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RESEARCH ARTICLE

An equilibrium analysis of the land use structure in the Yunnan Province, China

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Abstract Global land use structure is changing rapidly due to unceasing population growth and accelerated urbanization, which leads to fierce competition between the rigid demand for built-up area and the protection of cultivated land, forest, and grassland. It has been a great challenge to realize the sustainable development of land resources. Based on a computable general equilibrium model of land use change with a social accounting matrix dataset, this study implemented an equilibrium analysis of the land use structure in the Yunnan Province during the period of 2008–2020 under three scenarios, the baseline scenario, low TFP (total factor productivity) scenario, and high TFP scenario. The results indicated that under all three scenarios, area of cultivated land declined significantly along with a remarkable expansion of built-up area, while areas of forest, grassland, and unused land increased slightly. The growth rate of TFP had first negative and then positive effects on the expansion of built-up area and decline of cultivated land as it increased. Moreover, the simulated changes of both cultivated land and built-up area were the biggest under the low TFP scenario, and far exceeded the limit in the Overall Plan for Land Utilization in the Yunnan Province in 2020. The scenario-based simulation results are of important reference value for policy-makers in making land use decisions, balancing the fierce competition between the protection of cultivated land and the increasing demand for built-up area, and guaranteeing food security, ecological security, and the sustainable development of land resources.

Keywords land use, land use structure, computable general equilibrium model of land use change, social accounting matrix, scenarios, Yunnan Province

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1 Introduction

Global land use structure has undergone unprecedented changes because of human land use activities (Foley et al., 2005). Land use change has always been an important topic of research on regional environmental change, especially since the implementation of Land Use/Cover Change (LUCC) and Global Land Project (GLP) policies (Turner and Meyer, 1991; Veldkamp and Fresco, 1996; Lambin et al., 2001; Liu et al., 2002; Verburg et al., 2006c; Long et al., 2007; Levasseur et al., 2012). Land resources are of great importance to the provision of diverse ecosystem services (Zhao et al., 2004; Metzger et al., 2006). More and more attention has been paid to the extensive change of ecosystem service functions resulting from land use change. However, due to the rapid development of economy and urbanization, a large proportion of fertile cultivated land has been transformed into built-up area. Meanwhile, with the fast population growth, more and more forest and grasslands are reclaimed for cultivation in order to guarantee food security (Liu et al., 2003; Bender et al., 2005; Liu et al., 2010). Because of limited land resources and increasing human demands for land, land use competition among economic development, social development, and environmental protection efforts results in great changes in land use structure (DeFries et al., 2007; Carreño et al., 2012).

This kind of fierce competition takes place in many places of the world and has potentially undermined the capacity of ecosystems to sustain food production, maintain freshwater and forest resources, and regulate climate and air quality (Yan et al., 2009). In addition, it has caused many ecological problems, such as soil degradation (Zhao et al., 2005) and biodiversity reduction (Foley et al., 2005; Pauleit et al., 2005; Wang et al., 2005; Falcucci et al., 2007; Zhang et al., 2010; Wu et al., 2012). Obviously, it is still a key challenge to optimize land use structure, balance the trade-offs among fierce land use competitors, and to guarantee food security, ecological security, and the sustainable development of land resources (Lassoie and Sherman, 2010).

According to research on the key mechanisms behind land use change, the dominant long-term factor is the natural environment, while the dominant short-term factors are socioeconomic (Deng et al., 2008). In view of the current rapid socioeconomic development in China and elsewhere, researchers have studied the influence of socioeconomic factors on changes of land use structure (Verburg et al., 1999; Long et al., 2007; Xu et al., 2007; Figueroa et al., 2009). Land use change modeling is a well-accepted method for simulating and optimizing land use structures and for providing reference information for decision-makers (Verburg et al., 2006a). Currently, there are various models of land use change, including empirical and statistical models, agent-based models, cellular automata (ABM/CA) models, and computable general equilibrium models of land use change (CGELUC).

The CLUE-S (Conversion of Land Use and its Effects at Small regional levels) model is a typical example of an empirical and statistical model and is one of the most widely used land use change models (Overmars and Verburg, 2006; Verburg et al., 2006b, c; Overmars et al., 2007; Luo et al., 2010). However, simulations with this model are based on the historical trends of parameters, which may not surely reflect future dynamics. Meanwhile, owing to the presence of several interacting factors in land use, the ABM/CA model is appropriate for predicting land use change based on the temporal and spatial analysis of these factors (Parker et al., 2003; Grimm et al., 2005; Tian et al., 2011). However, it is difficult to characterize the rules behind different decision-making processes of land-use planning or land use practices.

