by combining the latest improved ecosystem service equivalent table per unit area and the actual situation of the study area [40]. By calculating the average grain-yield ratio of the whole country and the urban agglomeration around Poyang Lake from 2011 to 2020, the correction coefficient of the biomass factor in this region can be obtained as 1.15. The area ratio of paddy fields and dry land in the region was 3:1, and the weight of the value equivalent coefficient of the two was taken as the basic equivalent of cultivated land. Forest land was the average value of the basic equivalent of coniferous, coniferous and broad-leaved mixed, broad-leaved and shrub, and grassland corresponded to shrub; similarly, water body was the average value of the water system and wetland, unused land corresponded to bare land and construction land was 0. Since the economic value of a single equivalent factor was equal to 1/7 of the actual value of the average grain yield per unit [41], the economic value of an equivalent factor in the study area was calculated to be 2246.97 CNY/hm^2 (Table 2).

2.3.2. Delineation of Core Protected Area Using MCR

The essence of the 'anti-planning/NEGATIVE PLANNING' concept is to ensure the safety and functional stability of the ecosystem [42], and to realize the sustainable development of the ecological environment by giving priority to urban spatial planning in non-construction areas. The Getis-Ord GI* index was used to identify the hot and cold spots in the spatial distribution of ecosystem service values, and the spatial distributions of the high and low values of ecosystem services in the study area were obtained. The hotspots of ecosystem services under the 90% confidence level were regarded as the ecological sources according to the identification results of cold and hot spots [43]. Referring to the relevant papers [44,45], the land-use type, slope, elevation, terrain relief and vegetation coverage were selected as resistance factors, the weight of each resistance factor was determined by the AHP method and the comprehensive resistance surface was obtained through the superposition analysis function in ArcGIS. Finally, the minimum cost distance layer of the ecological protection of urban agglomeration around Poyang Lake was obtained by using the MCR model.

Table 2. The ESV coefficient per unit area of urban agglomeration around Poyang Lake.

Primary Classification	Secondary Classification	Cultivated Land	Forest Land	Grassland	Water Area	Unused Land
Provisioning service	Food production	3184.80	652.46	981.93	1692.53	0.00
	Raw material	432.82	1498.73	1447.05	943.17	0.00
	Water supply	−5084.05	775.20	801.04	14,057.04	0.00
Regulating service	Gas regulation	2584.02	4929.01	5090.51	3449.66	51.68
	Climate regulation	1337.23	14,748.27	13,462.72	7609.93	0.00
	Environmental purification	394.06	4321.77	4444.51	11,821.87	258.40
	Water flow regulation	5445.81	9651.30	9870.94	163,400.22	77.52
Supporting service	Soil fertility maintenance	684.76	6001.38	6201.64	4186.11	51.68
	Nutrient cycle maintenance	445.74	458.66	465.12	323.00	0.00
	Biodiversity protection	490.96	5465.19	5633.15	13,462.72	51.68
Cultural service	Aesthetic landscape	213.18	2396.67	2480.65	8553.09	25.84
Total		**10,129.34**	**50,898.65**	**50,879.27**	**229,499.34**	**516.80**

2.3.3. Optimization of Land-Use Structure Using GMOP

The GMOP model was developed from the GM (1, 1) model and gray system theory combined with multi-objective programming [46], which can grasp the overall regional situation and development goals according to the top-down policy planning [47]. The optimization result of land-use structure was obtained by inputting decision variables, constraint conditions and objective functions. We set up variables and established constraints from the land-use and socio-economic conditions, planning requirements and future development trends of the study area over the years, and determined the objective function according to the needs of different development benefits. LINGO 12.0 software was used to predict the land-use optimization plan of the urban agglomeration around Poyang Lake in 2030.

In the optimization of ecological goals, when the total ESV of land resources in the study area reached the maximum, the ecological benefits generated by land use were maximized. In the optimization of the economic goals, various types of land output were regarded as economic benefits, and the method of benefit coefficient was used to perform the calculations; that is, the area of various types of land was multiplied by the economic benefit coefficients of various types of land [48]. First, combined with the economic output proportion of each land use in the study area from 2011 to 2020, the AHP method was used to determine the benefits weight of each land use. The output benefit per unit area of cultivated land in 2030 was predicted by using the GM (1, 1) model. After obtaining the total benefit per unit area, the output per unit area of other types can be calculated. Based on this result, the objective function of land-use economic benefit was obtained. According to the *14th five-year plan for ecological environmental protection in Jiangxi Province*, *the planning of rehabilitation and rehabilitation of cultivated land*, *grassland, rivers and lakes in Jiangxi Province (2016–2030)*, *the planning of ecological urban agglomeration around Poyang Lake (2015–2030)*, *guidelines for village construction planning in Jiangxi Province* and *Jiangxi Province urban system planning (2014–2030)*, these acts form the content of planning texts used to understand the future development trends of various land uses. Constraining equations for each variable were established (Table 3).

Table 3. Land-use optimization decision variables, constraints and objective function.

	Constraint Type	Equation
Decision variables and constraints	Total area	$X_1 + X_2 + X_3 + X_4 + X_5 + X_6 + X_7 + X_8 = 9.23 \times 10^6$ hm^2
	Cultivated land (X_1)	291.58×10^4 hm$^2 \geq X_1 \geq 235.69 \times 10^4$ hm^2
	Forest land (X_2)	$X_2 \geq 505.56 \times 10^4$ hm^2
	Grassland (X_3)	28.98×10^4 hm$^2 \geq X_3 \geq 27.33 \times 10^4$ hm^2
	Water area (X_4)	63.29×10^4 hm$^2 \geq X_4 \geq 58.78 \times 10^4$ hm^2
	Urban land (X_5)	33.23×10^4 hm$^2 \geq X_5 \geq 14.17 \times 10^4$ hm^2
	Rural residential land (X_6)	10.73×10^4 hm$^2 \geq X_6 \geq 7.16 \times 10^4$ hm^2
	Other construction land (X_7)	16.94×10^4 hm$^2 \geq X_7 \geq 9.51 \times 10^4$ hm^2
	Total construction land	53.68×10^4 hm$^2 \geq X_5 + X_6 + X_7 \geq 39.32 \times 10^4$ hm^2
	Unused land (X_8)	5.30×10^4 hm$^2 \geq X_8 \geq 3.69 \times 10^4$ hm^2
The objective function	Ecological benefits	$F_1(X)\max = 1.01\ X_1 + 5.09\ X_2 + 5.09\ X_3 + 22.95\ X_4 + 0.05\ X_8$
	Economic benefits	$F_2(X)\max = 8.73\ X_1 + 1.46\ X_2 + 5.82\ X_3 + 2.91\ X_4 + 126.59\ (X_5 + X_6 + X_7)$

