Research Article

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Study on the influence mechanism of land use on carbon storage under multiple scenarios: A case study of Wenzhou

Abstract: Based on the perspective of conflict of interest between low-carbon ecology and economic and social development, this study explores the change mechanism of land use cover change (LUCC) and carbon storage (CS) in the context of "Dual-Carbon" goal and territorial spatial ecological governance, which is of great significance to optimize the construction path of "Dual-Carbon" goal and formulate low-carbon, ecological, high-quality, and sustainable economic and social policies in the urban areas. An integrated framework based on the System Dynamics model, the Patch Generation Land Simulation model, and the Integrated Valuation of Ecosystem Services and Trade-offs model was constructed to dynamically simulate the LUCC demand and CS of Wenzhou under four scenarios in 2035, and to analyze the spatial evolution mechanisms of LUCC and CS. The main results of the study show that in the Natural Development Scenario (NDS) and High-speed Urbanization Scenario (HUS), the expansion mechanism is similar, and the area of woodland decreases greatly, which is mainly caused by the rapid expansion of construction land and cultivated land. Under Low-carbon and High-quality Development Scenario (LHDS) and Ecological Safety Governance Scenario (ESGS), woodland and grassland increased significantly, mainly because low-carbon and ecological governance policies strengthened ecological land protection and limited construction land control. By 2035, the prediction results show that LHDS has the highest CS (2.231×10^5 kt), followed by ESGS (2.226×10^5 kt), NDS (2.191×10^5 kt), and HUS (2.142×10^5 kt). The range of increase and decrease was 0.189, −0.149, −1.676, −3.692%, and only in LHDS, CS increased by 42.05 kt. Therefore, in order to achieve the "Dual-Carbon" goal, Wenzhou needs to prioritize the combination of LHDS and ESGS to formulate relevant policies.

Keywords: "Dual Carbon" target, territorial spatial ecological governance, LUCC, SD-PLUS-InVEST coupled model, carbon storage, multi-scenario simulation

1 Introduction

Terrestrial ecosystem carbon storage (CS) is an important factor for climate regulation and ecological environment improvement [1,2], and climate change due to land use cover change (LUCC) induced by human activities directly affects ecosystem CS [3]. The conflict between economic and social development and low carbon ecology is becoming more and more serious, in order to alleviate the contradiction between coordinating economic development, LUCC, ecosystem functioning, and CS, carbon emissions in terms of LUCC and CS have received great attention in the research fields of global climate change and ecosystem functioning preservation [4,5].

CO_2 accounts for about 80% of China's total greenhouse gas emissions over the period 2005–2020, mainly from the consumption of energy such as coal, crude oil, and natural gas, and emissions from industrial processes as a result of economic development and urban expansion [6]. Achieving net-zero CO_2 emissions is critical for achieving "carbon neutrality" in the broadest sense [7], and China as one of the world's largest sources of carbon emissions, has the potential to become a carbon neutral country. China is one of the world's largest sources of carbon emissions [8,9]. In the past few years, the government has put forward the goal of achieving "carbon peak" by 2030 and "carbon

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neutrality" by 2060. At the same time, a nationwide ecological governance of national land space will be carried out to optimize the ecological environment and land use structure, adjust the economic development mode and energy consumption structure, reduce carbon emissions, and increase ecological CS, so as to accelerate the realization of the goal of "dual-carbon" and the optimization of territorial spatial ecological governance [10]. Quantitative assessment of future changes in sustainability can help policy makers make more scientific decisions on economic development strategies [11]. Therefore, it is extremely important to clarify the trend of LUCC and CS dynamics in the future under the constraints of multi-policy factors such as "dual-carbon" and territorial spatial ecological governance.

Due to the different development conflicts faced at different stages, the absolute and relative conflicts between LUCC and economic development will also change, and the coordination of economic and social development and low-carbon ecological conflicts is extremely important. Previous studies have shown that LUCC changes are greatly influenced by natural climate change and economic and social development [12,13]. At the same time, LUCC change is the most important factor affecting CS change in terrestrial ecosystems [14]. The study of dynamic change of LUCC is the basis of CS assessment, and it is usually necessary to consider LUCC and transfer management methods under different economic and social development contexts [15]. Predicting and optimizing the spatial pattern of LUCC to improve the regional CS is the main method to improve the CS. Models based on the dynamic simulation of LUCC under multiple scenarios include conversion of land use and its effects at small regional extent (CLUE-S) model [16], ANN-CA [17], future land use simulation (FLUS) model [18], Patch Generation Land Simulation (PLUS) model [19], Markov model [20], and logistic cellular automaton models [21]. In order to more deeply couple the economic and social subsystems, natural resources subsystems, and LUCC subsystems, and to develop multi-scenario simulation from the perspective of the conflict between economic and social development and low-carbon ecology, the system dynamics (SD) model is introduced into the LUCC prediction model, which is a kind of improved top-down model that can better reflect the nonlinear, dynamic, and systematic characteristics of the LUCC process, and is more effective in simulating LUCC under multi-scenario and superiority in simulating LUCC demand changes under multiple scenarios [22,23]. However, it is difficult to simulate the spatial structure of land [24]. Therefore, the combination of SD model with CLUE-S, artificial neural network cellular automata (ANN-CA), FLUS, PLUS, and other models can more accurately simulate the spatial changes in LUCC. However, the CLUE-S, FLUS, ANN-CA, and other models have the following

shortcomings compared with the PLUS model. First, CLUE-S and ANN-CA simulation quantities are smaller, which makes it difficult to perform multi-scenario simulations; second, FLUS is limited in the number of driving factors that can be incorporated into the simulation compared to PLUS; third, the simulation accuracy is poorer at the same image metric scale; and fourth, the CA models, such as CLUE-S and ANN-CA, lack the introduction of policy factors associated with planned development zones, which makes them unsuitable for multi-scenario LUCC and CS prediction [25]. Compared with previous CA models, the PLUS model combines the CA model with the patch generation simulation strategy, utilizes the advantages of other CA models [15], enhances the ability to simulate the real landscape pattern, retains the advantages of adaptive inertial competition and roulette wheel competition mechanism [26], and determines the development potential of each LUCC type through the Random Forest algorithm [27], and the simulation results are closer to the landscape pattern indicators of the real landscape, and is more suitable for future multi-scenario CS prediction. The simulation results are closer to the landscape pattern indicators of real landscapes, and can more accurately simulate the dynamic spatial changes of LUCCs, which is more suitable for future multi-scenario CS prediction. At the same time, in order to avoid the problem that it is difficult to carry out multi-scenario prediction with a single model of PLUS, the SD model is coupled, and the dynamic prediction and policy impact control advantages of the SD model are utilized to carry out the refined simulation of land use demand under multi-scenarios.

Field surveys [28], sample inventories [29], and ecosystem CS monitoring [30] are used to assess CS. Although traditional methods are accurate, they are difficult to measure large-scale and long time-series areas [31], and are difficult to be widely applied because of the large workload and low efficiency. With technological advances and the need for large-scale research, CS assessment models such as bookkeeping models [32,33], remote sensing models [34], CASA models [35], and ecosystem service evaluation and trade-off (InVEST) [36,37] models have been developed. Among the above models, the InVEST model has been widely used by researchers in the field of ecological CS research [38,39]. Compared with the above CS models, InVEST requires fewer types of data, is easy to obtain and operate, has fast computation and high accuracy in quantitative assessment, is capable of spatial and temporal visualization, and is more suitable for spatial analysis of CS triggered by changes in LUCC [40]. However, CS within the same LUCC type will show different attribute characteristics and spatial-temporal characteristics due to changes in the natural and economic and social environments [39], and their spatial compositions and the historical changes

in LUCC [41,42] will be significantly different, and the conflict between LUCC and CS and economic and social development will arise. LUCC conflict is the external manifestation of the competition for spatial resources [43]. Conflicts arise when various types of LUCC demands overlap spatially, or when LUCC stakeholders have incompatible interests with certain land types [44]. Uncontrolled LUCC can seriously affect ecological space and agricultural space [45]. Changes in LUCC conflicts based on specific social environments or institutional conditions have been of interest [46], but most of the existing studies have focused only on absolute LUCC conflicts [47] and have not explored the impacts of LUCC conflicts on spatial changes in CS under different development scenarios. LUCC types of CS also change over time in response to environmental changes [48,49]. In previous studies of LUCC and CS forecasting, researchers have focused more on optimizing LUCC and CS forecasting models, as well as exploring the impacts of LUCC on CS in different geographic spaces and under different scenarios. However, in the direction of absolute and relative LUCC conflicts, no in-depth research has been conducted on CS changes under the perspective of LUCC conflicts. Meanwhile, the mutual influence of LUCC and CS spatial mechanism changes has not been systematically analyzed.

In summary, there are still gaps in research on CS assessment and spatial mechanisms under the LUCC conflict perspective. In addition, there is a lack of research on LUCC and CS in the context of the "Dual-Carbon" goal and territorial spatial ecological governance. Therefore, based on this background, this study starts from the perspective of absolute and relative conflict of LUCC in low-carbon ecology and economic and social development. Natural Development Scenario (NDS), High-speed Urbanization Scenario (HUS), Low-carbon and High-quality Development Scenario (LHDS) and Ecological Safety Governance Scenario (ESGS) are set. Coupled with the SD-PLUS-InVEST model, the dynamic changes and development mechanisms of LUCC and CS under the four scenarios in Wenzhou City in 2035 are investigated, and the spatial changes in CS are characterized by absolute and relative conflicts under the background of the "Dual-Carbon" goal and the territorial spatial ecological governance. This will help to harmonize the conflicts between the "Dual-Carbon" goal, territorial spatial ecological governance, and economic and social development, and provide new ideas for the formulation of low-carbon, ecological, high-quality, and sustainable economic and social development policies.

2 Materials and methods

2.1 Study area

Wenzhou City is located in the southern part of Zhejiang Province, China, with a total area of 12,103 km², the terrain is dominated by mountains and hills, and belongs to the subtropical monsoon climate zone. It is rich in forest resources, totaling 7,075 km², with a per capita of 735 m², which is among the highest in the country (Figure 1). By the end of 2020, the household population is 8,287,000, and the
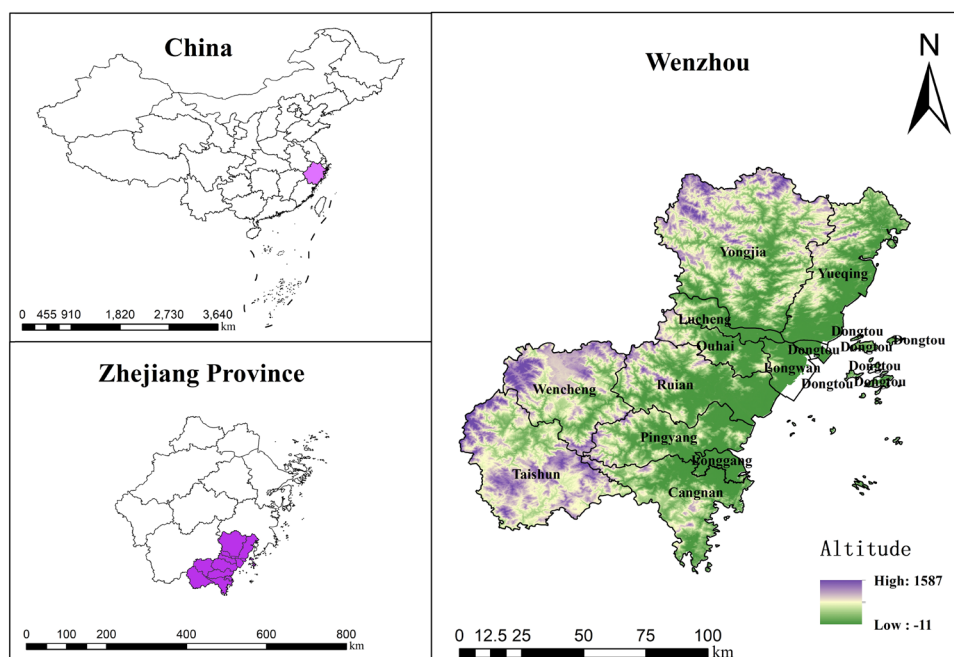

Figure 1: Geographic location of Wenzhou City.

resident population is 9,250,000, with the third highest gross domestic product (GDP) in Zhejiang Province. With the long-term high rate of economic growth, the ecological footprint per capita has risen year by year and the ecological deficit is serious, reaching a maximum of 1.68 ha per capita, resulting in enormous pressure on land from the consumption of natural resources and the depletion of a large stock of natural resources to support current development and consumption [50]. In the "13th Five-Year Plan" of Wenzhou City to control greenhouse gas emissions implementation program, it is proposed to achieve "carbon peak" in 2030. In addition, Wenzhou, as a national low-carbon pilot city, responds to the ecological governance of land space under the goal of "Dual-Carbon" [51,52]. It is actively exploring the requirements of adaptive transformation to create a low-carbon, ecological, high-quality sustainable development path with the characteristics of Wenzhou City [53,54].

