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Predicting Growth of City's Built-up Land Based on Scenario Planning

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Abstract: In this paper, method of scenario planning is applied to the study of land use planning, putting forward a new approach to analyze future growth of city's built-up land in the context of future uncertainty. By introducing economic and policy factors into land use system, a calculation model of urban built-up land is built based on the correlation between industries and land use. And using Chongqing Municipality from China as an example, we establish 6 different scenarios and simulate future development of city's land use from 2015 to 2020 under each scenario. The results indicate that Chongqing will meet fast urban expansion according to current trend and is in urgent need to improve its land use efficiency which shows strongest effect in controlling city size.

1. INTRODUCTION

At present, the overall planning of urban land use in China adopts the traditional method based on the "land use zoning and indicator controlling"(Cai et al., 2006), which lacks flexibility to respond to possible changes. Planning of urban size is highly linked with predicted size of population and constructional investment, which means that if there is discrepancy between prediction and actuality, planning will fail to play its guiding role and must meet frequent adjustments. While China's economy and society has entered a period of accelerating transformation, the contradiction between land supply and demand have become increasingly prominent in the rapid development of industrialization and urbanization, and uncertain factors of market economy have more and more influence on land utilization. Thus the traditional pattern of planning is unable to give adequate guidance and control on land use (Liu, Y. et al., 2008). Therefore, we are in an urgent need to find a new method of land use planning for modern China to improve its flexibility and adaptability to external environment.

Scenario planning is a planning method which specifically deals with environmental complexity and uncertainty, and is capable of comprehensively considering all kinds of factors and targets by describing the possible path of a system's future development with logic combination of variables. Different with traditional planning method that generates an isolated and ultimate blueprint, it can build a set of future scenarios that are systematic, coherent and dynamic. It does not require accurate prediction of the future, but analysis of possible paths so as to provide reference for plan-makers.

Scenario planning was firstly a military strategic planning method used by America in World War II (Zegras, Sussman, & Conklin, 2004). In 1967, Herman Kahn refined it into a business forecasting tool and gave definition to scenario analysis for the first time in *The Year 2000* (Kahn & Wiener, 1967). And since Royal Dutch Shell successfully avoid the impact of oil crisis in 1970s and 1980s by using scenario planning, the method has been widely used in business community (Chermack, Lynham, & Ruona, 2001). Afterwards, scholars gradually applied this method to the study of social and natural science, such as industry planning, transportation planning, land use simulation and other related fields. And scenario planning have become more mature from simple prediction of future possibilities and started to deeply explore the driving forces and key factors of social changes as well as the logical relationship inside. Many scholars have presented general method of scenario planning (Peterson et al., 2003), which are similar in essence: firstly, determine the core problem of a system; secondly, analyze key factors and driving forces of the system and their uncertainty; and finally, build and evaluate different scenarios.

In recent years, in the context of spatial and social dramatic changes, scenario planning has been valued and used by researchers of urban planning. In the field of urban planning, economic and social factors like population, policy and economy are often defined as main factors affecting land use, and based on different decision-making objectives and development directions of driving forces, correlation between factors and land utilization is built by econometric model, discrete dynamics model or others, according to which simulation of different future scenarios is conducted to analyze the possible development of land use (Dan & Xong, 2010; Zhou et al., 2012), demand of urban land (Sun & Yang, 2012), urban spatial strategy (Luo, Zhen, & Wei, 2008) and other key issues. Many researchers have used GIS technology as a tool to realize spatial visualization of land use scenarios, mostly based on system dynamics model (Deng et al., 2004; Han, H., Yang, & Song, 2015; He et al., 2005; Oana et al., 2011; Han, J. et al., 2009) and cellular automata model (CA) (Barredo et al., 2003; de Nijs, De Niet, & Crommentuijn, 2004; Hoogeveen & Ribeiro, 2005; Verburg et al., 2006; Wu & Webster, 1998) to simulate dynamic evolution of land use under the effect of driving factors. In addition, multi-criteria evaluation (MCE) (Niu, Song, & Gao, 2008; Pettit & Pullar, 2004; Plata-Rocha, Gómez-Delgado, & Bosque-Sendra, 2011), spatial regression (SR) (Hu & Lo, 2007), neural network (NN) (Almeida et al., 2008), agent-based model (ABM) (Valbuena et al., 2010) and other methods are also commonly used in quantitative simulation of future scenarios. So far, scenario planning has been successfully applied in urban planning of some cities but has not been introduced into practice in China. Existing researches in China mainly aimed at concept planning or quantitative study considering one factor among population, land use structure, economic development and ecological environment.