2.3.4. Optimization of Land-Use Spatial Pattern by FLUS

Model Introduction and Operation Process

The FLUS model optimized the traditional CA model and introduced an adaptive inertia competition mechanism based on the roulette mechanism [49], which reflected the uncertainty of the transformation of land-use change in the real world and improved the accuracy of land-use-change simulation [50]. It is suitable for simulating spatial change in land use. Firstly, the land-use data and driving factors were uniformly sampled and normalized. The suitability probability of each land type was calculated by applying the artificial neural network (ANN) model. Thereafter, in the cellular automaton with an adaptive inertia mechanism, the overall conversion probability of each cellular unit was calculated by combining the neighborhood influence factor, inertia coefficient, conversion cost and suitability probability. Finally, the roulette-selection mechanism was used to determine the land-use type to which the cell unit was converted, which reflected the micro-complex internal operation mechanism of land-use change from the bottom-top approach. The study simulated the spatial distribution of land use in 2020 with 2015 as the base period, and compared it with the actual spatial distribution in 2020 (Figure 3), using the Kappa coefficient and overall accuracy to verify the results. The calculated Kappa coefficient was 0.90 and the overall accuracy was 0.94, indicating the high precision of the experimental simulation [51]. The FLUS model can commendably simulate the spatial distribution of land use around Poyang Lake urban agglomeration.

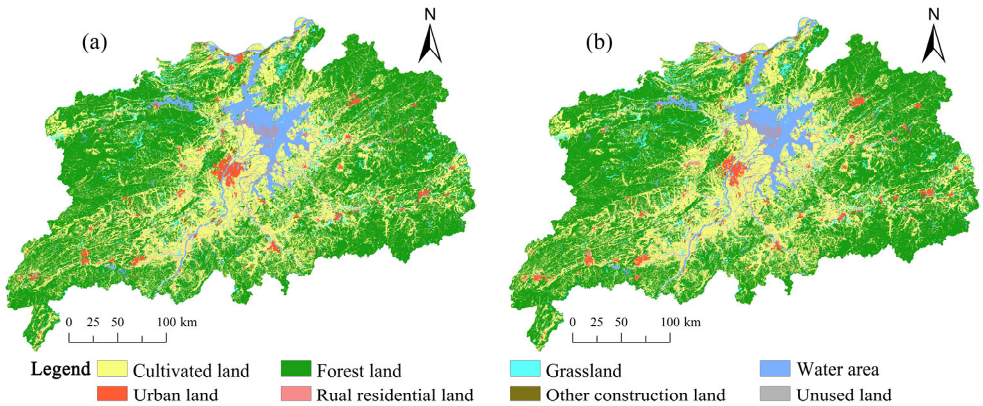

Figure 3. (**a**) Actual land-use pattern in 2020; (**b**) simulated land-use pattern in 2020.

Scenario Definitions

The change in demand for urban agglomeration development is a vital factor affecting the change in land space. Different development demands will guide different development directions of national land space. Setting up land-use simulation predictions under various scenarios can provide decision makers with a variety of decision-making perspectives. In this paper, the land-use demand and restriction factors under four designed scenarios were input into FLUS, and the dynamic changes of land use in space were obtained (Table 4).

Table 4. Development scenario setting of land use in urban agglomeration around Poyang Lake.

Scenario Type	Scenario Description	Objective Function	Space Restriction
BD_scenario	Follow the natural evolution of land-use types	Solving with Markov chain	No restriction
EC_scenario	Strengthen the conservation of ecological land and maintain the stability of ecological functions. Take the growth of ecological benefits as the main optimization goal	$F(X)max = 1.01\ X_1 + 5.09\ X_2 + 5.09\ X_3 + 22.95\ X_4 + 0.05\ X_8$	Restricted ecological core area
EP_scenario	Strengthen urban and rural constructions, further promote regional urbanization, drive infrastructure construction and industrial structure optimization. Take the growth of economic benefits as the main optimization goal	$F(X)max = 8.73\ X_1 + 1.46\ X_2 + 5.82\ X_3 + 2.91\ X_4 + 126.59\ (X_5 + X_6 + X_7)$	No restriction
CD_scenario	Strengthen the degree of comprehensive utilization of land resources. Promote rapid development of economic construction under the premise of guaranteeing sustainable development of ecological environment and steady speed of ecological construction.	$F_1(X)max = 1.01\ X_1 + 5.09\ X_2 + 5.09\ X_3 + 22.95\ X_4 + 0.05\ X_8$ $F_2(X)max = 8.73\ X_1 + 1.46\ X_2 + 5.82\ X_3 + 2.91\ X_4 + 126.59\ (X_5 + X_6 + X_7)$	Restricted ecological core area

BD_scenario: This scenario follows the natural evolution law of land-use types. Two periods of land-use data were selected from 2015 and 2020 and input into the Markov chain to predict the demand for land use in 2030, and without making any allowances for space constraints.

EC_scenario: Under this scenario, the areas with high ecological value were strictly protected and forbidden to develop, and maximizing the ecological benefits was the primary objective. Thus, in the process of optimizing the land-use structure, only the maximization of ecological benefits was taken as the objective function without considering the economic benefits, and the ecologically protected areas were designated by the MCR model as limiting factors.

EP_scenario: Social and economic development was paid the most attention in this scenario, and the goal was to pursue the benefits output of various land uses. For this reason, the maximization of economic benefits was regarded as the objective function without considering the ecological benefits, and no spatial limitation factor was set.

CD_scenario: This scenario emphasizes the harmonious development of ecology and economy. Under the premise of ensuring the stability of the ecological environment and the steady progress of ecological construction, it can also ensure the safety of urban expansion and the rapid development of the social economy. We used the ideal point approach to achieve the synchronous maximization of ecological and economic benefits [52] to obtain the optimized land-use structure. The ecological reserve was taken as a constraint factor.

2.3.5. Ecological–Economic-Effect Analysis of Land-Use Optimization

This paper analyzed the ecological–economic benefits of land from the changes in ecosystem service value and economic value before and after land-use optimization, and used Fragstats 4.2 software to analyze the landscape pattern characteristics from the two aspects of landscape type and landscape level. We referred to the landscape pattern index selection and ecological significance of the related literature [53], and mainly selected number of patches (NP), patch density (PD), landscape shape index (LSI), contagion (CONTAG), aggregation index (AI), landscape division index (DIVISION), patch cohesion index (COHESION), Shannon's diversity index (SHDI) and Shannon's evenness index (SHEI).