2.2 Research framework

The research framework of this study is as follows (Figure 2):
(1) Data collection: Economic and social data, natural resource data, and LUCC data were collected in the study area.
(2) Scenario setting: Four scenarios were constructed based on the background of the "Dual-Carbon" goal and territorial spatial ecological governance, as well as the absolute and relative conflicts between economic and social development and ecological and low-carbon perspectives.
(3) LUCC demand forecast: Based on the four scenarios, the SD model is applied to forecast the LUCC demand in 2035.
(4) LUCC simulation: Based on the results of LUCC prediction by the SD model, the PLUS model is used to simulate LUCC in 2035.
(5) CS measurement: The InVEST model is used, combined with the PLUS simulation results, to forecast the CS under the four scenarios in 2035.
(6) Analysis of results: The results are analyzed to resolve the dynamic changes and spatial mechanisms of LUCC and CS in the future.

2.3 Data sources and processing

2.3.1 Data sources

The basic data required for the SD model were obtained from the statistical yearbooks of Zhejiang Province and Wenzhou City. The data required for the PLUS model, the LUCC data, were the 30 m accuracy remote sensing data published by Wuhan University. The 30 m accuracy data provide detailed LUCC information with high accuracy, which can ensure the detailed capture of the complexity of LUCC changes and better reflect the spatial heterogeneity of land use, and also solve the problem of excessive data computation, which is suitable for the prediction of land use and CS [55,56]. The prediction drivers included 8 environmental factors and 13 economic and social factors, and the limiting factors were the open water and ecological function protection areas (Table 1), and the above factors are the main reasons influencing the LUCC changes. Meteorological data were obtained from the National Meteorological Science Data Center (http://data.cma.cn/), and the rest of the data were obtained from the Resource and Environmental Science and Data Center of the Chinese Academy of Sciences (www.resdc.cn) and Geospatial Data Cloud (www.gscloud.cn) (Table 1).

2.3.2 Data processing

The data processing flow is as follows:
(1) The raw vector data of LUCC were extracted and cropped by mask by ArcGIS 10.8 software, and then classified into six land use types, namely, cultivated land, woodland, grassland, water, construction land, and unused land by applying the reclassification tool.
(2) The digital elevation model data were processed by ArcGIS 10.8 software to obtain slope and direction data.
(3) Distances to waters, public service points, and roads were calculated using Euclidean distances in ArcGIS 10.8 software.
(4) Combined with the meteorological station data and statistics of Wenzhou's average annual temperature and average annual precipitation from 2005 to 2020, the raster data of Wenzhou at 30 km resolution were generated by spatial interpolation with ArcGIS10.8 software.
(5) The raster data of NDVI, GDP, population, night lights, and limiting factors were all processed by ArcGIS10.8 software, and after the unified coordinate system (CGCS2000_3_Degree_GK_CM_108E) was carried out, the raster data were processed by resampling and cropping. At the same time, it was ensured that the number of rows and columns of the 2005 and 2020 LUCC data was the same, and the projected coordinates of all raster data were identical.
(6) The SD model uses the underlying statistical yearbook data, which was standardized mainly through SPSS.26 Descriptive Statistics.
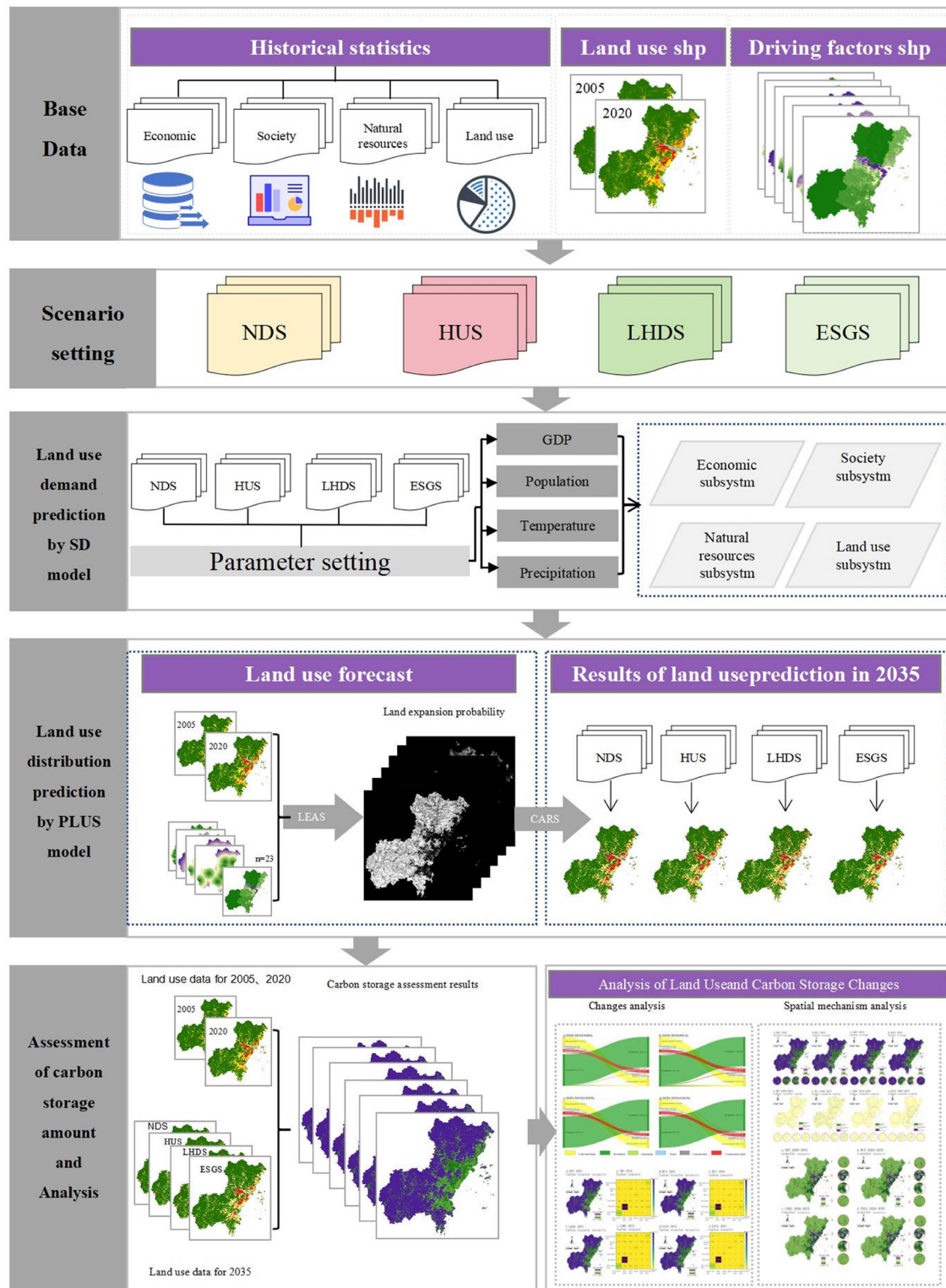
Figure 2: Research framework.

Table 1: LUCC driving factor data

Data type	Data name	Year	Precision/m	Data source
LUCC data	LUCC	2005 and 2020	30	(https://www.resdc.cn/)
Natural environment data	Elevation	2020	30	(http://soil.geodata.cn/)
	Slope	2020	30	(http://data.cma.cn/)
	Average annual temperature	2005–2020	30	(http://data.cma.cn/)
	Average annual precipitation	2005–2020	30	(https://www.gscloud.cn)
	Soil type	2020	30	Spatial processing
	Average humidness	2021	500	(https://www.resdc.cn/)
Socio-economic data	NDVI	2020	1,000	(https://www.resdc.cn/)
	Distance to river	2020	1,000	Spatial processing
	Distance to railway	2020	30	Spatial processing
	Distance to high ways	2020	30	Spatial processing
	Distance to provincial road	2020	30	Spatial processing
	Distance to express road	2020	30	Spatial processing
	Distance to main road	2020	30	Spatial processing
	Distance to secondary main road	2020	30	Spatial processing
	Distance to city branch	2020	30	Spatial processing
	GDP	2020	30	(https://www.resdc.cn/)
	Nighttime lighting index	2020	1,000	(https://www.resdc.cn/)
	Population density	2020	1,000	(https://www.resdc.cn/)
	Distance to dwelling place	2020	30	Spatial processing
	Distance to public service facilities	2020	30	Spatial processing
Limiting factor	Water	2020	30	(https://www.gscloud.cn)
	Ecological protection area	2020	1,000	(https://www.gscloud.cn)

2.4 Methods

2.4.1 Scenarios of future

Based on China's "Dual-Carbon" goal and the goal of territorial spatial ecological governance, Wenzhou City serves as a pioneer area for low-carbon ecology, high-quality development, and ecological security governance of territorial space. We assume that Wenzhou will follow the path of low-carbon, ecological and high-quality sustainable development in the future. At the same time, the impacts of relative and absolute conflicts between future economic and social development and ecological low-carbon on LUCC and CS were considered. Four scenarios are set up:

(1) CS under the NDS: According to the development trend of Wenzhou City from 2005 to 2020, it is sufficient to set up a natural development scenario and make basic restrictions on the transfer of land, without considering the restrictions on the change in LUCC by external policies.

(2) HUS: Under the high speed of urban development, the high economic growth has led to extreme encroachment of urban construction land and extremely high occupancy of other land [57]. LUCC changes in the urbanization process are mainly reflected in a 40% increase in the probability of transferring cultivated land, woodland, grassland, and water to construction land, and a 100% increase in the probability of transferring unused land to construction land. This shift not only increases the area of construction land in cities, but also reflects the high intensity demand for land resources in cities [58]. Therefore, the probability of shifting cultivated land, woodland, grassland, water, and unused land to construction land is higher in this scenario.

(3) LHDS: Construction land is the main factor leading to high carbon emissions [59]. In order to improve the low-carbon and ecological nature of economic development, alleviate the absolute conflict between economic development and ecological low-carbon, Wenzhou needs to take the sustainable development of the green low-carbon circular economy model to improve the CS comprehensively. Therefore, the transfer of woodland and grassland to construction land should be restricted. At the same time, the unused land should be transferred to land categories with higher CS such as woodland, grassland, and cultivated land [60].

(4) ESGS: In order to ensure urban ecological quality and ecological security, human interference in ecologically sensitive areas, ecologically fragile areas, and prohibited development zones should be minimized to create conditions for ecological governance and protection of

Table 2: Transfer cost matrix of each land use type under different development scenarios

LUCC	NDS						HUS						LHDS						ESGS					
	C	F	G	W	B	I	C	F	G	W	B	I	C	F	G	W	B	I	C	F	G	W	B	I
C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	1	1
F	1	1	1	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0	1	0	0	0	0
G	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0	1	0	0	0	1	0	0	0
W	0	0	0	1	0	0	1	1	1	1	1	1	0	1	1	1	1	0	0	0	0	1	0	0
B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	1	1
I	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0	0	1	1	0	0	0	1	1

Note: C: cultivated land, F: woodland, G: (grassland, W: water, B: (unused land): I (construction land).

national land space [61]. In this scenario, only land categories with low CS are allowed to be converted to land categories with high CS, and the occupation of construction land and cultivated land to forest land is restricted, and the protection of land categories with high CS, such as woodland, water, and grassland, is strengthened [62]. The LUCC prediction transfer parameters for the above four scenarios are given in Table 2.

