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The Application of Scenario Analysis in the Overall Planning of Land Use: A Case Study of Shangluo City in Shaanxi Province

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Abstract The overall planning of land use is a complex process of joint action of social system, natural and economic conditions. On the basis of summarizing the existing researches, we select Shaanxi's Shangluo City, located in the Qinba mountainous area as the study object, to expound the concept and steps of scenario analysis based on land use change data, under the guidance of ecological safety and sustainable development theory. We design four different scenarios of land use planning program in Shangluo City during the period 2006 -2020, and use grey linear programming model to analyze each scenario. The results show that the scenario analysis is feasible in the adjustment of land use structure in Shangluo City; operable in the determining of land use planning program on a macro-municipal scale.

Key words Overall planning of land use, Grey linear programming, Scenario analysis, Shangluo City

1 Introduction

The overall planning of land use is a systematic project with promoting sustainable use of land resources and regional sustainable development as the purpose. We need to comprehensively consider the relationship among economy, society and ecological environment. In determining the planning program, the pursuit of comprehensive benefits maximization is often taken as the goal. The mature analysis model in the area of land use planning mainly includes linear programming model, dynamic programming model, multi-objective decision-making model, fuzzy comprehensive evaluation model, system optimization model and other models[1-2]. The majority of existing methods put emphasis on the linear or certain relationship between planning elements[3-5], which can not well handle the non-linear, implicit, and uncertain functional relationship in the overall planning of land use, difficult to meet the dynamic and flexible needs of the overall planning of land use.

The operation of the overall planning system of land use has the dynamic and multi-objective characteristics. The adjustment of land use structure is regarded as the core of land use system[6]. The process of determining its planning program is complex, and we should consider combined effects of a variety of factors. Scenario analysis is a process of analyzing possible future events by considering alternative possible outcomes (sometimes called "alternative worlds"). Thus, the scenario analysis, which is a main method of projections, does not try to show one exact picture of the future. Instead, it presents consciously several alternative future developments. Consequently, a scope of possible future outcomes is observable. Not only are the outcomes observable, also the development paths leading to the outcomes. In contrast to prognoses, the scenario analysis is not using extrapolation of the past. It does not rely on historical data and does not expect past observations to be still valid in the future. Instead, it tries to consider possible developments and turning points, which may only be connected to the past. In short, several scenarios are demonstrated in a scenario analysis to show possible future outcomes. It is useful to generate a combination of an optimistic, a pessimistic, and a most likely scenario. Domestic scholars began to pay attention to scenario analysis from the late 1980s. It is mainly applied in the enterprise development strategy[7], land use change[8-9], landscape planning, environmental planning and other fields[10]. In land use planning program to determine the application of scenario analysis method has not yet formed a complete system. In determining the land use planning program, the application of scenario analysis method has not yet formed complete system.

We try to discuss the application of scenario analysis in determining the land use planning program, and take the case of determining the land use planning program of Shangluo City in Shaanxi Province for elaboration.

2 Scenario design and analysis of the land use planning program in the overall planning of land use

Scenario analysis can be divided into scenario design and application, of which the scenario design includes 5 -7 steps[10]. The scenario design and analysis of the overall planning of land use mainly includes the following five steps.

(i) Determining the core issue of scenario and establishing the core topic for discussion.

The scenario of the overall planning of land use should be

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designed for the particular object. Based on the profound understanding of the overall planning of land use (a systematic project), we should identify the core issue of scenario and use a unified question or point of view to determine which aspect that the scenario will probe into.

(ii) Determining the core elements.

The core element is a key factor that should be taken into full consideration when conducting scenario design. In the overall planning of land use, through the analysis of the land use structure and development trend, policy factor, economic factor, ecological environment safety factor, and other factors are selected as the key factors.

(iii) Representation of importance of the driving factors.

In scenario analysis, according to the uncertainty of the driving factors selected and its potential impact on the system, the policy, economic, and ecological factors are placed in a three-dimensional rectangular coordinate system, and each axial line represents a driving factor.

(iv) Constructing scenarios.

On the axis of the key driving factors, the location of scenario provides the basic plot or definition state for each scenario and the development along the direction of the key driving factors determines the differences between the different scenarios.

(v) Unfolding scenario and determining indicators.

