Chapter 6 Simulation of Structural Change in Land Use in Jiangxi Province Using the CGELUC Model

Structural change in regional land use is both a cause and component of regional environmental change and a response to regional environmental change, and has therefore been a concern of the academic community. Structural changes in regional land use driven by socioeconomic factors have been a particular focus of research (Greenberg et al., 1998; Seto et al., 2000; Weinstoerffer and Girardin, 2000; Krausmann et al., 2003; Yue et al., 2005). Socioeconomic factors come from different socioeconomic sectors, and their impacts on structural changes in regional land use intertwine. Existing models and methods such as conversion of land use and its effects at small regional extent (CLUE-S) (Verburg et al., 2002), cellular automata (Stevens and Dragicevic, 2007; Dawn et al., 2008), and ABM (Fontaine and Rounsevell, 2009; Polhill, 2009) have provided a good foundation for the study of regional environmental change. However, there is no research that explores structural change in regional land use with the interactive and joint effects of the various socioeconomic factors from a whole system perspective (Haberl et al., 2001; Liu et al., 2002; Kerr et al., 2003; Haberl et al., 2003; Seto and Kaufmann, 2003).

Land is a basic production factor and an important means of macroeconomic regulatory control, and is closely related to economic behavior and government policies. The Computable General Equilibrium of Land Use Change (CGELUC) model quantifies the relationship between these different factors. The CGELUC model is an equilibrium analysis model of land use change based on the theory of computable general equilibrium analysis. Using economic theory, the CGELUC model retrieves the coupled relationship between industrial development and structural changes in land use by conducting an equilibrium analysis. The model also quantitatively represents the relationship between regional development and land use change, and studies laws of the structural change in regional land use caused by regulatory policies. The CGELUC model links the factor market, commodity market and land use with the land rent and forms an equilibrium system covering multiple markets and sectors to simulate and provide scenario forecasts of structural change in regional land use.

X. Deng, *Modeling the Dynamics and Consequences of Land System Change*

Jiangxi Province is an important commodity grain production base in China, and is in the process of rapid economic development and gradually accelerated urbanization. The province has also converted cultivated land into forestry and grassland to improve conservation. Therefore, the land system change in Jiangxi Province mainly includes the processes of agricultural production, and conversion from cultivated land to built-up areas, forestry and grassland. In this chapter, we mainly explore how the land use structure changes in Jiangxi Province, what factors affect it and explanations of the driving mechanisms. Another consideration is that approximately 97% of Jiangxi Province is part of the Poyang Lake watershed, which is one of the world's important wetlands and an ecological protection area, so this study is also of significance to global ecological and environmental protection.

6.1 Design of the SAM in Jiangxi Province

The Social Accounting Matrix (SAM) is the basis of the CGELUC model. Compiling the SAM of Jiangxi Province mainly involves accounting for the GDP cash flow (income distribution), national income, total social supply and demand, and land use changes.

6.1.1 Overview of Jiangxi Province

Jiangxi Province is located in the southeast of China, on the southern bank of the lower reaches of the Yangtze River. The project *Returning Land for Farming to Forestry* began in 1999 and the percentage of forestry land use has reached 60% to date in the area between 24°29′ and 30°04′ N and 113°34′ and 118°28′ E. Jiangxi Province has a total area of 166 900 km^2 and had a population of 44 million in 2008. Jiangxi Province is surrounded by mountains to the south, east and west, and is relatively flat to the north. The central part of the province is hilly, and the whole terrain resembles a huge basin leaning to Poyang Lake in the north. There are more than 2 400 rivers in Jiangxi Province, including five major rivers: the Gan, Fu, Xin, Xiu and Rao rivers, making Jiangxi Province an ideal location for river transportation.

Jiangxi Province is bordered by Zhejiang and Fujian provinces to the east, Guangdong Province to the south, Hunan Province to the west, and Hubei and Anhui provinces to the north. The province adjoins the Yangtze River, and is a hinterland of the Yangtze River Delta, the Zhujiang River Delta and the Fujian Delta. The distances to crucial cities and ports in Shanghai, Guangzhou, Xiamen, Nanjing, Wuhan, Changsha, Hefei and other cities are generally between 600 and 700 km. There are 2 206 km of highways in Jiangxi Province, and the main routes into the province are all major highways.

Jiangxi has a sound ecological environment and rich resources. Jiangxi

Province is an important commodity grain production base and is in the process of rapid economic development and gradually accelerated urbanization. In addition, the conversion of cultivated land to forestry and grassland has been carried out to improve environmental conservation in the process of economic development. Therefore, the land use change in Jiangxi Province mainly includes the processes of agricultural production, and the conversion of cultivated land to built-up areas or forestry and grassland.

6.1.2 Compilation of the SAM in Jiangxi Province for 2007

The SAM is the basis of the CGELUC model. The SAM for Jiangxi Province required for the CGELUC model includes GDP cash flow (income distribution), the use of national income, total social supply and demand, and land use and land cover change. In the process of compiling the SAM for Jiangxi Province, the IO table for Jiangxi Province in 2007 is used as the basis, while the national economic equilibrium account is used as the standard when there is inconsistency between data from different sources, since the data in the national equilibrium account is relatively precise as it comes from annual statistical reports.

In compiling the SAM, the row and column data for the "activities", "commodity" and "elements" accounts were directly obtained from the IO table. Data related to land use conversion and land factors were mainly acquired from comparisons between 1:100 000 remote-sensing land use survey data of Jiangxi Province in 2001 and 2007. Tax, transfer payments between accounts, savings, and other data between accounts in other parts of the world were obtained from the *Statistical Yearbook of Jiangxi Province* in 2008 and the statistical data, related economic surveys and census data released by relevant departments. Other data that cannot be obtained from statistical reports can be obtained by calculations based on the principle that the row and column subtotals in the SAM are equal.

The structure of the SAM for Jiangxi Province in 2007 used in the CGELUC model is presented in Table 6.1. Given that the CGELUC model is used to simulate structural changes in regional land use under certain economic development conditions, it is necessary to include accounts related to changes in land use types and land use structure in the configuration of production activity module, the commodity module and the factor module in the compilation of the relevant SAM. These accounts are assigned corresponding values and included in the regional socioeconomic activities so that the structural change in regional land use caused by changes in different land use types, with different prices, during different periods and under different scenario hypotheses can be modeled.