3. Results and Analysis

3.1. ESV Analysis

The ESV of land use around Poyang Lake urban agglomeration was calculated by the equivalent factor method. The ESV in 2010, 2015 and 2020 was CNY 439.773, 438.726 and 437.161 billion, respectively, reflecting an overall downward trend. The spatial distribution of ESV in 2010–2020 shows that the eastern, southeastern, western and Poyang Lake areas of the study region are high-value areas of ESV distribution, which are mainly composed of water and forest land (Figure 4). Due to the high ecosystem service value coefficient per unit area of land in forest land and water area, and the large land area and concentrated distribution, the ecosystem service value in these areas is much higher than in other areas. With the decline in ESV, it is urgent to protect the ecological security of key ecological function areas and enhance the capacity of ecosystem services.

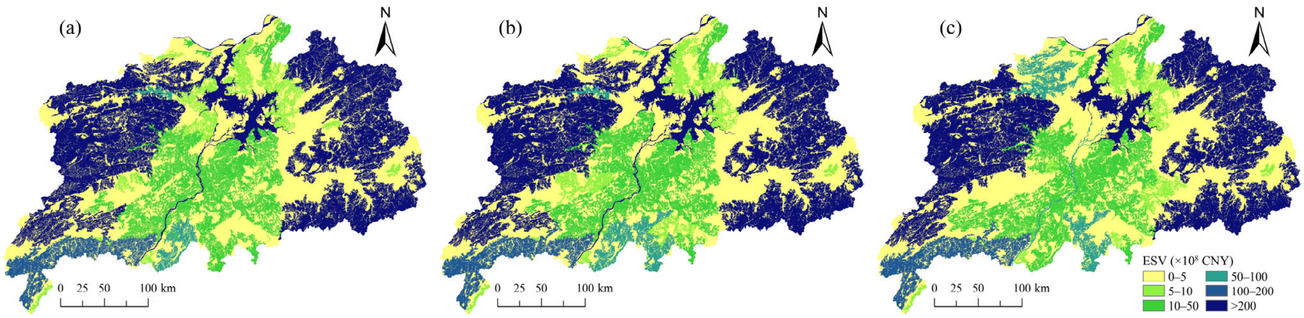

Figure 4. (**a**) Spatial distribution of ESV in 2010; (**b**) spatial distribution of ESV in 2015; (**c**) spatial distribution of ESV in 2020.

3.2. Delimitation of the Ecological Core Area

This paper used statistical concepts to classify the standard deviation of the minimum cost distance and determined the core area of ecological protection (Figure 5). The operation results of the minimum cumulative resistance model were divided into 9 categories (C1 to C9) with a variance of 1/2 standard deviation [42]. The quantitative differences of different categories were analyzed from the results of the variance classification, and the threshold of the core area was determined according to the discrepancy mutation. From the linear relationship between the standard deviation classification category and the number of grids, it can be determined that C1 (31.94%) is the core protected area, which is defined as a restricted or undeveloped area.

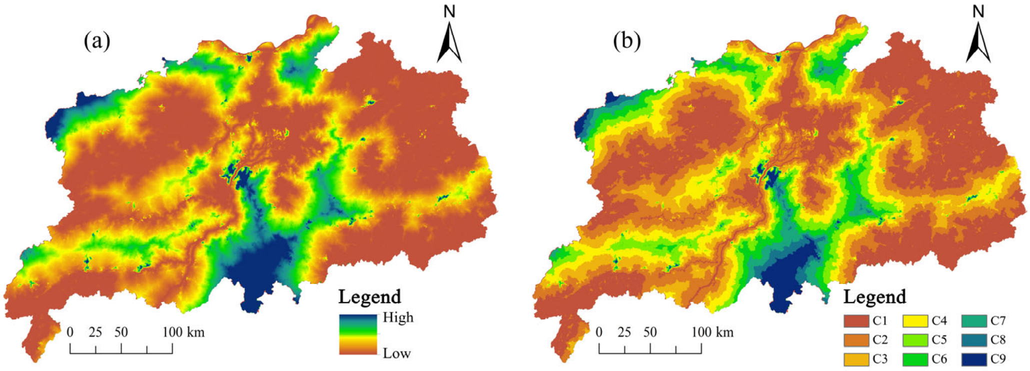

Figure 5. (**a**) Minimum cost distance; (**b**) standard deviation classification.

3.3. Land-Use Optimization

3.3.1. Optimization of Land-Use Structure

In this paper, land-use structure schemes under various scenarios in 2030 were obtained based on the Markov chain and GMOP model (Table 5). There were significant differences in the quantitative structure of land use in the four designed scenarios, in which cultivated land and rural settlements all showed a downward trend, while urban land and other construction land increased. Compared with the land use in 2020, there were obvious changes due to the direct and significant impacts on the ecological and economic benefits of cultivated land, forest land, construction land and unused land.

Table 5. Quantitative structure changes before and after land-use optimization under different scenarios.

Land-Use Type ($\times 10^4$ hm^2, %)	2020	2030							
		BD_Scenario		EC_Scenario		EP_Scenario		CD_Scenario	
		Area	Rate of Change	Area	Rate of Change	Area	Rate of Change	Area	Rate of Change
Cultivated land	292.55	286.22	−2.16	235.69	−19.44	273.91	−6.37	259.03	−11.46
Forest land	494.93	494.13	−0.16	553.63	11.86	505.56	2.15	514.28	3.91
Grassland	28.98	29.85	3.00	27.33	−5.69	27.33	−5.69	28.98	0.00
Water area	61.59	60.69	−1.46	63.29	2.76	58.78	−4.56	63.29	2.76
Urban land	14.17	23.06	62.74	22.66	59.92	33.23	134.51	33.23	134.51
Rural residential land	15.64	12.74	−18.54	7.15	−54.28	10.73	−31.39	7.91	−49.44
Other construction land	9.51	10.86	14.20	9.51	0.00	9.72	2.21	12.54	31.88
Unused land	5.32	5.40	1.50	3.69	−30.64	3.69	−30.64	3.69	−30.64

In the BD_scenario, the cultivated land, forest land and water area all declined, though the declines were small, and the grassland appeared to slightly increase. In general, the ecological land had a slight downward trend. Among the construction land, there was a significant increase in urban land and other construction land, with increases of 62.74% and 14.20%, respectively, compared to 2020, while there was a decrease of 18.54% in the rural residential land, demonstrating a general trend of growth.

