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Land Use Changes and Future Land Use Scenario Simulations of the China–Pakistan Economic Corridor under the Belt and Road Initiative

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Abstract: The China–Pakistan Economic Corridor (CPEC), as an important part of the Belt and Road Initiative, is of great significance for the promotion of sustainable development in the region through the study of land use change and the simulation of future multi-scenarios. Based on the multi-period land use data of the CPEC, this study firstly analyzed the spatial and temporal land use changes in the CPEC from 2000 to 2020 by using GIS technology, and, secondly, simulated the land use patterns of the CPEC under four scenarios, namely, natural development, investment priority, ecological protection, and harmonious development, in 2040 by using the Markov-FLUS model with comprehensive consideration of natural, socio-economic, and other driving factors. The results show the following: (1) The urban land, forest land, and grassland in the CPEC from 2000 to 2020 show an increasing trend, while the farmland, unutilized land, and water area categories show a decreasing trend. In terms of land use transfer changes, the most frequently transferred out is the conversion of unutilized land to grassland. (2) The FLUS model has high accuracy in simulating the land use pattern of the CPEC, and its applicability in the CPEC area is strong and can be used to simulate the future land use pattern of the CPEC. (3) Among the four different land use scenarios, the harmonious development scenario strikes a better balance between infrastructure construction, economic development, and ecological protection, and can provide a scientific basis for future land management in the CPEC, in order to highlight the importance of promoting economic growth and ecological protection and ultimately realize sustainable development.

Keywords: China–Pakistan Economic Corridor (CPEC); land use change; multi-scenario simulation; FLUS model; ecological environment

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1. Introduction

Since the 21st century, with the intensification of the globalization process and the deepening impact of climate change, the rationality and sustainability of land use have become the focus of global research and policy attention [1,2]. Against this background, the accurate prediction of the future trend of land use change, especially analysis combined with multi-scenario simulation, not only provides a scientific basis for mitigating the overexploitation of land resources and environmental degradation [3,4] but also provides a forward-looking perspective for countries to formulate and adjust their land use policies [5,6]. Therefore, research based on land use change can not only provide a scientific basis for the formulation of global and regional sustainable development policies but also provide a realistic path to the realization of the United Nations' sustainable development goals [7,8].

In the past decades, research on land use change has made remarkable progress. Using advanced tools such as remote sensing technology and geographic information systems (GIS), researchers have analyzed the spatial and temporal characteristics of land use change and its driving factors, revealing the interaction between multiple influences, such as economic, social, and environmental ones [9,10]. For example, the advancement of urbanization has led to a decrease in the areas of agricultural land and forests and a significant increase in urban land use, a change that not only affects the ecological function of the land but also exacerbates the loss of biodiversity and the degradation of ecosystem services [11,12]. On the contrary, studies have shown that effective land management policies can mitigate these negative impacts, and that sustainable utilization and ecological protection of land resources can be achieved through rational land planning and management measures [13–15]. In addition, researchers have explored how policy and economic factors drive land use change, proposing a multi-level and multi-dimensional analytical framework for a more comprehensive understanding of the dynamic characteristics and potential impacts of land use [16,17]. These studies not only deepen our understanding of land use change but also provide a theoretical basis for regional planning and ecological protection. However, the study of historical land use change alone is not sufficient to cope with future uncertainty. Multi-scenario modeling, as an important tool for predicting land use change, has received increasing attention from scholars in recent years. By constructing multiple future scenarios, this method helps researchers to assess the potential impacts of policy changes, environmental changes, and socio-economic development on land use, reveals the diversity and complexity of land use changes, and provides forward-looking information for policy formulation [18,19]. Specifically, scholars have used various simulation models, such as the CLUE-S model [20], CA-Markov model [21], FLUS model [22], PLUS model [23], etc., to simulate future land use changes based on different assumptions, such as economic growth, policy changes, and environmental constraints. These models not only help to predict possible evolutionary trends in land use but also provide policy makers with an effective planning basis and management recommendations. For example, studies based on multi-scenario simulations can reveal the potential impacts of different policy choices or environmental changes on land use, thus providing more forward-looking decision support for regional development and ecological conservation [24,25]. Further, multi-scenario modeling of land use change can also help researchers to identify the environmental and social risks that may arise under different scenarios and suggest coping strategies [5,26].

Despite the significant progress made by previous scholars in the study of land use change and multi-scenario simulations, which has provided a solid theoretical foundation and practical guidance for this research, current studies tend to focus on broader global or national scales or smaller administrative or watershed levels. There is a noticeable lack of research specifically focusing on land use change and future multi-scenario simulations within the China–Pakistan Economic Corridor (CPEC), a core region of the Belt and Road Initiative. The construction of the CPEC, as an important part of the Belt and Road Initiative, involves a large number of infrastructure projects, including transportation networks, energy development, and urban construction, which inevitably bring about land use changes in construction activities [27,28]. Consequently, it is necessary for us to study the land use changes and future multi-scenario simulations of the CPEC, otherwise it will lead to the following adverse effects. First, the lack of in-depth understanding of land use change in the CPEC may lead to inaccurate decision making in the management of land resources in the region, which in turn may affect the sustainability of the regional ecosystem. Second, the lack of future multi-scenario modelling will make it difficult for policy makers to cope with future uncertainties, especially under the combined pressures of global climate change and rapid urbanization. Therefore, the study of land use change in the CPEC and its future multi-scenario modeling is not only of great academic value but also of great practical significance and policy value under the framework of the Belt and Road Initiative. Based on the above background, this study will first systematically analyze the spatial and temporal land use changes in the CPEC from 2000 to 2020 using land use data from 2000, 2005, 2010, 2015, and 2020 with the support of GIS technology. On this basis, the Markov model will be applied to forecast the land use demand of the CPEC in 2040, covering four different scenarios: natural development, investment priority, ecological protection, and harmonious development. Finally, this study will simulate the spatial pattern of land use in the CPEC in 2040 under the four scenarios using the FLUS model by combining natural, socio-economic, and other multiple drivers.

2. Materials and Methods

2.1. Background to the Construction of the CPEC

The CPEC is an important part of the Belt and Road Initiative, which aims to promote the economic integration and development of the two countries and the neighboring regions by strengthening cooperation between China and Pakistan in various fields such as infrastructure, energy, transportation, and trade. The project, which began in 2013, runs through the Kashgar region in western China and the Gwadar port in Pakistan and is about 3000 km long, covering a wide range of infrastructure development along the route, including roads, railroads, energy pipelines, and ports. However, along with the increase in economic activities, the land use pattern is also facing great changes. In particular, with the expansion of infrastructure, transportation networks, and industrial parks along the CPEC, demand for urban land has risen dramatically, which could lead to a reduction in farmland and encroachment on ecological land, thus exacerbating land use conflicts. Therefore, the study of land use change in the context of the construction of the CPEC is not only of great theoretical significance but also provides a key basis for sustainable development and rational land resource planning in the region.

2.2. Study Area

The CPEC stretches from Kashgar in Xinjiang in the north to Gwadar in Pakistan in the south, with a total length of 3000 km. The study area ranges from 61.00° E to 79.52° E and from 23.50° N to 40.16° N and encompasses the entire territory of Pakistan (including Pakistani-administered Kashmir) and Kashgar in Xinjiang, with a total area of about 1,040,000 km^2 (Figure 1). The Kashgar region is located in China, bordering Iran to the west, Tajikistan and Afghanistan to the northwest, India to the east, and the Arabian Sea to the south. The region has complex geomorphologic types, containing such geomorphologic units as the Tarim Basin, the northern mountains, the Balochistan Plateau, and the Indus Plain, and a variety of climatic types, with average annual temperatures ranging from −7 °C to 28 °C and annual precipitation ranging from 100 mm to 1300 mm.

2.3. Data Source

This study involves a large amount of basic data and requires complex pre-processing, and the required data mainly include land use data, socio-economic data, basic geographic information data, and natural environment data (topography, soil, and climate data). The land use data were reclassified to obtain six land classes: farmland, forest land, grassland, water body, urban land, and unutilized land, and all the data were uniformly projected and converted using Krasovsky_1940_Albers, with a resolution of 300 m, and the numbers of rows and columns of the data were guaranteed to be completely consistent. Specific data sources are shown in Table 1.

