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# Impact of Land Use Change on the Spatiotemporal Evolution of Ecosystem Services in Tropical Islands: A Case Study of Hainan Island, China

**Mingjia Yang, Jiabao Luo, Lirong Zhu * and Peng Lu**

College of International Tourism and Public Administration, Hainan University, Haikou 570228, China; ming-jia@hainanu.edu.cn (M.Y.); jiabaoloana@hainanu.edu.cn (J.L.); phoenix03010490@hainanu.edu.cn (P.L.)
* Correspondence: zhulirong@hainanu.edu.cn

**Abstract:** Land use change drives the ecosystem service value (ESV) to some extent. Investigating the impact of land use distribution patterns under different scenarios on ESV is crucial for optimizing land spatial utilization in tropical island regions. This study employs a combination of multi-objective programming (MOP) and the patch-generating land use simulation (PLUS) model to simulate and predict the spatial distribution of land use in Hainan Island for the year 2030 under three scenarios: natural development, ecological protection priority, and tourism development priority. The ESV for these scenarios is then assessed to provide insights into the sustainable economic, social, and ecological development of tropical island regions. The results indicate the following: (1) Between 2010 and 2020, forest land was the dominant land use type in Hainan Island, accounting for 63% of the total area, followed by arable land. Land use changes were characterized mainly by increases in built-up land and grass land, which increased by 497.13 $km^2$ and 18.87 $km^2$, respectively, with decreases in other types. The largest area of land conversion was from forest land, which was predominantly converted to built-up land and arable land, measuring 259.97 $km^2$ and 174.49 $km^2$, respectively. (2) The PLUS model was used to simulate land use changes in Hainan Island, achieving a Kappa coefficient of 0.88 and an overall accuracy of 0.94, indicating a high consistency between the simulation results and actual data. (3) The ecological protection priority scenario yielded the highest ecosystem service values (CNY 72.052 billion), while the values under other scenarios decreased compared to 2020. The natural development scenario saw a decrease of CNY 1.821 billion, and the tourism development priority scenario saw a decrease of CNY 0.595 billion. Spatially, the ecological protection priority scenario also showed the greatest increase in areas with high ecosystem service values, particularly due to an increase in forest land area, which contributed to an overall increase in the ecosystem service values of the study area. This study offers a scientific foundation and a decision-making reference for selecting priority scenarios for tourism development on Hainan Island, aimed at supporting its future sustainable development. It emphasizes the protection of forest resources, the promotion of greening initiatives, and the achievement of a balance between ecological preservation and tourism activities.

**Keywords:** multi-scenario simulation; land use change; ecosystem service value; PLUS model; spatiotemporal change

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## 1. Introduction

Ecosystem service refer to the benefits that humans derive directly or indirectly from ecosystems, including provisioning services, regulating services, supporting services, and cultural services [1]. Ecosystem service value (ESV) is the primary metric for evaluating these services [2]. Land use/land cover (LULC) change is a significant driver of ESV, greatly impacting its value [3]. The United Nations Millennium Ecosystem Assessment indicates that human activities are depleting the Earth's natural capital and exerting substantial pressure on the environment, with 60% of global ecosystem services in decline [4]. To

quantitatively assess ESV, an increasing number of scholars have initiated research efforts. Costanza et al. were pioneers in proposing a method for estimating ESV, creating a global table of ecosystem service value coefficients, which has become a focal point for quantitative evaluation among global scholars [1]. Building on Costanza's research, Chinese scholar Xie et al. developed an ecosystem service value coefficient table tailored to China's development needs [5]. As research on this topic developed, more scholars began examining ESV changes from various perspectives, including different land use types [6,7], spatiotemporal scales [8,9], and watersheds [10,11]. They studied past and present regional LULC changes to estimate ESV variations and explored influencing factors. Recently, there has been a growing trend among scholars to use multi-scenario simulations to model future land use changes and assess ESV, thereby informing future land use planning.

As land use change simulation becomes a prominent research focus in contemporary academia, various models have been developed for this purpose. These include the CLUE-S model [12], the SD model [13], the CA–Markov chain model [14], the FLUS model [15], and the Random Forest–CA model [16]. The latest model, the patch-generating land use simulation (PLUS) model [17], offers a higher simulation accuracy. It can precisely simulate the nonlinear relationships underlying land use changes, thereby enabling more accurate assessments of the impacts of land use under different policy scenarios on potential ecosystem service functions. When coupled with the multi-objective optimization (MOP) algorithm, the simulation results from PLUS can better support planning policies that aim to achieve sustainable development.

As a tropical island, Hainan Island possesses an independent and complete ecological system. However, with the introduction and development of policies such as the International Tourism Island and Hainan Free Trade Port, significant changes in land use have occurred, exacerbating conflicts with the ecosystem. Therefore, exploring the relationship between land use and ESV, as well as optimizing land use, are not only crucial for improving Hainan Island's socioeconomic development and ecological stability, but also provide valuable insights for the sustainable development of other island regions, especially tropical islands.

To date, research on the impact of land use on ESV in tropical islands has primarily focused on past and present spatiotemporal changes, with relatively few studies on future land use trends. In this context, this paper pioneers the coupling of the MOP and PLUS model to simulate three scenarios for Hainan Island: natural development, tourism development priority, and ecological protection priority. These scenarios are used to predict changes in land use and ESV characteristics under each scenario. The specific objectives are as follows: (1) To investigate the spatiotemporal changes in land use and ESV in Hainan Island from 2010 to 2020; (2) to predict the land use distribution in Hainan Island for 2030 under three different scenarios using the PLUS model; (3) to analyze the impact of changes in different land use types on ESV.

This study aims to explore methods to enhance ESV in Hainan Island, providing a scientific theoretical basis for the high-quality development of tourism and sustainable ecological development. Additionally, it seeks to identify future land use development paths suitable for Hainan Island, formulate reasonable land use development plans, and offer scientific foundations for optimizing land resource allocation and improving the ecological environment.

## 2. Materials and Methods

### *2.1. Overview of the Study Area*

Hainan Island, situated at coordinates 18.80°–20.10° N and 108.37°–111.03° E, lies in the northwestern part of the South China Sea (Figure 1). It is separated from the Leizhou Peninsula to its north by the Qiongzhou Strait. The island includes 18 cities and counties and spans an area of roughly 34,000 square kilometers, making it China's second largest island. The climate is typically tropical monsoon marine, with consistently high temperatures and significant rainfall. Summers are long, and winters are nonexistent, with

an annual average temperature between 22.5 °C and 25.6 °C and yearly rainfall ranging from 1000 to 2500 mm. Hainan's terrain is primarily mountainous and hilly, featuring a central highland area that tapers off towards the edges. Prominent peaks, such as Wuzhi Mountain and Yingge Ridge, constitute the island's elevated core, which decreases in height as it extends outward. Land use is predominantly forests and agricultural land, with forests covering 62.1% of the area. Since Hainan's designation as an International Tourism Island in 2009 and the creation of the Hainan Free Trade Port in 2018, the island's economy has rapidly developed. This economic growth has caused a swift expansion of built-up land and substantial shifts in land use patterns, significantly affecting the ecosystem's structure and functionality on Hainan Island.