2.4.2 SD models

System dynamics treat complex systems as systems with multiple information causal feedback mechanisms, which is able to deal with nonlinear and time-varying problems and perform quantitative simulations [63]. Meanwhile, the SD model can reveal the complex relationship among LUCC, economic development, and ecological protection. And by simulating different development modes, it can effectively assess which development mode is most conducive to the long-term sustainability of the city [64,65]. Therefore, the SD model has been widely used in the simulation of urban composite systems and LUCC changes [66].

This study constructs a base model based on the linear regression relationship between the economic and social subsystem, the natural resource subsystem and the LUCC subsystem (Figure 3). The economic and social subsystem has the greatest impact on LUCC, and economic and social development leads to an increase in investment in all types
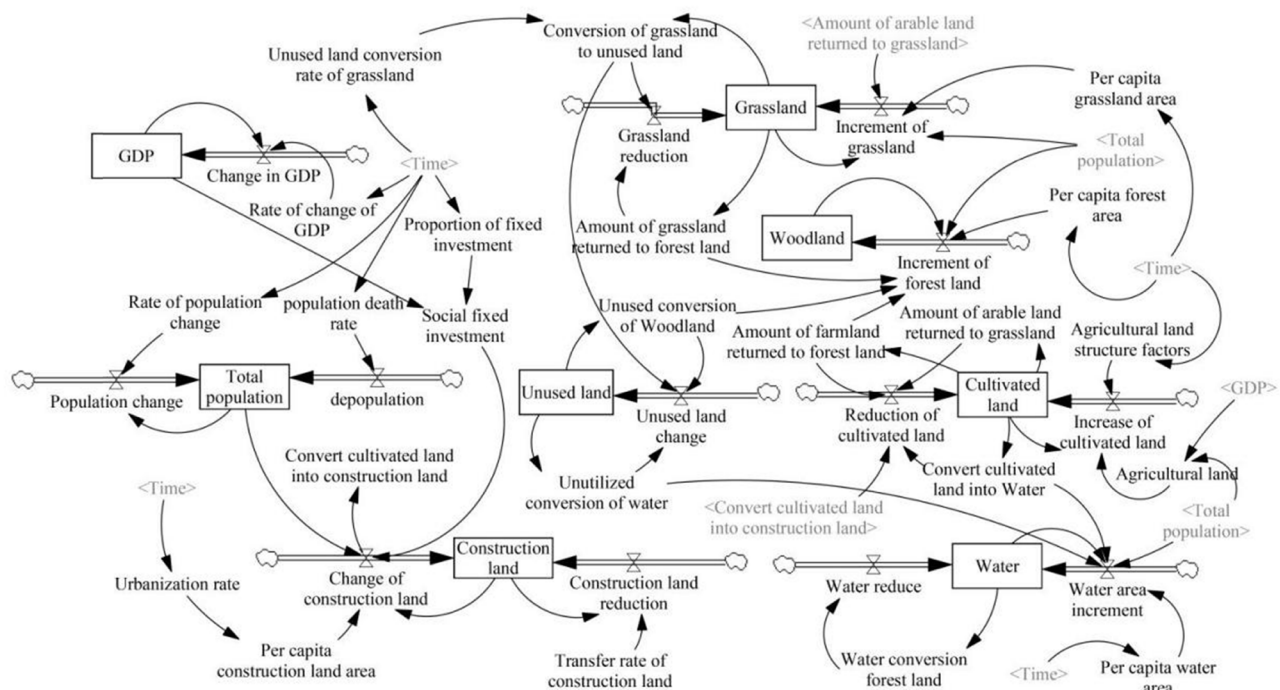
Figure 3: System dynamics model.

of social fixed assets and materials for survival, accelerating the expansion of cultivated land and construction land, and increasing the cost of ecological and environmental management. The population subsystem reflects the changes in urban and rural population, and the increase in population and GDP growth inevitably leads to a further increase in construction land, thus indirectly affecting the spatial pattern and occupancy of LUCC. The natural resources subsystem mainly affects the water use and temperature of cultivated land, woodland, grassland, and water. The LUCC subsystem reflects the spatial pattern and transfer of LUCC under different development scenarios.

Based on the LUCC data, economic and social data, and natural resource data of Wenzhou City from 2005 to 2020, the interactions between the subsystems and variables were simulated. After several calibrations, the parameters between the variables were determined and the model was constructed (Figure 3). The simulation period of the SD model is 2005–2035 with a time step of 1 year. The historical simulation phase is 2005–2020, and the real data in 2020 is used to evaluate the accuracy of the simulation model. The scenarios are simulated with a base year of 2020, and the parameters and policy constraints of different scenarios are input to simulate the four scenarios of LUCC demand in Wenzhou City in 2035.

2.4.3 PLUS models and model validation

The PLUS model is a patch-generated LUCC change simulation model, which contains two modules, the Land Expansion Analysis Strategy (LEAS) model and the multi-type stochastic seed-based (CARS) [15,26]. In this study, we extracted the land expansion data of Wenzhou City from 2005 to 2020 using the LEAS module, and analyzed the impact of drivers on land expansion through the Random Forest algorithm to identify and quantify the key drivers affecting the change in LUCC. The CARS module utilizes the analysis results of the LEAS module to further simulate the LUCC. Parameters such as domain weights are to be set in this module, and domain weights are set according to the proportion of the expansion area of different land types of the total area. The parameters are as follows: (1) LEAS: the value of the decision tree is 20, the sampling rate is 0.01, the mTny is 14, and the number of parallel threads is set to 1. (2) CARS: the neighborhood range is set to 3, the Thread is 6, the diminishing threshold coefficient is 0.5, the diffusion coefficient is 0.1, and the seed probability of the random patches is 0.0001.

Based on the 2005 and 2020 LUCC data (Figure 4), 23 impact factors were selected (Figure 5), including elevation, slope, mean annual temperature, mean annual precipitation, land type, mean annual humidity, NDVI, distance to off-river rivers, distance to important transportation routes, GDP, nighttime lighting, population density, distance to settlements, distance to points of public services, distance to governmental sites, and Ecological Reserve data. Among them, surface waters and ecological protection zones are the limiting factors. Surface waters are mainly composed of rivers, lakes, and coastal waters, which block the expansion and encroachment of urban land use with their natural barrier characteristics, while ecological protection zones are composed of river origins, water conservation areas and animal and plant protection zones, which limit the expansion of the city as an important ecological protection
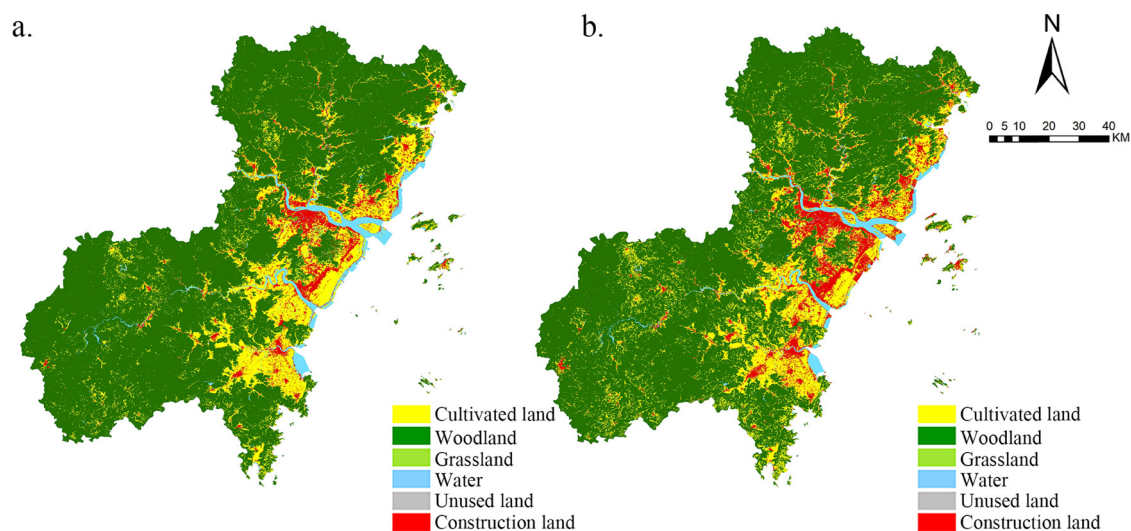

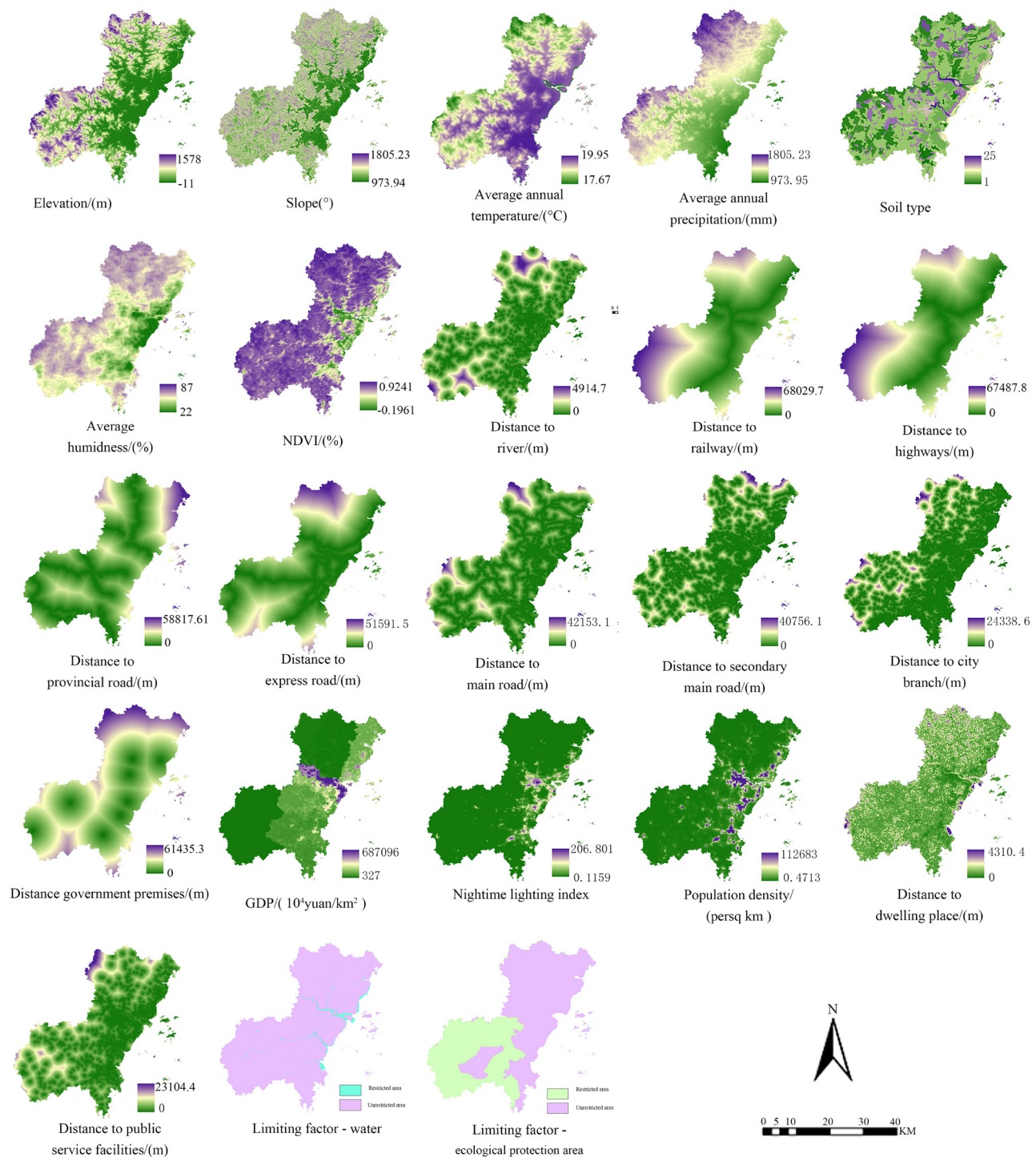**Figure 4:** LUCC in (a) 2005 and (b) 2020.