Certain indicators are selected, and then on the basis of the analysis of land use status, the scenario designed is quantified using relevant data and model, to simulate the land use structure under different scenarios. On the basis of evaluation of land adaptability in Shangluo City, 4 scenarios are established according to the actual situation of Shangluo City, farmland protection-oriented scenario(S_A); ecological efficiency-oriented scenario (S_B); economic efficiency-oriented scenario (S_C); comprehensive benefit-oriented scenario (S_D), as is shown in Fig. 1.

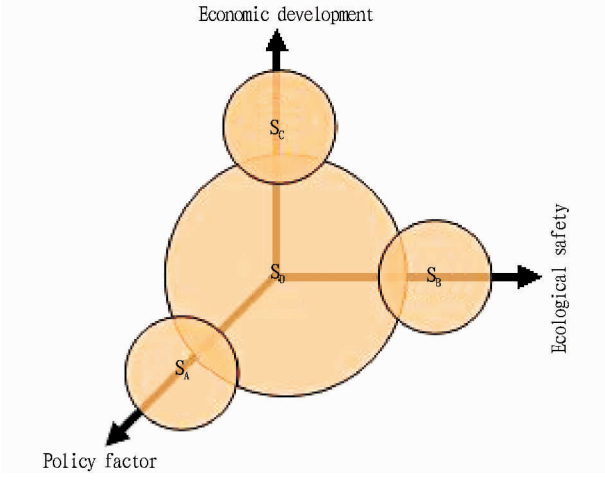

Fig. 1 The scenarios in the overall land use planning of Shangluo City

3 Case study

3.1 The study area and experimental data

3.1.1 Overview of the study area. Shangluo is a prefecture-level city in Shaanxi province of the People's Republic of China. Shangluo is close to Shangshan Mountain. Shangluo City is located in the southeast of Shaanxi Province, the south of the eastern Qinling Mountains, east to Nanyang City and Sanmenxia City in Henan Province, south to Shiyan City in Hubei Province, west to Ankang City, and north to Weinan City and Xi'an City. The city's total land area is 19 586.4 km^2, accounting for 9.36% of the province's total area. Shangzhou District, Luonan County, Danfeng County, Shanyang County, Shangnan County, Zhen'an County, and Zhashui County. At the end of 2005, the city's total population was 2.419 8 million, of which the agricultural population was 2.056 million, accounting for 84.97% of the total population, with the urbanization rate of 23%.

In accordance with the revision requirements of a new round of overall planning of land use, the planning range is the total land within the administrative area of Shangluo City; the planning base period is 2005, the planning period is 2006 – 2020, the near future planning period is 2006 – 2010, and the long-term planning is 2011 – 2020. In the process of planning, we should strictly protect arable land and basic farmland, protect and improve the ecological environment, ensure the necessary land for economic and social development, promote economical and intensive land use, and actively promote land consolidation.

3.1.2 Data sources. The classification of land use types in this article is based on *National Land Classification* (transitional period). The land data are from the survey data of land use change in Shaanxi Province (1997 – 2007), *Overall Planning of Land Use in Shangluo City* (1997 – 2010); the socio-economic data are from *Shaanxi Statistical Yearbook*, *Shangluo Statistical Yearbook* (1998 – 2008); other data are from Shangluo Bureau of Land and Resources and other relevant units.

3.1.3 Land use structure in Shangluo City in 2005. According to the survey data of land use change in Shaanxi Province (the unit of land area is hm^2, the same below). The land use structure of Shangluo City in 2005 is shown in Table 1. On the whole, the land utilization rate in Shangluo City is low; the agricultural land has a large share; the proportion of construction land is small; the area of other land is large, with a high proportion.

Table 1 The land use structure of Shangluo City in 2005

Land use types	Current area	Area proportion//%
Farmland (X_1)	199 723.0	10.20
Garden plot(X_2)	7 247.7	0.37
Woodland(X_3)	144 7278.7	73.89
Grassland (X_4)	129 691.7	6.62
Other agricultural land(X_5)	19 852.7	1.01
Designated town(X_6)	2 484.4	0.13
Rural residential land (X_7)	27 646.1	1.41
Mining land(X_8)	1 290.7	0.07
Transportation land(X_9)	4 074.9	0.21
Land used for water conservancy (X_{10})	1 333.7	0.07
Other construction land(X_{11})	247.9	0.01
Other land(X_{12})	117 766.0	6.01