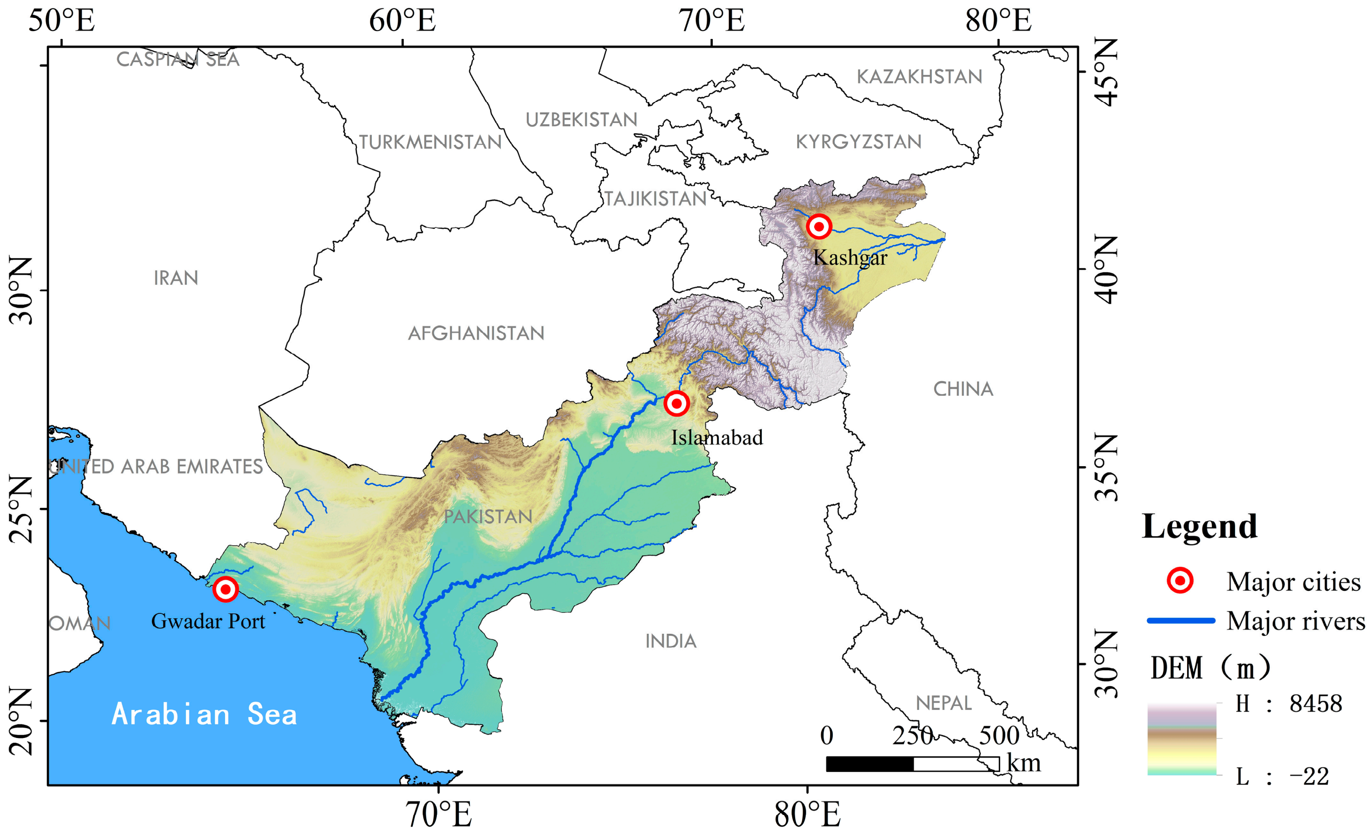

Figure 1. Overview of the study area.

Table 1. Data information sources.

Category	Data Name	Year	Data Source
Land database	Land use data	2000–2020	European Space Agency (http://maps.elie.ucl.ac.be/CCI/viewer/ (accessed on 3 January 2024)) [29]
Socio-economic data	Population distribution	2015–2020	WorldPop (https://hub.worldpop.org/geodata/listing?id=76 (accessed on 25 January 2024)) [30]
	GDP (NPP-VIIRS Nigh-time Lighting Data)	2015–2020	Google Earth Engine
Basic geographic information	Constructions Road River	2020	OpenStreetMap (https://openmaptiles.org/languages/zh/ (accessed on 25 January 2024)) [31]
Topography	Digital elevation model data Slope Slope direction	2020	SRTM (https://lpdaac.usgs.gov/products/srtmgl1v003/ (accessed on 6 January 2024)) [32]
Soil	Soil pH Quantity of sediment Organic carbon	2020	HWSD (https://lpdaac.usgs.gov/products/srtmgl1v003/ (accessed on 16 January 2024)) [33]
Climactic	Temperatures Quantity of rainfall	2015–2020	National Weather Data Center (https://www.ncdc.noaa.gov/cdo-web/datasets (accessed on 5 January 2024)) [34]

2.4. Technical Route

The general process of this study is divided into two parts (Figure 2). The macro part: firstly, different development scenarios are formulated through climate change, socio-economic changes, and land policy changes, and the Markov model is used to make a prediction of the future land demand. The micro part: the driving factors (topography, soils, and socio-economic and climatic factors) are collected, and the probabilistic probability is generated by using the ANN model and the neighboring domain weighting factor file, and parameters such as transfer costs, neighborhood weights, and adaptive inertia coefficients are adjusted, and, finally, future multi-scenario simulation results are generated using a roulette wheel competition mechanism.

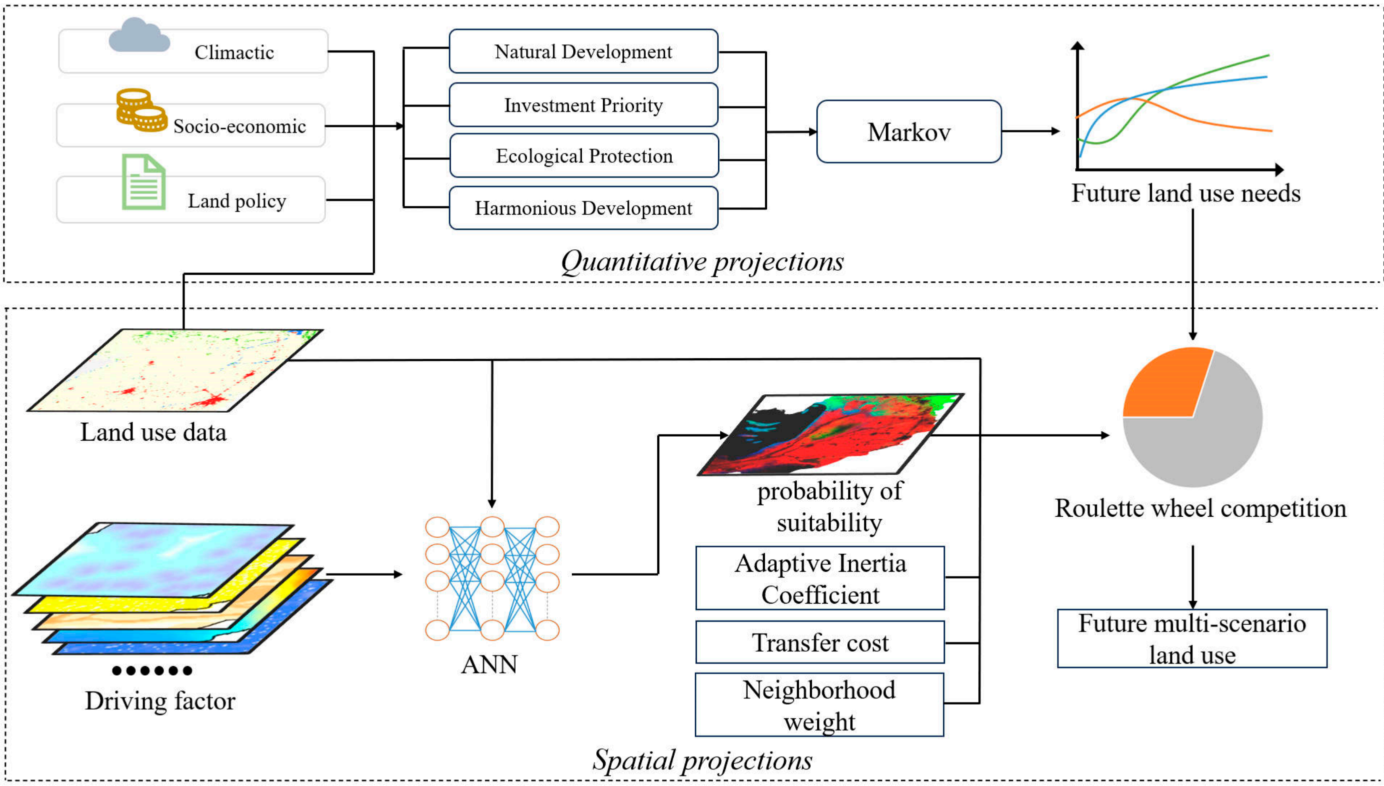

Figure 2. Technical route.

2.5. Method

2.5.1. Dynamic Degree

The land use dynamic degree is usually used to study the different types of land use dynamic changes in a particular region in a study period in an integrated situation. A smaller value indicates that land use dynamic changes in the study area are more stable, and a larger value indicates that land use dynamic changes in the study area are more drastic. The specific calculation formula is as follows [35]:

$$K = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \tag{1}$$

where K is the single land use dynamics in %; U_{a} and U_{b} are the initial land use data and the end land use data in km^2, respectively; and T is the length of the study period in years.

2.5.2. Transfer Matrix

The land use transfer matrix can analyze the structure and characteristic changes in different types of land by reflecting the quantitative relationships between different land types transforming into each other, effectively separating the characteristics of different types of land use changes [36]. It is expressed as

$$Sij = \begin{bmatrix} S_{11} & S_{12} & \dots & S_{1\mathrm{n}} \\ S_{21} & S_{22} & \dots & S_{2\mathrm{n}} \\ \dots & \dots & \dots & \dots \\ S_{\mathrm{n}1} & S & \dots & S \end{bmatrix} \tag{2}$$

where S_{ij} is the total area converted from land use type i to land use type j; and n is the total number of land use types in the region.

2.5.3. FLUS Model

The FLUS model is an integrated model used to simulate multiple types of land use scenarios by coupling human activities and natural effects, proposed by scholars such as Liu Xiaoping [37]. The artificial neural network (ANN) model establishes the relationship between the occurrence probability of each land use type and the driving factors by integrating multiple driving factors, and it derives the occurrence probability distribution of each land use type.