Figure 5: Driver and limiting factors.

site. Using LUCC data in 2005 as a simulation reference map, the PLUS model was run to obtain the LUCC simulation results in 2020. The accuracy of the PLUS model was evaluated by comparing the simulation results with the real LUCC data in 2020. If the accuracy of the results is high, the LUCC demand data predicted by the SD model for the four scenarios in Wenzhou City in 2035 are input into the PLUS model. Based on the LUCC data in 2020, the changes in the spatial and temporal pattern of LUCC in Wenzhou City in 2035 were simulated.

2.4.4 InVEST models

In this study, the CS module of the InVEST model was utilized to assess the CS of terrestrial ecosystems in Wenzhou City in 2035, based on LUCC data and carbon density data. Among them, the carbon module divides the ecosystem CS into four basic carbon pools: above-ground biogenic carbon, below-ground biogenic carbon, soil carbon, and dead organic carbon [67]. The calculation formula is as follows:

$$C_{\text{sum}} = \sum_{1}^{i}(C_{i-\text{above}} + C_{i-\text{below}} + C_{i-\text{soil}} + C_{i-\text{dead}}) \times A_i, \quad (1)$$

where i is the number of LUCC types; C_{sum} is the sum of ecosystem CS; $C_{i-\text{above}}, C_{i-\text{below}}, C_{i-\text{soil}}, C_{i-\text{dead}}$ are the carbon densities in above-ground, below-ground, soil, and dead organic matter in the ith type of LUCCs, respectively, and A_i is the area corresponding to the ith type of LUCC.

Carbon density is an important input parameter for the accurate assessment of CS by the InVEST model, which varies in different climatic zones [68]. In this study, the carbon density was corrected with reference to the carbon density of Jiangsu and Zhejiang regions and the data from previous carbon density studies [69,70]. The carbon density of dead organic matter for each LUCC type was estimated by referring to the IPCC 2006 national greenhouse gas emission inventory [71]. In this study, the carbon density correction method proposed by Alam *et al.* [72] and Shui *et al.* [73] was used for the correction, and the correction formula was as follows:

$$C_{\text{SP}} = 3.3968 \times \text{MAP} + 3996.1, \quad (2)$$

$$C_{\text{BP}} = 6.798 \times e^{0.0054 \times \text{MAP}}, \quad (3)$$

$$C_{\text{BT}} = 28 \times \text{MAT} + 398, \quad (4)$$

where C_{SP} and C_{BP} denote soil carbon density and biomass carbon density calculated by mean annual rainfall, respectively; C_{BT} represents biomass carbon density calculated by

Table 3: Carbon density value of each land use type in the study area (kt)

Land use type	Carbon above	Carbon below	Carbon soil	Carbon dead
Cultivated land	5.961	1.274	96.635	0.000
Woodland	68.781	21.734	132.572	8.131
Grassland	2.635	10.043	103.01	0.879
Water	0.685	0.000	83.962	0.000
Unused land	0.113	0.000	75.431	0.000
Construction land	0.113	0.000	77.631	0.000

mean annual temperature; and MAP and MAT represent mean annual rainfall and mean annual temperature, respectively. The corrected carbon density of each LUCC type in the study area is shown in Table 3.

3 Results

3.1 Change analysis of LUCC and CS from 2005 to 2020

3.1.1 Characterization and spatial mechanisms of LUCC from 2005 to 2020

From 2005 to 2020, the areas of woodland, grassland, and water in Wenzhou City decreased by 407.55, 2.02, and 55.66 km², respectively (Table 4). And the percentage also showed a decreasing trend, with woodland decreasing from 75.61 to 72.06%, grassland decreasing from 0.03 to 0.01%, and water decreasing from 2.28 to 1.79%. Among all LUCC types, Woodland had the largest decrease in area and constructed land had the largest increase in area. Cultivated land, unused land, and constructed land increased by 169.78, 0.065, and 295.38 km², respectively, all of which showed an upward trend, with cultivated land increasing from 17.39 to 18.87% and constructed land increasing from 4.69 to 7.27%. The land that has not been transformed accounts for 91.6% of the total land, the amount of shifting of cultivated land accounts for 4.6%, the amount of shifting of construction land accounts for 2.7%, the amount of shifting of woodland accounts for 1%, and the amount of shifting of the rest of the types of land is small accounting for about 0.01% (Table 4 and Figure 6). The results of the analysis are as follows: (1) Compared with the west, the terrain of the east coast is flat, with good conditions for cultivation and construction, and the expansion of cultivated land and construction land is more obvious. (2) The high speed of economic development and the rapid growth of urban and rural populations have increased the demand for food, leading to the occupation of large areas of ecological land (woodland, grassland, and water) in the west and north by cultivated land and construction land. (3) The rise of a large number of private enterprises in townships and counties has led to the rapid economic and social development of townships and increased demand for construction land, accelerating the expansion of construction land in the ecological area in the western and northern regions in the form of a point distribution (Figure 6).

Table 4: LUCC conversion in Wenzhou from 2005 to 2020 (km^2)

2005	2020						Roll-out total
	Cultivated land	Woodland	Grassland	Water	Unused land	Construction land	
Cultivated land	1602.88	474.42	0.97	48.70	0.01	2.11	2129.08
Woodland	114.75	8161.30	0.79	0.53	0.00	0.02	8277.38
Grassland	0.19	0.24	0.85	0.01	0.01	0.00	1.28
Water	8.65	0.22	0.04	278.43	0.00	4.91	292.24
Unused land	0.03	0.01	0.09	0.098	0.02	0.00	0.23
Construction land	250.43	19.98	0.55	37.88	0.10	527.90	836.83
Carry-over total	1976.93	8656.15	3.27	365.63	0.12	534.94	11537.03

3.1.2 Characterization and spatial mechanisms of CS from 2005 to 2020

Using the InVEST model to assess the CS in Wenzhou City in 2005 and 2020, the CS was 2.28×10^5 kt and 2.22×10^5 kt, respectively (Table 5), with a total decrease of 6.12×10^3 kt, and the CS of woodland decreased by 8.76×10^3 kt, and there was a decreasing trend in the CS from 2005 to 2020, with the total amount decreasing by 2.4%. In terms of LUCC types, the CS in descending order, is woodland, cultivated land, construction land, water, grassland, and unused land. From 2005 to 2020, the transfer and dynamics of CS of each land type (Table 6 and Figure 6), CS conversions of cultivated land, construction land, and woodland were 2.032×10^4 kt, 3.39×10^3 kt, and 1.20×10^3 kt, respectively, which are the main factors affecting the change in CS in Wenzhou from 2005 to 2020, and the CS transfer of the remaining land use is relatively small and less influential.

The analysis of four typical areas in Wenzhou City from 2005 to 2020 shows (Figure 6) that the areas with significant CS reduction are mainly areas *A* and *D*, where woodland and grassland are reduced in a large area, mostly distributed in point form in ecological service areas, with a wide range and a high density. The fringe areas of
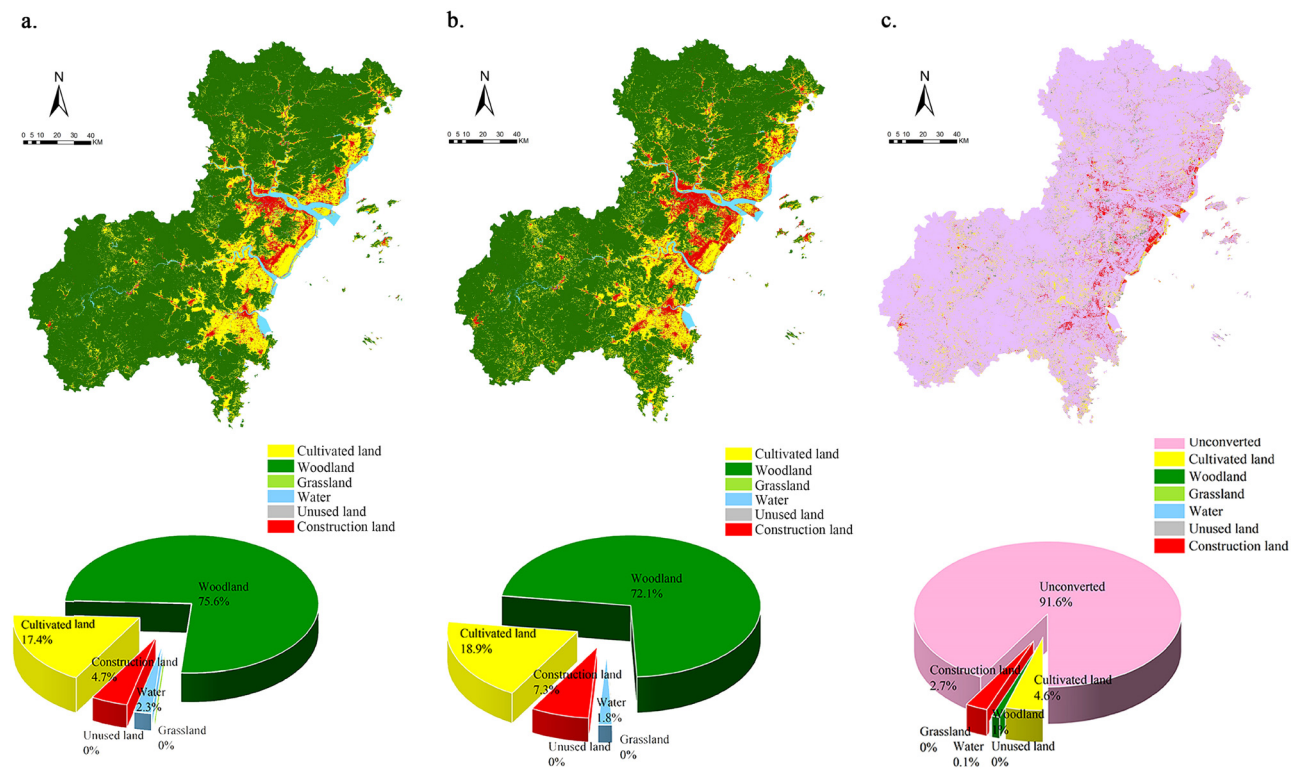

Figure 6: Distribution of LUCC space transfers from 2005 to 2020. (a) Year 2005. (b) Year 2020. (c) 2005–2020 land transfer.