In the EC_scenario, areas with a high ecological service value were strictly protected. Therefore, the forest land will have a relatively large increase, up 11.86% compared to 2020. In addition to the increase in the water area, the total area of cultivated land and grassland decreased by 19.44% and 5.69%, respectively. Among the construction land, the decline in rural settlements was outstanding, and other construction land remained unchanged. Overall, there was a significant increase in ecological land and a decline in economic land.

In the EP_scenario, ecological land tended to decrease as a whole. Compared to the land-use structure in 2020, the grassland and water areas will fall by 5.69% and 4.56%, respectively, while forest land showed a slight increase. In this scenario, the increase in urban land was observable, more than doubling. The rural residential area was on a decreasing trend because the rural land was entering a phase of reduction. Other construction land slightly increased. The overall growth of economic land was obvious.

In the CD_scenario, in order to obtain an eco-economic win–win outcome, ecological land and economic land are equated as far as possible to achieve balance and coordination. The increase in forest land and water area had smaller amplitudes, 3.91% and 2.76%, respectively, and grassland remained unchanged. The ecological land will remarkably increase, and ecological benefits will be dramatically improved. At the same time, cultivated land and rural settlements will decline, but the steady development of the economy will lead to a significant increase in urban land use and other construction land by 134.51% and 31.88%, respectively. In this scenario, the quantitative structure of land use is reasonable, and both ecological and economic benefits can be taken into account.

3.3.2. Optimization of the Spatial Pattern of Land Use

The spatial pattern of land-use optimization for the year 2030 was obtained by using the FLUS model combined with the results of land-use structure optimization and ecological reserve constraints (Figure 6). It can be observed that the grassland does not distinctly change spatially, and there will be sporadic subsidence in the EC_scenario and EP_scenario. Cultivated land, forest land, water area and construction land have obvious changes in the spatial layout, the unused land is chiefly concentrated in the area around Poyang Lake and presents no significant change.

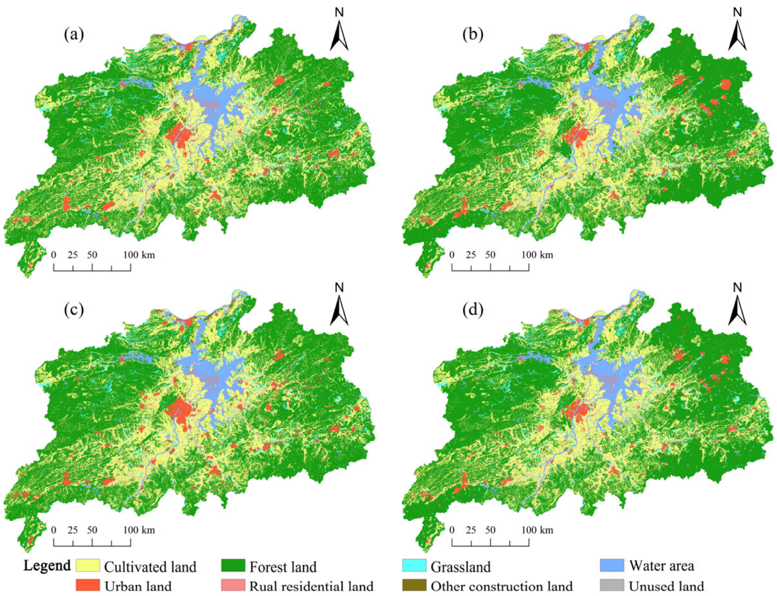

Figure 6. Spatial pattern of land-use optimization of urban agglomeration around Poyang Lake in different scenarios in 2030. (**a**) is BD_scenario; (**b**) is EC_scenario; (**c**) is EP_scenario; (**d**) is CD_scenario.

The phenomenon of spatial regression of cultivated land exists in all four scenarios, which is more evident in the EC_scenario, EP_scenario and CD_scenario, is concentrated in the east, southeast, west and southwest of the study area, and is mainly converted to forest land. Moreover, the reduction in cultivated land also includes the reasons for the occupation of construction land.

In the BD_scenario, the spatial distribution of forest land is almost unchanged with only sporadic regression. Compared to the spatial distribution in 2020, the growth in the EP_scenario is not apparent. In the EC_scenario and CD_scenario, the forest land is not converted to other land use, but expands marginally around it due to the ecological core area being set as a limit. Among them, the EC_scenario has a more pronounced expansion than the CD_scenario.

Grassland will not significantly change in the four development scenarios in 2030. In the BD_scenario, there are subtle marginal and infill growth phenomena, mainly in the north and south of the study area. In the EC_scenario and EP_scenario, the grassland distribution is relatively scattered and mostly patchy. There will only be scattered declines, mainly shifting to forest land and cultivated land. However, there is almost no change in the CD_scenario.

In the BD_scenario and EP_scenario, the water area has a certain shrinkage phenomenon, and it is more evident in the EP_scenario, mainly shifting to construction land. In both the EC_scenario and CD_scenario, the development of water areas is restricted due to the high ecological service value, and marginal expansion occurs around them.

In the total construction land, urban land and other construction land will expand in four scenarios in 2030, especially in the EP_scenario and CD_scenario, mainly by the expansion of the land itself to its periphery, resulting in the occupation of cultivated land, forest land and water. On the other hand, rural settlements show a shrinking phenomenon in all four development scenarios, and the most evident change is in EC_scenario and CD_scenario, which is mainly a change into cultivated land.

3.4. Comparison of Eco-Economic Effects of Land-Use Optimization

Based on various benefit-demand objectives, the ecological benefit, economic benefit and landscape pattern index of the urban agglomeration around Poyang Lake in different scenarios in 2030 were obtained and compared (Tables 6 and 7).

Table 6. Comparison of ecological and economic benefits in different scenarios.

Scenario	Ecological Benefit		Economic Benefit	
	Value/$\times 10^8$ CNY	Rate of Change (%)	Value/$\times 10^8$ CNY	Rate of Change (%)
2020	4371.61	-	8601.97	-
BD	4349.25	−0.51	9477.15	10.17
EC	4647.82	6.32	8186.63	−4.83
EP	4338.24	−0.76	10,254.81	19.21
CD	4479.51	2.47	10,160.35	18.12

Table 7. Comparison of landscape pattern index in different scenarios.