Since land use has numerous influencing factors that of high complexity and uncertainty, it should be studied as a dynamic system in which land use interacts with nature, society and economy. Taking the case of Chongqing Municipality from China, this paper attempts to use the method of scenario planning and probe into the evolution of urban size under comprehensive effect of key factors, so as to explore a new method of quantity control on built-up land for urban planning.

Main contents include: (1) system description: key factors and driving forces that affect the amount of built-up land are recognized and a set of future scenarios are designed considering different possible states of driving forces; (2) scenario simulation: a calculation model of urban built-up land is built based on the correlation among key factors of land use system and the development of built-up land in 2015-2020 under each scenario is simulated; (3) scenario analysis: the results of different scenarios are comparatively analyzed and suggestions about future land use are provided for Chongqing.

2. STUDY AREA

Chongqing, one of the four direct-controlled municipalities in China, consists of 24 districts and 14 counties, covering a land area of 82,402 km^2 with a population of more than 30 million. In the past decade, economic and population growth in Chongqin led to a rapid urban growth. Influenced by a number of push factors like high housing price, rapid industrialization, industrial suburbanization and weak planning, the city constantly expanded outward into the urban fringes and the size of built-up land has grown to about 6,800 km^2 by 2014. From 2003 to 2014, approximately 1,400 km^2 (including 756 km^2 of agricultural land) were transformed into constructional use in which about 25% were for industrial use, 22% for transportation, 17% for residential use and 15% for public service.

According to Overall Planning of Urban Land Use in Chongqing (2006-2020), the size of built-up land cannot be more than 7,044 km^2 by 2020, which shows limited scope for further increase in land of constructional use. However, rapid population growth and city expansion represent a daunting challenge to control the total quantity of built-up land.

3. SYSTEM DESCRIPTION

The change of land size in a city is a dynamic equilibrium under the interaction of land supply and demand which is influenced by population, economy, policy and so on (Liu, T. & Cao, 2011). By certain analytical method, future development of land supply and demand within a certain period of time can be approximately predicted. So the future scale of city's built-up land can be estimated by predicting land supply and demand.

The supply and demand of land resulted from the comprehensive function of various environmental and social factors. Based on previous studies and analysis on historical data of Chongqing, we found that there are mainly four key factors which have crucial influence on the amount of built-up land (as shown in Figure 1):

(1) Economic gross (GDP) is generated mainly through input and output on built-up land and its trend determines the future demand of built-up land.

(2) Land use efficiency has direct influence on demand of land and is mainly affected by technological development and policy guidance. For example, if policies lead to a land use pattern of high intensity or land use technology makes significant progress, rise of land use efficiency will be accelerated. Generally, land use efficiency of service and high-tech

industries are higher than others. And In this paper, GDP per area is used to gauge this factor.

(3) Economic structure refers to the composition of various sectors and industries of the economic aggregates, where there is intersectoral transformation among industries. It directly results in the structure of land use, thus has effect on land demand. Since different industries vary in land use efficiency, when industries with small occupation of land and high output take larger proportion, the demand of land will decrease to a certain extent.

(4) Supply policy of constructional land is established by state and local governments in China. Since under the current administration system in China, governments have a monopoly over supply of built-up land, supply policy directly determines the actual increment of land.