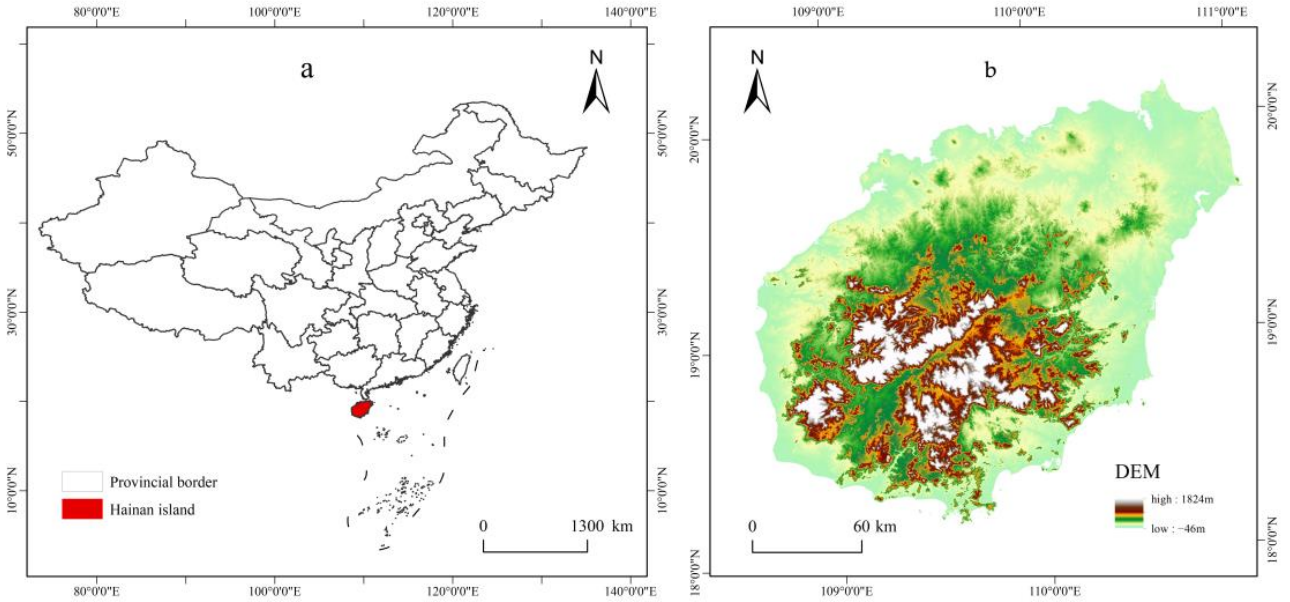



**Figure 1.** Study area in Hainan Island: (**a**) geographical location of Hainan Island; (**b**) topography of Hainan Island.

### *2.2. Data Sources*

The data underwent a series of preprocessing steps using ArcGIS 10.7, including projection transformations, clipping, and resampling. All raster data were standardized to a resolution of 30 m × 30 m. Detailed information about the data is presented in Table 1.

**Table 1.** Data information.

| Data Type | Data Name | Spatial Resolution | Data Sources |
|---|---|---|---|
| Land use | — | 30 m | http://www.resdc.cn, accessed on 10 July 2023 |
| Natural environment | DEM | 30 m | https://www.gscloud.cn, accessed on 10 July 2023 |
| | Slope | 30 m | Calculated using DEM using ArcGIS 10.7 |
| | Temperature | 1000 m | http://www.Resdc.cn, accessed on 10 July 2023 |
| | Precipitation | 1000 m | http://www.Resdc.cn, accessed on 10 July 2023 |
| | Soil type | 1000 m | http://www.Resdc.cn, accessed on 10 July 2023 |
| Social economy | GDP | 1000 m | http://www.Resdc.cn, accessed on 11 July 2023 |
| | POP | 1000 m | http://www.Resdc.cn, accessed on 11 July 2023 |
| Accessibility | Road, rail, and river vector data | — | http://www.webmap.cn, accessed on 11 July 2023 |

**Table 1.** *Cont.*

| Data Type | Data Name | Spatial Resolution | Data Sources |
|---|---|---|---|
| Tourism | Tourist attraction | — | Amap |
| | Hotel | — | Amap |
| | Restaurant | — | Amap |
| Statistical data | Grain production per-unit area | — | Hainan Province Statistical Yearbook<br>China Agricultural Statistical Yearbook |
| | Crop planting area | — | Hainan Province Statistical Yearbook<br>China Agricultural Statistical Yearbook |

### *2.3. Multi-Scenario Prediction Based on the MOP Model*

The MOP model is a crucial tool for optimizing the quantity and structure of land use. It provides scientific predictions for achieving optimal decisions based on a series of objective laws or subjective constraint data [18]. This study integrates the overall planning policies relevant to the study area and the rules governing land use development (Appendix A) to set up three scenarios to simulate land use types in 2030.

(1) Natural Development Scenario (ND): Land use changes follow the evolution trend of the study area from 2010 to 2020. The area of land use types in 2030 is estimated based on the Markov chain.

(2) Ecological Protection Priority Scenario (EP): This scenario ensures the maximization of ecological benefits, measured by the ecosystem service value. The ecological benefit estimation function is set as follows:

$$F_1(x) = \sum_{i=1}^{n} e_i x_i \quad (1)$$

where $F_1(x)$ is the total value of ecosystem services, $x_i$ represents the area of different land use types ($x_{1-6}$ stands for arable land, forest land, grass land, water land, built-up land, and unused land), and $e_i$ represents the ecosystem service value of each land use type. Specific coefficients are detailed in the Appendix A section.

(3) Tourism Development Priority Scenario (TD): Tourism is a sustainable industry based on resources and the environment, carried out by people as a socio-economic activity [19]. Thus, this scenario is set to maximize both economic development and ecological protection benefits. The tourism benefit estimation functions are as follows:

$$\max\{F_1(X), F_2(X)\} = \alpha F_1(X) + \beta F_2(X) \quad (2)$$

$$F_2(x) = \sum_{i=1}^{n} t_i x_i \quad (3)$$

where $F_2(x)$ is the total economic benefit, $x_i$ represents the area of different land use types, and $t_i$ represents the economic benefit of each land use type. Agricultural, forestry, animal husbandry, and fishery output values represent the economic benefits of arable land, forest land, grass land, and water land, respectively. The GDP of the secondary and tertiary industries represents the economic benefits of built-up land. Based on historical data from the "Hainan Statistical Yearbook" from 2010 to 2020, the GM(1,1) model is used to predict the economic benefits for 2030. Specific coefficients are detailed in Table 2. In Equation (2), $\alpha = 0.6$, $\beta = 0.4$.

**Table 2.** Economic and ecological efficiency coefficient corresponding to each land use type ($10^7$ yuan/km$^2$).

| Efficiency Coefficient | Arable Land | Forest Land | Grass Land | Water Land | Built-up Land | Unused Land |
|---|---|---|---|---|---|---|
| Economic efficiency coefficient | 1.85 | 0.07 | 4.05 | 5.53 | 46.88 | 0 |
| Ecological efficiency coefficient | 6.00 | 50.86 | 2.02 | 13.13 | 0 | 0.01 |

### *2.4. Optimization Simulation of Land Use Spatial Distribution Based on the PLUS Model*

The PLUS model is used for simulating land use change. It utilizes land use data from two periods and employs a random forest algorithm along with a cellular automata (CA) model to explore the expansion and driving factors of different land use types, determining the development probability for each type. The PLUS model improves the understanding of the relationships underlying land use and land use changes, enhancing the simulation of patch growth. It can reveal potential driving factors and their varying contributions to changes, facilitating sustainable land use when combined with multi-objective optimization [17].

This study uses land use data from 2010 to 2020 as a basis. Following previous research [20–22], 16 driving factors were selected: elevation, slope, temperature, precipitation, soil type, GDP, population, distance to highways, distance to major roads (national, provincial, and county roads), distance to railways, distance to tourist attractions, distance to hotels, distance to restaurants, and distance to rivers. These factors were used to assess the trends and drivers of land use change in Hainan Island from 2010 to 2020 (Figure 2) and to predict the spatial layout of land use in 2030 under different scenarios. To ensure the reliability of the simulation, the PLUS model must first simulate the 2020 land use data based on the 2010 data. These simulated data are then compared with the actual 2020 land use data for validation.