Scenario	NP	PD	LSI	CONTAG	AI	SHDI	SHEI	COHESION	DIVISION
2020	60,616	0.6569	166.8191	54.5152	78.3072	1.1984	0.5763	99.6653	0.9079
BD	61,285	0.6641	164.8621	53.5789	78.5673	1.2371	0.5949	99.6198	0.9170
EC	53,670	0.5816	146.3897	55.5351	81.0007	1.2021	0.5781	99.6499	0.9014
EP	62,345	0.6756	158.0102	54.5862	79.4693	1.2152	0.5844	99.5924	0.9150
CD	54,071	0.5859	148.6909	55.0920	80.6978	1.2117	0.5827	99.6500	0.9029

The ecological benefit in the EC_scenario is the highest, which is CNY 464.782 billion. However, the economic benefit is the lowest among the four scenarios, at CNY 818.663 billion, which is 4.83% lower than the actual benefit in 2020. Compared to the landscape pattern before land-use optimization, the NP, PD and LSI, representing the patch level, all decrease. Among the landscape-level indicators, CONTAG, AI, SHDI and SHEI all show an increasing trend, while COHESION and DIVISION decrease to some magnitude. These indicate that landscape fragmentation will decrease in this scenario in 2030, the landscape shape area will be regularized and the dominance and diversity will also increase. The landscape ecological security will be improved, but the economic backwardness will be aggravated due to the neglect of economic development while protecting the ecology. In contrast, economic land use shows a sharp rise in the EP_scenario, and the increase in land economic output leads to an acceleration in economic development and a remarkable increase in economic benefit, with a 19.21% increase compared to the actual benefits in 2020. The ecological benefit, however, is the lowest of the four scenarios, reduced by 0.76%. The patch and landscape levels are also lower than the EC_scenario, with an increase in NP and PD, illustrating that the degree of landscape fragmentation will increase. The BD_scenario has an increase in the economic benefit of 10.17% compared to 2020, but a decrease in ecological benefits of 0.51%. From the perspective of the landscape pattern index, the NP and PD increase, and CONTAG slightly decreases. Overall, the landscape pattern level is weaker than that of the EC_scenario. In the CD_scenario, both ecological and economic benefits increase, by 2.47% and 18.12%, respectively, compared to the actual benefits in 2020, achieving an eco-economic win–win situation. The patch and landscape levels are similar to the indicators in the EC_scenario, indicating that the overall landscape pattern will be excellent in 2030. The ecosystem could give full play to its ecological function.

The optimization results of the quantitative structure, the spatial pattern and the eco-economic benefits of land use were comprehensively analyzed. The development scenarios of EC and EP make the development of regional ecological land and economic land imbalanced, resulting in extremely uncoordinated ecological protection and economic construction. The BD_scenario fails to maximize the benefits. The layout of land-use types in the CD_scenario is more rational, and the optimal solution of ecological and economic benefits is simultaneously achieved. The overall landscape pattern is optimized.

4. Discussion

4.1. Coupled Model for Large-Scale Regional Land-Use Optimization

The key to optimizing land use is to find a balance between ecological land and economic land and meet the needs of human benefits to achieve a harmonious relationship between humans and nature [54]. However, how to make the limited land resources support economic development and ecological protection is a pressing challenge for each country. Few coupled models have incorporated ecosystem service security and are mostly applied to urban areas [31,55]. The land-use structure and ecological environment of different scale areas vary significantly. Therefore, it is important to study the optimization of land use in large-scale regions and consider ecological security to achieve a balance between ecosystem service functions and socio-economic development.

In this study, we proposed a coupled MCR-GMOP-FLUS model to optimize the land-use structure and spatial pattern of urban agglomerations. This combination of models effectively performs optimal planning for different optimization objectives and development strategies to obtain the optimal configurations spatially and for land-use structure [56]. The MCR model classifies the spatial hotspots of ESV distribution as ecological source areas, effectively delineating the core ecological protection areas. The GMOP model integrates the multiple benefits of urban agglomeration development, and obtains several optimal solutions for the quantitative structure of land use for decision makers to make further decisions by combining actual needs and planning objectives. The FLUS model combines ecological and mathematical models to simulate land-use changes on a large spatial scale by setting different development scenarios. In addition, the comparison between the ecological–economic benefits and landscape pattern indices before and after land-use optimization in different scenarios can provide intuitive reference and reference for land-use policy formulation. Therefore, the coupled model has strong applicability for land-use optimization in multi-scale regions.

4.2. Future Land Policy Formulation

The ecological urban agglomeration around Poyang Lake, as an essential economic sector to speed up the “Rise of Central China”, is a demonstration model area for practicing the national ecological civilization [57]. In the future, we should focus on dealing with the contradiction between ecological construction and economic development, strictly arrange all kinds of land use and establish the trinity concept of land construction and protection of “quantity–quality–ecology”. As urbanization advances, there is an inevitable trade-off between cultivated land protection and urban space. With the trend of decreasing cultivated land, it is inevitable to ensure the safe supply of food. This requires the delineation of permanent basic farmland protection lines, while improving science and technology to increase the efficiency of grain yields [58]. There will be a significant increase in urban land in Nanchang, Jingdezhen, Shangrao and Yichun in the future, mainly through the occupation of cultivated land and forest land. Thus, there is a need to scientifically delineate the urban growth boundary and strengthen inner-city land tapping to control the expansion rate and direction of construction land. As for the ecological security, the region has vast forest land, mainly located in the east and southeast of Shangrao City, the north of Jingdezhen City, the west of Jiujiang City, the northwest of Yichun City and the south of Pingxiang City. Additionally, the region has the largest freshwater lake in China—Poyang Lake. It has a high ecological value and ecological sensitivity, and it is crucial to delineate the ecological suitability zoning [59]. For the ecological core area, it is necessary to designate an ecological protection red line and conduct systematic ecological space protection and restoration. As for the outer edge of the core area, it is the buffer zone between the ecological and construction zones. The system stability is poor and the resistance to external disturbance is weak, so ecological restoration should be the main focus. Some areas can be reasonably guided to perform eco-tourism activities in appropriate amounts to shape the urban landscape.

4.3. Limitations and Research Outlook

Although this study optimized the regional land-use allocation based on the eco-economic equilibrium, there are still some deficiencies. We were unable to meet all the constraints to building because the data collected in the relevant land-use planning texts were limited. Some of the constraints were predicted and calculated according to the development trend in the state of natural development, which led to the introduction of a small amount of subjective judgment. Furthermore, there was a lack of comprehensive consideration for the selection of driving factors when calculating the comprehensive conversion probability of land-use types. The setting of neighborhood-factor parameters was obtained by referring to the relevant literature and continuous debugging, which was subjective to a certain extent. Different urban agglomerations have different development levels and dominant directions. With the vigorous development of urban agglomerations, the influencing factors of land-use change will become more complex and diversified, which requires the establishment of long-term and comprehensive data observation and consideration. Future research should have a clear insight into the changes in policies, industries and other aspects, and further determine the more objective and scientific influencing factors and model parameters.