Table 6.1 Policy variables included in the environmental protection scenario for land use changes in Jiangxi Province

Policy variable	Year	Amount
Discounted subsidy for returning cultivated land (yuan/ha)	2010	2 589
	2015	2 859
	2020	3 273
Cultivated land with gradient over 15 degrees (%)	2010	0.36
	2015	0.29
	2020	0.24

6.1.2.1 Structure of the SAM of Jiangxi Province

(i) Production activities

Using the IO table with 42 sectors in Jiangxi Province in 2007 and with reference to the national economy sector classification and code tables (GB/T47542007), the SAM for Jiangxi Province in 2007 used in the CGELUC model includes a total of 46 production sectors. These 46 production sectors are:

- Agriculture, forestry, animal husbandry and fishing (#1);
- Coal mining and dressing (#2);
- Petroleum and natural gas mining (#3);
- Metallic mining (#4);
- Non-metallic mining (#5);
- Food manufacturing and tobacco processing (#6);
- Textile manufacturing (#7);
- Garment leather, eider down and related products production (#8);
- Wood processing and furniture manufacturing (#9);
- Paper printing and stationery (#10);
- Petroleum processing, coking and nuclear fuel processing (#11);
- Chemical industry (#12);
- Non-metallic mineral products industry (#13);
- Metal smelting and rolling processing (#14);
- Metal products industry (#15);
- General and special equipment manufacturing (#16);
- Transportation equipment manufacturing (#17);
- Electrical, machinery and equipment manufacturing (#18);
- Communications equipment, computers and other electronic equipment manufacturing (#19);
- Manufacture of measuring instruments and machinery for cultural activity and office work (#20);
- Other manufacturing industries (#21);
- Waste scrap (#22);
- Electricity, heat production and supply (#23);
- Gas production and supply (#24);
- Water production and supply (#25);
- Construction industry (#26);

- Transportation and warehousing (#27);
- Postal and telecommunication services (#28);
- Information transmission, computer services and software industry (#29);
- Wholesale and retail trade (#30);
- Accommodation and catering (#31);
- Finance and insurance (#32);
- Real estate (#33);
- Leasing and business services (#34);
- Tourism (#35);
- Scientific research business (#36);
- Comprehensive technical services (#37);
- Other social services (#38);
- Education (#39);
- Health, social security and social welfare sector (#40);
- Culture, sports and entertainment (#41);
- Public administration and social organizations (#42);
- Cultivated land conversion (#43);
- Economic forestry conversion (#44);
- Grassland conversion (#45);
- Other types of land use conversion (#46).

(ii) Commodities

The classification of commodities was conducted in the same way as the classification of production activities described above. The compilation of the SAM for Jiangxi Province in 2007 is based on the assumption of the "pure sector", i.e., production activities and commodities correspond directly to each other and a particular production activity produces only one type of commodity.

(iii) Factors

The factors are divided into labor, capital and land. As we have used the CGELUC model to simulate the structural change in land use in Jiangxi Province, it is necessary to explicitly discuss the conversions of various types of land use in the model, rather than simply divide the land into four categories: cultivated land, economic forests, grassland and other types of land use.

(iv) Institutions

Institutions are divided into three categories: residents, businesses and government.

(v) Others

The other accounts mainly include the capital account and account of other regions in the world.

6.1.2.2 Data Process for the SAM of Jiangxi Province

The most important task is to enter the economic statistical data in the appropriate place in the SAM table after developing the basic account structure. Entering the data is one of the most complex and difficult tasks in the process of compiling the SAM. The data sources and handling processes in the sub-matrixes involved in the SAM table are discussed below based on the account structure described above.

The SAM compiled in this chapter is based on the GDP accounts for Jiangxi Province in 2007, but the data sources can be inconsistent when comparing data from the IO table with the GDP accounts in Jiangxi Province, for two main reasons. First, financial services are handled in different ways. In the IO table, the resident consumption includes the virtual consumption of financial services, but in the national accounts, the services of the financial sectors are treated as intermediate inputs and not included in the residents' final consumption. Second, tariffs are handled in different ways. In the IO table, import tariffs are included in value of the imports as intermediate inputs for various sectors, and the import accounting corresponding to commodities in other regions of the world also includes tariffs, which are used to offset the tariffs of imports consumed in the intermediate input. Therefore, the IO table needs amending as there are fewer parts in its final use section than in the accounting of annual regional GDP. Additionally, because there are a few accounts associated with land conversion in the accounts of the SAM for the CGELUC model, the calculated results will be bigger than the annual regional GDP accounting data with corresponding statistical data added in the revised IO table. Therefore, the IO table needs to be adjusted in the following ways to obtain a more accurate SAM table for Jiangxi Province in 2007.

(i) Adjustment of financial accounts

Data related to residents' final consumption in the "financial" sector needs to be added into the intermediate inputs of various sectors in proportion with the intermediate consumption of financial products in various departments as a framework, so that the residents' final consumption of products from the "financial" sector becomes zero. It is necessary to subtract the corresponding data from the "operation surplus" counted in the added value to maintain the equilibrium of the IO table.

(ii) Adjustment of tariffs

The import tariffs of intermediate inputs in the various departments need to be removed from the IO table and added into the "net tax on production" of added value. Similarly, it is necessary to add the corresponding tariffs into the "import" columns to balance the IO table. In other words, the columns of import tariff data for each sector according to relevant statistical information of "foreign economic trade" in *Statistical Yearbook of Jiangxi Province* in 2008 need to be identified, the calculation method for the import tariff rate and corresponding import tariffs for the year is combined, and the import tariff matrix based on the structure of intermediate inputs of products in the IO table is obtained. Next, the import tariff matrix is subtracted from the intermediate input matrix in the IO table, and the import tariff data for each sector are subtracted from the columns of imports. Finally, the import tariff data for each sector are subtracted from the net taxes on production.

(iii) Adjustment of land use Conversion account

The land use Conversion account is a unique feature of the CGELUC model, and the adjustment of this account directly influences the accuracy and reliability of the simulation results. The intermediate input section solves the problem of accounting for intermediate inputs in the land use conversion process and the amount of land conversion needed for the production of other sectors. The amount of land conversion inputs in the production activities of various sectors in Jiangxi Province in 2007 can be obtained by comparing the 1:100,000 remote sensing land use survey data for Jiangxi Province in 2001 and that in 2007. Furthermore, the intermediate inputs in land use conversion activities can be obtained by comparing the relevant data from the *Statistical Yearbook of Jiangxi Province* in 2007 and 2008.

The added value section needs to consider the total investment in various land factors. The land factors are included as part of the fixed capital, which satisfies the condition that the sum of the adjusted depreciation of fixed assets and total investment in land factors and business surplus equals the total fixed asset depreciation in the original IO table. The input land area can be directly obtained from the statistical yearbooks; the corresponding land price is estimated by incorporating the benchmark land prices and parcel land prices based on relevant rules and regulations in the *Interim Procedures of Prices of State-owned Urban Land in Jiangxi Province.*

The following sections explicitly explain the data sources in the submatrixes of the SAM based on the adjusted IO table of Jiangxi Province in 2007. The balance sheet of the constructed SAM is shown in Appendix 2.

Activities × Commodities: 46 × 46 matrix. The SAM established here is based on the "pure sector hypothesis", so the matrix is a diagonal matrix. The data in this section is obtained from the total outputs in the *Statistical Yearbook of Jiangxi Province* in 2008 as the total amount control data using the ratio of the outputs of each sector and the total output in the IO table as the structure.

Commodities × Activities: 46 × 46 matrix. This represents the intermediate inputs for each commodity. The total amount of intermediate inputs in the capital flow table of Jiangxi Province (1998–2007) is used for the control data, which are disaggregated using the intermediate inputs of the adjusted IO table of Jiangxi Province in 2007 as the structure.