The CGELUC model is different from the empirical and statistical model because it is a mechanism-based model which considers the computable general equilibrium. By studying the coupling relationship between socioeconomic factors and structural changes in land use, this model is advantageous in simulating any structural changes that are triggered by exogenous shocks, such as governmental policies and technical progress (Deng et al., 2012). With the CGELUC model, Deng (2011) simulated and predicted regional land use change under different scenarios in the Jiangxi Province from 2010 to 2020. Lin et al. (2013) elaborated the theory of the CGELUC model and calibrated the model in a case study of the Jiangxi Province. The results showed that the overall simulation accuracy reached 77.68%, while the simulation accuracy for forest reached 86.87%, which demonstrated that the CGELUC model was suitable for simulating regional land use change.

The overall goal of this study was to depict the land use competition among economic development, social development, and environmental protection efforts in the Yunnan Province with the CGELUC model. The remainder of this paper is organized in the following sections. In the second section, the general situation of the Yunnan Province is introduced; then data sources, the compilation of the social accounting matrix (SAM), scenarios design, and the CGELUC model are described one by one. The simulation results are reported in the third section, and the explanations of the results are reported in detail in the fourth section. The final section presents our conclusions.

2 Materials and methods

2.1 Study area

Located in southwestern China (between 97°32′39″E–106°11′47″E and 21°8′32″N–29°15′8″N; see Fig. 1), the Yunnan Province has a total area of 3.83×10^5 km^2 and a population, in 2007, of 45.14 million. It can be seen in Table 1 that forest, cultivated land, and grassland account for the majority of the total land area in the Yunnan Province, while water area, built-up area, and unused land account for a small percentage of the total land area. During 2002 to 2007, cultivated land, grassland, unused land, and water area in Yunnan Province decreased, while forest and built-up area increased continuously. This trend was closely related to the Grain for Green Program and to rapid urbanization.

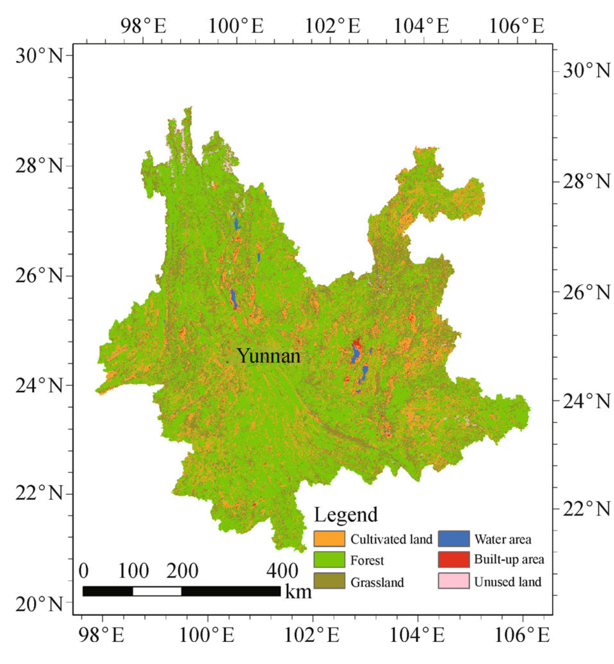

Fig. 1 Location and land use structure of the Yunnan Province in 2008.

Table 1 Land use area (km^2) in the Yunnan Province in 2002, 2005 and 2007

Year	Cultivated land	Forest	Grassland	Water area	Built-up area	Unused land
2002	78,379	228,271	51,088	5,424	9,300	10,732
2005	77,442	229,566	50,589	5,423	9,561	10,613
2007	77,190	229,820	50,291	5,387	9,964	10,542

Note: The data were calculated from the Land Use Change Survey Report of the Yunnan Province after reclassifying the land use types in the report into the six land use types in the SAM.

Highland accounts for 94% of the total land area in this province, and only 6% is relatively flat land suitable for cropping. Therefore, the overall quality of cultivated land in this province is relatively low. In addition, a large proportion of high-quality cultivated land in the dammed area has been occupied by built-up area. Soil erosion in the Yunnan Province is severe; according to the Overall Plan for Land Utilization for the Yunnan Province (2006–2020), from 1997 to 2005, cultivated land degraded by soil erosion reached 53 km^2 every year, accounting for more than 10% of the total decreased amount of cultivated land. In 2010, climate change led to extreme droughts and resulted in a sharp decrease in food production. The limited area of high-quality cultivated land, soil erosion, and extreme drought together threatened food security in the province as well as in the rest of China. This underscores the need for the protection of cultivated land in the dammed areas of the Yunnan Province.

The ecological environment in the Yunnan Province is quite fragile since there are frequently geological disasters such as landslides and debris flows, in addition to severe water and soil losses, rock desertification, and deterioration of water quality. The Yunnan Province is an important part of the southwestern forest area and has the second-largest natural forest area in China. The forests in this province play an important role in maintaining biodiversity and serve as an ecological security barrier in the southwest of China. A large proportion of cultivated land was gradually converted into built-up area due to rapid urbanization, followed by the conversion of large areas of forest and grassland into cultivated land. Although a series of policies regarding the return of farmland to its natural state were implemented in recent years, the quality of forest resources still remains very low. Grassland, the majority of which was native pasture, has degraded very seriously due to overgrazing. Therefore, it is urgent to protect forests and grasslands in order to enhance sustainable development for regional economies and guarantee regional and national ecological security.