5. Conclusions

This paper coupled the MCR model, the GMOP model and the FLUS model based on ESV for optimizing the land-use structure and spatial patterns of urban agglomeration around Poyang Lake in 2030 in different scenarios. We obtained the following conclusions. First, the ESV assessment result shows that the ESV has a decreasing trend in general from 2010 to 2020, and the high-value areas of ESV spatial distribution are mainly concentrated areas of forest land and water area. Second, the delineation of ecological protection areas indicates that the ecological core area of the urban agglomeration accounts for 31.94% of the total land area, mostly located in the east, west, southwest and Poyang Lake areas. Third, judging from the optimization results of the land-use structure and spatial pattern, the CD_scenario may be suitable for future development. Ecological land and economic land attain a balance. Forest land and the water area show an upward trend because of the ecological constraint condition, and their spatial expansion is more obvious. Grassland is almost unchanged. Due to the accelerated urbanization process, there is a significant expansion of urban land, and the cultivated land around it shrinks spatially, leading to a decrease in the area of cultivated land and an increase in construction land. Fourth, from the perspective of ecological–economic effects, the ecological and economic benefits in the CD_scenario are integrated, with an increase of 2.47% and 18.12%, respectively, compared to the current situation in 2020. The comprehensive benefits are better than the other three scenarios. Moreover, the landscape level is improved, with fewer landscape patches and less fragmentation. Land-use distribution becomes simple and regular, and landscape richness and agglomeration increases. The overall landscape pattern is improved.

In future research, we aim to explore more ways to assess the value of ecosystem services and establish a systematic data framework to analyze the driving forces of land-use change, in order to provide more accurate simulation methods for land-use optimization and apply them to territorial spatial planning.

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References

1. Brown, D.G.; Johnson, K.M.; Loveland, T.R.; Theobald, D.M. Rural Land-Use Trends in the Conterminous United States, 1950–2000. *Ecol. Appl.* **2005**, *15*, 1851–1863. [CrossRef]
2. Foley, J.A.; DeFries, R.; Asner, G.P.; Barford, C.; Bonan, G.; Carpenter, S.R.; Chapin, F.S.; Coe, M.T.; Daily, G.C.; Gibbs, H.K.; et al. Global Consequences of Land Use. *Sci. New Ser.* **2005**, *309*, 570–574. [CrossRef] [PubMed]
3. Hurtt, G.C.; Chini, L.P.; Frolking, S.; Betts, R.A.; Feddema, J.; Fischer, G.; Fisk, J.P.; Hibbard, K.; Houghton, R.A.; Janetos, A.; et al. Harmonization of Land-Use Scenarios for the Period 1500–2100: 600 Years of Global Gridded Annual Land-Use Transitions, Wood Harvest, and Resulting Secondary Lands. *Clim. Chang.* **2011**, *109*, 117–161. [CrossRef]
4. Li, M.; Shan, R.; Hernandez, M.; Mallampalli, V.; Patiño-Echeverri, D. Effects of Population, Urbanization, Household Size, and Income on Electric Appliance Adoption in the Chinese Residential Sector towards 2050. *Appl. Energy* **2019**, *236*, 293–306. [CrossRef]
5. Gu, R.; Liu, S. Nonlinear Analysis of Economic Policy Uncertainty: Based on the Data in China, the US and the Global. *Phys. Stat. Mech. Its Appl.* **2022**, *593*, 126897. [CrossRef]
6. Vliet, J.V. Direct and Indirect Loss of Natural Area from Urban Expansion. *Nat. Sustain.* **2019**, *2*, 755–763. [CrossRef]
7. Vliet, J.V.; Eitelberg, D.A.; Verburg, P.H. A Global Analysis of Land Take in Cropland Areas and Production Displacement from Urbanization. *Glob. Environ. Chang.* **2017**, *43*, 107–115. [CrossRef]
8. Ligmann-Zielinska, A.; Church, R.L.; Jankowski, P. Spatial Optimization as a Generative Technique for Sustainable Multiobjective Land-use Allocation. *Int. J. Geogr. Inf. Sci.* **2008**, *22*, 601–622. [CrossRef]
9. Groot, J.C.J.; Yalew, S.G.; Rossing, W.A.H. Exploring Ecosystem Services Trade-Offs in Agricultural Landscapes with a Multi-Objective Programming Approach. *Landsc. Urban Plan.* **2018**, *172*, 29–36. [CrossRef]
10. Liao, G.; He, P.; Gao, X.; Lin, Z.; Huang, C.; Zhou, W.; Deng, O.; Xu, C.; Deng, L. Land Use Optimization of Rural Production–Living–Ecological Space at Different Scales Based on the BP–ANN and CLUE–S Models. *Ecol. Indic.* **2022**, *137*, 108710. [CrossRef]
11. Polasky, S.; Nelson, E.; Camm, J.; Csuti, B.; Fackler, P.; Lonsdorf, E.; Montgomery, C.; White, D.; Arthur, J.; Garber-Yonts, B.; et al. Where to Put Things? Spatial Land Management to Sustain Biodiversity and Economic Returns. *Biol. Conserv.* **2008**, *141*, 1505–1524. [CrossRef]
12. Strauch, M.; Cord, A.F.; Pätzold, C.; Lautenbach, S.; Kaim, A.; Schweitzer, C.; Seppelt, R.; Volk, M. Constraints in Multi-Objective Optimization of Land Use Allocation—Repair or Penalize? *Environ. Model. Softw.* **2019**, *118*, 241–251. [CrossRef]
13. Bateman, I.J.; Harwood, A.R.; Mace, G.M.; Watson, R.T.; Abson, D.J.; Andrews, B.; Binner, A.; Crowe, A.; Day, B.H.; Dugdale, S.; et al. Bringing Ecosystem Services into Economic Decision-Making: Land Use in the United Kingdom. *Science* **2013**, *341*, 45–50. [CrossRef]