Commodities × Residents (or Commodities × Government): 46 × 1 matrix. This shows the residents' (or government's) consumption of various commodities and land use conversions. To conveniently address the issue, it is assumed that the residents' (or government's) consumption of various commodities and land use conversions are reflected in the intermediate input section, and the direct consumption is zero. The residents' (or government's) consumption of various commodities is redistributed proportionately based on data from the adjusted IO table and combining the total amount of the residents' (or government's) consumption (the real object commodity exchange) from the capital flow table of Jiangxi Province (1998–2007).

Commodities × Capital: 46 × 1 matrix. This matrix records the sum of the fixed capital generating in the production processes of various commodities and stock changes. It is obtained by the correct adjustment of data in the IO table using the total savings amounts at home and abroad in the funds flow table for Jiangxi Province (1998–2007) as the control data and the total amount of generating capital in the adjusted IO table for Jiangxi Province in 2007 as the structure.

Commodities × other regions in the world: 46 × 1 matrix. This matrix records the exports of different commodities. Here the sum of exported land use conversion is set to be zero as land use conversion generally happens at a regional scale. The export sums for all commodities are mainly sourced from the relevant statistical data in *Statistics Yearbook of China Customs* and statistical data on "foreign economic trade" in the *Statistical Yearbook of Jiangxi Province* in 2008. It is noted that the export data in the IO table for Jiangxi Province in 2007 uses the producer price, which is obtained from the conversion of the free on board (FOB) prices with the conversion coefficients. However, the SAM used in the CGELUC model requires FOB prices. Therefore, before entering the relevant data in the SAM, we calculated conversion coefficients for exports from Jiangxi Province in 2007 by combining the relevant data in *China's Customs Statistical Yearbook*, then depreciating the export data with the export conversion coefficients obtained previously to determine the export amount calculated with the FOB price. The sum of imported and exported commodities in the "Foreign Economic Trade" section in the *Statistical Yearbook of Jiangxi Province* in 2008 was used as the control data, and was disaggregated after combining the converted export structure in the IO table.

Labor × Activities: 1 × 46 matrix. This represents the payment the labor factors obtained from production activities in different sectors and land use conversion processes. The payments involved here cannot be obtained directly from the relevant statistics because land use conversion takes place among various sectors of the CGELUC model. This sub-matrix data are generally entered by splitting payment of the labor factor input into the production activities in other sectors when compiling the SAM for Jiangxi Province in 2007. First, the intermediate input in the IO table before and after adjustment is compared and the proportion of commodities input into different land conversion activities by various sectors to the total intermediate input is calculated. The proportion of the payment mentioned above is then subtracted from workers' payments in each sector respectively based on the proportion, and this is added to the workers' payment for land use conversion. Finally, payment of the labor factor in the SAM can be obtained by disaggregating the statistical sum of "employment and wages" in the *Statistical Yearbook of Jiangxi Province* in 2008 and combining the workers' payment item in the revised IO table.

(Capital + land use types) × Activities: 5 × 46 matrix. The adjustment method for the corresponding items in the IO table has been described in detail above. This sub-matrix is obtained by a simple adjustment using the sum of the capital gains obtained from the national economic accounting data as the structure.

Resident × labor: workers' payment. This matrix is obtained by summarizing the calculation results of the "Labor × activity" sub-matrix.

Resident × investment: residents' investment income. This includes the income from individuals and family businesses. In national accounting, the household sector is also a production account, the scope of which includes the production activities of farmers and individual business households. This item can be calculated based on "net business income" and "family business income" from the "average cash income and expenditure of urban household per month per person (2007)" and "country resident income and composition" in the *Statistical Yearbook of Jiangxi Province* in 2008 and combining the rural and urban population in "households and population (from 1978 to the end of 2007)".

Resident × (Corporation + Government): 1 × 2 matrix. This represents the sum of regular transfers and property expenditure by enterprises and the government to residents. The data come from surveys of urban and rural residents in the *Statistical Yearbook of Jiangxi Province* in 2008. The transfer payments from the government to residents mainly include: government pension and social welfare benefits of 992.79 million yuan[①], social security benefits expenditure of 3.217 87 billion yuan, policy-related subsidy expenditure of 1.152 59 billion yuan and administrative institution pensions of 1.303 99 billion yuan.

Resident × other regions in the world: regular transfers from other regions in the world to residents. This matrix is obtained from the "average cash income and expenditure of urban household per person per month (2007)" and "income and composition of rural household" in the *Statistical Yearbook of Jiangxi Province* in 2008 and incorporates the SAM balance theory.

Government × Activity: 1 × 46 matrix, representing the net amount of production tax. This sub-matrix is obtained by further adjusting the corresponding data items in the adjusted IO table in a similar way to the adjustment of worker payments because the land use conversion activities also need to pay some production tax.

Government × Commodities: import tariffs. If the import tariff on land use conversion is set at zero, the tariffs on other commodities can be adjusted with reference to the adjustments in the IO table described previously.

Government × Resident: the direct tax on residents including regular transfers such as individual income tax and social security contributions. Personal income tax is acquired from the "local revenue" in the *Statistical Yearbook of Jiangxi Province* in 2008 (767.73 million yuan). Social security contributions mainly include old-age insurance, unemployment insurance, medical insurance, industrial injury insurance and maternity insurance, which are included in statistical data for "finance, banking, insurance" (3.394 96 billion

① Renminbi (RMB/¥).

yuan).

Investment × Resident: household savings. This matrix is obtained based on "balance of savings deposits of urban and rural residents (1978–2007)" in the *Statistical Yearbook of Jiangxi Province* in 2008 (27.711 13 billion yuan).

Other regions in the world × Commodities: 1 × 46 sub-matrix, representing the importation of various commodities. It is important to note that imports in the SAM refer to freight liner terms, while the IO tables use producer price. The data are adjusted using similar methods to those of the export items.

6.2 Design of the CGELUC Model for Jiangxi Province

The CGELUC model links the factor market, commodity market and land uses with the price of commodities or services produced by consuming land, and forms an equilibrium system covering multiple markets and sectors to carry out a simulation and scenario analysis of the structural change in land uses. When the marginal cost of employing one type of land use is lower than that of employing others, expansion of this type of land use will result in more benefits.

6.2.1 GAMS Operating Environment

The general algebraic modeling system (GAMS) is application-oriented mathematical programming software developed by experts of the World Bank. It is an advanced modeling language. Statements in this language are concise and easy for the model constructer to understand, which greatly improves user efficiency and extends the applications of mathematical programming techniques in policy analysis and decision-making.

6.2.1.1 Basic Characteristics of the GAMS

General principles

The design of the GAMS incorporates relational database theory and mathematical programming methods. The relational database provides a structural framework for the general data organization and transformation, while the mathematical programming provides a way to state and solve problems. The basic ideas are as follows:

- Various algorithms can be applied without changing the representation of the models, and new problem solving methods can be added without modifying the existing model;
- The statement of optimization is independent of the data used, and the separation between the logical structure and data means that increasing

the scale of a problem will not increase the complexity of the statement;
- The application of a relational data model automates the allocation of computer memory, so the user does not have to worry about memory problems for large and complex models.