The ANN model's probability of law occurrence for the land use type k at the training time t for the raster cell p in the model is denoted as [38]

$$p(p,k,t) = \sum_j w_{j,k} \times \frac{1}{1+e^{-net_j\ (p,t)}} \tag{3}$$

where $p(p, k, t)$ is the suitability probability of the kth land use type on the grid p at time t; $w_{j,k}$ are the adaptive weights between the hidden layer and the output layer; $net_j(p, t)$ are the signals that are received by the neuron j in the hidden layer from all the input neurons on the grid cell p at time t.

Then, the overall probability is calculated using the obtained raster occurrence probability with the neighborhood effect and inertia coefficient of the raster. The neighborhood effect indicates the degree of the influence of the surrounding land use raster cells on the central raster cell, which is calculated by the model [37].

$$\Omega_{p.k}^{t} = \frac{\sum_{N\times N} con\left(c_p^{t-1}=k\right)}{N\times N-1} \times w_k \tag{4}$$

where $\sum_{N\times N} con(c_p^{t-1}=k)$ represents the total number of rasters (p) occupied by the kth land use type at the moment of the latest iteration at $N \times N$ (N = 3 in this study); and w_k represents the variable weights in the different land use types.

The adaptive inertia coefficient $AI_{\rm k}^{\rm t}$ at time t for the kth site is as follows [39]:

$$AI_k^t \begin{cases} = AI_k^{t-1} & \left|D_k^{t-2}\right| \le \left|D_k^{t-1}\right| \\ = AI_k^{t-1} \times \frac{D_k^{t-2}}{D_k^{t-1}} & 0 > D_k^{t-2} > D_k^{t-1} \\ = AI_k^{t-1} \times \frac{D_k^{t-1}}{D_k^{t-2}} & D_k^{t-1} > D_k^{t-2} > 0 \end{cases} \tag{5}$$

where $AI_{\rm k}^{\rm t}$ denotes the inertia coefficient of the land use type k at the iteration time t; and D_k^{t-1} denotes the difference between the macro demand and the actual quantity of the land use type k at the moment $t-1$. The inertia coefficient is defined for the current land use type occupying the raster cell; if the current land use type is not the land use type k, the inertia coefficient for the land use type k is set to 1 and the probability of combining the land use type k with the raster cell does not change.

Considering four factors, namely, the suitability probability of the raster, the adaptive inertia coefficient, the neighborhood weights, and the conversion cost, the overall conversion probability $TP_{p,k}^t$ of the raster p with the land use type k at the moment t is obtained as follows [37]:

$$TP_{p,k}^t = P_{p,k} \times \Omega_{p,k}^t \times AI_k^t \times (1 - sc_{c\to k}) \tag{6}$$

where $P_{p,k}$, $\Omega_{p,k}^t$, and AI_k^t are the probability of suitability, neighborhood effect, and adaptive inertia coefficient, respectively; and $sc_{c\,\to\,k}$ is the conversion cost from the land use type c to land use type k.

2.5.4. Neighborhood Weight

The neighborhood weight parameter is used to study the expansion intensity of different land types, and the parameter ranges from 0 to 1. The closer it is to 1, the stronger the land's expansion ability is. Neighborhood weighting parameters for the four different land use scenarios in this study are shown in Table 2.

Table 2. Neighborhood weighting parameters for four different land use scenarios in 2040 for the CPEC.

	Farmland	Forest Land	Grassland	Water Area	Urban Land	Unutilized Land
Natural Development	0.7	0.5	0.6	0.4	0.7	0.4
Investment Priority	0.4	0.3	0.4	0.2	1	0.2
Ecological Protection	0.2	1	0.6	0.3	0.2	0.2
Harmonious Development	0.5	0.7	0.6	0.4	0.9	0.4

2.5.5. Transfer Costs

In the model analysis, the transfer cost matrix of the land types is modified to realize the simulation of the four development scenarios, and, in the cost matrix, 1 represents that the land type can be transferred, and 0 indicates that it cannot be transferred. In order to construct the land use transfer cost matrix and calculate it in the context of the actual situation of the CPEC, *a*, *b*, *c*, *d*, *e*, and f represent farmland, forest land, grassland, water area, urban land, and unutilized land, respectively (Table 3).

Table 3. Parameterization of the cost matrix in the multi-scenario model.

Mark	Natural Development						Investment Priority						Ecological Protection						Harmonious Development					
	a	***b***	***c***	***d***	***e***	***f***	***a***	***b***	***c***	***d***	***e***	***f***	***a***	***b***	***c***	***d***	***e***	***f***	***a***	***b***	***c***	***d***	***e***	***f***
a	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	0
b	1	1	1	1	1	1	0	1	0	0	1	0	0	1	0	0	0	0	0	1	1	0	0	0
c	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	0	1	0	1	0	1	0
d	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	0	0
e	0	0	0	0	1	0	0	0	0	0	1	0	0	1	0	0	1	0	0	0	0	0	1	0
f	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1

2.5.6. Scenario Settings

(1) Natural Development

Basic description: The natural development scenario is the change in land use under the nature of the CPEC without considering any external disturbance and without any change in the existing land use pattern.

(2) Investment Priority

Basic description: The investment priority scenario focuses on the regional socio-economic impacts of the CPEC project and focuses on socio-economic development. In this scenario, changes in regional economic and population growth that may result from infrastructure upgrades, improvements in energy shortages, and changes in the investment climate are considered, as well as increases in regional productivity from factors such as cooperation on agricultural projects. As a result, population growth, economic growth, and technological progress are all expected to be higher under this scenario than under other development scenarios.

Probability settings (adjusted on the basis of the natural development Markov) [40,41]: farmland to urban land × 4, forest land to urban land × 4, grassland to urban land × 4, unutilized land to urban land × 4.

(3) Ecological Protection

Basic description: The ecological protection scenario aims to consider the health and sustainable development of ecosystems, especially in the context of the implementation of the CPEC project. Under this scenario, the focus is on the protection and restoration of ecosystems to ensure the sustainable utilization of natural resources and ecological balance. Government and stakeholder actions will focus on ecosystem protection, biodiversity conservation, land use planning, and environmental pollution control. In addition, the ecological protection scenario will involve raising public awareness, strengthening environmental monitoring and governance systems, and promoting renewable energy and a low-carbon economy.

Probability settings [42,43]: farmland to grassland × 1.4, farmland to forest land × 7, unutilized land to grassland × 1.5, forest land to farmland × 0.1, forest land to grassland × 0.2, forest land to urban land × 0.1, forest land to unutilized land × 0.2, grassland to farmland × 0.5, grassland to forest land × 7, water area to forest land × 2, water area to grassland × 1.5, unutilized land to forest land × 7.

(4) Harmonious Development

Basic description: The harmonized development scenario was developed in the current context of the CPEC and the government's vision for the future of the region in terms of ecological protection and restoration. Similar to the investment priority scenario, the construction of the CPEC in this scenario will have a positive impact on the socio-economic development of the region. In addition, the government's focus on and investment in environmental protection will also have an impact on the region's population, economic growth, and climate change scenarios.

Probability settings [44,45]: farmland to urban land × 3, farmland to forest land × 2, farmland to grassland × 1.4, forest land to urban land × 1.4, grassland to forest land × 1, unutilized land to grassland × 1.4, unutilized land to urban land × 2.

To summarize, trends in the ecological and economic evolution and development of the CPEC under future multi-scenario simulations are shown in Figure 3.

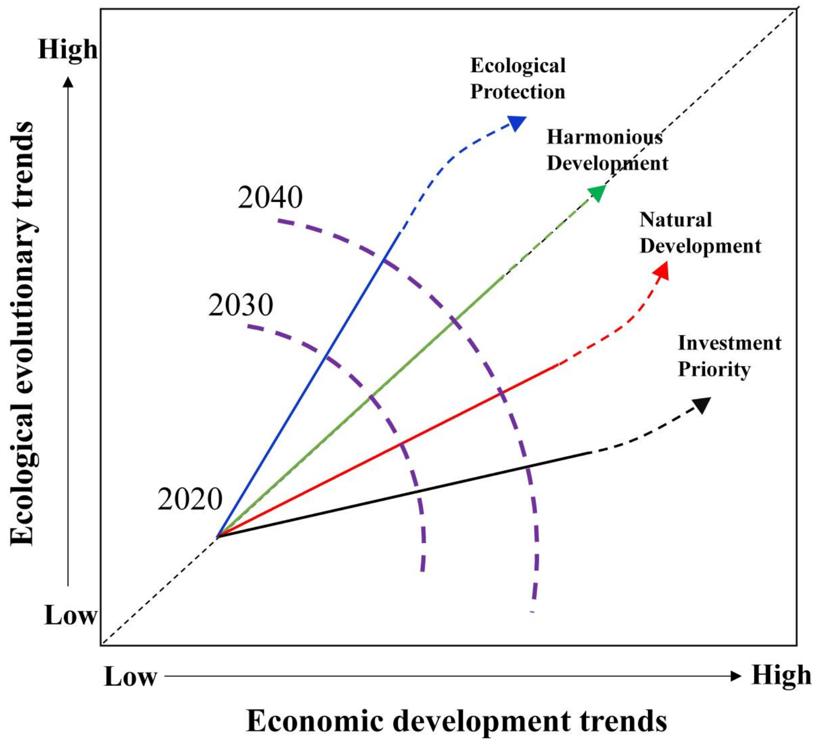

Figure 3. Trends in the ecological and economic evolution and development of the CEPC under future multi-scenario simulations.