3.2 Scenario simulation of land use planning program in Shangluo City

3.2.1 Model establishment. The grey linear programming model[11] has good ability to solve nonlinear problems and the features of adaptability, making up for the deficiencies of the general linear programming model, and the mathematical model is as follows:

$$f(x)=\sum_{j=1}^{m}c_jx_j\rightarrow\max \quad (1)$$

$$\sum_{j=1}^{m}a_{ij}\leqslant(\geqslant)b_i(i=1,2,\cdots,n) \quad (2)$$

$$x_j\geqslant 0 \quad (j=1,2,\cdots,m) \quad (3)$$

where expression (1) is the objective function; expression (2) is constraint condition; expression (3) is non-negative constraint condition; x_j is land use type; c_j is the efficiency coefficient vector; a_{ij} is the constraint coefficient; b_i is the constraint constant.

3.2.2 Variable setting. On the basis of classification of current land use, combined with land resource characteristics in Shangluo City and land use planning requirements, we fully take into account the operability of the relevant data and certainty of the efficiency coefficient of the objective function, and set 12 decision-making variables (X_1 is farmland; X_2 is garden plot; X_3 is woodland; X_4 is pastures; X_5 is other agricultural land; X_6 is urban land; X_7 is rural residential land; X_8 is independent industrial and mining land; X_9 is transportation land; X_{10} is water conservancy land; X_{11} is other construction land; X_{12} is other land).

3.3 Constraint conditions and establishment of objective function

The establishment of constraint conditions is mainly based on land resources, social needs and ecological requirements that are closely related to land use structure. The setting of constraint conditions is shown in Table 2.

Table 2 Constraint factors and their expression of land use structure optimization in Shangluo City

Constraint factors		Expression of constraint factors
Total factor	The total population	The population density of agricultural land and urban construction land is calculated at 1.06 people/hm^2 and 210.19 people/hm^2, respectively, and the total population is predicted to reach 2 603 046 in 2020: $1.06(X_1+X_2+X_3+X_4+X_5+X_7)+210.19X_6\leqslant 2603046$
	Land area	$X_1+X_2+X_3+\cdots+X_{11}+X_{12}\leqslant 1\,958\,637.5$
Macro planning	Agricultural land constraints	Farmland: $X_1\geqslant 189\,227.0$; $X_1\leqslant 199\,723.0$
		Garden plot: $X_2\geqslant 7\,247.7$
		Woodland: $X_3\geqslant 1\,447\,278.7$
		Grassland: $X_4\leqslant 129\,691.7$
		Other agricultural land: $X_5\leqslant 19\,852.7$
	Construction land constraints	The total size of construction land: $X_6+X_7+X_8+X_9+X_{10}+X_{11}\leqslant 37\,077.6$
		The size of urban and rural construction land: $X_6+X_7+X_8\leqslant 31\,421.2$
		Land for mining and industry: $X_6+X_8\leqslant 3\,775.1$
		By 2020, the size of newly added construction land $\leqslant 6\,160.0$
	Basic farmland constraints	By 2020, the basic farmland area $\geqslant 17\,6667.0$
	Other land constraints	$X_{12}\leqslant 117\,766.0$
Ecological environment	Forest coverage	In 2020, the forest coverage rate is not less than 80%: $X_3\geqslant 1\,958\,637.5*80\%$
	Grassland area	The area of grassland is not less than the current area: $X_4\geqslant 129\,691.7$
Economic constraints	Urban land	$X_6\geqslant 2\,484.4$
	Independent land for industry and mining	$X_8\geqslant 1\,290.7$
	Transportation land	$X_9\geqslant 4\,074.9$
Nonnegative constraints		$X_1,X_2,\cdots,X_{12}\geqslant 0$

(i) Maximization of the ecological benefits. We take the ecological service value of all land use types per unit area as the variable coefficient, and establish the objective function based on the ecosystem service value, to predict the quantitative structure of land use in Shangluo City when the ecological benefits are maximized.

Based on the model for calculation, the ecological service value of non-farm construction land is taken 1; other land use types make reference to the research conducted by Xie Gaodi, *et al.*[12], and are revised according to the actual situation of Shangluo City. The economic value of natural food yield in farmland of Shangluo City is calculated at 733.7 yuan/(hm^2 · a). Thus, the ecological service value of different ecosystems per unit area in Shangluo City is derived.