### *2.5. Evaluation of ESV*

The ESV for each land use type is calculated based on the per-unit area ESV assessment method proposed by Xie et al. [23,24]. This study uses the ESV coefficient table for Hainan Province revised by Lei Jinrui et al. [25], along with the average grain price during the study period in Hainan Island, which is 2.98 CNY/kg. Consequently, the economic value of the ESV per-unit area in Hainan Island is determined to be 152,846.72 CNY/km$^2$. The ESV coefficients for Hainan Island are shown in Table 3. The formula for calculating the ESV is as follows:

$$\mathrm{ESV} = \sum_{i=1}^{n} A_i \times VC_i \quad (4)$$

where ESV is the ecosystem service value of the study area, i represents the land use type, $A_i$ is the area of the i-th land use type in the study area, $VC_i$ is the per-unit area ESV of the i-th land use type.

**Table 3.** Hainan Island ecosystem service value coefficient table/(CNY hm$^{-2}$a$^{-1}$).

| Primary Functions | Secondary Functions | ESV Coefficient | | | | | |
|---|---|---|---|---|---|---|---|
| | | Arable Land | Forest Land | Grass Land | Water Land | Unused Land | Total |
| Provisioning services | Food production | 1197.93 | 302.39 | 337.28 | 767.61 | 11.63 | 2616.84 |
| | Raw material supply | 2663.36 | 697.82 | 500.11 | 430.32 | 34.89 | 4326.51 |
| | Water resource supply | −1058.37 | 360.54 | 279.13 | 6326.94 | 23.26 | 5931.50 |
| Regulating services | Gas regulation | 953.69 | 2302.82 | 1756.19 | 1558.47 | 127.93 | 6699.11 |
| | Climate regulation | 500.11 | 6885.20 | 4652.16 | 3430.97 | 116.30 | 15,584.74 |
| | Purify the environment | 139.56 | 2012.06 | 1535.21 | 5326.72 | 360.54 | 9374.10 |
| | Hydrological regulation | 1314.24 | 4500.96 | 3407.71 | 73,550.65 | 244.24 | 83,017.80 |

**Table 3.** *Cont.*

| Primary Functions | Secondary Functions | ESV Coefficient | | | | | |
|---|---|---|---|---|---|---|---|
| | | Arable Land | Forest Land | Grass Land | Water Land | Unused Land | Total |
| Supporting services | Soil retention | 779.24 | 2802.93 | 2139.99 | 1884.12 | 151.20 | 7757.48 |
| | Maintaining nutrient cycles | 162.83 | 209.35 | 162.83 | 151.20 | 11.63 | 697.82 |
| | Biodiversity | 186.09 | 2547.06 | 1942.28 | 6059.44 | 139.56 | 10,874.42 |
| Cultural services | Esthetic Landscape | 81.41 | 1116.52 | 860.65 | 3849.66 | 58.15 | 5966.40 |
| Total | | 6920.09 | 23,737.65 | 17,573.53 | 103,336.10 | 1279.34 | — |

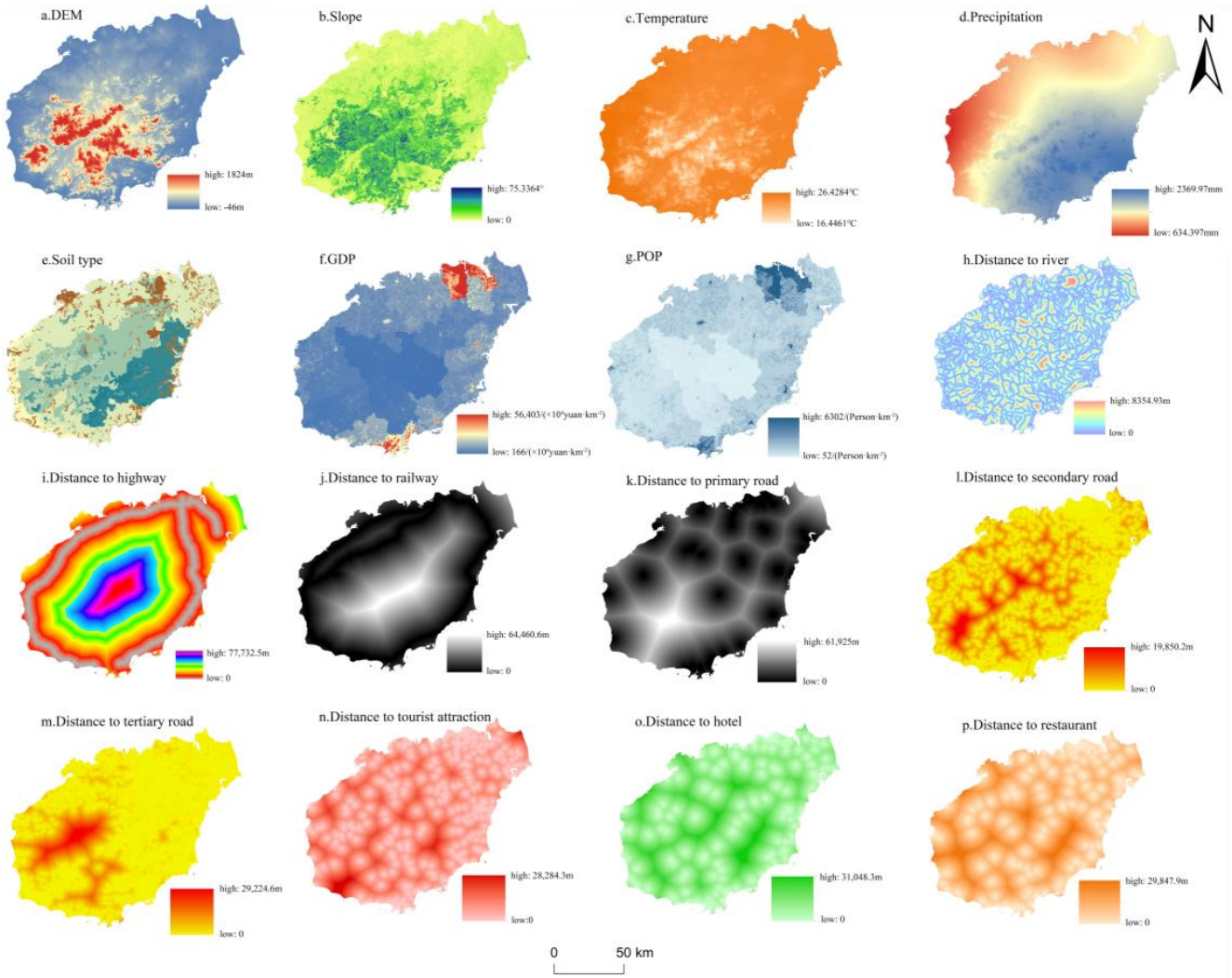



**Figure 2.** Various driver factors in the study area: (**a**) DEM, (**b**) slope, (**c**) temperature, (**d**) precipitation, (**e**) soil type, (**f**) GDP, (**g**) POP, (**h**) distance to river, (**i**) distance to highway, (**j**) distance to railway, (**k**) distance to primary road, (**l**) distance to secondary road, (**m**) distance to tertiary road, (**n**) distance to tourist attraction, (**o**) distance to hotel, and (**p**) distance to restaurant.

## 3. Results

### *3.1. Dynamic Characteristics of Land Use Changes*

#### 3.1.1. Changes in Land Use Type Area

Analyzing the land use area data from 2010 to 2020 (Table 4), it is evident that Hainan Island's landscape is primarily dominated by forest land and arable land. Forests cover roughly 63% of the island, while arable land makes up about 26%. Over the past decade, grass land and built-up land are the only land types to have expanded. Built-up areas experienced the most notable growth, increasing by 497.13 $km^2$, while grass lands grew by 18.87 $km^2$. On the other hand, forest land and arable land significantly decreased, by 297.85 $km^2$ and 204.98 $km^2$, respectively. Other land types showed minimal changes. When considering the rates of change over the decade, built-up land had the highest increase (55.35%), and water land experienced the most minor change, decreasing by −0.71%.