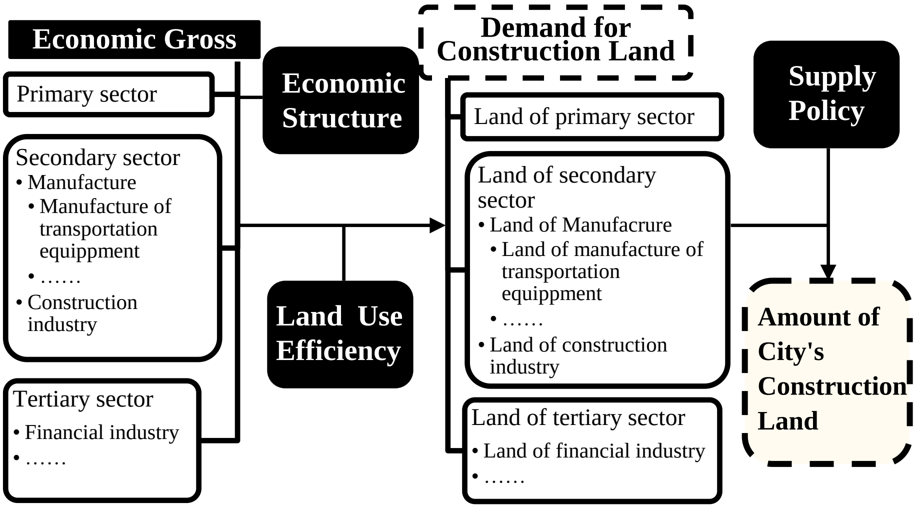


Figure 1. Influencing mechanism of key factors on size of built-up land

3.1 Uncertainty analysis

Through the analysis of existing data of Chongqing, it can be found that the growth rate of Chongqing's GDP has undergone a huge increase and gradual decline in the past decade, which makes it feasible to forecast its short-term future development by trend extrapolation. And since various situations may occur in the development of technology and government management, the other three factors all have high uncertainty. Land supply policy may be strict or loose according to the speed of land expansion. Land use efficiency may grow slowly as current trend, or rise rapidly stimulated by government guidance. And economic structure may also have substantial change if a structural adjustment policy is introduced. Several driving forces to the three uncertain factors are summarized and possible future states of each are listed in Table 1.

Table 1. Uncertainty analysis of key factors

Uncertain key factors	Driving forces	Possible future states
Economic structure	Structural adjustment	A1:no adjustment
		A2:structure adjusted (raise the proportion of industries with higher land use efficiency)
Land use efficiency	Intensive utilization	B1:no special control on land use intensity
		B2:motivation on improvement of land use efficiency

Land supply policy	Control on supply	C1:no control on land supply
		C2:control on supply of built-up land

3.2 Scenario setting

Many possible future scenarios can be formed from combination of different states of driving forces. And in this paper, 6 scenarios (as shown in Table 2) of future urban land use are selected for their relatively higher possibility of occurrence.

Table 2. Setting of scenarios

Name of scenarios	Economic structure	Land use efficiency	Land supply policy
scenario1(S1)	No adjustment(A1)	Slowly grow(B1)	loose(C1)
scenario 2(S2)	No adjustment(A1)	Rapidly grow(B2)	loose(C1)
scenario 3(S3)	adjusted(A2)	Slowly grow(B1)	loose(C1)
scenario 4(S4)	adjusted(A2)	Rapidly grow(B2)	loose(C1)
scenario 5(S5)	No adjustment(A1)	Slowly grow(B1)	strict(C2)
scenario 6(S6)	adjusted(A2)	Slowly grow(B1)	strict(C2)

3.2.1 Economic structure

In this paper, economic structure is detailedly classified into three levels: (1) the first level is consist of three sectors: the primary, secondary and tertiary sector; (2) the second level includes industry of construction and manufacture which compose secondary sector, and industries of fiancé, wholesale and retail, real estate, hotels and catering and others which compose tertiary sector; (3) the third level includes all the industries inside manufacturing industry.