The objective function is determined as follows:

$$\begin{aligned}\mathrm{Max}f_1(X)=&5\,796.2X_1+14\,607.9X_2+2\,011.3X_3+\\&8\,545.5X_4+2\,818.6X_5+X_6+X_7+X_8+\\&X_9+33\,015.4X_{10}+X_{11}+5\,285.1X_{12}\end{aligned}$$

(ii) Maximization of the economic benefits. We use the relevant statistical data concerning Shangluo City from 1999 to 2007, to predict the output efficiency of different land use types.

Other construction land X_{11} and other land X_{12} basically do not generate economic benefits. Considering the needs of mod-

el calculation, we set the coefficient of X_{11} and X_{12} in the objective function at 1. The objective function is determined as follows:

$$\begin{aligned}\mathrm{Maxf}_2(X) = {} & 45\,830.8X_1 + 43\,076.2X_2 + 1\,272.5X_3 + \\ & 47.8X_4 + 2\,177.4X_5 + 38\,385.4X_6 + 30.8X_7 + \\ & 2\,036.3X_8 + 637\,870.1X_9 + 17.7X_{10} + X_{11} + X_{12}\end{aligned}$$

(iii) Maximization of the comprehensive benefits. Considering the development positioning of Shangluo City and development ideological guidance of South Shaanxi, in the process of maintaining rapid economic development, promoting the improvement in the regional ecological environment, is conducive to meeting the needs of Shangluo City as water source protection zone in South-to-North water diversion.

Maximization of the comprehensive benefits is regarded as the optimization objective of regional land amount structure. Based on the expert scoring method, we calculate the weight of ecological and economic benefits at 0.35 and 0.65, respectively, and take it as the objective model of maximization of the comprehensive benefits. The objective function is as follows:

$$\mathrm{Maxf}_3(X) = 0.35 \times \mathrm{Maxf}_1(X) + 0.65 \times \mathrm{Maxf}_2(X)$$

Based on the calculation, we get the land use planning program oriented by three different kinds of efficiency (Table 3).

3.4 Scenario analysis of the overall planning of land use in Shangluo City

3.4.1 Farmland protection-oriented scenario(S_A). The farmland in Shangluo City is mainly the sloping land, with small amount and poor quality. The protection of farmland and basic farmland are under great pressure. Considering the impact of farmland protection policy and the policy of returning farmland to forests, based on the land suitability evaluation results in Shangluo City, we predict the changes in the needs of various land use types oriented by farmland protection in the period 2005 – 2020 (Table 4).

Table 3 The current land use structure and the optimization program in Shangluo City

Land use types	Area in 2005	Ecological efficiency program	Economic benefits program	Comprehensive benefits program
X_1	199 723.0	192 321.0	189 175.9	190 276.7
X_2	7 247.7	7 333.3	7 331.3	7 332.0
X_3	1 447 278.7	1 524 125.2	1 506 654.9	1 512 769.5
X_4	12 9691.7	129 333.3	129 333.3	129 333.3
X_5	19 852.7	18 208.5	17 408.5	17 688.5
X_6	2 484.4	2 906.9	4 508.8	3 948.1
X_7	27 646.1	24 068.2	2 5223.8	24 819.3
X_8	1 290.7	1 383.1	2 342.4	2 006.6
X_9	4 074.9	4 225.1	6864.4	5 940.6
X_{10}	1 333.7	2 024.3	1329.2	1572.5
X_{11}	247.9	247.9	247.9	247.9
X_{12}	117 766.0	52 460.7	68 217.1	62 702.5

Table 4 The needs of various land use types in the period 2005 – 2020

Land use types	The year 2005	The year 2020	Value in variation // hm^2	Amplitude // %
X_1	199 723.0	193 561.8	−6 161.2	−0.31
X_2	7 247.7	7 261.3	13.6	0.00
X_3	1 447 278.7	1 501 357.7	54 079.0	2.76
X_4	129 691.7	128 367.5	−1 324.2	−0.07
X_5	19 852.7	17 412.3	−2440.4	−0.12
X_6	2 484.4	2 906.9	422.5	0.02
X_7	27 646.1	24 068.2	−3 577.9	−0.18
X_8	1 290.7	1 683.1	392.4	0.02
X_9	4 074.9	4 129.7	54.8	0.00
X_{10}	1 333.7	1 333.7	0.0	0.00
X_{11}	247.9	317.7	69.8	0.00
X_{12}	117 766.0	76 237.6	−41 528.4	−2.12

In this scenario, on the basis of the problems facing farmland protection in Shangluo City, we should further strengthen the protection of farmland, and strictly control the farmland used for construction.