**Table 4.** Changes in land use types in Hainan Island from 2010 to 2020.

| Land Use Types | | Arable Land | Forest Land | Grass Land | Water Land | Built-Up Land | Unused Land |
|---|---|---|---|---|---|---|---|
| 2010 | Area ($km^2$) | 8876.33 | 21,724.03 | 1133.28 | 1280.02 | 898.24 | 96.76 |
| | Proportion | 26.10% | 63.88% | 3.33% | 3.76% | 2.64% | 0.28% |
| 2020 | Area ($km^2$) | 8671.36 | 21,426.18 | 1152.15 | 1270.94 | 1395.37 | 88.86 |
| | Proportion | 25.50% | 63.01% | 3.39% | 3.74% | 4.10% | 0.26% |
| Area change from 2010 to 2020 ($km^2$) | | −204.98 | −297.85 | 18.87 | −9.08 | 497.13 | −7.90 |
| Area change rate from 2010 to 2020 | | −2.31% | −1.37% | 1.67% | −0.71% | 55.35% | −8.16% |

#### 3.1.2. Analysis of Land Use Type Transitions

Figure 3 illustrates the land use type transitions in Hainan Island from 2010 to 2020. The largest area transitioned from forest land, which primarily converted to built-up land (259.97 $km^2$), arable land (174.49 $km^2$), water land (44.44 $km^2$), and grass land (41.72 $km^2$). Arable land followed, with conversions to built-up land (247.90 $km^2$), forest land (160.53 $km^2$), water land (34.61 $km^2$), and grass land (10.98 $km^2$). Water land saw significant transitions to arable land (41.85 $km^2$), forest land (23.87 $km^2$), and built-up land (22.72 $km^2$). The areas transitioning out of unused land and built-up land were relatively small. In terms of area transfer into different land use types, built-up land had the largest increase, mainly from forest land and arable land, with transition areas of 259.97 $km^2$ and 247.90 $km^2$, respectively. Arable land followed, with significant inputs from forest land (174.49 $km^2$) and water land (41.86 $km^2$). Forest land also increased, primarily from arable land (160.53 $km^2$) and grass land (27.80 $km^2$). Grass land and unused land experienced smaller transfer areas.

Figure 4 illustrates the changes in land use types on Hainan Island between 2010 and 2020. These changes are most evident in coastal regions and urban centers across various counties and cities. Coastal areas, popular for tourism, underwent significant transformations due to the construction of tourism-related infrastructure, leading to the conversion of arable, forest, and water lands into built-up land. In urban centers, the expansion of built-up areas primarily reduced arable and forest lands. In the northern part of Wenchang, large portions of built-up land were reverted to arable and forest land. Meanwhile, in Wanning, Ledong, and Dongfang, substantial areas of water land were changed into arable and forest land. Around Niuluoling Reservoir, forest, arable, and grass lands were mainly transformed into water land.

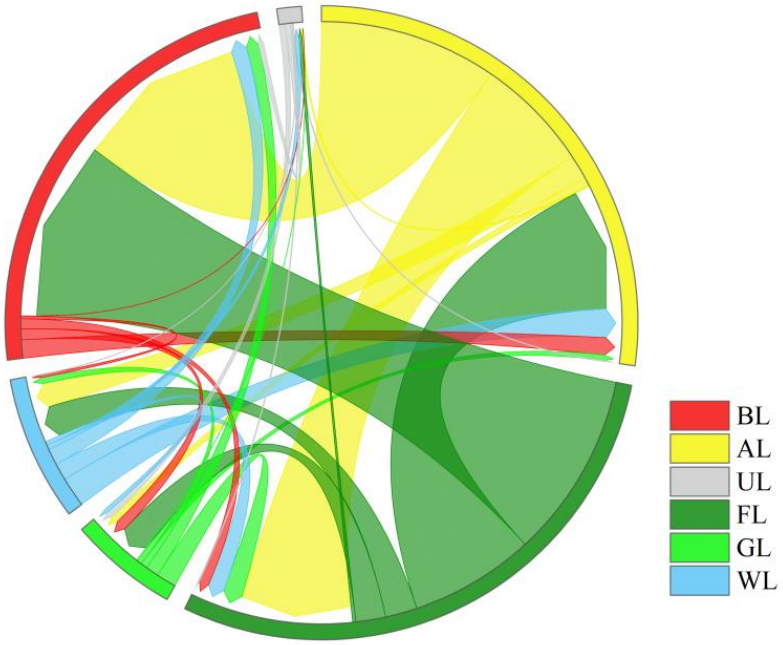



**Figure 3.** Changes in the quantity of land use type transfer in Hainan Island from 2010 to 2020.

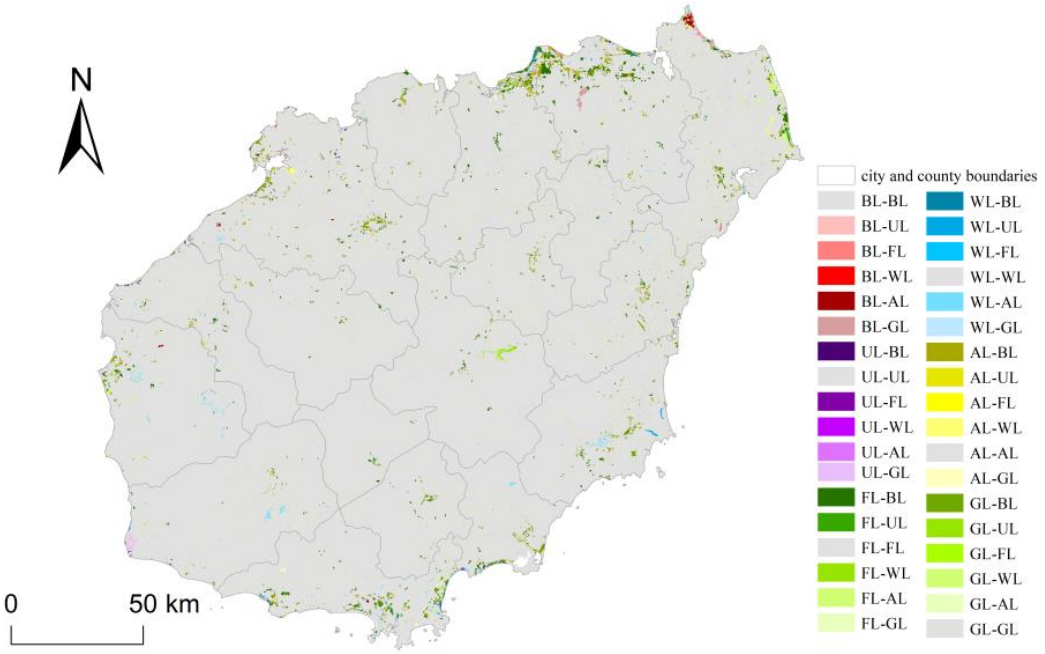



**Figure 4.** Spatial distribution of land use type transfer in Hainan Island from 2010 to 2020.

### *3.2. Analysis of Drivers of Land Use Change*

Using land use data from 2010 to 2020, the PLUS model was employed to analyze the factors driving land expansion. The contribution of 16 different driving factors to the changes in various land types was determined, as shown in Figure 5.