Universal documents

The statement of the GAMS program makes it easily understood by both users and the computer. The program itself is the model documentation and it is very similar to conventional mathematical methods. Its features are as follows:
- The program makes full use of the precision and compactness of mathematical expressions;
- Data input and result output reports both use the most conventional methods wherever possible;
- Descriptive language is a part of the definition of the corresponding symbols, and it can be displayed simultaneously when necessary;
- A document stores all the information for the model.

Portability

The GAMS can operate in different computer environments, and model data can be conveniently converted between different types of computers and operating systems.

Open interface

The GAMS itself is just a text file without any special editing procedures or graphic input and output functions. Users can generate the GAMS procedures using their own familiar word processing tools. This open structure guarantees the compatibility of the GAMS in existing and future user environments.

Model library

The GAMS encloses a large number of formulated model programs. Users can quote the existing models or conveniently reconstruct and apply formulated technology.

6.2.1.2 Model Structure

The GAMS provides a consistent modeling environment and supports different mathematical methods and algorithms. It can handle linear, nonlinear and mixed integer optimization problems. The model is generated independently of specific algorithms, and users follow the same rules for different issues. There are three types of products in the GAMS software family.

Basic modules of the GAMS

This module contains the GAMS software language, BDMLP[1] linear planning algorithms and the GAMS model library.

Integrated systems that combine modified specific algorithms, including:

- GAMS/CONOPT provides the independent high-performance CONOPT non-linear algorithm;
- GAMS/CPLEX includes the linear and mixed integer programming algorithms of CPLEX specially modified for GAMS;
- GAMS/DICCPT can solve large-scale non-linear mixed integer programming problems with many non-linear and MIP algorithms;
- GAMS/LAMPS uses the LAMPS linear and mixed-integer algorithm;
- GAMS/LOQO is a specially modified interior-point algorithm, which is used to solve large structural problems;
- GAMS/MILES is used to solve mixed complementary problems such as non-linear complementarities and variational inequalities;
- GAMS/MINOS contains the very mature and widely used MINOS algorithm, which is specially amended to a format acceptable to GAMS;
- GAMS/MPSGE is the programming language and solving method for the economic equilibrium model;
- GAMS/OSL provides simple linear, mixed integer programming and interior-point algorithms for solving big complex problems;
- GAMS/XA is a modified version of professional linear and mixed integer programming system XA;
- GAMS/ZOOM is a mixed-integer of ZOOM and linear algorithm of XMP;

Modules connected with special solving algorithms including:

- GAMS/CPLEX LINK for calling the CPLEX program;
- GAMS/MPSX LINKT for using GAMS as a modeling system for the MPSX linear and mixed-programming algorithm of IBM;
- GAMS/OSL LINK is used to connect optimization subroutines, including linear, mixed integer and interior-point algorithms;
- RGAMS/SCICONIC LINK is used to link the linear and mixed-programming algorithms of GAMS and SCI-CONIC;

6.2.2 Structure of the CGELUC Model for Jiangxi Province

Jiangxi is an important water and soil conservation area in China, so in large forested areas, the forestry policy has an important influence on structural

[1] GAMS/BDMLP is an LP and MIP solver that comes free with any GAMS software and is intended for small to medium sized models. GAMS/BDMLP was originally developed at the World Bank by Brooke, Drud and Meeraus (1985) and is now maintained by GAMS Development. GAMS/BDMLP is running on all platforms for which GAMS is available.

changes in local land use. Therefore, the CGELUC model structure in Jiangxi Province, described below, includes the following: quantitative thematic analysis of land use, macroscopic econometric modeling, spatial variations in land use, analysis of impacts of regional agricultural policy, and scenario analysis of regional forestry policy. The relationships between these basic functional structures reflect the way socioeconomic factors drive structural changes in regional land use (Fig. 6.1).

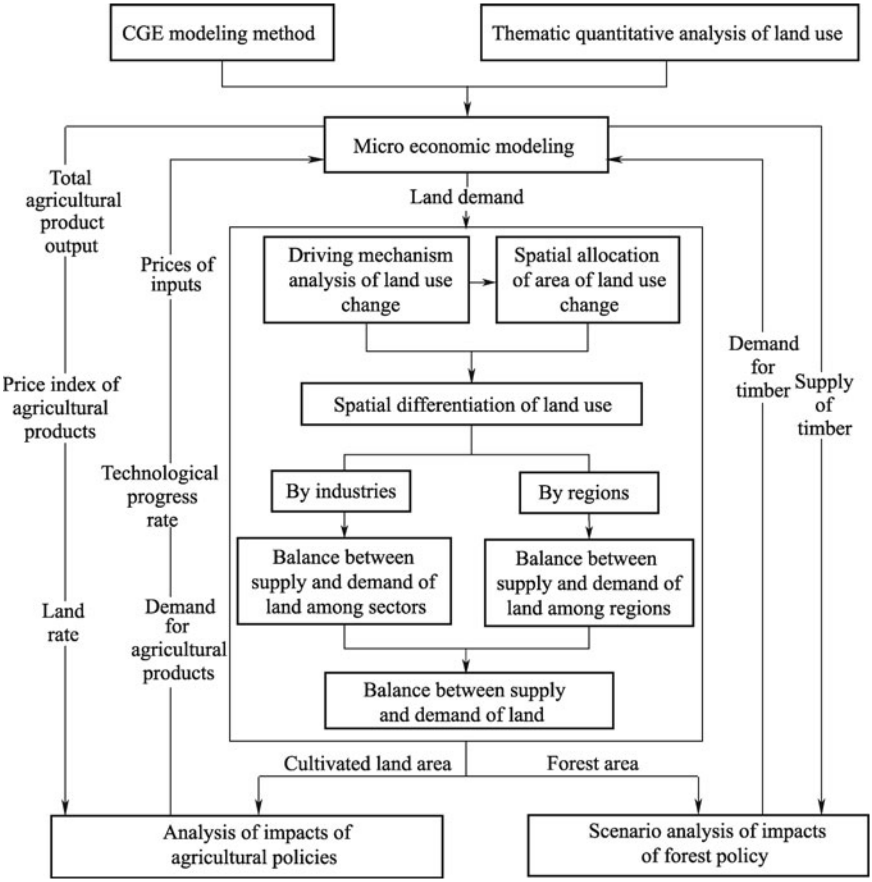

Fig. 6.1 Simulation framework of structural changes in land use in Jiangxi Province based on the CGELUC model.

The quantitative thematic analysis of land use is used to simulate the expansion of land such as urban, infrastructure, and tourism land, given a certain direction. Macroscopic econometric modeling is used to construct models by dividing the national economy into different compartments based on different research purposes, where the economic behavior in all sectors is determined by the objective function of benefit maximization. The spatial variation in land use allocates the land area of each sector onto a 1×1km grid and reintegrates the area of cultivated land and forestry, using them as input variables in the analysis of the impacts of regional agricultural policy and the scenario analysis of regional forestry policy.