In 2020, the decrease rate of the cultivated land area will be 0.31%; the growth rate of woodland will be 2.76%; the decrease rate of grassland and other agricultural land will be 0.07% and 0.12%, respectively; the growth rate of urban land will be 0.02%; the decrease rate of rural residential land will be 0.18%; the decrease rate of construction land and other land will be 0.14% and 2.12%, respectively.

Overall, the woodland and other land experience the greatest changes. After adjustment, the land use structure in Shangluo City is still focused on woodland, grassland and other agricultural land; urban land shows the expansion trend to some extent.

3.4.2 Ecological efficiency-oriented scenario(S_B). Considering the influence of environmental factors and requirements of ecological safety barrier protection, we predict the eco-efficiency-oriented land use changes on the basis of the objective func-

tion of the ecosystem service value (Table 5).

Through calculation, the amplitude of changes in the woodland and other land in Shangluo City is the greatest under this scenario. The woodland increases by 3.92%, and other land decreases by 3.33%. The area of ecological farmland decreases slightly, with a decrease of 0.38%; the area of garden plot is basically constant, with a slight increase. Affected by the policy of returning farmland to forestry, the woodland area increases considerably; the area of urban land, and land for transportation and water conservancy, increases slightly; the area of residential land decreases; the area of other land decreases greatly, with continuous improvement in the land use rate. The woodland area increases greatly, in line with the requirements of ecological environment construction objective in Shangluo City, which is of great significance to adjustment of land use structure, soil and water conservation, improvement in the ecological environment, and the realization of the eco-efficiency goal.

The economic development of Shangluo City is at a low level, needing the expansion of urban construction land to promote economic development. At present, the development of Shangluo City has not yet reached the stage of relying on the intensive use of construction land to improve the level of economic development. Practice has proved that the blind pursuit of eco-efficiency will impede economic growth to a certain extent, leading to deformed land use structure.

3.4.3 Economic efficiency-oriented scenario(S_C). Taking into account the impact of various economic factors, we calculate economic efficiency-oriented land use demand changes, by predicting the output efficiency of various types of land, as is shown in Table 5. After calculation, we find that the area of urban land and the land for transportation and water conservancy increases greatly, with an increase of 0.10% and 0.14%, respectively, which meets the requirements of improved level of urbanization in Shangluo City on the transport facilities, perfecting the infrastructure in Shangluo City, breaking the traffic bottleneck constraining its economic development, and greatly promoting the economic development in Shangluo City.

Under this scenario, the area of farmland and other land decreases prominently, with a decrease of 0.54% and 2.53%, respectively. With economic development, the area of arable land will continue to decrease, which poses challenges to the basic farmland protection and food security in Shangluo City, and brings about pressure on the protection of the ecological environment, resulting in more prominent supply and demand contradiction of resources in Shangluo City.

In short, the simple pursuit of economic efficiency, ignoring the social and ecological benefits, makes the capacity of ecological environment beyond expected levels, resulting in deformed land use structure.

3.4.4 Comprehensive benefit-oriented scenario(S_D). In order to achieve the coordinated and sustainable development of economy, society and ecological environment, we comprehensively consider the impact of policy, economy and environmental factors; on the basis of weighing reasonable ratio of ecological and economic benefits, establish the objective function of the overall efficiency to calculate comprehensive benefit-oriented various types of land use demand changes, as is shown in Table 5.