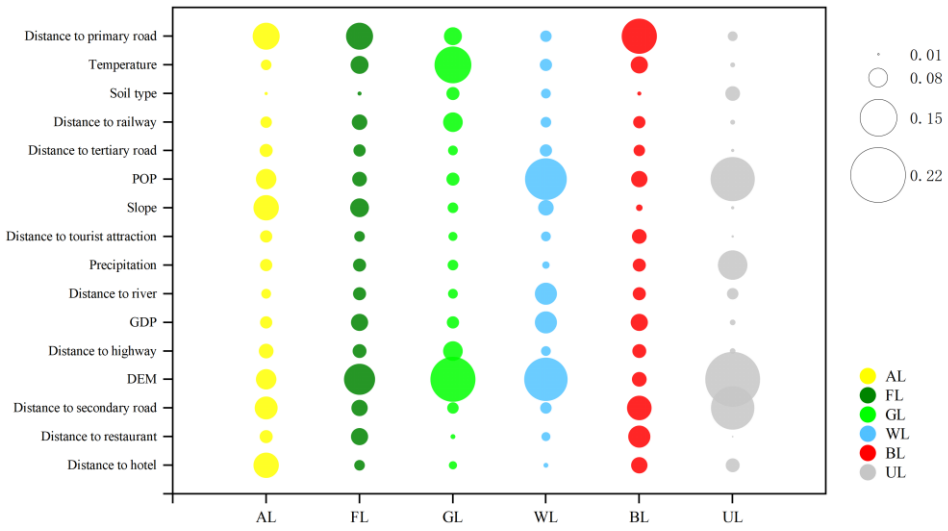



**Figure 5.** Contribution of different driving factors to land use change.

Changes in arable land are mainly related to the distribution of roads and hotels, slope, and population. During the process of urbanization and tourism development, arable land is often encroached upon for urban expansion and the construction of tourism infrastructure. Arable land tends to favor flat terrain, making slope a particularly significant factor. Population changes have a dual impact on arable land; an increase in population can lead to higher demand for arable land, thereby increasing its area, but it can also lead to greater demand for housing and infrastructure, which encroaches on arable land. Changes in forest land are closely linked to the DEM (digital elevation model), road distribution, slope, and temperature. The undulating terrain affects the distribution of forest land, while slope and temperature influence the distribution and growth of vegetation types. Road construction leads to deforestation, reducing forest area and causing forest fragmentation. Grass land changes are associated with the DEM, temperature, and road distribution. The contribution rate of the DEM to grass land expansion is 0.18, and the contribution of temperature is 0.14. Both the DEM and temperature affect the distribution and growth of grass land, while road construction impacts grass land expansion. Water body changes are related to the DEM, population, GDP, and river distribution. Population growth and economic development increase the exploitation and utilization of water resources, thereby affecting changes in water land. The DEM also influences the distribution of water land. The expansion of built-up land is significantly correlated with the distribution of roads at all levels, hotel distribution, and GDP, as well as population. Their contribution rates are all above 0.06, with the contribution rate of primary road distribution reaching 0.14. Road construction drives changes in built-up land use by promoting the development and utilization of surrounding areas. The distribution of hotels and GDP indicates that tourism and economic development promote the expansion of built-up land. Population growth increases the demand for built-up land, particularly for residential and commercial uses. Furthermore, DEM has the greatest impact on unused land, reaching a contribution rate of 0.22. Therefore, DEM, temperature, population, and GDP are important factors influencing land use change, while infrastructure development, such as roads and hotels, serves as a significant driving force for land development.

### *3.3. Land Use Structure Prediction under Different Scenarios*

Using the PLUS model, we simulated and forecasted land use areas under various scenarios, as presented in Table 5. In the natural development scenario, the land use change follows the pattern observed from 2010 to 2020, with a sharp decrease in arable and forest land, a slight reduction in water areas, and a considerable increase in built-up land. Compared to 2020, arable land shrunk by 182.84 $km^2$, forest land by 285.23 $km^2$, and water

land by 5.78 km$^2$, while built-up areas expanded by 455.32 km$^2$. Grass land shows a slow growth trend. In the ecological protection priority scenario, ecological red lines and policies restricting the growth of built-up land result in an increase in forested areas. Although the expansion rate of built-up land is slower than in the natural development scenario, it continues to grow. Compared to 2020, forest land grows by 173.17 km$^2$, while grass land declines by 115.21 km$^2$. Under the tourism development priority scenario, expanding tourism infrastructure leads to a substantial rise in built-up land. Compared to 2020, arable land, forest land, and grass land decreased by 182.84 km$^2$, 111.68 km$^2$, and 115.21 km$^2$, respectively. The proportion of unused land on Hainan Island is small and decreases in all three scenarios compared to 2020.

**Table 5.** Prediction of land use structure in Hainan Island under different scenarios from 2020 to 2030.

| Land Use Types | Land Use Status in 2020 | | Natural Development | | Ecological Protection Priority | | Tourism Development Priority | |
|---|---|---|---|---|---|---|---|---|
| | Area (km$^2$) | Proportion | Area (km$^2$) | Proportion | Area (km$^2$) | Proportion | Area (km$^2$) | Proportion |
| Arable land | 8671.36 | 25.50% | 8488.52 | 24.96% | 8488.52 | 24.96% | 8488.52 | 24.96% |
| Forest land | 21,426.18 | 63.01% | 21,140.95 | 62.17% | 21,599.35 | 63.52% | 21,314.5 | 62.68% |
| Grass land | 1152.15 | 3.39% | 1176.81 | 3.46% | 1036.94 | 3.05% | 1036.94 | 3.05% |
| Water land | 1270.94 | 3.74% | 1265.16 | 3.72% | 1265.16 | 3.72% | 1270.94 | 3.74% |
| Built-up land | 1395.37 | 4.10% | 1850.69 | 5.44% | 1534.91 | 4.51% | 1813.98 | 5.33% |
| Unused land | 88.86 | 0.26% | 82.72 | 0.24% | 79.97 | 0.24% | 79.97 | 0.24% |
| Total | 34,004.85 | 100.00% | 34,004.85 | 100.00% | 34,004.85 | 100.00% | 34,004.85 | 100.00% |

### *3.4. Spatial Simulation of Land Use Based on the PLUS Model*

To validate the model, the simulated land use results for 2020 were compared with the actual 2020 data using the PLUS model (Figure 6). The simulation achieved a Kappa coefficient of 0.88 and an overall accuracy of 0.94. A Kappa coefficient closer to 1 indicates a higher consistency between the simulation results and the actual data. A Kappa value greater than 0.8 signifies a high level of model reliability [26]. This high reliability suggests that the model can effectively simulate the spatial dynamic changes in land use on Hainan Island.

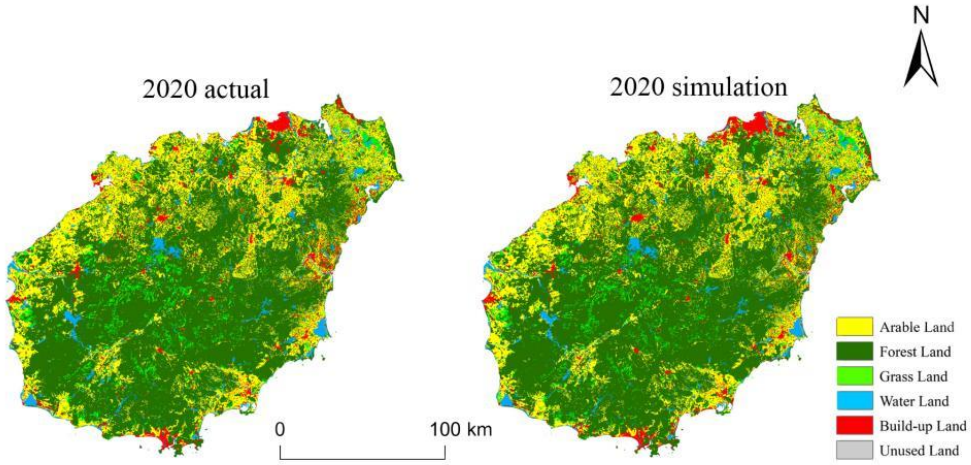



**Figure 6.** Comparison of actual land use status and simulation in Hainan Island in 2020.

Using the 2020 land use data, we input the land use predictions for three future scenarios into the PLUS model to simulate the spatial distribution of land use on Hainan Island for 2030 (Figure 7). The results indicate that while the overall spatial distribution of land use on Hainan Island remains broadly similar across different scenarios, there are