There has been rapid socioeconomic development in the Yunnan Province, with the gross domestic product (GDP) increasing by 2.59 times and the population increasing by 8.5% from 2000 to 2010 (Table 2). It is assumed that the total population will reach 50.62 million in 2020, which will inevitably result in a very high demand for built-up area. Meanwhile, the “Develop the West” Strategy in China aims to accelerate construction in the Yunnan Province and develop it into the bridge connecting Southeast Asia and South Asia with China, which consequently makes it necessary to implement more road construction and hydroelectric development. As a result, the increasing demand of new infrastructure construction for land resources and energy will exert even more pressure on the local land and make it more difficult to meet the demands for built-up area.

It is evident that there is an increasingly strong contradiction between policies aiming at the protection of forest, grassland, and cultivated land areas, and the rigid demands for built-up area resulting from population growth, economic development, urbanization, industrialization, and infrastructure construction. Therefore, the current structural change of land use in the Yunnan Province is characterized by competition among forest/grassland, cultivated land, and built-up area. The challenge of balancing this competition must be addressed quickly. Consequently, it is of great importance to consider ecological security, food security, and the development demands of urbanization and industrialization in strengthening the optimization of land use structure and guaranteeing the sustainable development of land resources.

2.2 Data sources

To compile the SAM for the Yunnan Province in 2002, the land use data in 2002 and 2007 were collected from the Land Use Change Survey Reports of the Yunnan Province in 2003 and 2008, and the area dataset of the Yunnan Province in 2008 with more specific land use classifications, which was released by the Land and Resources Department in the Yunnan Province. The relevant socioeconomic data were also collected, including the IO (Input-Output) table of the Yunnan Province in 2002, with some complementary data from the 2003 Yunnan Statistics Yearbook and the 2003 Financial Yearbook.

2.3 Methods

The methods used to optimize and predict the land use structure in the Yunnan Province can be described in the following three main steps: 1) Compilation of the SAM dataset, including the land resources account, social development account, and environmental protection account, which together serve as the basis for running the CGELUC model; 2) Future scenarios design; 3)

Table 2 Socioeconomic parameters of the Yunnan Province

Socioeconomic parameters	Year		
	2000	2005	2010
GDP/(billion CNY)	201.12	347.29	722.42
Population/($\times 10^4$)	4,240.80	4,450.40	4,601.60
Proportion of urban residents/%	23.36	29.50	34.81
Ratio of primary industry/%	21.47	19.29	15.34
Ratio of secondary industry/%	41.43	41.26	44.62
Ratio of tertiary industry/%	37.10	39.46	40.04

Data source: Yunnan Statistics Yearbook in 2001, 2006 and 2011.

Table 3 The simplified framework of SAM

	Activity	Factor	Institution	Tax	Investment	Rest of world	Social development	Environment protection
Activity	Matrix A							
Factor								
Institution								
Tax								
Investment								
Rest of world								
Land Resource	Matrix B						Matrix C	Matrix D

Note: Matrix A in this table refers to the traditional part of SAM, Matrix B refers to the land demand of economic development, Matrix C indicates the land demand of social development, and Matrix D indicates the land demand of environmental protection. The shaded part has no data.

Simulation of the land use structure in the Yunnan Province from 2008 to 2020 applying the CGELUC model.

2.3.1 Compilation of the SAM in the Yunnan Province in 2002

The SAM has been widely used as the basis of the Computable General Equilibrium (CGE) model, the construction of which facilitates the calibration of the model. However, traditional SAM approaches have often failed to include land resource accounts and the relationship between structural changes in regional land use and socioeconomic behaviors. An extended SAM dataset including land resources, social development, and environmental protection accounts was developed in order to quantify the contribution of land resource allocation to social development, economic development, and environmental protection, and to provide an integrated database for calibrating the CGELUC model. The simplified framework of the SAM is presented in Table 3. It consists of two parts, the first part is the traditional SAM component (Matrix A), which represents the entire economic operation process including production, allocation, consumption, and accumulation during a certain period. The second part describes the land resources used for production activities in the socioeconomic system (Matrix B), social development (Matrix C), and environmental protection (Matrix D). A more specific description of the compilation of this particular SAM is provided in the subsequent part of this paper.