Table 5: CS in 2005 and 2020 (10 kt)

Land use type	2005		2020	
	Carbon (10 kt)	Proportion (%)	Carbon (10 kt)	Proportion (%)
Cultivated land	2053.43	9.01	2211.48	9.94
Woodland	20014.57	87.79	19138.79	86.02
Grassland	3.81	0.02	1.49	0.01
Water	309.50	1.36	247.37	1.11
Unused land	0.09	0.00	0.17	0.00
Construction land	415.88	1.82	650.58	2.92
Summary	22797.28	100.00	22249.88	100.00

Table 6: CS transfers (10 kt) in different land categories from 2005 to 2020

Land use type	Cultivated land	Woodland	Grass land	Water	Unused land	Construction land
Cultivated land	1664.91	1096.94	1.13	41.224	0.01	1.64
Woodland	119.18	18870.39	0.92	0.45	0.01	0.01
Grassland	0.19	0.54	0.99	0.01	0.01	0.01
Water	8.98	0.50	0.04	235.68	0.001	3.82
Unused land	0.03	0.01	0.10	0.08	0.018	0.01
Construction land	260.11	46.18	0.64	32.06	0.08	410.41

the main urban areas of *B* and *C*, where the CS is reduced, are distributed in piecemeal form, with a large area, and are mostly areas of woodland and cultivated land. The part of CS increasing is mainly the new cultivated land and construction land along the east coast and river, and the space of CS increasing is distributed in a narrow band with a small area. The spatial change in CS is consistent with LUCC in Wenzhou from 2005 to 2020, which is influenced by economic and social development (Figure 7). In the past

10 years, ecological CS technology has mainly focused on the exploration of loamy carbon sequestration, carbon capture, utilization, and storage (CCUS) technology, and ecological spatial restoration is considered to be the best natural solution with low cost and high CS. Therefore, in the future, Wenzhou should increase the investment in ecological and environmental management and restoration of land space to solve the problem of declining CS in Wenzhou at the level of ecological CCUS [74].
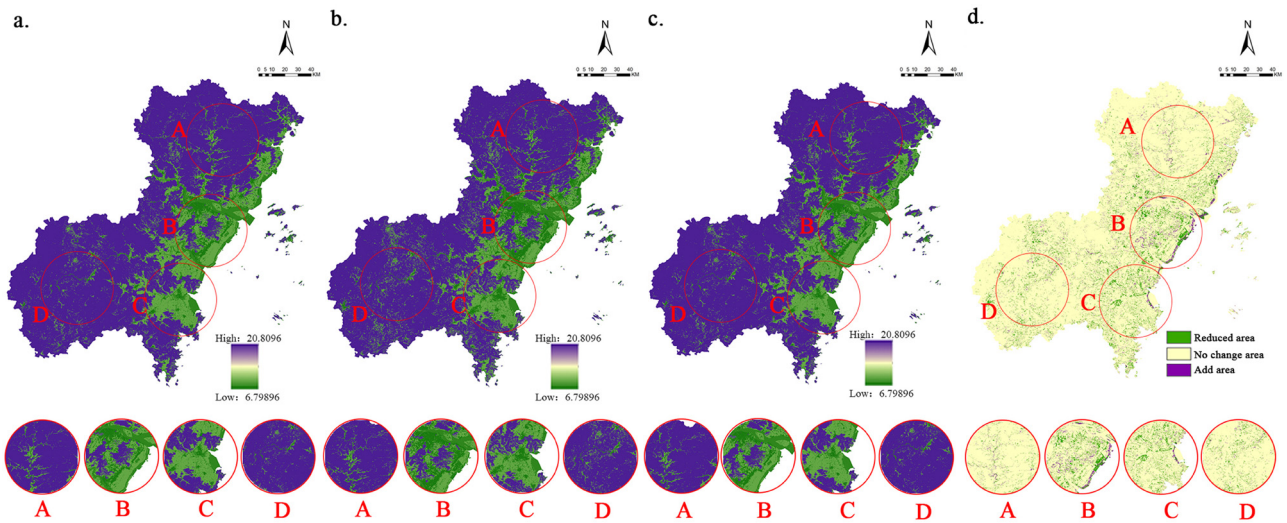

Figure 7: Dynamics of CS from 2005 to 2020. (a) 2005 CS, (b) 2020 CS, (c) 2020 CS intensity, and (d) 2005–2020 carbon transfer region.

Table 7: LUCC prediction accuracy (km^2)

Year	Cultivated land	Woodland	Grassland	Water	Unused land	Construction land
2020 true (km^2)	2163.4263	8261.9586	1.3230	205.3071	0.1791	833.4999
2020 forecast (km^2)	2213.8573	8172.2156	1.4293	215.0721	0.1101	863.9569
Error	0.0233	−0.0109	0.0804	0.0476	−0.0835	0.0365

3.2 LUCC demand forecast based on SD modeling

Based on the statistical data of Wenzhou City from 2005 to 2020, the values of SD model variables are set, and the LUCC demand in 2020 is simulated by combining natural resource data, economic and social data, and policy factors. Then, the simulation results in 2020 are compared with the real data in 2020 to calibrate the accuracy. The results show that the errors between the simulated data and the real data are less than 10% and mostly within 5%, with high model accuracy and good model structure (Table 7).

Based on the 2020 data, the economic and social development parameters under different scenarios were substituted into the SD model for simulation, and the results were obtained (Table 8). The results show that by 2035, the LUCC demand under the four scenarios in Wenzhou City vary greatly, and the area of cultivated land and construction land both increase. The growth rate of cultivated land area is HDS, NDS, ESGS, and LHDS in descending order; the growth rate of construction land is HDS, NDS, ESGS, and LHDS in descending order. The area of woodland, grassland, water, and unused land under the four scenarios show a decreasing trend in general, among which the area of woodland, grassland, water, and unused land decreases the most significantly under HDS. Grassland and unused land under ESGS have a small increasing trend. Cultivated land, woodland, and water have smaller changes in the LHDS and ESGS, which is mainly due to the fact that these two scenarios pursue high-quality, low-carbon ecology, maximize the coordination of the absolute conflict between the interests of economic development and ecological and low-carbon, and limit the disordered transfer between construction land and other land with low-carbon and ecological policies, which increases the amount of ecological land transfer (Figure 8).

3.3 LUCC simulations based on the PLUS model

3.3.1 Change analysis of LUCC in multi-scenario from 2020 to 2035

Based on the PLUS model for the 2005–2020 LUCC simulation, it can be seen that from the accuracy calibration process, the PLUS model has higher sensitivity to the accuracy and quality of the driving vector data, and the use of 500 and 1,000 m low-precision driving factors will directly reduce the accuracy of the LEAS module and increase the LUCC simulation error. In this study, the data used are mostly 30 m, and the overall accuracy of PLUS model is 91.86%, and the kappa coefficient is 0.91, which is high, indicating that the model is effective for LUCC simulation results. Based on the LUCC data in 2020, the LUCC demand simulated by SD under the four scenarios is substituted in the PLUS model, and the simulation results are as follows (Figures 9 and 10). The results show that cultivated land and construction land account for about 30% of the total land under NDS and HUS, and the transfer ratio of the two is 43 and 53%, respectively. Woodland accounted for 67–69% of the total land, and the changes in woodland, grassland, and water were all less than 3%, and most of the land shifted to construction land and cultivated land. Because of the absolute priority of economic development, economic and social development and low-carbon ecology are in absolute conflict, which is not conducive to the realization of the goal of "Dual-Carbon" and territorial spatial ecological governance.

Table 8: Multi-scenario land demand in 2035 (km^2)

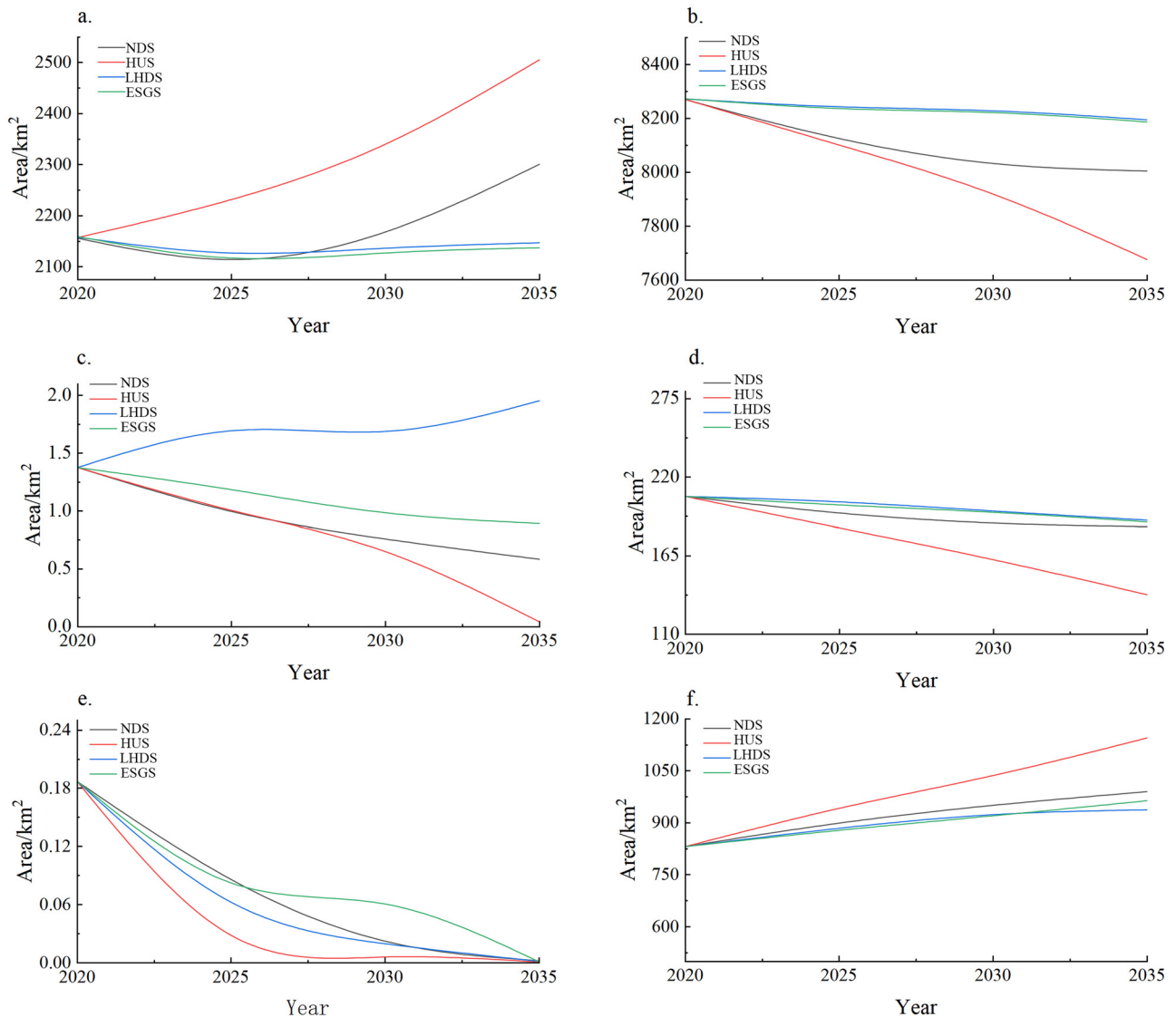| Scenarios	Cultivated land	Woodland	Grassland	Water	Unused land	Construction land
NDS	2300.7676	8004.5715	0.5826	189.2505	0.0013	969.9568
HUS	2505.4972	7676.8982	0.0413	137.7814	0.0010	1145.0519
LHDS	2247.0106	8090.2258	1.9538	189.8802	0.0016	936.5507
ESGS	2236.9492	8075.9770	0.8921	188.5445	0.0012	963.5868

Figure 8: Changes in demand for different land types from 2020 to 2035. (a) Cultivated land. (b) Woodland. (c) Grassland. (d) Water. (e) Unused land. (f) Construction land.

Under the LHDS and ESGS, woodland accounts for 70–73% of the total land, and from the perspective of land transfer, the transfer ratio is 46%, while cultivated land and construction land account for about 27% of the total land, and the transfer ratio is 24 and 28%, respectively. As a result of advocating low-carbon and high-quality development, ecological protection and ecological governance of land space, and focusing on the protection of ecological land, the area of this type of land transferred to cultivated land and construction land is relatively small, and the trend of returning and expanding the area of woodland and grassland is obvious, and the conflict of interests between economic development and ecological and low-carbon is relatively small, mostly relative, which is conducive to low-carbon and high-quality development.