significant changes in specific areas. Compared to 2020, the expansion of built-up land by 2030 is particularly noticeable, predominantly occurring in coastal regions. In the natural development scenario, the expansion of built-up land is pronounced in Haikou, Sanya, and the eastern coastal cities and counties. This expansion significantly encroaches on arable land due to the increasing demand for built-up land driven by urbanization and economic development. Arable land, typically found in flat areas, is relatively easy and cost-effective to develop. The central region sees an increase in grass land area. In the ecological protection priority scenario, the rate of built-up land expansion in coastal areas is slower than in the natural development scenario. There is a significant expansion of forest land, mainly in the central region and eastern coastal areas, with reduced encroachment from built-up land. This indicates that policy constraints effectively protect the environment. Under the tourism development priority scenario, a rapid expansion of built-up land is observed in areas with well-developed tourism industries. The substantial increase in tourism-related land use encroaches on forest and grass land areas. The expansion of built-up land is particularly prominent in Wanning, driven by the development of hotels, restaurants, and tourist attractions. For instance, the artificial land reclamation and natural surfing environment at Sun and Moon Bay have spurred the development of the entire bay's tourism industry, enhancing tourism infrastructure such as dining and accommodation and leading to a significant expansion of built-up land.

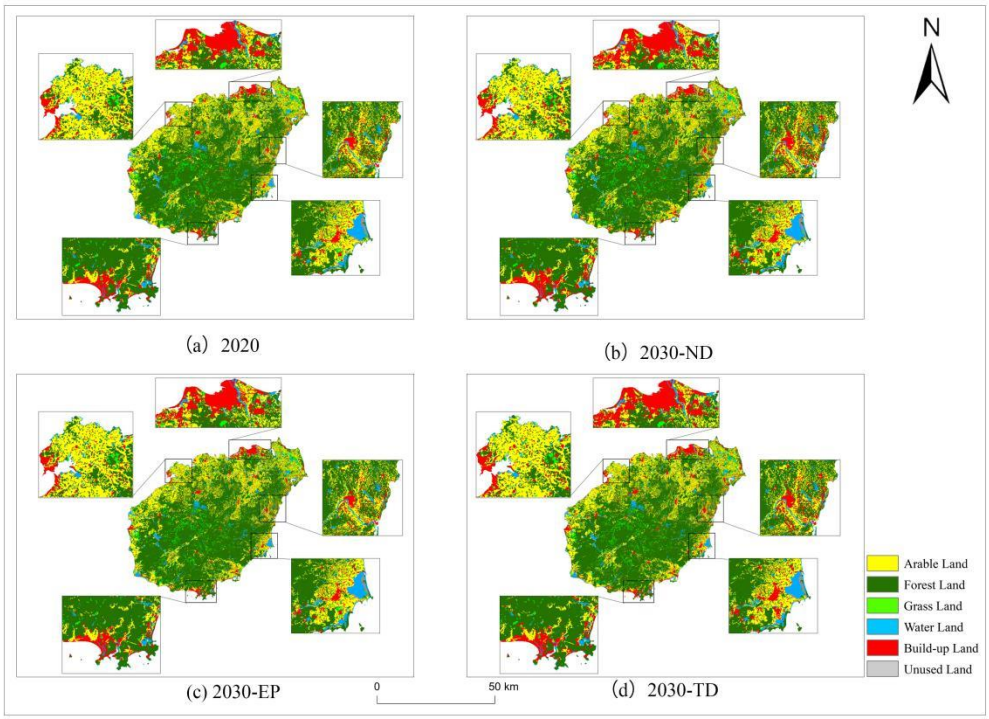



**Figure 7.** Simulation of land use change in Hainan Island under different scenarios in 2030.

Overall, the central region of Hainan Island, constrained by ecological protection red lines, shows relatively stable changes in land use types across all scenarios, dominated by forest land, grass land, and arable land. Built-up land expansion primarily occurs outward from existing urban areas. In coastal regions, built-up land expansion is very prominent in all scenarios, especially in the natural development and tourism development priority scenarios. The eastern coastal areas experience more significant built-up land expansion compared to the west. Haikou, as the provincial capital with a larger population and more developed tourism industry, shows the most pronounced built-up land expansion among all cities and counties. In the west, built-up land expansion is mainly concentrated in Dongfang and Danzhou cities.

### *3.5. Evaluation of Ecosystem Service Value under Different Scenarios*

We utilized the simulated spatial distribution of land use to assess the ESV in various scenarios (Table 6). A 5 km × 5 km grid was used to compare the ESV for 2020 with the forecasted ESV for three different future scenarios (Figure 8).

**Table 6.** ESV of each land use type in 2020 and 2030 under different scenarios (CNY $10^6$).

| Land Use Types | 2020 | 2030 | | |
|---|---|---|---|---|
| | | Natural Development | Ecological Protection Priority | Tourism Development Priority |
| Arable land | 6000.65 | 5874.13 | 5874.13 | 5874.13 |
| Forest land | 50,860.71 | 50,183.64 | 51,271.77 | 50,595.61 |
| Grass land | 2024.73 | 2068.07 | 1822.27 | 1822.27 |
| Water land | 13,133.41 | 13,073.67 | 13,073.67 | 13,133.40 |
| Unused land | 11.37 | 10.58 | 10.23 | 10.23 |
| Total | 72,030.88 | 71,210.09 | 72,052.07 | 71,435.64 |

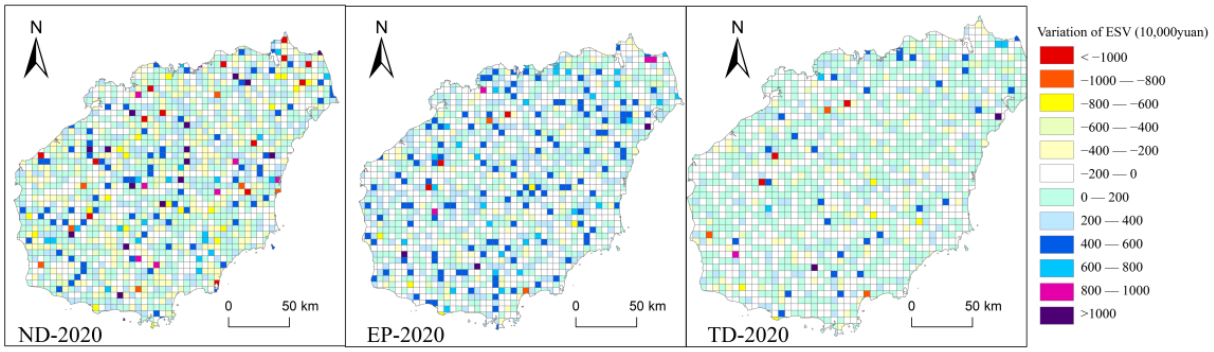



**Figure 8.** Changes in ecosystem service value under different scenarios compared with 2020.

In the natural development scenario, the ESV of Hainan Island is projected to decline from CNY 72.031 billion in 2020 to CNY 71.210 billion, representing a total decrease of CNY 1.821 billion. This reduction is mainly driven by the considerable increase in built-up land and the corresponding decrease in forest and water areas, which results in a lower ESV. In contrast, the ecological protection priority scenario predicts an ESV of CNY 72.052 billion, reflecting an increase of CNY 22 million from 2020. This increase is primarily due to restrictions on the outward expansion of built-up land and an increase in forest areas, enhancing the overall ESV. Under the tourism development priority scenario, the ESV is anticipated to be CNY 71.436 billion, a decrease of CNY 595 million from 2020. While this value surpasses the natural development scenario, it falls short of the ecological protection priority scenario. This scenario seeks a balance between economic growth and environmental preservation, limiting the conversion of forest land to other types more effectively than the natural development scenario. Moreover, the rate of built-up land expansion is slower than in the natural development scenario, resulting in a higher ESV than the natural development scenario.