3. Results

3.1. Characteristics of Spatial and Temporal Changes in Land Use

3.1.1. Analysis of Land Use Types

According to the statistics on the area of land use types in the CPEC on ArcGIS, the distribution and share of land types from 2000 to 2020 are shown in Figure 4. The CPEC was mostly dominated by farmland, grassland, and forest land. In 2020, the areas of farmland, grassland, and forest land were 25.46%, 24.99%, and 6.70%, respectively; the areas of urban land and water area were 0.47% and 0.68%, respectively; and the area of unutilized land was 41.69%. From a spatial point of view, in the northern part of the CPEC, mostly unutilized land and grassland were dominant. In the middle part, there were rivers flowing from north to south, and farmland accounted for a larger share. In the western part, mostly unutilized land and grassland were dominant, with a high proportion of unutilized land, and the southernmost part of the corridor was dominated by forest land and farmland. The urban land was mainly distributed in the hinterland of the CPEC.

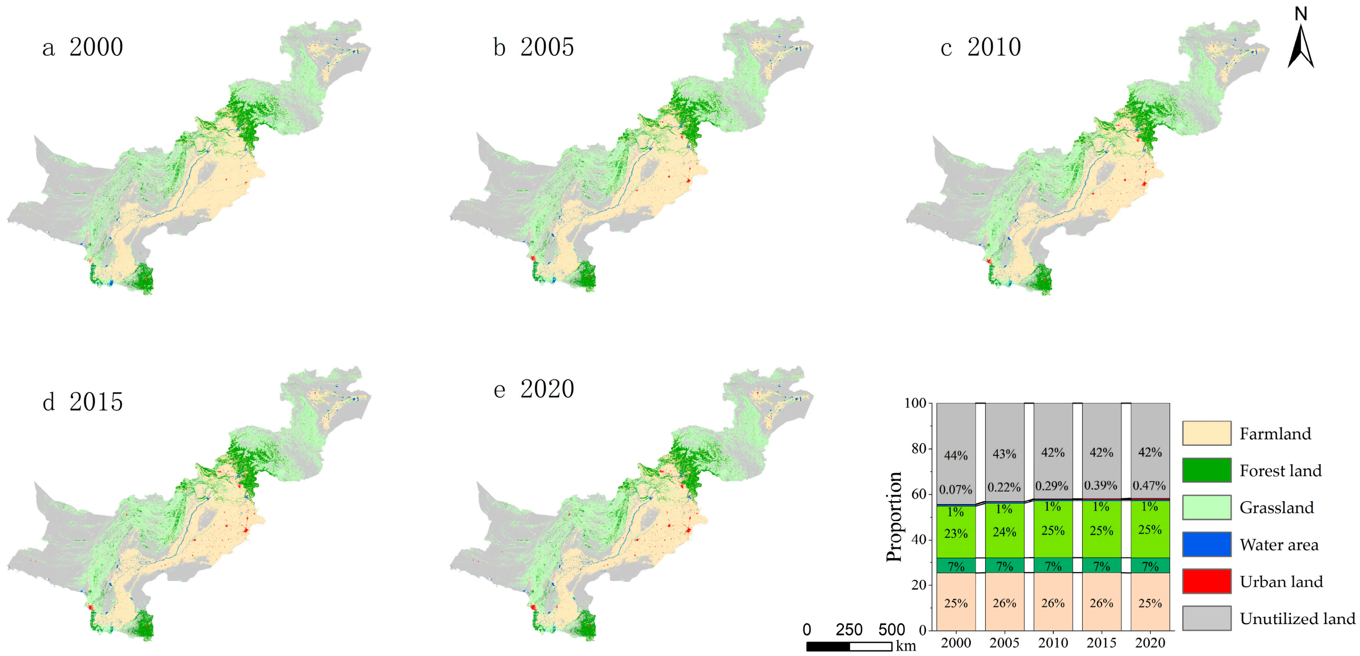

Figure 4. Land use changes in the CPEC, 2000–2020.

3.1.2. Analysis of Structural Changes

From 2000 to 2020, the most significant change in the type of land use in the CEPC was in the urban land use. As of 2020, the total land area of urban land had reached 5.5×10^4 km^2, and the increase in the area of urban land had reached 565%. The area of farmland had increased by a net amount of 5.1×10^2 km^2 in 20 years, and the rate of change in grassland had been 0.515% in 20 years. The area of water areas and unutilized land had both decreased. The net decrease in the area of unutilized land had been 3.2×10^5 km^2, and the area of unutilized land had been converted to grassland by a large amount (Figure 5). From a spatial point of view (Figure 6), the increase in the area of urban land was mainly in the eastern part of the CEPC, the increase in grassland was mainly in the western part of the middle part of the CEPC, where there was little anthropogenic activity and a large amount of herbaceous plants, and the decrease in the area of unutilized land was mainly in the middle part of the CEPC. The above results show that the changes over a period of 20 years were mainly the process of the increase in urban land and the conversion of unutilized land into grassland.

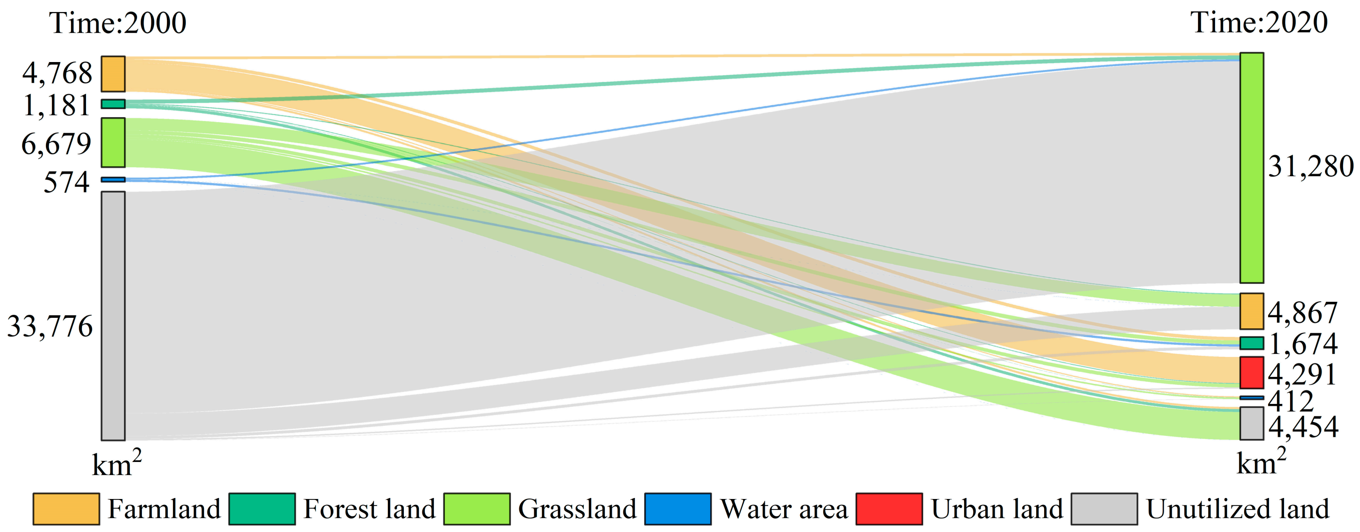

Figure 5. Sankey diagram of land use change, 2000–2020.