3.3.2 Analysis of spatial mechanism of LUCC change 2020–2035

From the analysis of the four typical change regions in (Figures 9 and 11), it can be seen that the expansion of LUCC space under different scenarios is highly differentiated. Under NDS and HUS, the rapid expansion of construction land leads to a significant reduction in cultivated land in regions B and C. The expansion of construction land in regions A and D occupies a large amount of ecological space, such as woodland and grassland, with a significant reduction in woodland, and the construction land is widely distributed in a large point-like manner within the ecological zone. Under HUS, the expansion of construction land
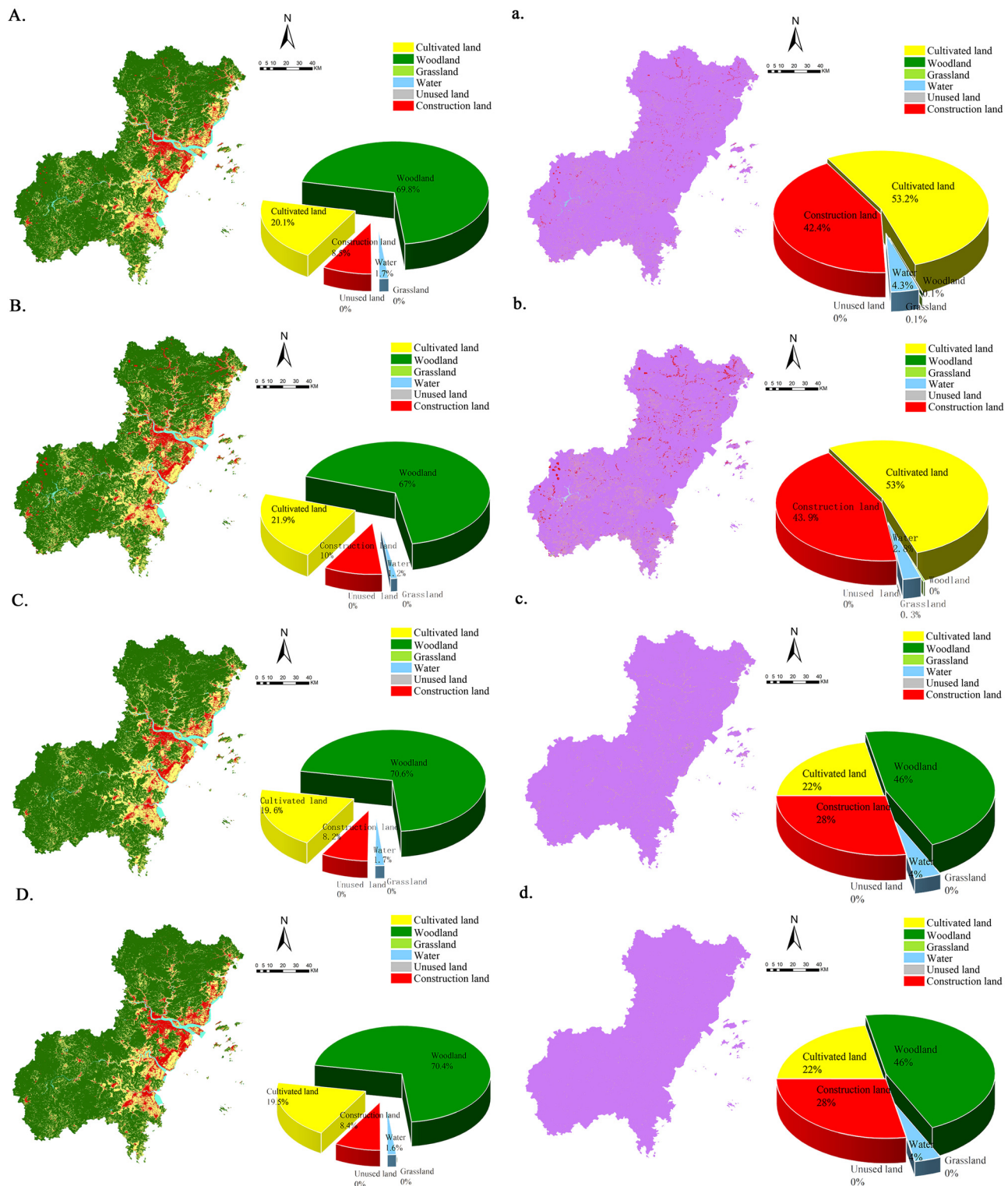
Figure 9: Multi-scenario land modeling, land transfer space, and LUCC ratio in 2035. (A) NDS 2035 Land prediction; (a) NDS 2020–2035 transfer region; (B) HUS 2035 Land prediction; (b) HUS 2020–2035 transfer region; (C) LHDS 2035 Land prediction; (c) LHDS 2020–2035 transfer region; (D) ESGS 2035 Land prediction; (d) ESGS 2020–2035 transfer region.

within the ecological zone seriously breaks the ecological protection space. The expansion of construction land and cultivated land under the LHDS is similar to that of the

ESGS, and the space of woodland and grassland in the ecological space of regions A and D is better preserved and not extensively destroyed. The land transfer in regions
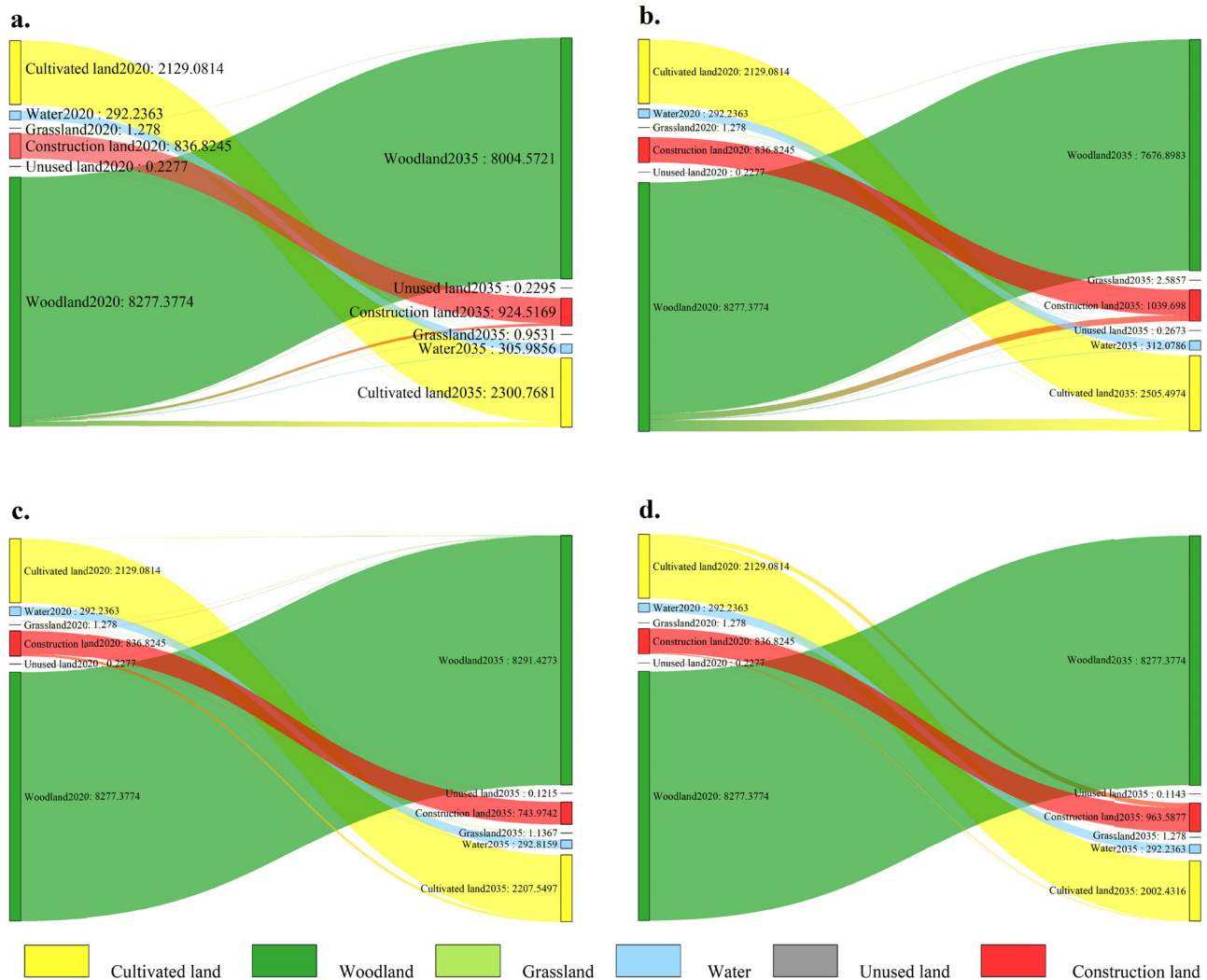
Figure 10: Transfer of different land types. (a) 2020–2035 (NDS). (b) 2020–2035 (HUS). (c) 2020–2035 (LHDS). (d) 2020–2035 (ESGS).

B and D is dominated by woodland, construction land, and cultivated land, which is mainly transferred to the space of construction land, with the overall expansion of a smaller magnitude.

3.4 CS measurement in multi-scenario based on InVEST modeling

3.4.1 Dynamic analysis of CS from 2020 to 2035

The dynamic simulation of CS was unfolded based on the SD-PLUS-InVEST model, which has a longer development time, greater data demand, higher sensitivity to the accuracy of the LUCC data, and more complex requirements than the static model, but the dynamic model has high accuracy and many prediction scenarios, which makes it more suitable for predicting spatial changes in CS over long time periods [75]. The results of the four scenarios simulated by SD-PLUS were substituted in the InVEST model to assess the changes in CS in Wenzhou City under different scenarios from 2020 to 2035 (Table 9 and Figure 12). The variability of CS under different scenarios is significant (Figure 10). In 2035, the CS under NDS, HUS, LHDS, and ESGS is 2.191×10^5 kt, 2.142×10^5 kt, 2.231×10^5 kt, and 2.226×10^5 kt, with an increment of −1.676, −3.692, 0.189, and −0.149%, respectively. Under the four scenarios, the CS in Wenzhou City from 2020 to 2035 shows different degrees of changes, and the CS of NDS, HUS, and ESGS decreases by 3.730×10^3 kt, 8.214×10^3 kt, and 33.09 kt, respectively, and the CS under LHDS increases by 42.05 kt. The largest changes in CS of land use types under the four scenarios were in woodland and cultivated land, with CS of
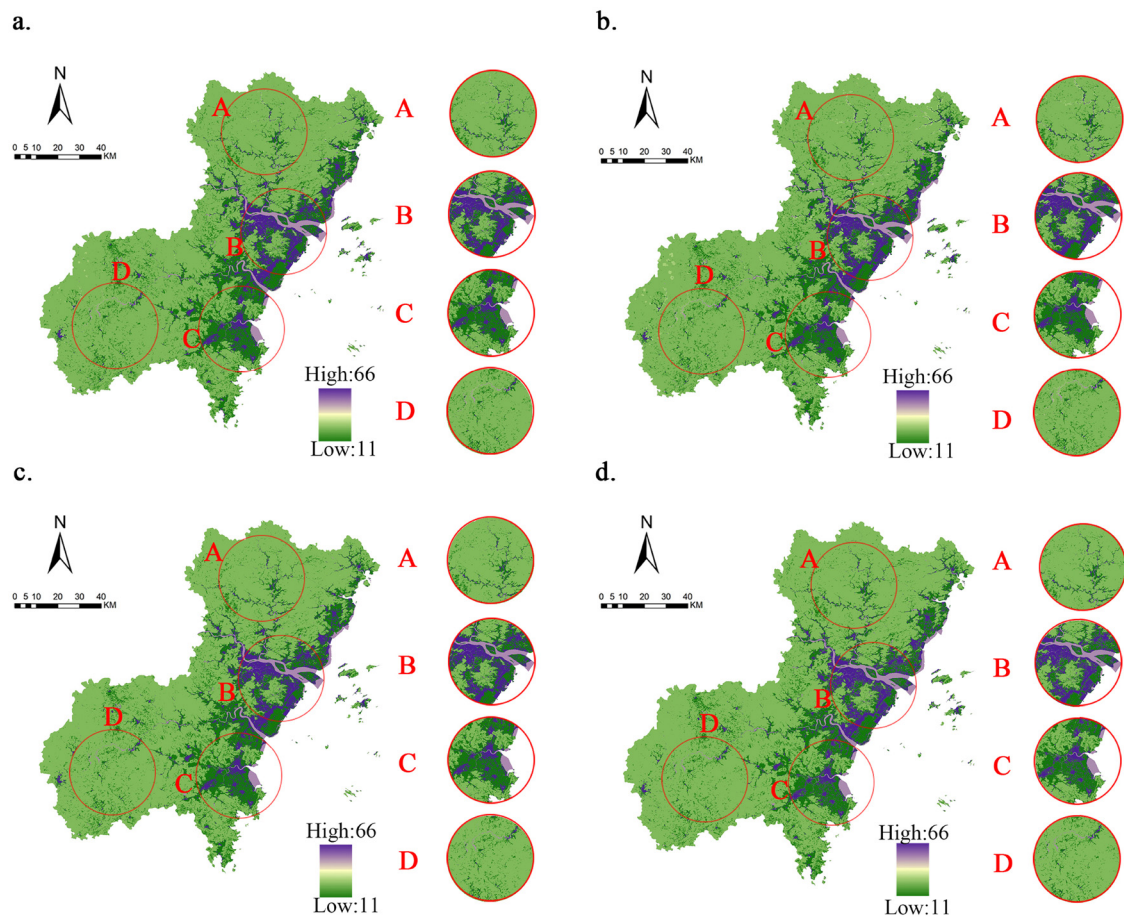
a.

b.

c.

d.