In this study, the traditional part of the SAM integrated the production activities of 42 departments into three categories of industries, primary, secondary, and tertiary. Factor accounts included the labor account and capital account, and institution accounts included the household account and government account. The government account was further subdivided into the direct tax account, indirect tax account, and tariff account, in order to analyze the effects of different government taxes on the structural change of land use in the CGELUC model more specifically. In addition, the investment account and the rest of the world account were also incorporated into the SAM, and therefore this part of the SAM contained 12 accounts. In the compilation process of the SAM in 2002, the IO table of the Yunnan Province in 2002 was used as the basis of the matrix. Data for most accounts were directly obtained from the IO table, including production activity accounts and factor accounts. Transfer payments among accounts, taxes, investments, and other data for the rest of the world account were obtained from the Statistical Yearbook and Financial Yearbook of the Yunnan Province in 2003. Other data that were not directly available were integrated into the matrix based on the principle that the row and column subtotals were equal in the SAM.

In the land resource allocation part of the SAM, the land resource accounts were classified into six accounts on the basis of land use type, (cultivated land, forest, grassland, water area, built-up area, and unused land). Since the total demand for land resources was composed of the land demands of economic development, social development, and environmental protection, the social development and environmental protection accounts were also included in the SAM. In this study, the land demand of economic development was defined as the land demand driven by consumption demands for commodities and services; the land demand of social development referred to public land, such as land for military installations, embassies and consulates, religious institutions, prisons, and cemeteries; the land demand of environmental protection was primarily comprised of the natural reserves, ecological engineering, etc.

The data for different types of land used for production activity, social development, and environmental protection were obtained on the basis of the land use status in the Yunnan Province in 2002. Before the compilation of the land resource allocation component of the SAM, the land use classifications in the Land Use Change Survey Report were first reclassified into the six land use types in the SAM (Table 4) according to the definitions of land use types in the 2002 national land classification of China. The area of the six land use types in 2002 generated with this approach (Table 1) were then allocated to the relevant accounts as follows. All of the cultivated land belonged to the primary industry account. With respect to the forest, grassland and water area, the primary industry account included timber production forests and economic forests, pastureland, and water areas for fisheries. The remaining part was allocated to the environmental protection account. Agricultural built-up land and rural residential areas in built-up areas were allocated to the primary industry account; special use areas belonged to the social development account; industrial land, salt fields, and land for water conservancy facilities were occupied by the secondary industry account; and traffic land was allocated to the tertiary industry account. The remaining land, namely urban areas, was allocated to the secondary and tertiary industry accounts based on the proportions of employees in these two industries. A part of the SAM in the Yunnan Province in 2002 is presented in Table 5.

2.3.2 Design of future scenarios

Total factor productivity (TFP), an indicator of technical progress, is one of the fundamental driving forces of economic development. TFP was used as an exogenous shock variable in the computable general equilibrium model in many studies (Ianchovichina et al., 2001; Das et al., 2005; Otto et al., 2008). To study the contribution of technical progress to land use structure, three scenarios, the baseline scenario, high TFP scenario, and low TFP scenario, were designed in this study to simulate the changes of land use structure in the Yunnan Province corresponding to different levels of growth rate of TFP.

The baseline scenario assumed that the growth rate of TFP remained at the average level during the period 2000–2008. The high and low TFP scenarios assumed that the growth rate of TFP was two standard deviations (of the 2000–2008 TFP) higher or lower than the growth rate of TFP under the baseline scenario, respectively.

2.3.3 The CGELUC model

The CGELUC model was used to simulate the dynamics of land demand from economic development, social development, and environmental protection efforts on the basis of three hypotheses: 1) the structural changes in land use were driven by the land demands in the region; 2) in terms of area, the total land supply equaled the total land demand, which consisted of the land demands from economic development, social development, and environmental protection; 3) water area was assumed to be constant in this study since water area mainly depended on the precipitation and the amount of available upland water and varied seasonally, and the influence of human activities was usually not significant.

The CGELUC model was introduced to optimize the land use structure, with the goal of maximizing the overall land use efficiency through the appropriate allocation of land resources in order to meet the land demands of economic and social development as well as environmental protection (Lin et al., 2013). The simulation framework of the structural dynamics of land use in the Yunnan Province on the basis of the CGELUC model is displayed in Fig. 2. The core equations of the CGELUC model are listed in the following section.

Eq. (1) depicts the maximization of overall land use efficiency (in terms of utility), and Eqs. (2)–(4) depict the land use utility functions for social development, economic development, and environmental protection.

$$\max\ U = {U_{\mathrm{soc}}}^{\alpha}{U_{\mathrm{eco}}}^{\beta}{U_{\mathrm{ent}}}^{\gamma}, \tag{1}$$

$$U_{\mathrm{soc}} = \sum\nolimits_i R_i SocA_i, \tag{2}$$

$$U_{\mathrm{ent}} = \sum\nolimits_i r_i EntA_i, \tag{3}$$

and

$$U_{\mathrm{eco}} = \prod\nolimits_j X_j^{\omega_j}, \tag{4}$$

where U is the total land use utility; U_{soc}, U_{eco}, and U_{ent}, respectively, denote the land use utility for social development, economic development, and environmental protection; $SocA_i$ and $EntA_i$ denote the areas of land use type i for social development and environmental protec-