According to the Chongqing's 12th Five-Year Plan (2011-2015), since 2011 the city has undergone adjustment on the second and third level of economic structure, which mainly involved an increase in the proportion of financial industry, communication equipment manufacturing and pharmaceutical industry as well as decrease in the proportion of inefficient manufacturing industries. And the 13th Five-Year year Plan (2016-2020) has similar plan about economic adjustment.

So in order to evaluate the effect of Chongqing's adjustment on economic structure on the size of city's built-up land, we set:

(1) In the scenario of "structure adjusted" (A2), all levels of economic structure will develop as the current trend (2003-2014), which simulates future development under existing policy;

(2) In "no adjustment" (A1) scenario, the second level structure inside tertiary sector and the third level structure in manufacturing industry will develop as the trend during 2003-2010, in order to simulate city's development without implementation of structure-adjusting policy with counterfactual analysis.

3.2.2 Land Use Efficiency

To facilitate our study, we have built a land-use classification by occupancy of three economic sectors, based on existing classifications and previous researches (Dan & Xong, 2010; Liu, P.-H. & Hao, 2003) and obtain statistics about GDP per area of land occupied by three sectors of 2003-2014, based on official land use data. It can be found that the growth rate of

GDP per area on land of three sectors has increased from 2003 and gradually decreased since 2010. We set:

(1)In the scenario of "land use efficiency slowly grow"(B1), GDP per area on land of each economic sector will grow at the lowest rate during 2003-2014;

(2)In the scenario of "rapidly grow"(B2), GDP per area will continue the current trend of rapid growth and increase at AAGR (Average annual growth rate) during 2003-2014 (as shown in Table 3).

Table 3. Future growth rate of GDP per area on land of each economic sector under different scenarios

Scenario	Growth rate of GDP per area on land occupied by		
	Primary sector	Secondary sector	Tertiary sector
B1	6.81%	7.66%	6.45%
B2	11.03%	11.82%	11.16%

3.2.3 Supply policy of built-up land

We set: (1) In the scenario of "loose supply policy"(C1), the demand of built-up land will be fully met;

(2) In the scenario of "strict supply policy"(C2), only 50% of land demand will be provided each year.

4. SCENARIO SIMULATION

4.1 Model building

Based on high correlation among economic output, economic structure and land use (Wang, Ying, & Wang, 2005), we build a calculation model which is able to calculate the amount of city's built-up land with relevant data of detailedly-classified economic industries. Formulas is as follows:

(1)The demand of land for industry m in year n is:

$$L_m(n) = G(n) * \frac{W_m(n)}{E_m(n)}$$

(2)The demand of built-up land in year n is:

$$\begin{aligned} L_D(n) &= L_1(n) + L_2(n) + \cdots + L_m(n) \\ &= L_{\text{Primary sector}}(n) * \theta(n) + L_{\text{Secondary sector}}(n) \\ &\quad + L_{\text{Tertiary sector}}(n) \end{aligned}$$

(3)The amount of built-up land in year n is:

$$L(n) = \begin{Bmatrix} [L_D(n) - L(n-1)] * S(n) + L(n-1), L_D(n) > L(n-1) \\ L_D(n) \qquad ,L_D(n) \le L(n-1) \end{Bmatrix}$$

where the notations refer to the following descriptions:

L(n): Total amount of city's built-up land in year n(km^2);
G(n): City's GDP of year n(100 million yuan);
W_m(n): The proportion that industry m takes in local economy in year n;
E_m(n): GDP per area of land occupied by industry m in year n(100 million yuan/km^2);
S(n): The ratio of the area of supply to the area of demand of new built-up land in year n;

$\theta(n)$: The ratio of the area of rural residential land to the area of land of primary economic sector in year n.

Model input $W_m(n)$: a predictive model for compositional data is used for trend extrapolation of data of economic structure, which mainly includes log ratio transformation and least squared regression analysis of data (for detailed formula see (Aitchison, 1982). History data of 2003-2014 is obtained from Chongqing's yearbook from official website (http://www.cqtj.gov.cn/).

$G(n)$: in this paper, Brown's linear trend model is used for trend extrapolation of Chongqing's GDP (history data is also from Chongqing's yearbook), and predicted GDP of 2015-2020 is obtained(as shown in Figure 2).