14. Groot, R.D.; Brander, L.; Ploeg, S.V.D.; Costanza, R.; Bernard, F.; Braat, L.; Christie, M.; Crossman, N.; Ghermandi, A.; Hein, L.; et al. Global Estimates of the Value of Ecosystems and Their Services in Monetary Units. *Ecosyst. Serv.* **2012**, *1*, 50–61. [CrossRef]
15. Chakir, R.; Gallo, J.L. Predicting Land Use Allocation in France: A Spatial Panel Data Analysis. *Ecol. Econ.* **2013**, *92*, 114–125. [CrossRef]
16. Verburg, P.H.; Tabeau, A.; Hatna, E. Assessing Spatial Uncertainties of Land Allocation Using a Scenario Approach and Sensitivity Analysis: A Study for Land Use in Europe. *J. Environ. Manag.* **2013**, *127*, S132–S144. [CrossRef]
17. Ma, S.; Wen, Z. Optimization of Land Use Structure to Balance Economic Benefits and Ecosystem Services under Uncertainties: A Case Study in Wuhan, China. *J. Clean. Prod.* **2021**, *311*, 127537. [CrossRef]
18. Zhang, H.; Zhang, Z.; Dong, G.; Yu, Z.; Liu, K. Identifying the Supply-Demand Mismatches of Ecorecreation Services to Optimize Sustainable Land Use Management: A Case Study in the Fenghe River Watershed, China. *Ecol. Indic.* **2021**, *133*, 108424. [CrossRef]
19. Li, C.; Wu, Y.; Gao, B.; Zheng, K.; Wu, Y.; Li, C. Multi-Scenario Simulation of Ecosystem Service Value for Optimization of Land Use in the Sichuan-Yunnan Ecological Barrier, China. *Ecol. Indic.* **2021**, *132*, 108328. [CrossRef]
20. Glover, F.; Martinson, F. Multiple-Use Land Planning and Conflict Resolution by Multiple Objective Linear Programming. *Eur. J. Oper. Res.* **1987**, *28*, 343–350. [CrossRef]
21. Lin, J.; Li, X. Large-Scale Ecological Red Line Planning in Urban Agglomerations Using a Semi-Automatic Intelligent Zoning Method. *Sustain. Cities Soc.* **2019**, *46*, 101410. [CrossRef]
22. Mirghaed, F.A.; Mohammadzadeh, M.; Salmanmahiny, A.; Mirkarimi, S.H. Decision Scenarios Using Ecosystem Services for Land Allocation Optimization across Gharehsoo Watershed in Northern Iran. *Ecol. Indic.* **2020**, *117*, 106645. [CrossRef]
23. Yanfang, L.; Dongping, M.; Jianyu, Y. Optimization of Land Use Structure Based on Ecological GREEN Equivalent. *Geo Spat. Inf. Sci.* **2002**, *5*, 60–67. [CrossRef]
24. Ma, S.; He, J.; Liu, F.; Yu, Y. Land-Use Spatial Optimization Based on PSO Algorithm. *Geo Spat. Inf. Sci.* **2011**, *14*, 54–61. [CrossRef]
25. Verburg, P.H.; Overmars, K.P. Combining Top-down and Bottom-up Dynamics in Land Use Modeling: Exploring the Future of Abandoned Farmlands in Europe with the Dyna-CLUE Model. *Landsc. Ecol.* **2009**, *24*, 1167–1181. [CrossRef]
26. Yu, J.; Chen, Y.; Wu, J.; Khan, S. Cellular Automata-Based Spatial Multi-Criteria Land Suitability Simulation for Irrigated Agriculture. *Int. J. Geogr. Inf. Sci.* **2011**, *25*, 131–148. [CrossRef]
27. Liu, Y.; Hou, X.; Li, X.; Song, B.; Wang, C. Assessing and Predicting Changes in Ecosystem Service Values Based on Land Use/Cover Change in the Bohai Rim Coastal Zone. *Ecol. Indic.* **2020**, *111*, 106004. [CrossRef]
28. Hong, W.; Guo, R.; Su, M.; Tang, H.; Chen, L.; Hu, W. Sensitivity Evaluation and Land-Use Control of Urban Ecological Corridors: A Case Study of Shenzhen, China. *Land Use Policy* **2017**, *62*, 316–325. [CrossRef]
29. Ouyang, X.; Xu, J.; Li, J.; Wei, X.; Li, Y. Land Space Optimization of Urban-Agriculture-Ecological Functions in the Changsha-Zhuzhou-Xiangtan Urban Agglomeration, China. *Land Use Policy* **2022**, *117*, 106112. [CrossRef]
30. Cheng, L.; Sun, H.; Zhang, Y.; Zhen, S. Spatial Structure Optimization of Mountainous Abandoned Mine Land Reuse Based on System Dynamics Model and CLUE-S Model. *Int. J. Coal Sci. Technol.* **2019**, *6*, 113–126. [CrossRef]
31. Ma, Y.; Wang, M.; Zhou, M.; Tu, J.; Ma, C.; Li, S. Multiple Scenarios-Based on a Hybrid Economy–Environment–Ecology Model for Land-Use Structural and Spatial Optimization under Uncertainty: A Case Study in Wuhan, China. *Stoch. Environ. Res. Risk Assess.* **2022**, *2022*, 1–24. [CrossRef]
32. Farrow, A.; Winograd, M. Land Use Modelling at the Regional Scale: An Input to Rural Sustainability Indicators for Central America. *Agric. Ecosyst. Environ.* **2001**, *85*, 249–268. [CrossRef]
33. Cotter, M.; Berkhoff, K.; Gibreel, T.; Ghorbani, A.; Golbon, R.; Nuppenau, E.-A.; Sauerborn, J. Designing a Sustainable Land Use Scenario Based on a Combination of Ecological Assessments and Economic Optimization. *Ecol. Indic.* **2014**, *36*, 779–787. [CrossRef]
34. Hu, H.; Pan, L.; Jing, X.; Li, G.; Zhuo, Y.; Xu, Z.; Chen, Y.; Wang, X. The Spatiotemporal Non-Stationary Effect of Industrial Agglomeration on Urban Land Use Efficiency: A Case Study of Yangtze River Delta, China. *Land* **2022**, *11*, 755. [CrossRef]
35. Qian, L. Model Development for Optimized Land Usage in Urban Agglomeration Zone Using Bee Colony Algorithms. *Microprocess. Microsyst.* **2021**, *81*, 103739. [CrossRef]
36. Ellis, E.C.; Goldewijk, K.K.; Siebert, S.; Lightman, D.; Ramankutty, N. Anthropogenic Transformation of the Biomes, 1700 to 2000: Anthropogenic Transformation of the Biomes. *Glob. Ecol. Biogeogr.* **2010**, *19*, 589–606. [CrossRef]
37. Costanza, R.; d'Arge, R.; Groot, R.D.; 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]
38. Xie, G.; Zhang, C.; Zhang, L.; Chen, W.; Li, S. Improvement of the Evaluation Method for Ecosystem Service Value Based on Per Unit Area. *J. Nat. Resour.* **2015**, *30*, 1243–1254. [CrossRef]
39. Li, J.; Liao, Q.; Shen, S.; Liu, X.; Liao, J. Study on the Spatiotemporal Changes of Land Use and Ecosystem Services Value (ESV) of the Green Heart Area in the Changsha-ZhuzhouXiangtan (CZT) City Group. *Chin. Landsc. Archit.* **2022**, *38*, 100–105. [CrossRef]
40. Wang, L.; Zhang, S.; Tang, L.; Lu, Y.; Liu, Y.; Liu, Y. Optimizing Distribution of Urban Land on the Basis of Urban Land Use Intensity at Prefectural City Scale in Mainland China. *Land Use Policy* **2022**, *115*, 106037. [CrossRef]
41. Xie, G.; Lu, C.; Leng, Y.; Zheng, D.; Li, S. Ecological assets valuation of the Tibetan Plateau. *J. Nat. Resour.* **2003**, *18*, 189–196. [CrossRef]