As shown in Figure 8, under the natural development scenario, the changes in ESV are quite noticeable. The areas with significant deterioration in ESV are primarily concentrated in coastal cities and counties, while regions with improvements are mostly located in the central areas, forming a pattern of higher ESV in the center and lower ESV around the periphery. In contrast, the ecological protection priority scenario shows significant differences from the natural development scenario. More areas across the island experience improvements in ESV, with enhancements spread throughout the island. In the tourism development priority scenario, areas with substantial increases in ESV are mainly found in Haikou and Wenchang, while regions with significant decreases are concentrated

in Lingao and Baisha counties. Most other cities and counties exhibit relatively stable ESV fluctuations.

### *3.6. Impact of Different Land Use Type Changes on Ecosystem Service Value*

As illustrated in Figure 9, the ecosystem ESV of forest land on Hainan Island far exceeds that of other land types, significantly influencing the total ESV. This is mainly due to the extensive forest coverage, which encompasses 63% of the island. Forests offer vital ecosystem services, including gas and climate regulation and soil conservation. The land use types are ranked based on their contribution to Hainan Island's ESV: forest land, water land, arable land, grass land, and unused land. The ESV of water land primarily arises from its roles in hydrological regulation, water resource supply, environmental purification, and biodiversity support. Arable land notably contributes to the production of food and raw materials. Unused land is most valuable for environmental purification and hydrological regulation.

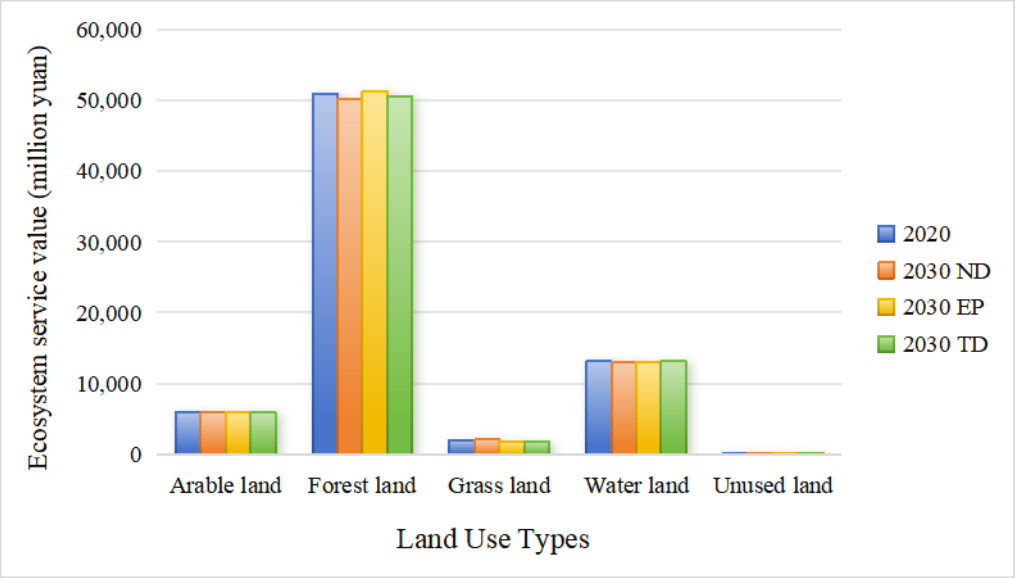



**Figure 9.** Ecosystem service value of different land use types under different scenarios.

Forest area changes are the main drivers of ESV variations under the natural development, ecological protection priority, and tourism development priority scenarios. In the natural development scenario, forest area decreases the most relative to 2020, resulting in the lowest overall ESV. This underscores how a reduction in forest area diminishes ESV. Conversely, there is a shift towards forest land in the ecological protection priority scenario, and the conversion rate to built-up land slows. This leads to the most significant increase in forest area among the three scenarios, yielding the highest total ESV and emphasizing the critical role of ecological protection in boosting ESV.

The tourism development priority scenario promotes ecotourism, striving to balance economic growth with ecological conservation and increasing forest area. Consequently, the ESV in this scenario surpasses the natural development scenario, demonstrating that balancing economic development with ecological protection can enhance ESV.

## 4. Discussion

Tropical islands possess unique ecosystems and cultural systems [27], maintaining relatively intact natural and cultural landscapes [28]. These environments offer destinations for tourists seeking romantic escapes or a break from reality [29]. Tourism often serves as the primary industry for tropical islands, generating revenue and promoting economic diversification [30]. However, rapid tourism development, while boosting the local economy, also poses threats to the ecological environment. For instance, the development of

tourism projects can encroach on green spaces, reduce vegetation cover, exacerbate soil erosion, and harm aquatic ecosystems. Additionally, the unique characteristics of island ecosystems make them more vulnerable to external disturbances, with slow recovery rates following damage. Given the limited land area, optimizing land use is particularly crucial for islands. This study employs the MOP-PLUS model to predict future land use types for Hainan Island and assesses the changes in ESV based on these predictions.

Land use change is a critical driver of ESV variations. Dynamic land use changes can lead to shifts in ESV, making the construction of different development scenarios an essential aspect of current ESV research. With the rapid development of land use models, more researchers are utilizing these models to set different scenarios for predicting future land use changes and analyzing ESV trends, thereby optimizing land use. For example, Gao et al. [31] and Li et al. [32] used the CA–Markov model to construct different development scenarios to study the impact of land use changes on ecosystem service value across different regions and scales. In this paper, the MOP model is employed to consider past development in the study area and the different land type requirements of various policies. Aside from establishing natural development and ecological protection priority scenarios, this study innovatively constructs a tourism development priority scenario. The aim is to evaluate the ecosystem service value under multiple scenarios on Hainan Island and optimize the spatial pattern of the study area, responding to the academic demand for creating tourism development scenarios to match actual regional development needs.

From the characteristics of land use changes, built-up land saw the largest increase, mainly converted from forest land and arable land (Figure 3), with a total increase of 497.13 $km^2$, followed by grass land, with an increase of 18.87 $km^2$. Forest and grass land decreased significantly, by 297.85 $km^2$ and 204.98 $km^2$, respectively. The growth rate of built-up land was 55.35%, the most significant change, while the water area had the smallest change rate at −0.71%. In terms of land use type transfers, forest land had the largest area transferred out, converting to built-up land, arable land, water land, and grass land by 259.97 $km^2$, 174.49 $km^2$, 44.44 $km^2$, and 41.72 $km^2$, respectively. Built-up land saw the largest area transferred in, mainly from forest land and arable land, with 259.97 $km^2$ and 247.90 $km^2$, respectively. The rapid growth of built-up land is primarily due to the development of Hainan International Tourism Island, aiming to enhance service quality and improve tourism infrastructure to reach world-class standards, consistent with the findings of Jin et al. [33].

In the natural development scenario, built-up land increased by 455.32 $km^2$, the most significant increase, consistent with the findings of Li et al. [26,34]. Despite the differences in study regions, spanning tropical, subtropical, temperate, and cold temperate zones, the results consistently show a significant expansion of built-up land in the natural development scenario, indicating that unrestrained urbanization drives notable built-up land expansion, a primary driver of land use change. In the ecological protection priority scenario, forest land increased by 173.17 $km^2$ compared to 2020, aligning with Liu et al. [35]. This increase is due to the constraints of ecological red lines, protecting forest land from encroachment and slowing built-up land growth, consistent with sustainable development principles. In the tourism development priority scenario, the expansion rate of built-up land is slower than in the natural development scenario, with a more significant increase in forest land, falling between the natural development and ecological protection priority scenarios, consistent with the findings of Li et al. [36]. This scenario follows the development path of "both green mountains and golden mountains", balancing ecological protection and economic development, particularly in regions dominated by tourism.