The analysis of the impacts of agricultural policy in Jiangxi Province is mainly used to simulate agricultural production under the constraints of agricultural policy impact factors in Jiangxi Province. The scenario analysis of forestry policy in Jiangxi Province is used to simulate and calculate the supply of forest products in Jiangxi Province under forestry policy constraints, i.e., the percentage difference between timber demand and cut timber volumes.

The CGELUC model restrains the behavior of economic agents in Jiangxi Province with the objective function of benefit maximization in the macroscopic econometric modeling. The model calculates a new balance with a series of new parameters generating from the analysis of impacts of agricultural policy and the scenario analysis of forestry policy of Jiangxi Province, and then systematically analyzes the impacts of the implementation of agricultural and forestry policies on agricultural production in Jiangxi Province.

6.2.3 Scenario Design

Five scenarios, baseline, economic priority, environment protection, biofuel development and agricultural subsidy, were developed in this study to simulate the structure changes in land uses in Jiangxi Province under various policies.

6.2.3.1 Design of the Baseline Scenario and the Economic Priority Scenario

The baseline scenario assumes that the change in area of various land use types maintains the current trends and rate. The area ratios among cultivated land, forestry, grasslands, water areas, built-up areas and unused land are predicted on this basis (Priess et al., 2007; Cramb et al., 2009). The economic priority scenario focuses on policies for future industrial structure adjustment and technological change that will promote rapid population growth and economic development. This scenario assumes that the standard deviations of the birth rate and GDP growth rate in Jiangxi Province will double and the mortality rate will be consistent with that of the baseline scenario.

6.2.3.2 Scenario Designs for Other Policies

Scenarios under different policies are also modeled. These scenarios include: predicting the impacts on environmental protection with the return of cultivated land to forestry; biofuel development; and the implementation of appropriate agricultural subsidy strategies on the structural change in land use in Jiangxi Province from the perspectives of environmental protection, biofuel development and agricultural subsidies (Pfaff and Sanchez-Azofeifa, 2004).

The environmental protection scenario considers the impacts of returning cultivated land based on slope classification and subsidy policies for returning cultivated land on land use change. The slope information in 1 km grid land use types was extracted from the data of Jiangxi Province in 1:250 000 topographic maps, and the slope was divided into six grades: 0°, 0°–3°, 3°–8°, 8°–15°, 15°–25°, and > 25°. Land use conversion affects the areas of cultivated land, forestry and grassland, and leads to an increase or a decrease in the area of different land use types, but the final sum of the areas of these land use types must be equal to the total land area of Jiangxi Province. The national subsidy for returning cultivated land is 2 250 kg raw grain and a 300 yuan living allowance for each hectare per year in the southern provinces. The raw grain subsidy has been converted into cash based on the food price in Jiangxi Province to make calculations easier in this chapter (Table 6.1). The subsidy for returning cultivated land is set at 2 589 yuan/ha in the environmental protection scenario based on a trend analysis of food price change during the implementation process of the subsidy policy described in this research.

The biofuel development scenario mainly considers the influence of the biofuel development programs and the biofuel development subsidy on the spatiotemporal pattern of land use. The main influencing factors considered in this scenario include the subsidy for production of crops and timber, average per capita car ownership, agricultural research investment and agricultural investment (Table 6.2). The biofuel subsidy directly contributes to the increased growth of fuel crops and timber, and the 2010 subsidy for fuel production crops and timber is 447 yuan/ha in this scenario. With the improved living standard of the Chinese people, cars have gradually become popular, and the gradual increase of average per capita car ownership has also led to increased energy demands. However, non-renewable oil, natural gas and other natural energy resources are limited, and biofuel is expected to be the main energy source in the future. Changes in the average per capita car ownership are expected to affect the development of biofuel. The average per capita car ownership is set to 37.7 per 1 000 people in 2010 based on the development rate of average per capita car ownership. Biofuel technology is not yet mature, and investment in agricultural research represents the investment in

Table 6.2 Policy variables included in the biofuel development scenario for land use changes in Jiangxi Province

Policy variable	Year	Amount
Subsidy for production of fuel crops and timber (yuan/ha)	2010	447
	2015	598.5
	2020	801
Agricultural investment (100 million yuan)	2010	411.6
	2015	604.8
	2020	888.6

the development of biofuel technology, and the amount of investment determines the rate of development of biofuel technology to some extent. Agricultural investment affects biofuel technology development and also affects the development of fuel production crops and timber.

The agricultural subsidy scenario considers the impacts of national agricultural subsidies and other subsidies related to agriculture for land use change in Jiangxi Province. The main impact factors considered under this scenario are the agricultural subsidy and grain price (Table 6.3). With economic development, agricultural costs increase and the grain price falls, farmers' enthusiasm for growing crops declines rapidly, many farmers get conventional jobs, and most of the cultivated land may turn into unused land. The agricultural subsidy encourages farmers to continue growing crops and stabilizes agricultural development in Jiangxi Province, guaranteeing the grain supply in Jiangxi Province. The subsidy is estimated to be 417.45 yuan/ha in 2010 in the agricultural subsidy scenario based on the current economic development speed. The grain price is also an important factor affecting the change in area of cultivated land, as the grain price directly determines the farmers' income.

Table 6.3 Policy variables included in the agricultural subsidy scenario for the land use changes in Jiangxi Province

Policy variable	Year	Amount
Agricultural subsidy (yuan/ha)	2010	27.83
	2015	37.40
	2020	50.41
Grain price (yuan/kg)	2010	1.73
	2015	2.21
	2020	2.82

6.3 Analysis of Simulation Results of Land Use Structure in Jiangxi Province

Using the CGELUC model, we estimated the area changes in land uses in Jiangxi Province during 2010–2020 under different scenarios, which may help to explore the rules and characteristics of the structural changes in land uses affected by the different policies.

6.3.1 Land Use Change Based on Different Scenarios

The areas of the different land use types in Jiangxi Province from 2010 to 2020 are predicted, and rules and features of land use change in different scenarios are explored based on the driving mechanism analysis module of spatial heterogeneity of land use change in the CGELUC model.

6.3.1.1 Analysis of the Baseline Scenario

There is evident heterogeneity in the land use change in Jiangxi Province under the baseline scenario. The amount of cultivated land reduces each year, and the model prediction indicates that cultivated land will decrease by 278 400 ha during 2010–2020, with an annual average decrease of 27 843 ha, an annual growth rate of −0.94%. The proportion of cultivated land area is also gradually decreasing from 18% of the total land area in 2010 to 17% in 2015 and 16% in 2020. The forestry area shows a substantially increasing trend, with increases of 136 480 and 138 760 ha from 2010 to 2015 and 2015 to 2020, respectively, with an annual growth rate of 0.263%. The proportion of forestry area will increase from 62% in 2010 to 64% in 2020. By contrast, the changes in the grassland area will not be obvious. The grassland in Jiangxi Province will experience an annual average reduction of 0.10% from 2010 to 2015. The grassland will reduce by 400 ha annually on average from 2010 to 2015, and by 390 ha per year from 2015 to 2020. Predictions indicate that the water area change is minimal, decreasing by 1 180 ha from 2010 to 2015, and 1140 ha from 2015 to 2020, with an annual average rate of decrease of 0.024%. The built-up area, however, will increase each year, but the growth rate varies from 2010 to 2015, it will increase by 49 180 ha, and the increase will be 49 070 ha from 2015 to 2020, with an annual average increase rate of 1.30%. As the proportion of the built-up area in Jiangxi Province is not large, this remains at around 5% from 2010 to 2020 (Fig. 6.2).