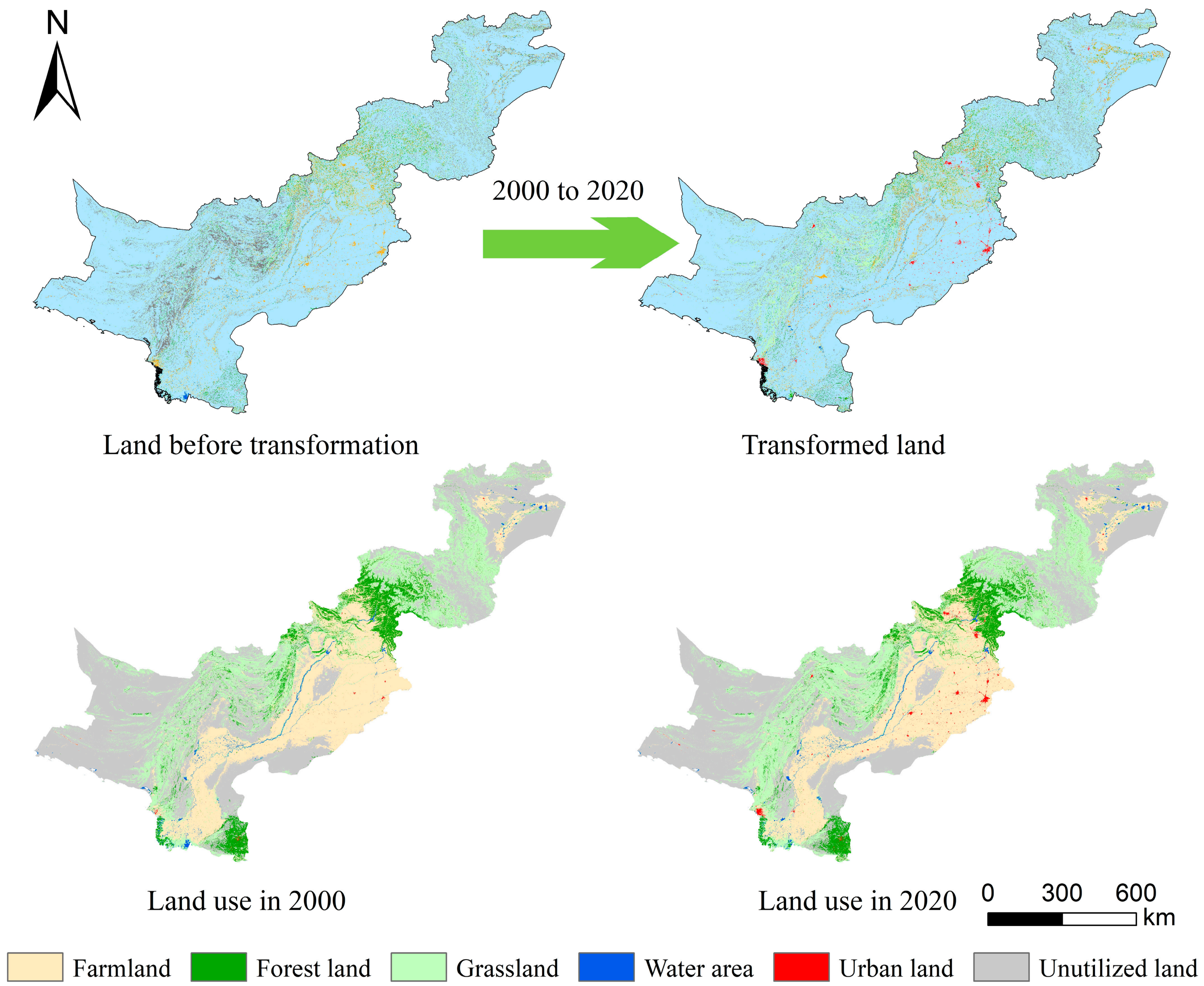

Figure 6. Land use transfer matrix for the CPEC, 2000–2020.

3.1.3. Dynamic Degree Analysis

The following table is based on the combined land use dynamics formula and the single land use dynamics formula (Table 4).

Table 4. Change range and dynamic degree of land use types in the CPEC.

Types	2000–2005		2005–2010		2010–2015		2015–2020	
	Variation	Dynamic Degree	Variation	Dynamic Degree	Variation	Dynamic Degree	Variation	Dynamic Degree
Farmland	9313	0.057%	13,774	0.083%	−6581	0.040%	−14,061	0.085%
Forest land	−4226	0.097%	3048	0.070%	1396	0.032%	6400	0.147%
Grassland	152,464	1.019%	130,505	0.830%	−3058	0.019%	14,257	0.087%
Water area	−341	0.076%	−3041	0.683%	1191	0.277%	524	0.120%
Urban land	18,985	41.470%	9415	6.691%	12,522	6.668%	11,284	4.507%
Unutilized land	−176,201	0.608%	−153,701	0.547%	−5470	0.020%	−18,404	0.067%
General	19,622.6	0.37%	15,775.4	0.30%	4055.13	0.080%	7958.34	0.015%

From the perspective of the single dynamic degree in 2000–2020, the most significant changes were all in urban land, followed by grassland; it can be concluded that the economy had developed rapidly and urbanization had been accelerated with the support of the government in these 20 years. The land use area of the urban land in 2020 had produced a great change compared to that of the urban land in 2000, which can be derived from the fact that the economy had grown sharply and then developed steadily in these two decades. However, the decrease in farmland also reflects that the contradiction between agriculture and urban and rural construction activities had been further intensified and aggravated. According to the comprehensive dynamic degree, the speeds of the land use changes in the four phases of the CPEC were gradually decreasing, but they were all relatively flat and the changes were not strong, indicating that socio-economic activities did not have a great influence on the development of the CPEC.

3.2. FLUS Simulation Results and Process

3.2.1. Accuracy Verification

The data for the accuracy test were based on the 2010 and 2015 land use data of the CPEC, and this model was applied to predict the land use raster data in 2020, and the overall accuracy and Kappa coefficient were calculated by comparing the results of this simulation with the actual 2020 land use data (Figure 7). The Kappa coefficient was greater than 0.8, which means that it had reached the statistically satisfactory status [46,47]. The Kappa coefficient of this simulation result was recorded as 0.88, and the overall accuracy was 0.889. The simulation accuracy reached a high level, and this model is suitable for simulating the change in land types in 2040 in the CPEC.

3.2.2. Driving Factor Analysis

Land use change is subject to the roles of multiple factors, related to natural factors and human factors, including natural, social, economic, and other internal and external factors. With reference to related research [46–50] and the actual situation of the study area, the appropriate driving factors were selected from the three aspects of the natural, socio-economic, and locational conditions (Figure 8). Natural conditions included driving factors generated by natural effects such as elevation, slope, slope direction, temperature and precipitation. Socio-economic conditions included driving factors generated by human effects such as GDP and population. Locational conditions included the road as an important driving factor, as transportation is an important indicator of urban development.

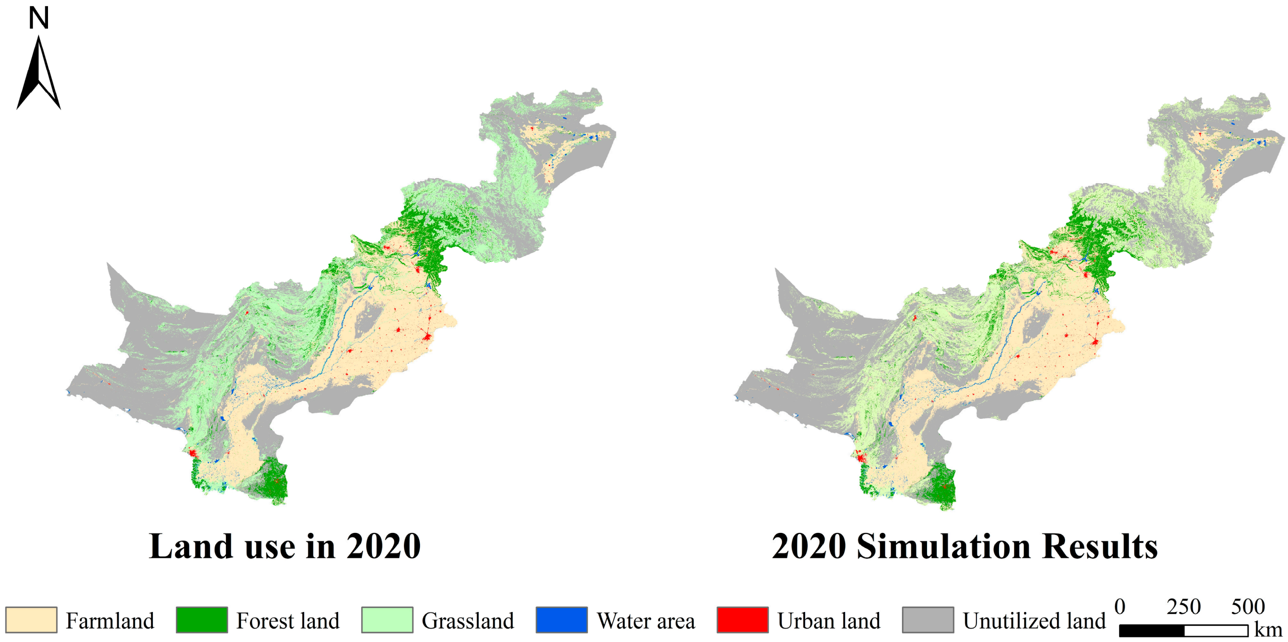

Figure 7. Current land use status and simulation results of the CPEC in 2020.

3.2.3. Analysis of Results of Multi-Scenario Simulations

Multi-scenario simulation aims to study the land use changes in the CPEC under the influence of different policies, in order to visualize the influence and effect of policy development on the spatial distribution of land in the CPEC. Therefore, this study simulated the spatial distribution of land use in the CPEC in 2040 based on the nature development scenario, investment priority scenario, ecological conservation scenario, and harmonious development scenario. The proportions of land use categories in 2020 and 2040 in the CPEC are shown in Figure 9, under the four scenarios of natural development, investment priority, ecological protection, and harmonious development. The proportion of farmland decreases by 0.40% or more compared to 2020. The proportion of urban land shows a significant increasing trend, showing a good development, and the investment priority scenario has a larger proportion of urban land. The proportion of forest land increases compared to 2020, and the proportion of forest land in the ecological protection scenario is higher than in the other three scenarios. The proportion of grassland increases compared to 2020 and is also the highest under the ecological protection scenario. The proportion of forest land rises compared to 2020, and the proportion of forest land under the ecological protection scenario is higher than those under the other three scenarios. The proportion of grassland rises compared to 2020, and the proportion of grassland under the ecological protection scenario is also the largest. This shows that the ecological protection scenario contributes to the implementation of the relevant policies of green ecology.

Based on the changes in the land use requirements (Figure 10), the magnitude of change is different for each land use category. The magnitudes of change in the land use categories confirm the development requirements of the different scenarios, and the various changes are characterized by the development of their own scenarios. In the simulation, the proportion of farmland and unutilized land decreases, and the proportion of forest land, grassland, water area, and urban land increases. The conversion of farmland tourban land is the most significant change under the influence of the economy, and nature conservation measures, such as returning farmland to forest land, are of great significance in the ecological protection scenario.