Table 4 Reclassified land use types for the equilibrium analysis of land use structure

Land-use types in the 2002 national land classification of China			Reclassified land use types in SAM
Class one	Class two	Class three	
Farmland	Cultivated land		Farmland
	Garden plot		Forest
	Forest		Forest
	Pastureland		Grassland
	Other farmland	Land for animal husbandry	Built-up area
		Land for agricultural facilities	Built-up area
		Rural road	Built-up area
		Pond	Water area
		Water area for aquaculture	Water area
		Land for irrigation and water Conservancy	Water area
		Paths through fields	Farmland
		Grain-drying area	Built-up area
Built-up area	Residential area and industrial land	City	Built-up area
		Town	Built-up area
		Rural residential area	Built-up area
		Industrial land	Built-up area
		Salt field	Built-up area
		Special use area	Built-up area
	Traffic land		Built-up area
	Land for water Conservancy facilities		Built-up area
Unused land	Unused land	Native grassland	Grassland
		Other unused land	Unused land
	Other lands		Water area

Table 5 SAM of the Yunnan Province, denoting land resource accounts in 2002

		Activities			Social development	Environmental protection
		Primary industry	Secondary industry	Tertiary industry		
Commodities/(100 million CNY)	Primary industry	107.25	142.74	14.54	0	0
	Secondary industry	116.21	1,198.85	344.49	0	0
	Tertiary industry	66.31	385.31	361.27	0	0
Land resources/km^2	Cultivated land	78,379	0	0	0	0
	Forest	31,901	0	0	0	196,370
	Grassland	7,848	0	0	0	43,240
	Built-up area	5,797	1,764	1,395	344	0
	Water area	964	0	0	0	4,460
	Unused land	0	0	0	0	10,732

tion, respectively; X_j is the demand for the j^{th} product; α, β and γ are the utility weight values; R_i, r_i, and ω_j are the transition parameters.

In Eq. (4), the land use utility for economic development depends on the product quantity and consumption types. Meanwhile, the product output, which is related to the product quantity for consumption, is dependent on the quantity of factors, including the land factor for economic

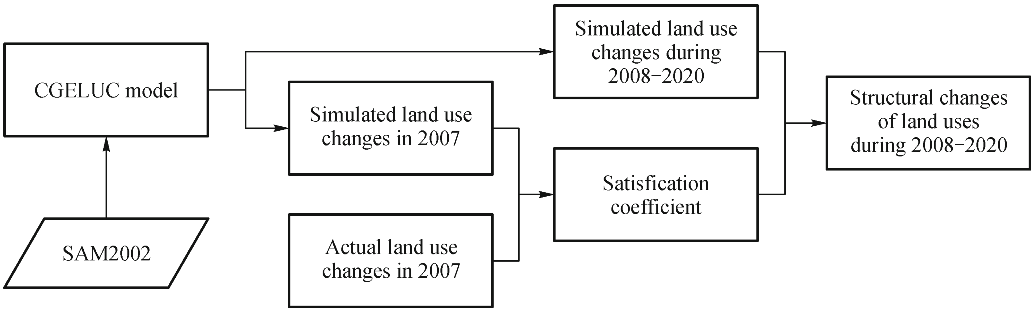

Fig. 2 Simulation framework of the structural changes in land use in the Yunnan Province on the basis of the CGELUC model.

development, as shown in Eq. (5).

$$P_j = (\sum_i EcoA_{ij})^{\eta_j} Lab_j^{\mu_j} Cap_j^{\nu_j}, \quad (5)$$

where $EcoA_{ij}$, Lab_j, and Cap_j denote the area demand for the i^{th} land type and the labor demand and capital demand in the production of product j, respectively; η, μ, and ν are the production weight values.

Next, we calculated the total land demand (in terms of area) of different land use types (A_i) using Eq. (6). The sum of these areas equals the total land area in the region (A), as indicated in Eq. (7).

$$A_i = SocA_i + EntA_i + \sum_j EcoA_{ij}. \quad (6)$$

$$A = \sum_i A_i. \quad (7)$$

The final change in demand of the i^{th} land use type (DA_i) can be expressed with Eq. (8):

$$DA_i = A_i - a_i, \quad (8)$$

where a_i refers to the area of the i^{th} land use type during the initial period.

Given the fact that not all demands with regard to land use change can be met in reality, a satisfaction coefficient of land use change was calculated based on the final land demand change and the actual change in area in the initial period with Eq. (9). Next, we used this coefficient to predict the land use change in the subsequent period.

$$\delta_i = RA_{i0}/DA_{i0}, \quad (9)$$

where RA_{i0} is the actual change in area of the i^{th} land use type in the initial period; DA_{i0} is the final demand in the change of area of the i^{th} land use type in the initial period.

3 Results

The structural changes in land use in the Yunnan Province during the period 2008–2020 were predicted under different scenarios with the CGELUC model (Fig. 3). The results are presented in the sections below.