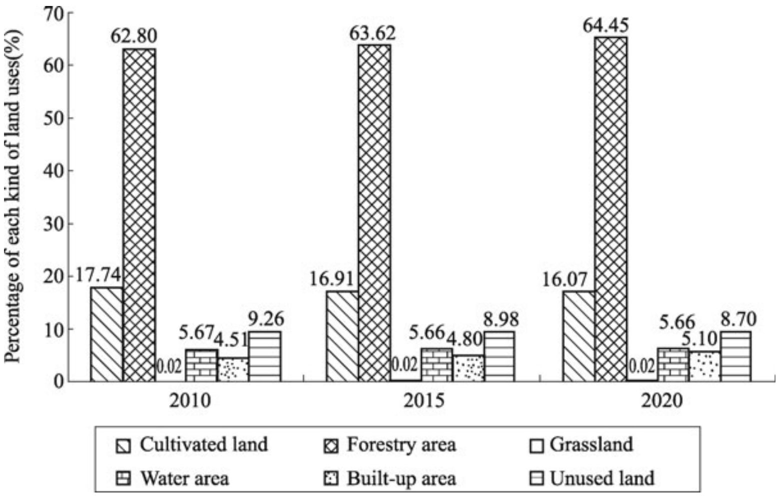

Fig. 6.2 Land use structure in the baseline scenario in Jiangxi Province in 2010, 2015 and 2020.

6.3.1.2 Analysis of the Environmental Protection Scenario

Under the environmental protection scenario, the land use change in Jiangxi Province varies significantly (Yang et al., 2009). The area of cultivated land decreases each year, with predictions indicating a reduction of 273 017 ha from 2010 to 2020, with an annual average reduction of 27 300 ha. The annual reduction rate of 0.92% means that the cultivated land area will reduce gradually, reducing by 132 650 ha from 2010 to 2015, and 140 370 ha from 2015 to 2020. Cultivated land in Jiangxi Province will account for 18% of the total land area in 2010 and 17% and 16% in 2015 and 2020, respectively. By contrast, the forestry area shows a substantial increase; predictions indicate that the forestry area in Jiangxi Province will increase by 138 620 and 136 670 ha from 2010 to 2015 and 2015 to 2020, respectively, with an annual average growth rate of 0.263%. The proportion of forestry area in Jiangxi Province will increase each year, from 62% in 2010 to 64% in 2020. However, the changing trend in grassland is less evident with an annual average decrease rate of 0.39%. Predictions indicate that the water area will reduce by 1 180 ha from 2010 to 2015 and 1 090 ha from 2015 to 2020, with an annual average decrease rate of 0.24%. The built-up area will increase each year, but the growth rate varies from 2010 to 2015, it will increase by 49 680 ha, and it will increase by 45 950 ha from 2015 to 2020, with an annual average increase rate of 1.27% (Fig. 6.3).

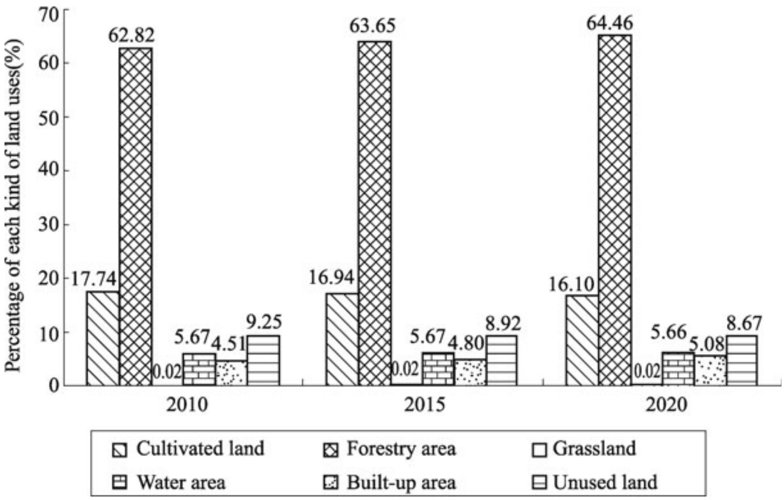

Fig. 6.3 Land use structure under the environmental protection scenario in Jiangxi Province in 2010, 2015 and 2020.

6.3.1.3 Analysis of the Biofuel Development Scenario

In the biofuel development scenario, the cultivated land in Jiangxi Province reduces each year, and predictions indicate that cultivated land will reduce by 263 016 ha from 2010 to 2020, with an annual average reduction of 26 300 ha and an annual reduction rate of 0.888%. The proportion of cultivated land will gradually reduce from 18% in 2010 to 16% in 2020. The forestry area shows substantial growth; predictions indicate that from 2010 to 2015 and 2015 to 2020, the forestry area in Jiangxi Province will increase by 238 620 ha and 179 670 ha, respectively, with an annual average growth rate of 0.399%. The proportion of land in forestry in Jiangxi Province will increase from 62% in 2010, to 64% in 2015 and 65% in 2020. The changing trend in grassland is less obvious. The grassland in Jiangxi Province will decrease with an annual average rate of 0.07% from 2010 to 2020. The grassland area will decrease by 19 ha from 2010 to 2015, and 19.2 ha from 2015 to 2020. Predictions also indicate that the water area will reduce by 3 095 ha from 2010 to 2015 and a further 2 201 ha from 2015 to 2020. However, the built-up area will increase each year, but the growth rate varies, the built-up area will increase by 50 685 ha from 2010 to 2015 and by 47 945 ha from 2015 to 2020, with an annual average rate of increase of 1.31% (Fig. 6.4).

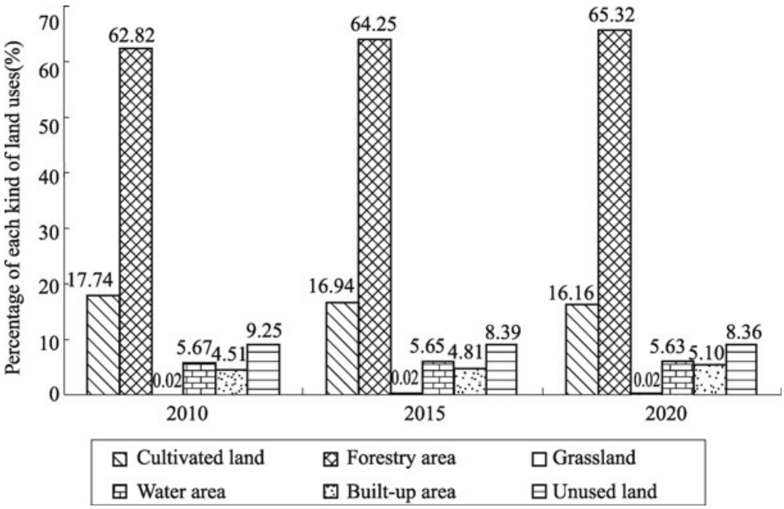

Fig. 6.4 Land use structure under the biofuel development scenario in Jiangxi Province in 2010, 2015 and 2020.