$\theta(n)$: by analyze official land use data from China's Ministry of Land and Resources(http://www.mlr.gov.cn/), the ratio of area of rural residential land to land area of primary sector in Chongqing can be calculated from the following formula: $\theta(n) = 5.24\% * (1 + 0.2235\%)^{n-2009}$.

$E_m(n)$: due to the lack of data about land use efficiency of industries in the second and third level in Chongqing, we borrow relevant data of other areas from previous studies (Li et al., 2008; Lu et al., 2013), and use it in study of Chongqing after adjustment which is based on regional differences in land use efficiency. The adjusting formula is as followed:

$$E_m(n_1, Chongqin) = E_m(n_2, other\ area) / \frac{GDP_{secondary\&tertiary\ sector}(n_2, other\ area)}{L(n_2, other\ area)} * \frac{GDP_{secondary\&tertiary\ sector}(n_1, Chongqin)}{L(n_1, Chongqin)}$$

By inputting these data to the calculation model, calculated amount of built-up land in 2003-2014 ban be obtained. And after comparing calculated amount with actual one, subjective adjustment is introduced to $E_m(n)$ of time-points with large deviation for the reason of calculating accuracy. The final adjusted data of $E_m(2014)$ is as shown in appendix 1. And future $E_m(n)$ can be calculated based on $E_m(2014)$ and the growth rate (a_m) set in Table 3: $E_m(n)$= $E_m(2014) * (1 + a_m)^{n-2014}$.

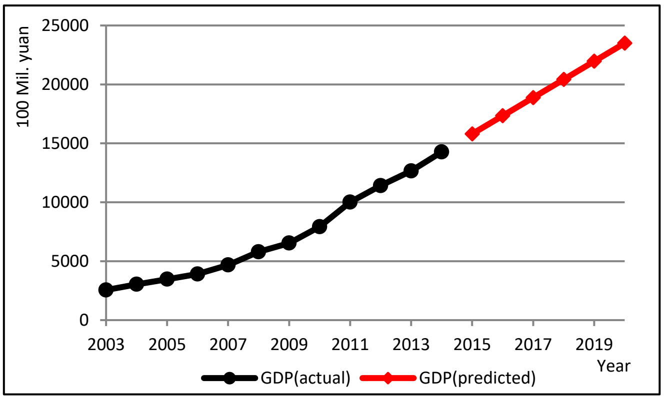


Figure 2. Predicted GDP of Chongqing in 2015-2020

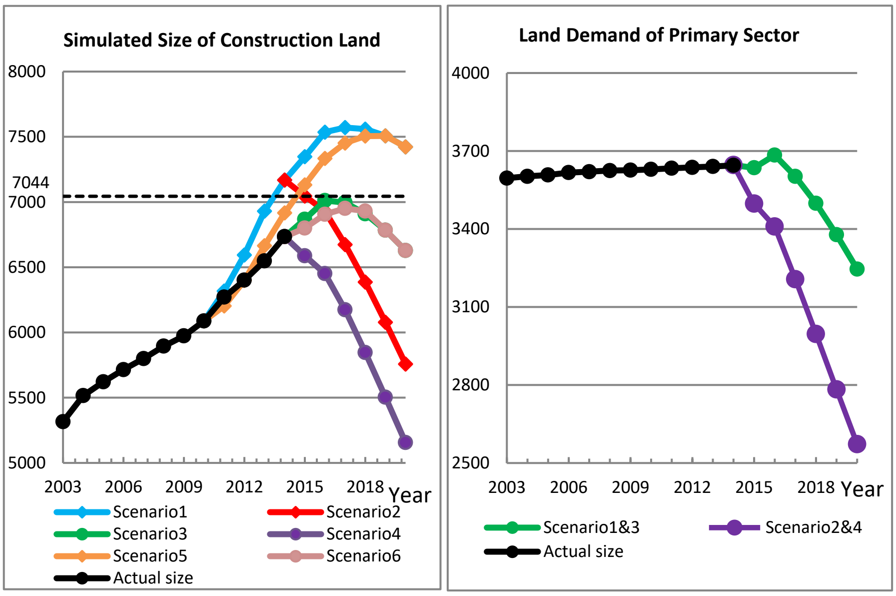
4.2 Simulation results

Through the above steps, the predicted amount of built-up land and land demand of the three economic sectors under each scenario are obtained (as shown in Figure 3).