Figure 11: Transfer intensity of LUCC in multi-scenario. (a) NDS 2020–2035 transfer intensity. (b) HUS 2020–2035 transfer intensity. (c) LHDS 2020–2035 transfer intensity. (d) ESGS 2020–2035 transfer intensity.

woodland decreasing by 6.3×10^3 kt and 1.338×10^4 kt under NDS and HUS, respectively, and CS of cultivated land increasing by 1.78×10^3 kt and 3.91×10^3 kt, respectively; CS of woodland under NDS and HUS was 325 kt and 20 kt, respectively, and CS of cultivated land under NDS increased by 8.10×10^2 kt, cultivated land CS decreased by 1.32×10^3 kt under HUS. CS of construction land under NDS, HUS, and ESGS showed an upward trend with an

increase of 6.80×10^3 kt, 1.58×10^3 kt, and 9.90×10^3 kt, respectively, and a decrease of 7.2×10^2 kt under LHDS, while the remaining land use types showed smaller changes in the total CS withdrawal. CS in Wenzhou City tends to have an overall decreasing trend from 2020 to 2035, with the largest decreases under NDS and HUS, the small decrease of CS under ESGS and the small increase under LHDS all benefit from the constraints of the policies of ecological

Table 9: CS in multi-scenarios

LUCC	2020 (10 kt)	2020 (10 kt)			
		NDS	HUS	LHDS	ESGS
Cultivated land	2053.43	2389.81	2602.46	2292.98	2079.93
Woodland	20014.57	18508.01	17750.37	19171.27	19138.79
Grassland	3.81	1.11	3.01	1.33	1.49
Water	309.50	259.01	264.17	247.86	247.37
Unused land	0.09	0.17	0.20	0.09	0.09
Construction land	415.88	718.76	808.30	578.40	749.13

protection, low-carbon development and territorial spatial ecological governance, which emphasize the strict protection of woodland, cultivated land, grassland, and water in development, and the effective coordination of the absolute and relative conflicts between the economic and social development and the low-carbon ecological interests.

3.4.2 Spatial analysis of CS from 2020 to 2035

The spatial distribution of CS in 2035 is shown in Figure 13. Under NDS and HUS, the areas with decreasing woodland and decreasing CS are widely distributed in a sporadic point-like manner in regions A and D. The reason for this is that the urbanization rate in the western and northern woodland areas has increased, and the construction land for economic development and township settlements has increased, leading to the encroachment of a large amount of woodland and grassland space, and the encroachment of the economic and social development space on the space for low-carbon ecological services is in an absolute conflict, which results in the space with higher CS becoming smaller.

The changes in CS under LHDS and ESGS are similar, with woodland significantly higher than cultivated land. Under LHDS, the area of CS increase is significantly larger

than the area of CS decrease, and the areas of CS decrease are mainly located in the areas of coastal cultivated land and construction land expansion in B and D. The construction land and cultivated land in the ecological reserves in A and D under LHDS and ESGS are significantly reduced compared with those in NDS and HUS. At the same time, the occupation of space for economic and social development and space for low-carbon ecological services is in a balanced state, with mostly relatively conflicting and non-conflicting interests, and there is a significant increase in the space with higher CS in the region.

4 Discussion

4.1 Impact of LUCC on CS in multi-scenario

This study investigates the impacts of four scenarios of LUCC, namely, NDS, HUS, LHDS, and ESGS on CS under the background of "Dual-Carbon" target and territorial spatial ecological governance in Wenzhou City from the perspectives of absolute and relative conflicts between different economic and social development modes and low-
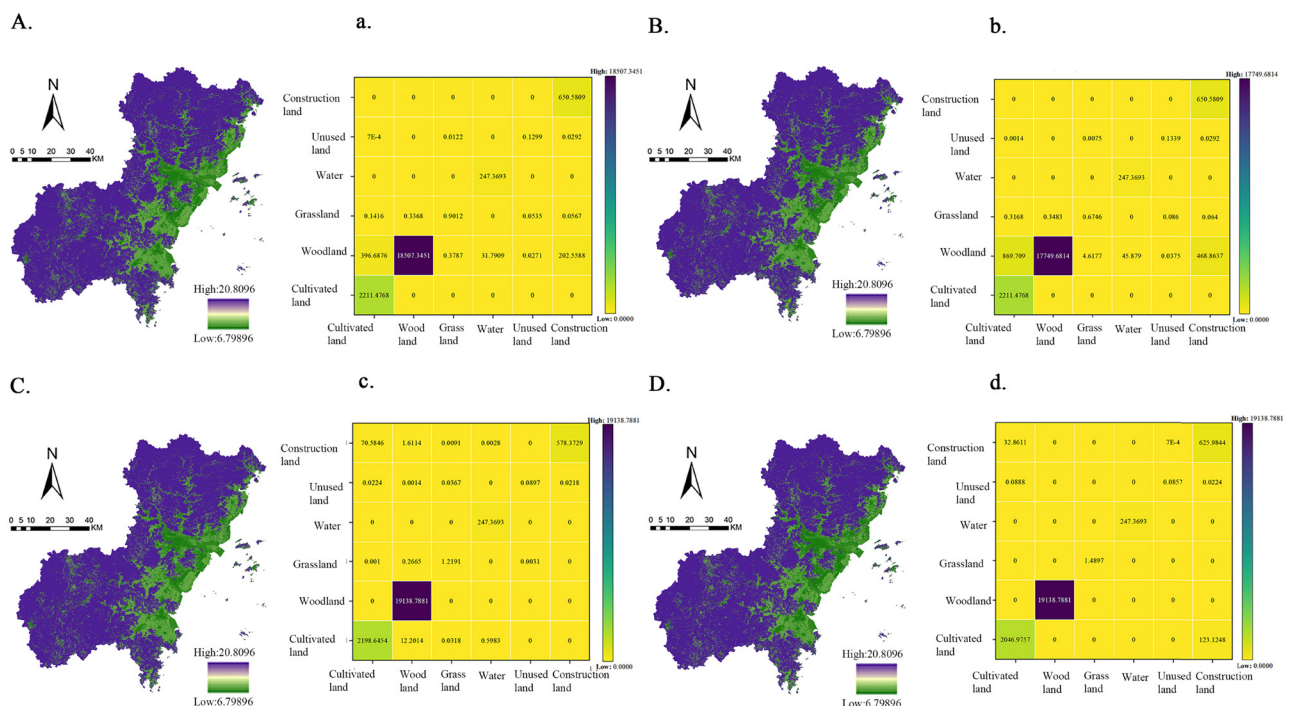

Figure 12: Intensity of change in CS and heat map of transfers. (A) NDS 2035 carbon transfer intensity; (a) NDS 2035 carbon transfer. (B) HUS 2035 carbon transfer intensity; (b) HUS 2035 carbon transfer. (C) LHDS 2035 carbon transfer intensity; (c) LHDS 2035 carbon transfer. (D) ESGS 2035 carbon transfer intensity; (d) ESGS 2035 carbon transfer.
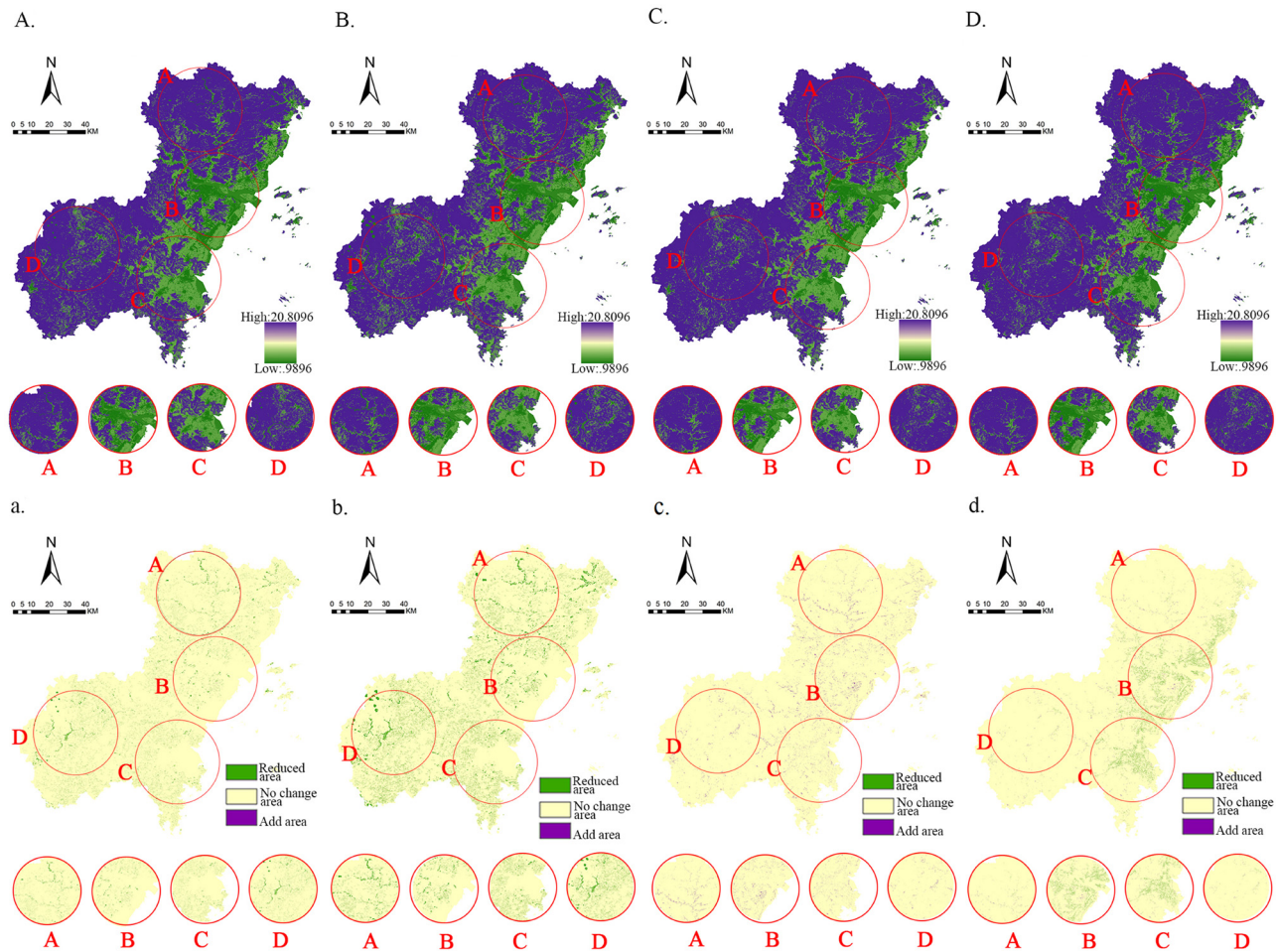
Figure 13: Spatial distribution and dynamic transfer of CS. (A) NDS 2035 CS; (B) HUS 2035 CS; (C) LHDS 2035 CS; (D) ESGS 2035 CS. (a) NDS 2020–2035 carbon transfer region; (b) HUS 2020–2035 carbon transfer region; (c) LHDS 2020–2035 carbon transfer region; (d) ESGS 2020–2035 carbon transfer region.

carbon ecology. There is significant spatial heterogeneity in LUCC and CS changes in the study area from 2020 to 2035. Under the four scenarios, the amount of transfer and spatial change in each type of land varies greatly. The expansion of construction land, woodland, and cultivated land is highly influenced by economic and social development and ecological and environmental protection policies, while the change in cultivated land area is more influenced by both population growth and the red line of cultivated land protection [76,77]. Under the relative and absolute conflict between economic and social development and low-carbon ecology, the large expansion of construction land will inevitably lead to the encroachment of land with higher CS in ecological space, resulting in lower CS, which is consistent with the results of previous researchers [78].