Regarding changes in ESV, the spatial variation in the natural development scenario shows a pattern of high central and low peripheral values, consistent with the findings of Han et al. [37]. This pattern is mainly because the central region of Hainan Island is largely forested, with high ESV, while coastal areas, especially Haikou and Sanya, are more suitable for built-up land expansion due to their relatively flat terrain. Rapid economic and tourism development in these areas leads to increased infrastructure demand, resulting in

rapid built-up land expansion and lower ESV. Among the three scenarios, the ecological protection priority scenario has the highest ESV, while the natural development scenario has the lowest, similar to the findings of Han et al. [38]. The higher ESV in the ecological protection priority scenario is primarily due to increased forest land and slower built-up land growth. In the tourism development priority scenario, the ecological environment is better than in the natural development scenario, and economic development is better than in the ecological protection priority scenario. This scenario shows positive trends in both ecological environment and economic development, where a good ecological environment and economic development support high-quality tourism resource development, which in turn promotes ecological protection, forming a positive feedback loop [39].

Based on the natural development scenario, if land use expansion is not constrained by 2030, the rapid increase in built-up land will improve infrastructure but reduce forest and arable land areas. This not only weakens the carbon sequestration capacity of forests, exacerbating the pressures of global climate change, but also directly impacts biodiversity conservation and the maintenance of ecological balance. Consequently, it diminishes the ecosystem service values, such as gas regulation, climate regulation, hydrological regulation, soil conservation, and biodiversity, thereby hindering coordinated socio-economic and ecological development. The ecological protection priority scenario indicates a significant slowdown in built-up land expansion and an increase in forest area, with an ESV higher than in 2020. This scenario aligns with the development concept of resource and environmental protection and ecological civilization construction but does not guarantee high-quality economic development. Tourism is one of the three key industries focused on in the "Overall Plan for the Construction of Hainan Free Trade Port" and one of Hainan's four billion-level industries. Accelerating the construction of an international tourism consumption center is a strategic position determined by the central government for Hainan. The tourism development priority scenario constructed under this policy background shows that although built-up land area increases compared to 2020, it is less than in the natural development scenario. Forest land area slightly decreases compared to 2020, with a slight decline in ESV. This aligns with the "Implementation Plan for Establishing and Improving the Value Realization Mechanism of Ecological Products in Hainan Province", which suggests "exploring ecological value and transforming ecological environmental resources into unique industrial advantages".

This study also analyzes the impact of different driving factors on land use changes, echoing the call by Liu et al. to analyze the driving mechanisms of land use changes on Hainan Island in conjunction with socio-economic development [35]. Policymakers can use these empirical results as a basis for policy formulation. For example, changes in arable land area are significantly driven by the distribution of roads and hotels, slope, and population. When arable land area is threatened, careful consideration should be given to the construction and development of roads and hotels, or to expanding arable land by cultivating slopes or managing migrant populations. However, different land types are interdependent, with trade-offs, so caution is needed to avoid "one-size-fits-all" policies that could have wide-reaching consequences.

It is clear that forest land plays a crucial role in the ecosystem service value of Hainan Island. From a perspective that prioritizes tourism development, this study presents the following recommendations for Hainan Island's future development. (1) Strictly Control the Expansion of Built-up Land and Strengthen Forest Resource Protection: Given the significant contribution of forest land to Hainan Island's ecosystem service value, it is essential to implement stringent land use control measures to prevent excessive encroachment on forest resources. Protection strategies should extend beyond the areas designated as ecological red lines, focusing on the long-term maintenance of forest land outside these zones. This approach will help fully safeguard forest resources and maintain ecological balance; (2) Enhance the Ecological Service Value of Coastal Tourism Areas and Promote Greening Initiatives: Considering the relatively low ecosystem service value in developed coastal tourism areas, diverse strategies such as large-scale tree planting and reforestation

projects are recommended. These efforts will increase forest areas and improve the quality and diversity of forest ecosystems. Such actions will not only beautify the environment but also effectively enhance Hainan Island's overall ecosystem service value, fostering a synergistic development between tourism and ecology; (3) Scientifically Plan Unused Land to Achieve the Harmonious Coexistence of Ecology and Tourism: The government should scientifically and rationally plan the use of unused land to maximize the efficient utilization of limited land resources while ensuring the safety and stability of the existing ecological environment. Regular assessments of ecosystem service values should be conducted, with land use planning and sustainable development strategies dynamically adjusted based on assessment results. This approach will provide scientific guidance for future land use and development on Hainan Island.

This study still has some limitations. In selecting land use driving factors, not all factors could be identified. Therefore, the focus was primarily on the availability and usability of data, using existing data as a basis for predicting future land use. Additionally, due to the relatively large scale of this study, land use types were categorized into only six classes (arable land, forest land, grass land, water land, built-up land, and unused land). A more detailed classification of land use types would yield ecosystem service values closer to reality. Therefore, future research could incorporate more precise land use data and utilize higher-resolution socio-economic and natural data, considering the actual conditions of the study area, to achieve more accurate predictions of regional ecosystem service values.

## 5. Conclusions

This paper constructs three scenarios—natural development, ecological protection priority, and tourism development priority—to simulate the spatial layout of land use in Hainan Island by 2030. It evaluates the ecosystem service values and changes under different scenarios.

Between 2010 and 2020, the area of built-up land in Hainan Island increased the most, with a total increase of 497.13 $km^2$ over the decade. Conversely, the area of forest land decreased the most (by 297.85 $km^2$). The impact of various socio-economic and natural driving factors on changes in different land types shows significant differences.

In 2030, under different simulated scenarios, the overall spatial distribution of land use in Hainan Island remains generally similar, but notable changes occur in certain areas, with the expansion of built-up land being the most pronounced.

Simulations for Hainan Island in 2030 show that the ecosystem service values under the natural development, ecological protection priority, and tourism development priority scenarios are CNY 71.21 billion, CNY 72.05 billion, and CNY 71.44 billion, respectively. Among these, the tourism development priority scenario aligns most closely with Hainan Island's development strategy.

The ecosystem service value of forest land is dominant and significantly higher than other land types. Fluctuations in forest land area greatly influence the overall ecosystem service value.

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**Data Availability Statement:** The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

**Table A1.** Constraints of the MOP model.

| The Name of the Constraint | Constraint Expression | Interpretation |
| --- | --- | --- |
| Total land area | $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 = 34{,}004.85$ | The total area of each land use type remains unchanged. |
| Area of arable land | $x_1 \geq 8488.52$ | The arable land area predicted by the Markov model is used as the lower limit. |
| Area of forest land | $21{,}100 \leq x_2 \leq 25{,}369.14$ | The 20% increase in forest land area predicted by the Markov model is used as the upper limit, and the forest land area specified in the Hainan Provincial Land and Space Planning (2020–2035) is used as the lower limit. |
| Area of grass land | $1036.94 \leq x_3 \leq 1412.17$ | The upper limit is the 20% increase in grass land area predicted by the Markov model, and the lower limit is the 10% decrease in grass land area in 2020. |
| Area of water land | $x_4 \geq 1265.16$ | The water land area predicted by the Markov model is used as the lower limit. |
| Area of built-up land | $1534.91 \leq x_5 \leq 1850.69$ | The upper limit is the built-up land area predicted by the Markov model, and the lower limit is the 10% increase in built-up land in 2020. |
| Area of unused land | $79.97 \leq x_6 \leq 82.72$ | The upper limit is the unused land area predicted by the Markov model, and the lower limit is a 10% decrease in unused land in 2020. |

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