3.1 Structural changes in land use under the baseline scenario

Under the baseline scenario, the land use changes in the Yunnan Province were found to vary significantly among different land use types. The amount of cultivated land was predicted to decrease year by year. The simulation result indicated that the area of cultivated land would have decreased by 287.06 km^2 by 2015, with an annual change rate of –0.046%, and the area of cultivated land would have decreased by 468.16 km^2 by 2020, with an annual change rate of –0.047%. The proportion of cultivated land was predicted to be steady at around 20% from 2008 to 2020 in the Yunnan Province. The forest area was predicted to increase by 38.68 km^2 from 2008 to 2015 and 24.4 km^2 from 2016 to 2020, with an annual growth rate of 0.002%. The grassland area would demonstrate a slight increase, with an annual growth rate of 0.001% during the period 2008 to 2020. The built-up area presented a substantially increasing trend, with an increase of 234.46 km^2 and 147.92 km^2 from 2008 to 2015 and from 2016 to 2020, respectively, with an annual growth rate of 0.294%. With respect to unused land, the annual growth rate was predicted to be 0.1%.

3.2 Structural changes in land use under the high TFP scenario

Under the high TFP scenario, the area of cultivated land in Yunnan Province would decrease year by year, with a decrement of up to 598.15 km^2 by 2015 and 1,028.65 km^2 by 2020, decreasing by 0.103% every year on the average. In contrast, the simulation result indicated that forest area would increase by 80.59 km^2 and 58 km^2 from 2008 to 2015 and from 2016 to 2020, respectively. As the annual growth rate was quite small, the proportion of forest area in the Yunnan Province was predicted to remain at around 60%. The changing trend of grassland area was less obvious, with the total grassland area predicted to decrease

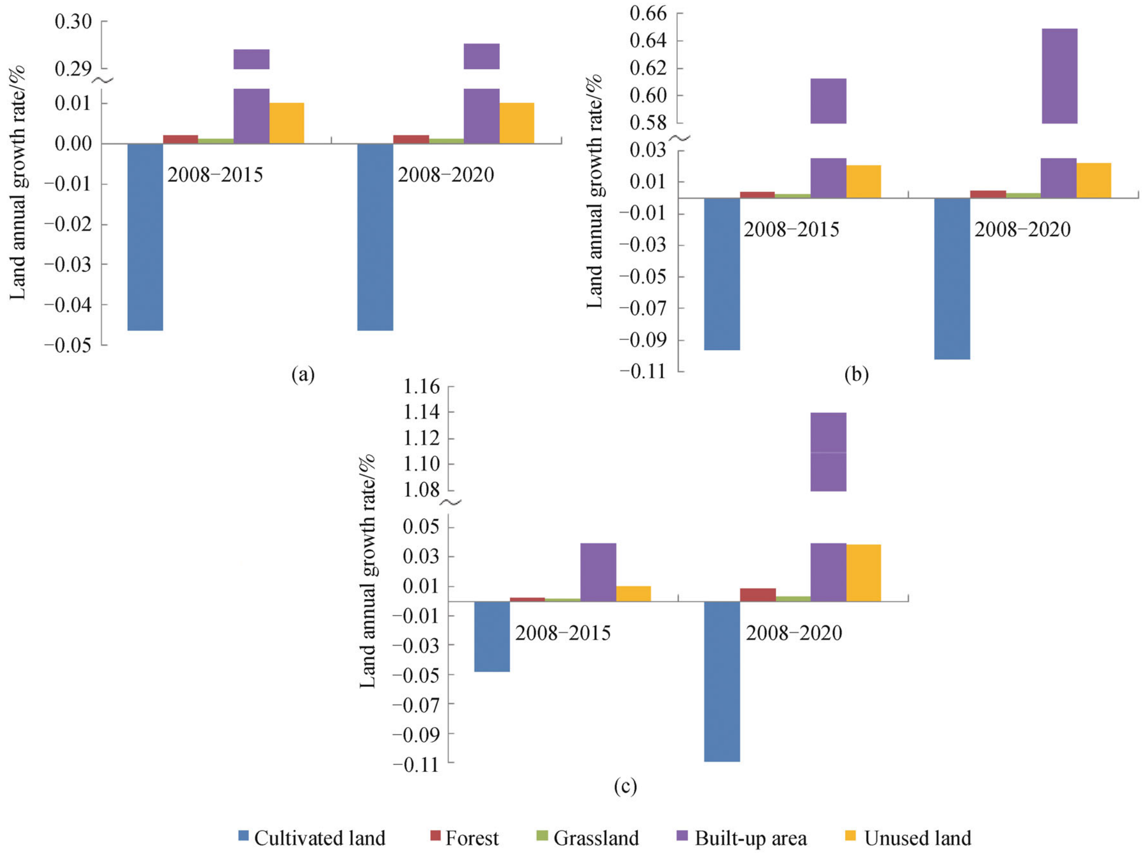

Fig. 3 Annual growth rates of the area of different land use types in the Yunnan Province during the periods. 2008–2015 and 2008–2020 under different scenarios: (a) baseline scenario; (b) high TFP scenario; (c) low TFP scenario.

by merely 11.43 km^2 from 2008 to 2015, and 8.23 km^2 from 2016 to 2020, respectively. However, the result indicated that the built-up area would exhibit substantial growth, increasing by 488.55 km^2 from 2008 to 2015 and 351.62 km^2 from 2016 to 2020, with an annual growth rate of 0.649%. Unused land would show a less evident trend, with an annual growth rate of only 0.022%.