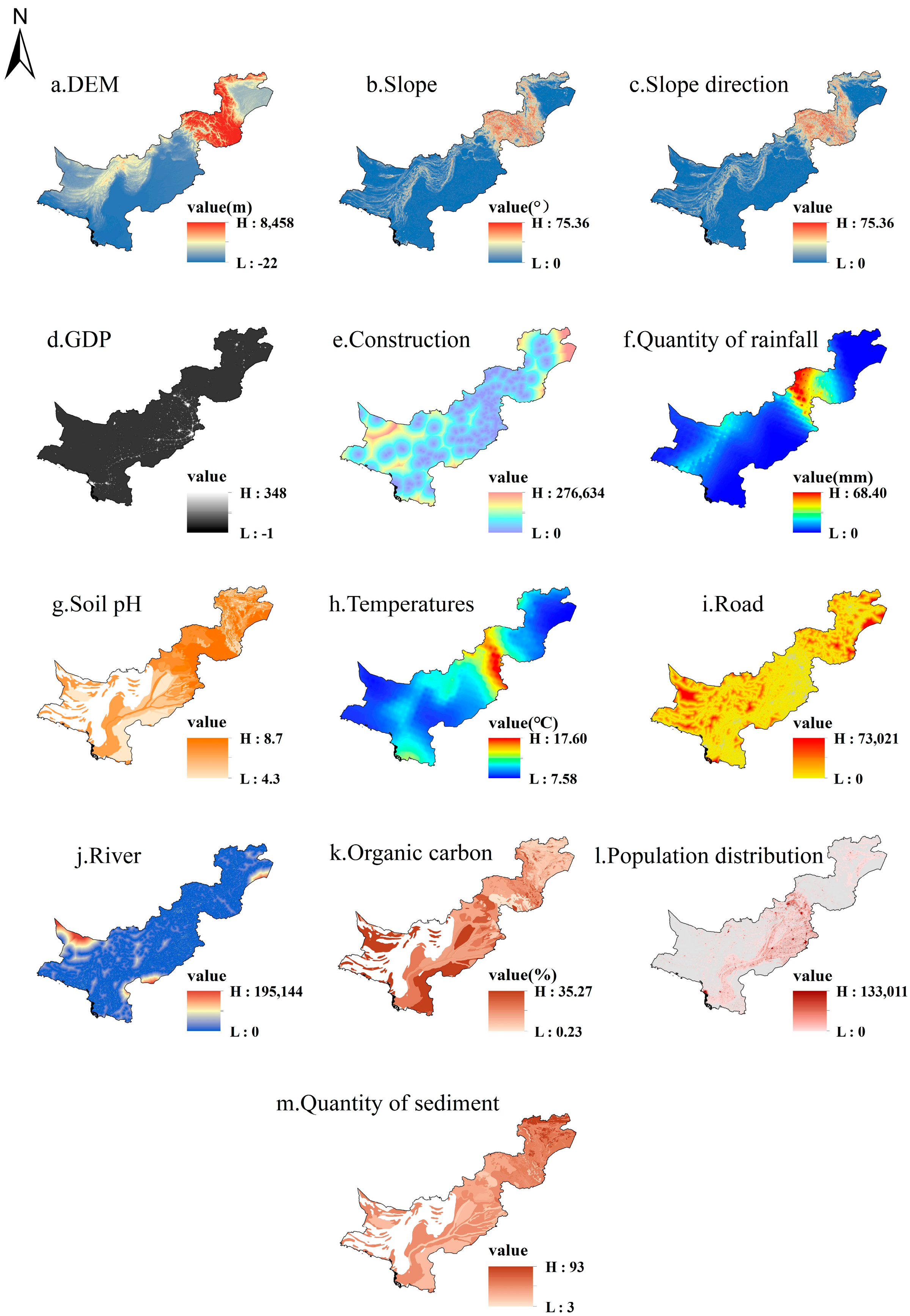

Figure 8. Drivers of land use change in the CPEC.

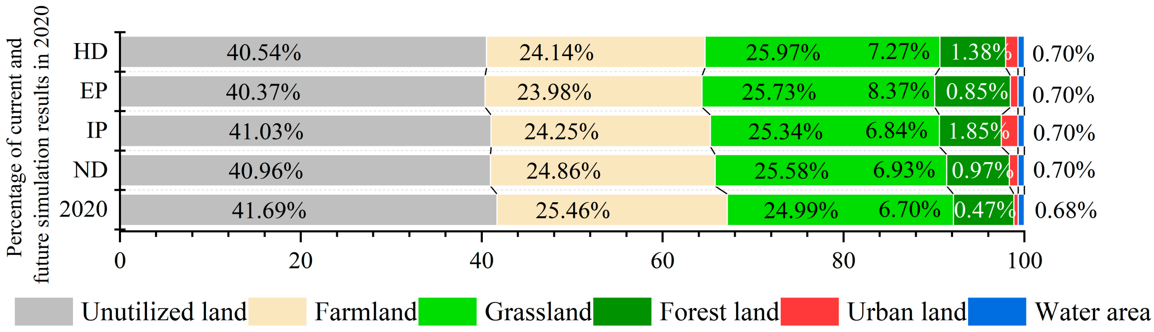

Figure 9. Multi-scenario simulation of land use shares for 2020 and 2040.

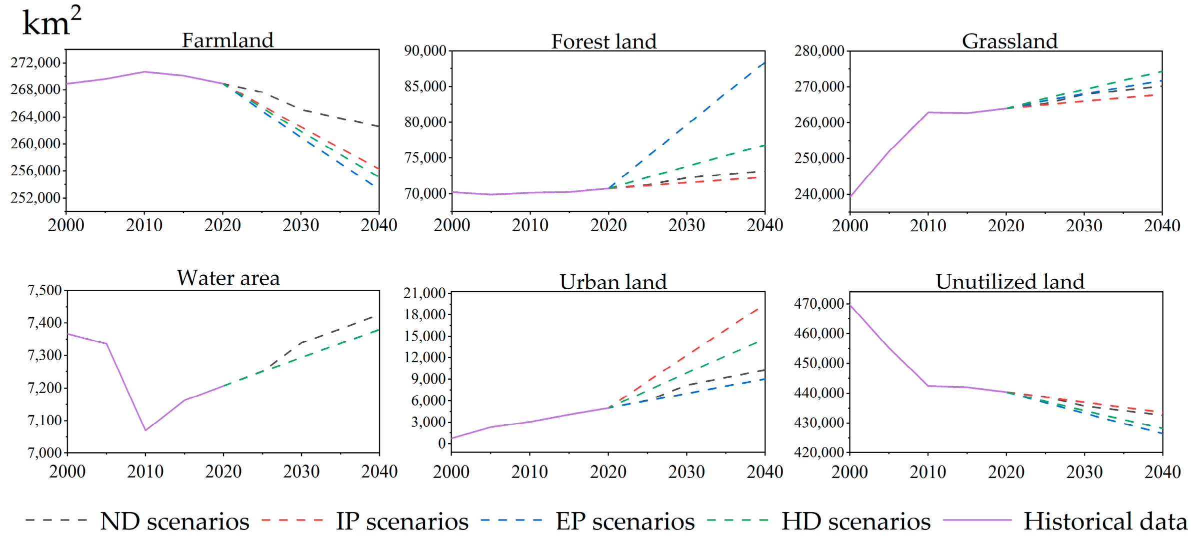

Figure 10. Four hypothetical scenarios were designed using Markovian forecasting to project future land use demand in the CPEC.

(1) Natural Development Scenarios

Natural development means that various land types are not constrained by external conditions, and the trend of land use change under this scenario depends on local government policies and socio-economic conditions, focusing on land conversion under natural conditions. The simulation results of this scenario are shown in Figure 11, which combines Figures 9 and 10 to show that there are different decreases in farmland and unutilized land, with farmland decreasing by 6.4 $\times$ 10^3 km^2 and unutilized land decreasing by 7.8 $\times$ 10^3 km^2 by 2040. Land change follows the normal natural law of change, and to meet the needs of urban expansion and economic development, the urban land in the results for 2040 accounts for 0.97% of the area, increasing by 0.50% compared to 2020; the area expands by 5.3 $\times$ 10^3 km^2 and is not subject to a variety of constraints. The natural development of the construction of the land also steadily grows. The annual dynamic degree increases by 5.26%, compared to 2000, and the total annual dynamic degree in the 20 years from 2000 to 2020 rose sharply. Overall, the natural development scenario is balanced and consistent with the country's development needs, and measures still need to be improved and revised. From a spatial point of view, the urban land is mainly concentrated in the east and the central parts of the country, and the concentration of development is mainly in those two densely populated points and the connecting lines of the two cities. In the future, the CPEC will occupy the farmland resources even further as a result of the rapid socio-economic development supported by the policies of the governments of the various regions and the acceleration of the urbanization process; at the same time, the farmland is sufficient for use, so it is possible to introduce more new agricultural technologies to make effective use of the farmland.