Among the three scenarios, the optimal allocation program of the land use structure under economic efficiency-oriented scenario is the most scientific and reasonable. Under this scenario, due to the impact of the policy of farmland protection and returning farmland to forests, the area of woodland increases at the highest rate of 3.34%, and the farmland area decreases by 0.48%, between the magnitude under farmland protection-oriented scenario, ecological efficiency-oriented scenario and the magnitude under economic efficiency-oriented scenario. With the land development, the land utilization rate is constantly improved, and the area of other land is ceaselessly reduced. In the period 2005 – 2020, the area of other land increases by 2.81%; the area of urban construction land, and land for transportation and water conservancy increases by 0.07% and 0.11%, respectively. Oriented by the comprehensive benefit, increase in the area of woodland, on the one hand, enhances the stability of the land ecosystem, and on the other hand, compresses the supply of land needed by the food security and land for construction, posing higher requirements on the level of intensive use of farmland, construction land and other land.

Table 5 Changes in various types of land use needs under different scenarios in the period 2005 – 2020

Land use types	Ecological efficiency-oriented scenario		Economic efficiency-oriented scenario		Comprehensive benefit-oriented scenario	
	Value in variation//hm^2	Amplitude//%	Value in variation//hm^2	Amplitude//%	Value in variation//hm^2	Amplitude//%
X_1	−7402.0	−0.38	−10 547.1	−0.54	−9 446.3	−0.48
X_2	86.5	0.00	83.6	0.00	84.3	0.00
X_3	76846.5	3.92	59 376.2	3.03	65 490.8	3.34
X_4	−358.4	−0.02	−358.4	−0.02	−358.4	−0.02
X_5	−1644.2	−0.08	−2 444.2	−0.12	−2 164.2	−0.11
X_6	422.5	0.02	2 024.4	0.10	1 463.7	0.07
X_7	−3577.9	−0.18	−2 422.3	−0.12	−2 826.8	−0.14
X_8	92.4	0.00	1051.7	0.05	715.9	0.04
X_9	150.2	0.01	2 789.5	0.14	1 865.7	0.10
X_{10}	690.6	0.04	−4.5	−0.00	238.8	0.01
X_{11}	0.0	0.00	0.0	0.00	0.0	0.00
X_{12}	−65 305.3	−3.33	−49 548.9	−2.53	−55 063.5	−2.81

3.5 Summary On the basis of analyzing the current situation of land use structure in Shangluo City, we comprehensively consider the policy factors, and conduct horizontal comparative analysis of different scenarios of land use structure in Shangluo City, to get the following conclusions.

(i) The land use planning program in Shangluo City under the comprehensive benefit-oriented scenario is more scientific. The sustainable development of regional land use should aim to ensure food security and achieve the proper coordination between the ecological benefits, and socio-economic benefits, on the basis of conforming to the national policy. The blind pursuit of maximization of ecological efficiency under the ecological efficiency-oriented scenario, or the simple pursuit of maximization of economic efficiency under the economic efficiency-oriented scenario, ignores the ecological benefits and social benefits, likely to lead to deformity of land use structure.

(ii) It is suitable for Shangluo City to develop forest-based compound mode of operation combining agriculture and forestry, and establish three-dimensional complex ecosystem, in order to better give play to the role of water conservation land and the Guanzhong ecological barrier in South-to-North water diversion, protect the wetland and prevent soil erosion.

4 Conclusions and discussions

At present, the scenario analysis is mostly used in the field of policy and strategic decision-making. On the basis of the existing studies and the practice of formulating the overall planning of land use, we propose to apply the scenario analysis to the overall planning of land use, and take the case of Shangluo City for case study. The results show that the scenario analysis is feasible in the adjustment of land use structure in Shangluo City; operable in the determining of land use planning program on a macro-municipal scale. The analysis pattern " grey linear programming model (taking into account the policy factors) + scenario analysis" advanced in this article, is the new exploration of the regional overall planning method of land use. In the formulation of the overall planning program of land use, scenario analysis can break the status quo thinking, and fully consider the impact of policy changes and various uncertainties in the process of social, economic, environmental development on changes in the land use structure, which is not restricted to existing technology method.

However, in the process of using scenario analysis for formulating the overall planning program of land use, we must avoid few types of scenario and similar end state; put aside the impact of prejudiced idea by first impressions, to test the internal consistency and validity of one program. The linear programming model is a single objective programming model, lacking flexibility, which does not consider the national policies and other factors difficult to quantify in the setting of constraint conditions, resulting in some limitations in this pattern. Therefore, we try to seek flexible the optimization model to aid the scenario analysis, to improve the scientificity, rationality and effectiveness of scenario setting, providing new ideas for the revision of a new round of land use planning.

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