3.3 Structural changes in land use under the low TFP scenario

The simulation result indicated that there would be significant heterogeneity in the changes of area of different land use types under the low TFP scenario. Cultivated land would still show a decreasing trend, with a predicted decrement of 1809.98 km^2 and an annual change rate of −0.18% from 2008 to 2020. This result suggested that the cultivated land area would decrease by 297.93 km^2 from 2008 to 2015 and by 1512.05 km^2 from 2016 to 2020. Forest area was predicted to exhibit a slightly increasing trend, with an annual growth rate of 0.009% on the whole and an increment of 40.14 km^2 from 2008 to 2015 and 216.52 km^2 from 2016 to 2020, respectively. The grassland area would show no significant change, with an increment of only 5.69 km^2 from 2008 to 2015 and 17.3 km^2 from 2016 to 2020, respectively. On the other hand, the change of the built-up area was predicted to be significant, with an annual growth rate of 1.14%. By 2020, the built-up area would have increased by 1476.99 km^2. The simulation result indicated that the proportions of built-up area would account for 2.66% and 2.99% of the total land area in 2015 and 2020, respectively. By comparison, there would be no obvious change in the area of unused land, the proportion of which was predicted to remain almost unchanged during the period 2008–2020.

4 Discussion

4.1 Comparative analysis of the land use structures under different scenarios

In this study, the CGELUC model was used to optimize and predict trends in the land use structure in the Yunnan Province from 2008 to 2020 under three scenarios. This equilibrium analysis was performed on the basis of maximization of total land use utility, which comprised the land use utilities for economic development, social development, and environmental protection. Before that, a comparison was made between the simulation results under the baseline scenario and actual land use change in the Yunnan Province from 2002 to 2005. The results showed that the simulation accuracies all reached above 65%, while the simulation accuracy for cultivated land reached 83.40%, which proved that the CGELUC model met the demand of simulation accuracy (Table 6).

The comparison of the simulation results of the land use change trends under different scenarios indicated that a remarkable decline in the area of cultivated land and an increase in the built-up area under all the three scenarios are common. The same tendency was found in Japan during 1950–2006 and in the central Arizona – Phoenix region of the United States during 1912 to 1995 (Himiyama, 1998; Jenerette and Wu, 2001; Yoshida et al., 2012). This result indicated that no matter what level the TFP was, economic development was always a necessity for rapid urbanization and rapidly increasing urban populations, and cities had to supply land suitable for the construction of production facilities, residential areas, and other infrastructures, which would undoubtedly promote an increase in the demand for built-up area. To meet this demand, cultivated area would have to be converted into built-up area. Besides, the simulation result also indicated there would be a slight increase in the proportions of forest, grassland, and unused land under all three scenarios. Land allocated for environmental protection, including part of the forest, grassland, and unused land, would play an important role in promoting the total land use utility.

The simulation results also indicated that there were obvious differences in structural changes of land use under different scenarios, especially the degree of decrease of cultivated land area and the consequent increase of the area of built-up land. For example, the decrease of cultivated land and increase of built-up area under the baseline scenario was much less than that under the other two scenarios. The growth rate of TFP had a negative effect on the expansion of built-up area and decline of cultivated land under all the three scenarios at first. However, as the growth rate of TFP increased, the effect turned out to be positive at last. Under the low TFP scenario, the growth rate of TFP was low, which indicated there was very limited contribution of technical progress to economic growth. Besides, since the mode of economic development in the Yunnan Province was very extensive, it led to the demand for more input of built-up area under the low TFP scenario, and consequently, a large amount of cultivated land was inevitably converted into built-up area.

Under the baseline scenario, as the growth rate of TFP increased, technical progress exerted an increasingly positive effect on economic development, and consequently, there was less increase of built-up area and less decline of the area of cultivated land. Under the high TFP scenario, as the growth rate of TFP further increased, the extensive economy was transformed into an intensive economy and would embrace faster development. Overall, on one hand, the input of built-up area for production would decrease due to the technical progress; and on the other hand, the rapid economic development would promote the acceleration of urbanization, and consequently a large proportion of the rural population would turn into urban population, which would lead to the conversion of a lot of cultivated land into built-up area for infrastructures and recreation.