6.3.1.4 Agricultural Subsidy Scenario

Under the agricultural subsidy scenario, the cultivated land in Jiangxi Province still reduces each year, and predictions indicate that the cultivated land area will reduce by180 017 ha from 2010 to 2020, with an annual average reduction of 18 001 ha and an annual decrease rate of 0.608%. The proportion of cultivated land in Jiangxi Province is predicted to reduce gradually from 18% in 2010 to 17% in 2020. Predictions also indicate that the forestry area will increase by 92 672 ha and18 730 ha from 2010 to 2015 and 2015 to 2020 respectively, with an annual average growth rate of 0.179%. The proportion of forestry in Jiangxi Province will increase from 62% in 2010 to 63% in 2020. Changes in grassland are not apparent. Predictions indicate that the water area will reduce by 1 201 ha from 2010 to 2015 and 229 ha from 2015 to 2020, with an annual average rate of decrease of 0.024%. The built-up area will increase each year, but the growth rate gradually decreases, it will increase by 24 945 ha from 2010 to 2015 and 7 463 ha from 2015 to 2020, with an annual average rate of increase of 0.993% (Fig. 6.5).

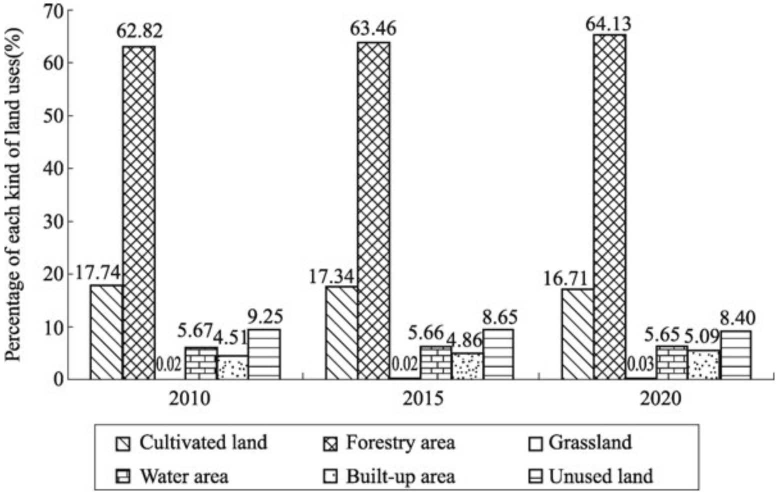

Fig. 6.5 Land use structure under the agricultural subsidy scenario in Jiangxi Province in 2010, 2015 and 2020.

6.3.1.5 Economic Priority Scenario

Under the economic priority scenario, the land use change in Jiangxi Province varies significantly. The cultivated land area decreases each year in this scenario. Predictions indicate that the cultivated land will reduce by 334 920 ha from 2010 to 2020, with an annual average reduction of 33 494 ha, and an annual rate of reduction of 1.131%. The proportion of cultivated land will gradually decline from 18% of the total land area in 2010 to 17% in 2015 and to 16% in 2020. The forestry area shows a slight growth trend; predictions indicate that the forestry area will increase by 122 640 ha and 92 640 ha from 2010 to 2015 and 2015 to 2020 respectively, with an annual average growth rate of 0.205%. The proportion of forestry area in Jiangxi Province will increase from 62% in 2010 to 64% in 2020. By contrast, the change in grassland will be slower, decreasing with an annual average rate of reduction of 0.121% from 2010 to 2020. The grassland will reduce by 126 ha from 2010 to 2015 and 120 ha from 2015 to 2020. Predictions indicate that water area will change proportionally to a lesser extent than the other land use areas.

The water area will decrease by 3 162 ha from 2010 to 2015, and 1 564 ha from 2015 to 2020, with an annual average rate of decrease of 0.049%. The built-up area will increase each year, and its growth rate will also increase each year: the annual average rate of increase in the built-up area will be 1.602% from 2010 to 2015 and 2.062% from 2015 to 2020. The built-up area is predicted to increase by 62 899 ha from 2010 to 2015 and by 89 058 ha from 2015 to 2020, with an annual average rate of increase of 1.997%. As the proportion of the built-up area in Jiangxi Province is not large, this will remain at around 5% from 2010 to 2020. The variation in unused land is significant; the proportion of the unused land area is 9% between 2010 and 2015, but by 2020, it will decrease to 8% (Fig. 6.6).

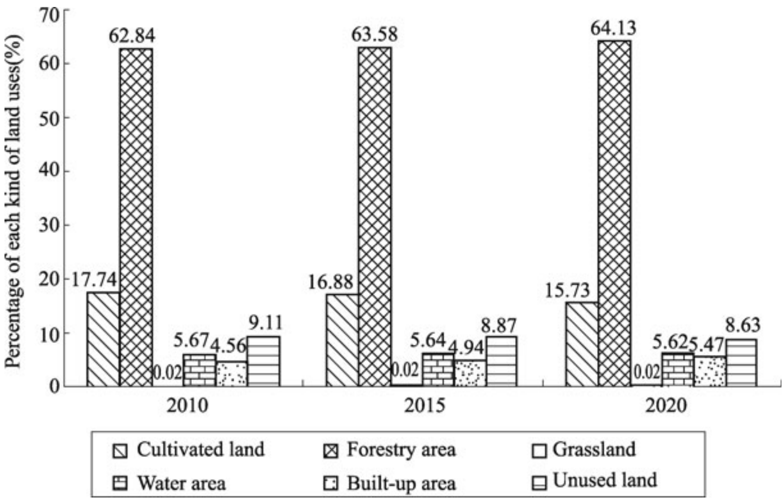

Fig. 6.6 Land use structure under the economic priority scenario in Jiangxi Province in 2010, 2015 and 2020.

6.3.2 Comparative Analysis of Land Use Structure under Different Scenarios

The predictions of land use change based on the CGELUC model reflect the rules and features of the change in various land types under different scenarios (Fig. 6.7). The cultivated land area in Jiangxi Province shows declining tendency with the results of all five scenarios, but the decrease in cultivated land is slowest under the agricultural subsidy scenario and the fastest under the economic priority scenario. Unlike the estimates of the baseline scenario, the environmental protection and biofuel development scenarios have no obvious impacts on the change in cultivated land in Jiangxi Province.