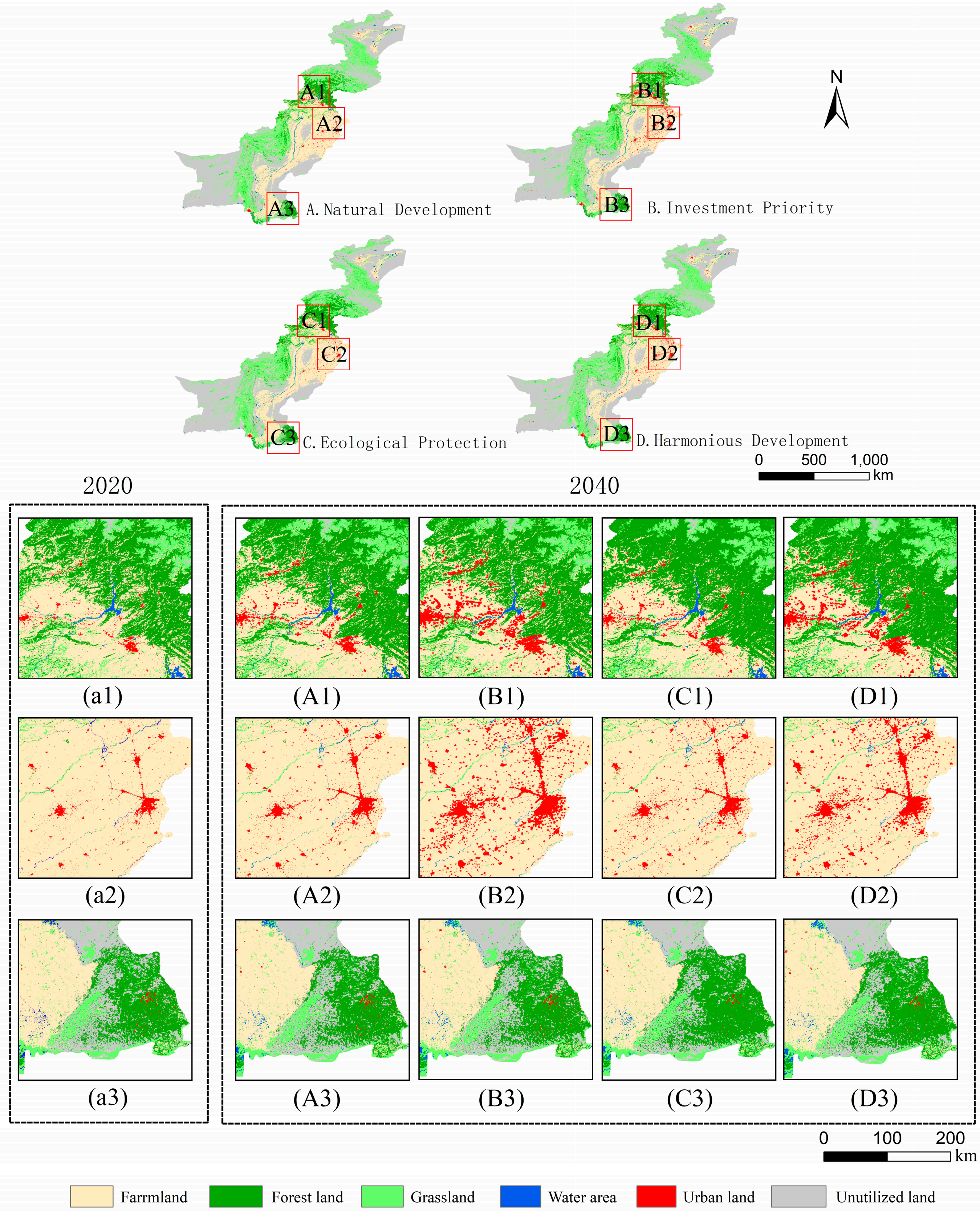

Figure 11. Local zoom-in maps of land use in the China-Pakistan Economic Corridor in 2020 (**a1**–**a3**); Local zoom-in maps of land use in the China-Pakistan Economic Corridor in 2040 under the Natural Development (**A1**–**A3**), Investment Priority (**B1**–**B3**), Ecological Protection (**C1**–**C3**), and Harmonious Development (**D1**–**D3**) scenarios.

(2) Investment Priority Scenarios

The investment priority scenario is a development scenario dominated by the expansion of urban land. In this scenario, the expansion of urban land is more rapid, and it is difficult to secure ecological land effectively. The share of building land, the focus of expansion in this scenario, is significantly higher than in the remaining three scenarios. In this scenario, the area of built-up land expands by 1.5×10^4 km^2 compared to 2020, representing an increase of 1.38%. This expansion often comes at the expense of ecological resources and is based on the principle of inducing the remaining land categories to shift more towards building land. Figure 11 shows that the development centers are mainly located in the east, extending outward in a diffuse pattern, and most of the new urban land is converted from farmland. However, in Pakistan, local subsidiaries set up by foreign investors are regarded as local firms, and, in general, these subsidiaries do not need to obtain approval from the Ministry of the Interior for acquiring land, a policy that has greatly simplified the operational process of foreign firms and improved the efficiency of their investments. Over the years, the energy construction of the CPEC project has occupied half of the corridor's construction, becoming one of the fields with the largest investment, the fastest progress, and the most remarkable results, and the energy construction has also promoted the leapfrog development of Pakistan's power supply capacity and facilitated the rapid growth in the economy. The operation of rail transportation not only facilitates people's travel and increases the level of consumption, but also adds a modern atmosphere to the city. Finally, the two sides will also continue to deepen practical cooperation, focusing on promoting the construction of the CPEC, accelerating the progress of transportation infrastructure and energy projects, and steadily and solidly advancing the corridor's support of livelihood projects. Through this series of cooperation and efforts, the CPEC will bring more development opportunities and benefits to both countries.

(3) Ecological Protection Scenarios

The ecological protection scenario, as a forward-looking development model, prioritizes ecological protection over economic development to ensure the preservation of ecological resources. Under this scenario, the governments of the CPEC demonstrate their deep concern for and strong commitment to the natural environment, and through a series of policy measures and practical actions, they effectively curb the trend of ecological resource decline that could be caused by economic development. Forest land, as a vital component of the ecosystem, receives particularly prominent attention in ecological conservation scenarios. Through strict land management, afforestation, and ecological restoration projects, the area of forest land does not reduce as a result of economic construction but instead remarkably expands, with a share of 8.37%, which is a significant increase from the previous level. This not only provides a broader habitat for wildlife but also enhances the carbon sink function of the ecosystem, which is important for mitigating global climate change. At the same time, grassland, as an ecological barrier connecting unutilized land with farmland, is effectively protected and utilized under the scenario. The expansion of grasslands not only separates different types of land and reduces the risk of land degradation but also promotes ecosystem diversity and stability. The rational use of grassland resources also provides strong support for the development of the local livestock industry and promotes the prosperity of the rural economy. It is worth mentioning that Pakistan's Protected Areas Initiative has played a key role in the ecological conservation scenario. The initiative has not only identified and protected natural wonders and ecologically sensitive areas in the country but has also galvanized the young generation's enthusiasm and involvement in nature conservation. This power of social mobilization has injected new energy and hope into the cause of ecological conservation in the CPEC.

(4) Harmonized Development Scenarios

This scenario needs to consider the above three development scenarios in an integrated manner, taking into account the economy and at the same time safeguarding the ecological environment from man-made damage, so the land use changes under this scenario are more complex, and there are more frequent transitions between types of places. The development of this scenario is based on a sustainable development model in which the economy and nature coexist in harmony, compared to the natural development scenario, which requires adjusting the conversion costs of farmland to ecological land (forest land and grassland), farmland to urban land, ecological land to farmland, and ecological land to urban land. There is more farmland, forest land, and grassland compared to in the investment priority scenario, and more urban land compared to in the ecological protection scenario. This scenario is more biased towards ecological protection, but the trend is more gentle, with a lower decline in farmland, stable changes in forest land and grassland, and a rapid expansion of urban land. Therefore, this scenario balances the changes between investment, ecological protection, and natural development, and is conducive to the sustainable development of the region. In order to meet the different development approaches of the CPEC, multiple considerations were made to choose the best as a suitable development model for the region.

4. Discussion

4.1. Land Use Change in the CPEC

This study used GIS technology to explore the changes in land use types in the CPEC during the period of 2000–2020, and the results showed that the land use type transformation mainly comprised the process of the growth in construction land with the decrease in farmland and the conversion of unutilized land into grassland. Of these, the increase in built-up land amounted to 565%, with the increase being spatially distributed mainly within Pakistan, a phenomenon that is associated with multiple driving causes. First, rapid economic growth and population surges have driven urbanization and industrialization, increasing the demand for infrastructure and housing and promoting massive urban expansion [50]. The implementation of the CPEC has further exacerbated this change, especially during the construction of transportation corridors and special economic zones, where unused and farmland has been developed on a large scale for construction [51]. At the same time, rural ecological pressures brought about by climate change have led to significant urban migration, indirectly contributing to the expansion of urban land [52]. First, the large-scale infrastructure construction of the CPEC has directly led to the conversion of farmland to urban land, especially in the special economic zones and industrial parks along the route, resulting in the occupation of a large amount of farmland [51]. Second, with the acceleration of urbanization, urban expansion along the CPEC has brought about a high demand for land resources, leading to a significant reduction in the area of surrounding farmland [51–53]. Finally, the implementation of ecological restoration policies has also led to the reduction in some farmland, such as the implementation of the project of returning farmland to forest land and grassland in Kashgar [54]. The increase in forest land is mainly due to the implementation of a series of ecological protection policies. The increase in forest land in the Kashgar region is due to the implementation of a series of major ecological restoration projects such as the "Three-North Protective Forest Project" [55,56], whereas the increase in forest land area in Pakistan is due to the implementation of the "Billion Tree Tsunami Reforestation" and other nature conservation projects [57]. The increase in grassland is distributed, on the one hand, in the Sulaiman Mountains region and Brahui Range region west of the central part of the CPEC, which have been affected by global warming in recent years, with the melting of large areas of permanent snow; the increase in water sources has led to significant improvements in the local desert ecosystems, with a consequent increase in grassland [58]. On the other hand, the northern part of Pakistan is also experiencing significant grassland growth, which is closely related to the grazing management and grassland conservation policies proposed by its government [59]. The degradation of grasslands due to overgrazing has been mitigated with the strengthening of regional grazing management, which has led to the gradual restoration of degraded unutilized land to grassland. In addition, local governments have adopted a protective policy on the rational development of unutilized land, restricting the expansion of industrial land, reserving more unutilized land for ecological protection and promoting the natural recovery of grasslands [60].