A low-carbon ecological development model and better policy conditions for territorial spatial ecological governance can effectively increase the area of woodland, grassland, and water. Ecological lands such as woodland and grassland are more inclined to expand to more ecologically healthy areas, which can effectively increase CS [79]. Woodland, water, grassland, and unused land decrease to varying degrees under all four scenarios, mainly from the expansion of cultivated land and construction land, with a large decrease in land with higher CS under NDS and HUS, and a small decrease in land with higher CS under LHDS and ESGS.

It was found that policy constraints, moderate reductions in GDP and population growth, and increased investment in ecological protection and management could restore the quality of CS in localized areas, and could effectively contribute to CS growth [80,81]. This is consistent with the results of Wang's previous study on the dynamic assessment of CS in Bortala City in the context of climate change using the SD-PLUS-InVEST model [82]. In-depth analysis of spatial heterogeneity, different development conflict perspectives and changes in land types under development scenarios reveal

the main drivers of CS changes. under LHDS and ESGS, the expansion of woodland and cultivated land is the main driver of CS changes; Under NDS and HUS, the expansion of cultivated land to construction land, forest land to cultivated land and construction land is the main driving factor of CS decline; under LHDS, expansion of grassland, unused land to woodland and Cultivated land is the main driver of CS increase.

4.2 Implications and recommendations

In recent years, with the development of the economy and the increase in the intensity of land development, the ecological environment has been increasingly damaged, the area of grassland and woodland has been reduced, resulting in the decline in CS, and the conflict of interest between economic and social development and low-carbon ecology is obvious. With the development of territorial spatial ecological governance in China, Wenzhou will optimize the LUCC structure, increase CS, achieve the "Dual-Carbon" goal, complete the work of territorial spatial ecological governance, and realize the high-quality, low-carbon ecological and safe development.

From the predicted results of LUCC and CS in 2035, the "Dual-Carbon" target, territorial spatial ecological governance, and ecological security and protection policies have a great impact on the future CS in Wenzhou City. From the results of CS in the past years, it can be seen that the largest carbon reservoir in the type of LUCC in Wenzhou City is Woodland, followed by cultivated land. Therefore, the protection of woodland and cultivated land is decisive for the future CS, while the protection of water and unused land should also be emphasized, which is in line with the current idea of territorial spatial ecological governance and cultivated land protection. The implementation of the above land ecological protection work will directly promote the implementation of land use policies under the LHDS and ESGS development models. However, in the context of the "dual-carbon" goal and the territorial spatial ecological governance, and in order to improve the ecological CS at the same time, it will be difficult to implement the land development model with high energy consumption and expansion under the NDS and HUS. In the future planning, the impacts of the formulation of low carbon strategy, territorial spatial ecological governance, and the delineation of three zones and three lines on CS in the study area need to be studied in depth. Based on the above, we propose the following development strategies.

(1) As a pilot city of low-carbon ecology, Wenzhou should accelerate the pace of low-carbon ecological city construction and strengthen ecological environmental protection. Wenzhou has many hills and mountains, woodland is the main land, and woodland is the land with high CS. Wenzhou has a developed economy and a large population, and there is an absolute conflict of interest between the high growth rate of economic and social development and low-carbon ecology, and the woodland, as an important ecological land, is at the core of the conflict, and the loss of a large area of woodland from 2005 to 2020 has led to a significant decline in CS, so it is necessary to particularly increase the protection of woodland, which is conducive to slowing down the decline in CS, and the formation of a stable pattern of CS [83].

(2) Based on Wenzhou's "Dual-Carbon" goal and territorial spatial ecological governance pattern, the city will strictly implement the national ecological protection red line policy, ensure the protection and governance of important ecological barriers, ecological patches and ecological corridors, improve the management system of important ecological service zones, change the absolute conflict of interests between economic and social development and low-carbon ecology, and enhance the carbon sink function of ecological land [84]. Terrestrial ecosystems are the largest carbon reservoirs, and CS varies greatly among different vegetation types, so improving the vegetation richness of ecological service spaces can effectively build a stable spatial pattern of CS [85].

(3) In response to the spatial heterogeneity of CS under LUCC types in Wenzhou City under different development scenarios, it is essential to adopt refined land use classification in the future under LHDS and ESGS, to improve the classification accuracy of land use types through the combination of high-resolution remotely sensed data and field surveys, to strengthen the ecological governance of the land, and to delineate the precise red line for ecological governance and protection, so as to enhance CS more accurately under different land use types [86]. Under NDS and HUS, a long-term carbon cycle monitoring network should be established to regularly collect and analyze CS data under different land use types in order to understand their dynamic trends, and to promote sustainable land management techniques, such as rational crop rotation, conservation tillage, and increasing the internal vegetation cover of construction land, etc., which can help to improve the soil organic carbon content and reduce carbon emissions. At the same time, the government should encourage urban builders, farmers, and land managers to adopt land use and management methods

that are conducive to carbon sequestration to improve CS and achieve economic and low-carbon co-development by formulating relevant policies and providing low-carbon subsidies, etc. [87,88].

(4) As an important economic and social development pivot in the Yangtze River Delta region and Zhejiang Province, Wenzhou should accelerate the transformation of its economic development model. Wenzhou should promote a new low-carbon and high-quality development model, increase investment in urban green infrastructure and homeland ecological security governance, and increase scientific and technological investment in low-carbon ecological construction, so as to turn the absolute conflict between economic and social development and ecological low-carbon into relative conflict and non-conflict, and improve ecological quality and CS. In promoting economic transformation to improve the quality of the ecological environment of the entire region and harmonizing the conflict between economic and social development and low-carbon ecological construction, the adoption of the LHDS and ESGS development models can jointly promote economic and social development and achieve the goals of "Dual-Carbon" and territorial spatial ecological governance.

4.3 Strengths and limitations

In this study, the spatial and temporal dynamics of LUCC and CS are simulated by coupled SD, PLUS, and InVEST models based on four scenarios of NDS, HUS, LHDS, and ESGS, which provide a new way to simulate the dynamics of the future LUCC under the dual contexts of different socio-economic development and "dual-carbon" target and the target of territorial spatial ecological governance, as well as under the absolute and relative conflict between socio-economic development and low-carbon ecological land use. The coupled SD and PLUS models can simulate the changes in LUCC demand and spatial differentiation patterns from different socioeconomic development scenarios with higher accuracy, and can better simulate LUCC changes and predict LUCC trends. The InVEST model is one of the most commonly used models for assessing CS because it has various advantages, including lower data requirements, less intensive calculations, and higher accuracy of conclusions.

However, the InVEST model oversimplifies the process of the carbon cycle by assuming that carbon sequestration in a region varies regularly and linearly over time [89]. Meanwhile, the InVEST model only considered the carbon density of different land types, ignoring the effects of seasonal changes in vegetation type, vegetation growth on

carbon density [90,91], and did not consider in detail the carbon emission factors of socioeconomic development due to energy use. In future studies, more policies can be considered to limit CS changes under vegetation growth and seasonal changes, and field studies can be combined with prediction models to improve the accuracy of CS prediction. Meanwhile, the SD-PLUS-InVEST model in this study can be combined with the dynamic simulation of energy consumption for urban land use and economic development in future research, which can more accurately simulate the changes in energy consumption during urban expansion and economic development, supplement the influence factors of the socioeconomic subsystems in the SD model, and improve the simulation accuracy, which will in turn improve the prediction accuracy of PLUS and InVEST [92,93].

5 Conclusion

Under the background of "Dual-Carbon" target and territorial spatial ecological governance, we weigh the relative and absolute conflicts of resource utilization between low-carbon development, territorial spatial ecological governance, and economic and social development, and simulate the changes in LUCC and CS under different development scenarios with high accuracy by combining the comprehensive research models of SD model, PLUS model, and InVEST model. The changes in urban LUCC and CS under different development scenarios were simulated with high accuracy to explore the spatial evolution mechanism of LUCC and CS, and to provide effective references for the future to improve CS to achieve the "Dual-Carbon" goal, complete territorial spatial ecological governance and restoration, and build high-quality development. The conclusions of this study are as follows:

(1) During the period from 2005 to 2020, the area of Woodland in Wenzhou City decreased by 407.5 km^2, the area of construction land increased by 295.38 km^2, and the area of cultivated land increased by 169.78 km^2. About 63.5% of the transferred land was transferred as construction land, with cultivated land converted to construction land as the most important type of transfer.

(2) The total amount of CS in Wenzhou City in 2005 and 2020 is 2.28×10^5 kt and 2.22×10^5 kt, respectively, with a total decrease of 6.12×10^3 kt. Among them, the CS of woodland has decreased by 8.76×10^3 kt, which is a decreasing trend year by year, and the total amount of CS has decreased by 2.4%. During the period of high economic and population growth, the demand for

construction land rose sharply, and the transfer of woodland to cultivated land and construction land was the main reason for the decline in CS.

(3) There is spatial heterogeneity in the prediction results of LUCC changes under NDS, HUS, LHDS, and ESGS. The overall change pattern is similar under LHDS and ESGS, with rapid expansion of woodland in the northern and western parts of the study area and a reduction in the large-scale uncontrolled expansion of construction land. Under NDS and HUS, the expansion of construction land within the ecological reserve and natural area in the western and northern parts of the study area is significant and the expansion area is large. Under HUS, the expansion of construction land and cultivated land is rapid to woodland, grassland, and unused land.

(4) From 2020 to 2035, CS decreases under NDS, HUS, and ESGS and increases under LHDS. By 2035, CS under LHDS is the highest (2.23×10^5 kt), followed by ESGS (2.22×10^5 kt), NDS (2.19×10^5 kt), and HUS (2.14×10^5 kt). Overall, CS under NDS and HUS decreased the most, while the decrease in CS under LHDS and ESGS tended to moderate relatively.

(5) Therefore, in order to guarantee the development of Wenzhou's economic and social construction, the realization of the "dual-carbon" goal and the harmonious development of territorial spatial ecological governance, the development path and norms are formulated in conjunction with LHDS and ESGS. Wenzhou needs to refer to the "Carbon Emission Trading Management Measures (Trial)," "China's Country Program for the Implementation of the 2030 Agenda for Sustainable Development," "Paris Agreement," and other legal means to implement carbon tax, subsidies, and eco-efficiency standards and enhance the legitimacy of the ecological CS under the "dual-carbon" goal and the territorial spatial ecological governance.

Author contributions: W.Q. analyzed the data and proposed the idea, X.H. wrote the draft and analyzed the experiments, G.X. was involved in experimental validation and visualization, J. H. was involved in data collection and processing, K.L. constructed the model, and X.J. participated in the construction of model, proposed research ideas, and revised the manuscript.

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