4.2 Comparative analysis of land use structures between the simulation results and the Overall Plan for Land Utilization

In the Overall Plan for Land Utilization in the Yunnan Province (2006–2020), the local government outlined the planned land use changes during 2006–2020. This study made a comparative analysis of the projected land use structure in 2020 between the official plans and the simulation results. Since the land use types in the Overall Plan for Land Utilization were different from that in this study, they were first integrated into the six land use types mentioned above.

It was apparent that the simulated changes of both cultivated land and built-up area under the low TFP scenario far exceeded the limit in the plan, and so did the decline of cultivated land under the high TFP scenario (Table 7). Besides, according to the simulation results, the loss of cultivated land and increase of built-up area would be the largest under the high TFP scenario in 2015 and under the low TFP scenario in 2020. So the potential risk of food security under the low TFP scenario was the greatest in the long term. Anyway, economic development is a necessity for the coming decades in China, as was the case in the Yunnan Province. However, if the growth rate of TFP is low, there will be limited contribution of technical progress to economic development. Extensive economic and social development would lead to the blind expansion of the production scale, followed by a sharp increase of the demand for built-up area, and as a result

Table 6 Comparison between the simulation change under the baseline scenario and actual change in the Yunnan Province from 2002 to 2005

	Cultivated land	Forest	Grassland	Built-up area	Unused land
Actual change	–937.00	1295.00	–499.00	261.00	–119.00
Simulated change	–772.1	862.3	–347.9	336	–78.3
Deviation/%	17.60	–33.41	30.28	28.74	34.20

Table 7 Comparison of projected land use changes between the CGELUC simulation and official plans in 2020 (km^2)

	Simulation results			Planned changes
	Baseline scenario	High TFP scenario	Low TFP scenario	
Cultivated land	– 468.16	– 1,028.65	– 1,809.98	– 921
Built-up area	382.38	840.17	1476.99	1323

there will be high potential risks to food and ecological security.

Therefore, to settle the fierce competition between the protection of cultivated land and the rigid demand for built-up area and to guarantee the sustainable development of land resources in the long term, it is crucial for decision-makers to increase the growth rate of TFP and enhance the contribution of technical progress to economic development in the Yunnan Province.

5 Conclusions

Changes in the land use structure in the Yunnan Province over the period 2008 to 2020 were analyzed with the CGELUC model on the basis of a SAM dataset under three scenarios, the baseline scenario, high TFP scenario, and low TFP scenario. The SAM included land resources, social development, and environmental protection accounts, which helped to investigate the competition among different land use types and to optimize the land use structure through maximizing the total land use utility for economic development, social development, and environmental protection.

The simulation results showed that under all three scenarios, the area of cultivated land declined significantly along with a remarkable expansion of the built-up area, while the area of forest, grassland, and unused land increased slightly. In addition, the growth rate of TFP had first negative and then positive effects on the expansion of built-up area and decline of cultivated land as it increased. Moreover, the simulated changes of both cultivated land and built-up area were the biggest under the low TFP scenario, and far exceeded the limit in the Overall Plan for Land Utilization of the Yunnan Province in 2020. Results for the Low TFP scenario indicated that in the long run, the potential risks to food security and ecological security were the highest due to the low growth rate of TFP and extensive economic development.

From the above simulated results, in order to guarantee food security, ecological security, and the sustainable development of land resources in the long run, it is crucial for decision-makers to increase the growth rate of TFP, to enhance the contribution of technical progress to economic development, and to ensure intensive economic development in the Yunnan Province. In addition, since the decline of cultivated land was the common trend across all three scenarios, while the Yunnan Province was always an important granary of China, strict protections should be given to the cultivated land in the dammed area in order to guarantee food security. Then, to meet the rigid demands for built-up area, policy-makers can make full use of the plentiful mild slope of low mountains and hills in the Yunnan Province, exploit them rationally, and expand new spaces for built-up area. In conclusion, policy-makers are advised to increase the growth rate of TFP and enhance the contribution of technical progress to economic development, to exploit the plentiful mild slope of low mountains and hills in the Yunnan Province rationally, and to expand new spaces for built-up area in order to balance the fierce competition between efforts to protect cultivated land and the rigid demand for built-up area, and to guarantee food security, ecological security, and the sustainable development of land resources in the long term.

This case study in the Yunnan Province suggested that the CGELUC model based on a SAM dataset was a useful tool in optimizing the land use structure. However, there are still several limitations in this study. First, the compilation of the SAM dataset was based on the IO table, which was usually provided only at the provincial level, and therefore limited in its application at lower geographical or geopolitical levels. Secondly, during the compilation process of SAM, production activities were integrated into three categories, primary industry, secondary industry, and tertiary industry; the production activities could be further divided into more specific departments depending on their degrees of influence on the land use structure if additional data are available. In addition, the relationship between the land use structure and production activities can be characterized more accurately. Future studies may apply the CGELUC approach at levels below the provincial level, such as the county level, and thereby classify production activities more accurately.

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