42. Liu, P.; Hu, Y.; Jia, W. Land Use Optimization Research Based on FLUS Model and Ecosystem Services–Setting Jinan City as an Example. *Urban Clim.* **2021**, *40*, 100984. [CrossRef]
43. Wu, J.; Yue, X.; Qin, W. The Establishment of Ecological Security Patterns Based on the Redistribution of Ecosystem Service Value: A Case Study in the Liangjiang New Area, Chongqing. *Geogr. Res.* **2017**, *36*, 429–440. [CrossRef]
44. Wang, Y.; Pan, J. Building Ecological Security Patterns Based on Ecosystem Services Value Reconstruction in an Arid Inland Basin: A Case Study in Ganzhou District, NW China. *J. Clean. Prod.* **2019**, *241*, 118337. [CrossRef]
45. Wei, Q.; Halike, A.; Yao, K.; Chen, L.; Balati, M. Construction and Optimization of Ecological Security Pattern in Ebinur Lake Basin Based on MSPA-MCR Models. *Ecol. Indic.* **2022**, *138*, 108857. [CrossRef]
46. Zhang, H.; Zhang, X. Land Use Structural Optimization of Lilin Based on GMOP-ESV. *Trans. Nonferrous Met. Soc. China* **2011**, *21*, s738–s742. [CrossRef]
47. Verburg, P.H.; Soepboer, W.; Veldkamp, A.; Limpiada, R.; Espaldon, V.; Mastura, S.S.A. Modeling the Spatial Dynamics of Regional Land Use: The CLUE-S Model. *Environ. Manag.* **2002**, *30*, 391–405. [CrossRef]
48. Ma, B.; Huang, J.; Li, S. Optimal Allocation of Land Use Types in the Beijing-Tianjin-Hebei Urban Agglomeration Based on Ecological and Economic Benefits Trade-Offs. *Prog. Geogr.* **2019**, *38*, 26–37. [CrossRef]
49. Liu, X.; Liang, X.; Li, X.; Xu, X.; Ou, J.; Chen, Y.; Li, S.; Wang, S.; Pei, F. A Future Land Use Simulation Model (FLUS) for Simulating Multiple Land Use Scenarios by Coupling Human and Natural Effects. *Landsc. Urban Plan.* **2017**, *168*, 94–116. [CrossRef]
50. Li, X.; Chen, G.; Liu, X.; Liang, X.; Wang, S.; Chen, Y.; Pei, F.; Xu, X. A New Global Land-Use and Land-Cover Change Product at a 1-Km Resolution for 2010 to 2100 Based on Human–Environment Interactions. *Ann. Am. Assoc. Geogr.* **2017**, *107*, 1040–1059. [CrossRef]
51. Lin, W.; Sun, Y.; Nijhuis, S.; Wang, Z. Scenario-Based Flood Risk Assessment for Urbanizing Deltas Using Future Land-Use Simulation (FLUS): Guangzhou Metropolitan Area as a Case Study. *Sci. Total Environ.* **2020**, *739*, 139899. [CrossRef]
52. Gu, J.; Zhang, X.; Xuan, X.; Cao, Y. Land Use Structure Optimization Based on Uncertainty Fractional Joint Probabilistic Chance Constraint Programming. *Stoch. Environ. Res. Risk Assess.* **2020**, *34*, 1699–1712. [CrossRef]
53. Yohannes, H.; Soromessa, T.; Argaw, M.; Dewan, A. Impact of Landscape Pattern Changes on Hydrological Ecosystem Services in the Beressa Watershed of the Blue Nile Basin in Ethiopia. *Sci. Total Environ.* **2021**, *793*, 148559. [CrossRef]
54. Zheng, W.; Ke, X.; Xiao, B.; Zhou, T. Optimising Land Use Allocation to Balance Ecosystem Services and Economic Benefits—A Case Study in Wuhan, China. *J. Environ. Manag.* **2019**, *248*, 109306. [CrossRef]
55. Sun, X.; Crittenden, J.C.; Li, F.; Lu, Z.; Dou, X. Urban Expansion Simulation and the Spatio-Temporal Changes of Ecosystem Services, a Case Study in Atlanta Metropolitan Area, USA. *Sci. Total Environ.* **2018**, *622*, 974–987. [CrossRef]
56. Liao, W.; Liu, X.; Xu, X.; Chen, G.; Liang, X.; Zhang, H.; Li, X. Projections of Land Use Changes under the Plant Functional Type Classification in Different SSP-RCP Scenarios in China. *Sci. Bull.* **2020**, *65*, 1935–1947. [CrossRef]
57. Dai, L.; Liu, Y.; Luo, X. Integrating the MCR and DOI Models to Construct an Ecological Security Network for the Urban Agglomeration around Poyang Lake, China. *Sci. Total Environ.* **2021**, *754*, 141868. [CrossRef]
58. Gu, C.; Guan, W.; Liu, H. Chinese Urbanization 2050: SD Modeling and Process Simulation. *Sci. China Earth Sci.* **2017**, *60*, 1067–1082. [CrossRef]
59. Ding, M.; Liu, W.; Xiao, L.; Zhong, F.; Lu, N.; Zhang, J.; Zhang, Z.; Xu, X.; Wang, K. Construction and Optimization Strategy of Ecological Security Pattern in a Rapidly Urbanizing Region: A Case Study in Central-South China. *Ecol. Indic.* **2022**, *136*, 108604. [CrossRef]