4.2. Multi-Scenario Simulation of Land Use Change in the CPEC

First, although the applicability of the FLUS model has been widely verified at different scales around the world, no scholars have yet used the FLUS model in the CPEC, so its applicability in the CPEC has yet to be verified. However, this study simulated and validated the current land use status of the study area in 2020 using the FLUS model based on CPEC 2015 land use data and 13 land use change drivers selected from natural, socio-economic, and locational aspects. The results show that the Kappa validation coefficient between the simulation results and the actual results is as high as 0.88, which indicates that the simulation accuracy of the FLUS model is high, and its applicability in the CPEC is verified. It also provides a reference for future scholars who intend to use the FLUS model to explore the future change pattern of land use in the CPEC or other regions in Central Asia.

Secondly, this study realized the simulation of four different land use scenarios for 2040 in the study area using a coupled Markov–FLUS model based on the CPEC 2020 land use data. Undoubtedly, the predictive simulation of future land use changes can enable decision makers to grasp the spatial and temporal dynamics of land use under different scenarios in the future, so as to formulate reasonable land allocation strategies, effectively resolve land use conflicts, such as between agriculture and urbanization and economic development and ecological protection, and mitigate ecological and environmental risks such as land degradation and the loss of biodiversity. Specifically for this study, the land use changes under different development scenarios show a significant hierarchy: (1) In the investment priority scenario, the expansion of construction land is the most pronounced change, and the implementation of major CPEC policies continues to promote the implementation of major projects in infrastructure, transportation, and energy [61–63], leading to a significant increase in the demand for construction land, especially in regions with accelerated urbanization where farmland is converted into construction land in large quantities. In contrast, the expansion of construction land under the harmonious development scenario is more moderate and more focused on the balance between economic growth and environmental protection, especially in the geographically complex Kashgar region, where infrastructure development is more prudent, and in the central and western parts of Pakistan, where the government reduces damage to ecologically sensitive areas through coordinated development. (2) The development potential of unutilized land shows obvious differences in different scenarios, with the investment priority scenario rapidly converting unutilized land into construction land through infrastructure development, especially along the main corridors of the CPEC. In contrast, the harmonious development scenario focuses on the orderly development of unutilized land and the enhancement of regional ecological services through ecological projects such as forest land and grassland restoration to balance economic and ecological needs. (3) In terms of the changes in farmland, the most drastic changes farmlandare found in the investment priority scenario and the ecological protection scenario, with the former resulting in large-scale conversion of farmland into urban land, due to infrastructure construction, and the latter occupying farmland due to the implementation of ecological restoration projects. In contrast, the harmonious development scenario maintains stable farmland, and the changes in land use are relatively mild. In terms of forest land change, there are significant increases under the ecological conservation scenario and the harmonious development scenario, and forest land in Kashgar will rely on government planning and natural restoration driven by China's strong ecological restoration policy [64,65], while west-central Pakistan will continue to curb land degradation through ecological restoration projects and reforestation; similar considerations were made in the studies by Chen et al. [66] and Aziz [67] on land use change in Pakistan. (4) Grassland increases in all four scenarios, especially in the ecological protection and harmonious development scenarios, where conversion of unused land to grassland under climate change will continue to drive the increase in the area of grassland. Although forest restoration takes away some of the grassland, causing the increase to flatten, the overall trend is positive and still increasing. The trend of future grassland changes in the CPEC is confirmed in the studies of Bi et al. [68] and Fu et al. [69]. (5) The area of water bodies shows a small increase in all four scenarios, and further development of agriculture and industry in the CPEC in the future will inevitably lead to an increase in water demand responses, which in turn will drive the construction of water storage facilities such as reservoirs. The increase in reservoirs, which serve critical functions such as flood control, power generation, and irrigation in arid regions, also coincides with future demand in the study area [70]. In addition, several reservoir construction projects are involved in the CPEC cooperative program, further supporting the region's need for water resource management [71]. In summary, the harmonious development scenario demonstrates a more ideal balance between infrastructure construction, economic development, and ecological protection, resulting in a sustainable land use pattern. This study provides a scientific basis for land management through multi-scenario simulations, helping decision makers to make more informed choices between economics and ecology and demonstrating that protecting ecosystems and maintaining farmland stability while promoting economic growth is key to achieving long-term sustainable development.

The above analysis suggests that the region will experience rapid socio-economic growth with the advancement of the CPEC construction, including in infrastructure, improved transportation networks, and population growth [61,72]. This will lead to an increased demand for food, housing, and energy, among other things, which in turn will exacerbate conflicts over urban land, farmland, and forest land [57,67]. Expansion of urban land may compress farmland and threaten food security, while the reduction in ecological land is detrimental to environmental quality. In the future, the CPEC construction should enhance the efficiency of land resource utilization by increasing technical inputs and implementing projects in key areas of cooperation, such as agriculture, thereby alleviating the land use conflicts faced by the study area in the course of development [73]. However, neglecting ecological protection may have a negative impact on long-term sustainable development. Overexploitation will reduce ecological space and the number of ecosystem services, thereby exacerbating climate change [57,67]. In order to balance the economy and the environment, it is necessary to strengthen ecological protection policies and promote the restoration of forest land and wetlands to ensure the sustainable development of the CPEC [71].

4.3. Research Limitations and Future Perspectives

First, this study quantitatively analyzes the past, present, and future land use status and its changing trends in CPEC. However, it does not further investigate the driving mechanisms behind them, which may lead to a lack of in-depth understanding of the underlying causes of land use change and thus limit policy makers from formulating more scientifically sound management measures. Considering that land use change is jointly influenced by a variety of driving factors (e.g., economic, social, environmental, policy, etc.), and there are often complex feedback relationships between these factors [74]. In the future, we can consider introducing a system dynamics model, which can reveal the key linkages and influence paths between the driving factors by studying the causal relationships and feedback loops in the complex system [75]. This will provide a scientific basis for understanding the intrinsic mechanisms of land use change and at the same time provide a reference for policy makers to make decisions under different development scenarios, to balance the conflict between economic development and environmental protection, and to ensure the sustainable utilization of land resources.

Second, this study is dominated by a top–down macro perspective, focusing on regional-scale land use change simulations, and lacks a consideration of individual decision-making behaviors and local interactive processes. This shortcoming limits, to some extent, the application of research results in guiding the development of specific industries and optimizing land use efficiency. To compensate for this limitation, future research could introduce an agent-based model (ABM) to explore the micro driving mechanisms behind land use change through a bottom–up approach. The ABM model is able to simulate the behavior and decision-making process of individuals (e.g., farmers, firms, local governments, etc.) under different policies, market conditions, and environmental changes, and it can thus capture the cumulative impacts of these micro behaviors on the macro land use pattern [76].

Finally, this study fails to effectively incorporate the long-term impacts of climate change and extreme weather events into land use patterns. As global climate change intensifies, the CPEC is likely to face greater uncertainty in both ecological and agricultural production [77]. Future research should further integrate climate models (e.g., CMIP) or climate scenario analyses into land use simulations to improve the accuracy of predicting land use changes under extreme climatic conditions and to provide more forward-looking recommendations for decision makers.

5. Conclusions

Based on the multi-period land use data of the CPEC from 2000 to 2020, this study firstly systematically analyzed the land use changes in the CPEC from 2000 to 2020 based on GIS technology and secondly simulated the land use pattern of the CPEC in 2040 in a multi-scenario manner by using the Markov-FLUS model. The main conclusions obtained from this study are as follows:

(1) The land use types in the CPEC from 2000 to 2020 were mainly dominated by farmland, forest land, and grassland. In terms of land use quantity changes, urban land, forest land, and grassland showed an increasing trend, while farmland, unutilized land, and water area land types showed a decreasing trend. In terms of land use transfer changes, the most transferred land was unutilized land, which was mainly converted to grassland, concentrated in the mountainous areas of central and western Pakistan.

(2) The FLUS model was used to simulate the current land use status of the CPEC in 2020, and the results showed that the simulation accuracy was as high as 0.88, indicating that the FLUS model has a strong applicability in the CPEC.

(3) The multi-scenario simulation of land use found that the urban land expansion is most obvious in the investment priority scenario, while the harmonious development scenario focuses on balancing economic growth and ecological protection, with changes in unutilized land, farmland, and forest land all showing significant scenario differences. Overall, the harmonious development scenario strikes a better balance between infrastructure development, economic development, and ecological protection, and it can provide a scientific basis for the future land management of the CPEC; it highlights the importance of promoting economic growth and ecological protection and ultimately realizing sustainable development.

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