The forestry area in Jiangxi Province shows an increasing tendency with

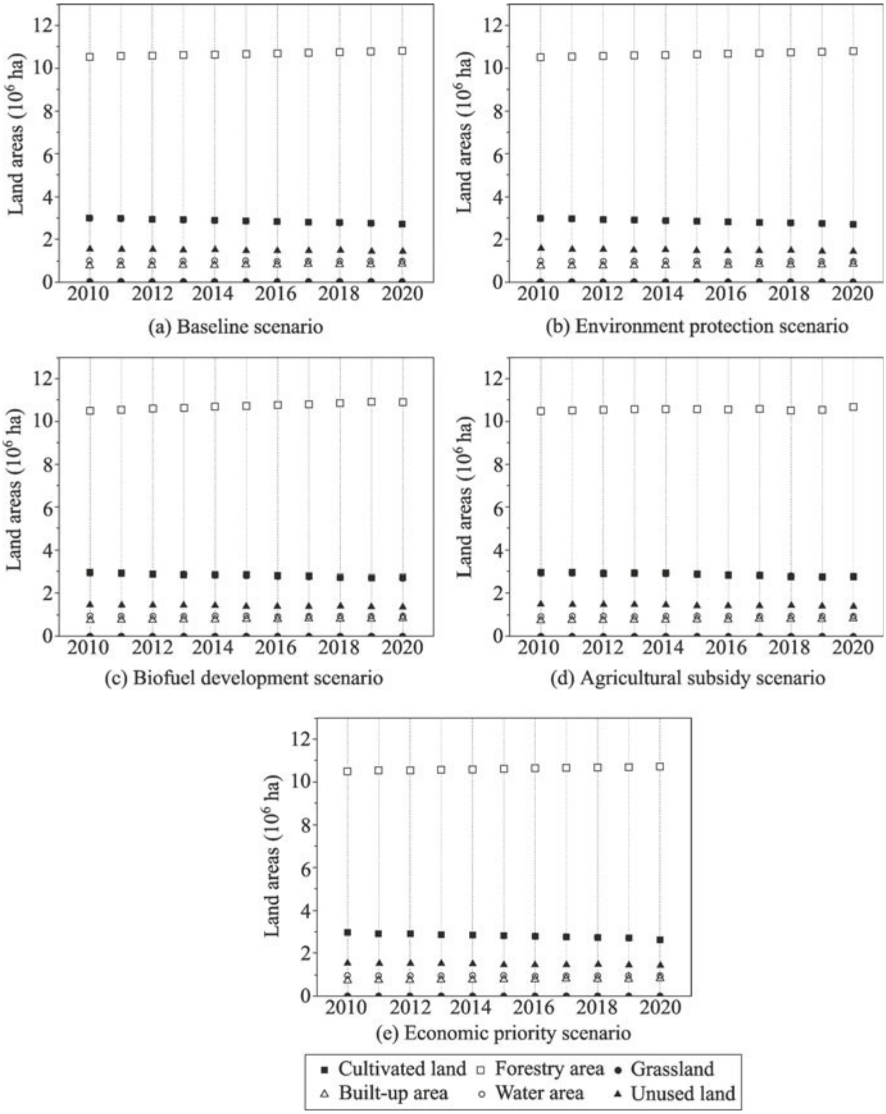

Fig. 6.7 Area change in cultivated land in Jiangxi Province from 2010 to 2020 under various scenarios.

the results of all five scenarios, and its rate of increase is highest under the biofuel development scenario and lowest under the agricultural subsidy scenario. This may be because biofuel development planning and biofuel subsidies can directly promote the growth of fuel crops, while agricultural subsidies play negative roles in promoting the conversion from cultivated land to forests (Fig. 6.7). Comparatively, the forestry area expansion in Jiangxi Province under the baseline and environmental protection scenarios is more significant than that under economic priority scenario.

The changes in grassland in Jiangxi Province are not consistent under agricultural subsidy scenario and biofuel development scenario (Fig. 6.7). Take biofuel development scenario as an instance, while experiencing a slight decline in the period of 2010–2014, the grassland area in Jiangxi Province expands rapidly during 2015–2020, which may be related to a lagged effect of policy implementation. Overall, the agricultural subsidy policy, biofuel development planning and biofuel subsidies have positive effects on the expansion of grassland in Jiangxi Province. However, the baseline, environmental protection and economic priority scenarios have no overall impacts on the grassland in Jiangxi Province. Because Jiangxi Province lies on the middle and lower reaches of Yangtze River, in southeastern China, the proportion of grassland in the total land area is relatively small, so the influence of the five different scenarios on the grassland in is less significant than for other land types.

The water area of Jiangxi Province shows a declining tendency in the results of all five scenarios (Fig. 6.7). The rate of decline is relatively low under the baseline and environmental protection scenarios and is highest under the economic priority scenario. The biofuel development and agricultural subsidies scenarios both influence the decrease in water area in Jiangxi Province.

The built-up area in Jiangxi Province shows an increasing tendency in the results of all five scenarios (Fig. 6.7). The rate of increase is fastest under the economic priority scenario, while the other four scenarios do not have significantly different impacts on the built-up area in Jiangxi Province.

In the results of all five scenarios, the unused land in Jiangxi Province shows a declining tendency (Fig. 6.7). The rate of decline is highest under the biofuel development scenario, and the policy of agricultural subsidies also has significant impacts on unused land in Jiangxi Province. The baseline, environmental protection and economic priority scenarios also cause a decrease in the unused land in Jiangxi Province. Irrespective of the scenario simulation, the change in unused land area is not significant, and perhaps related to the fact that the proportion of unused land in the total land area in Jiangxi Province is not large.

By comparing the simulation results for land use change between the different scenarios, we can determine the competition and succession laws for various land use types under different scenarios and at different temporal scales. By integrating the simulation results based on scenario design, we find that cultivated land, water area and unused land in Jiangxi Province all show declining trends in the simulation results for all different scenarios. The rate of decline for cultivated land is lowest under the agricultural subsidy scenario and highest under the economic priority scenario; the decrease in water area is comparatively slow under the baseline and environmental protection scenarios and the fastest under the economic priority scenario; the unused land decreases fastest under the biofuel development scenario and agricultural subsidies also have an obvious impact on unused land in Jiangxi

Province.

The simulation results for different scenarios can provide policy-makers with a reference for understanding how land use planning affects land use types. About 97% of the land in Jiangxi Province is part of the Poyang Lake watershed, which is a world-famous wetland and ecological nature reserve. Therefore, this research is also of global significance for ecological and environmental protection.

6.4 Summary

Simulations and scenario based predictions of the structural change in land use in Jiangxi Province using the CGELUC model were conducted, and are discussed in this chapter. Changing trends in land use structure were obtained for a baseline scenario, environmental protection scenario, biofuel development scenario, agricultural subsidies scenario and economic priority scenario from 2010 to 2020. The succession laws and competition among various land use types in Jiangxi Province over the next 10 years are also illustrated.

The simulation results show that cultivated land in Jiangxi Province presents a decreasing trend and forestry area an increasing trend in all five scenarios; the grassland has a slight increase in the economic priority scenario, and it does not change significantly in the other four scenarios; the water area presents declines slightly in all five scenarios; while the built-up area presents increases in all five scenarios; the unused land area does not change significantly in any scenarios except the biofuel development and economic priority scenarios in which it slightly decreases.

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