5. SCENARIO ANALYSIS

5.1 Analysis of Simulation results

From the simulated future size of built-up land (scenario 1>5>2>3>6>4), it can be found that when other factors unchanged, adjustment of economic structure, improvement of land use efficiency and strict control on land supply are all conductive to decrease city size. When land use efficiency grow slowly (scenario1), built-up land scale will continue its quick expansion before 2018 and shrink after 2018. And when land use efficiency grow rapidly (scenario2&4), the demand of built-up land shows an trend of substantial decline. By comparing scenario 3 and 4 with 1 and 2, adjustment of economic structure shows good effect on reducing increment of built-up land even with slow growth of land use efficiency. And from scenario 5 and 6, cutting 50% of supply in newly needed land only contributes to a 1-4% reduction in land size. Thus, it can be concluded that improvement of land use efficiency have the strongest effect which can substantially reverse the trend of land expansion, followed by structural adjustment and strict supply.



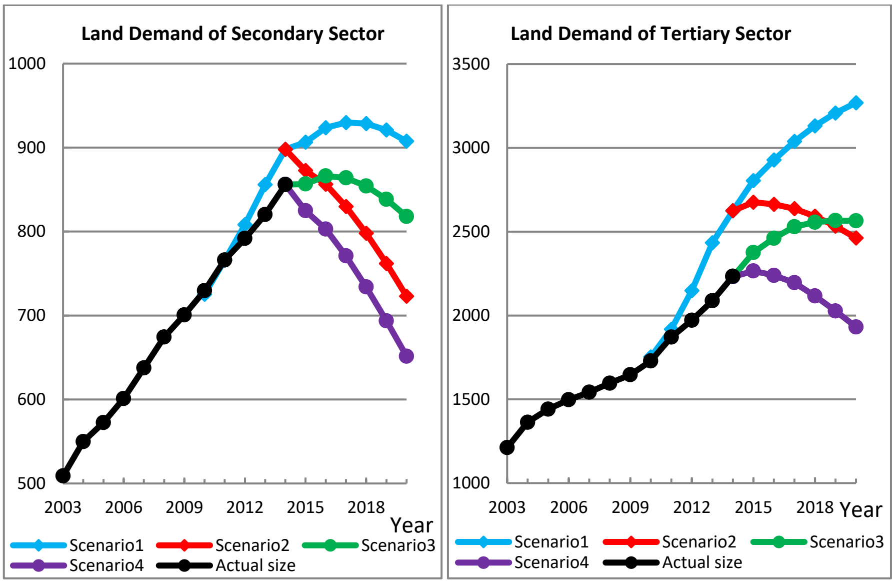


Figure 3. Predicted amount of built-up land (upper left) and land demand of three economic sectors in 2015-2020 under each scenario (km^2)

And from the simulated outcome of land demand of each sector, it can be found that land demand of primary and secondary sectors have greater reduction under the effect of improvement of land use efficiency. Especially when utilization efficiency of agricultural land increase faster, the area of rural residential land can reduce by 1/5 by 2020, even if GDP per area of primary sector. And the effect of adjustment on economic structure is mainly reflected in the decrease (about 1/5) in land demand of tertiary sector.

From counterfactual simulation in scenario1&5, if Chongqing did not implement adjusting policy in 2011, size of built-up land will grow much faster than actual size in 2011-2014, even if only 50% of demand is met. Thus we can conclude that Chongqing's policy of adjusting economic structure did have positive effect on retarding urban expansion, through elimination of inefficient industries and promotion of high-output ones.

According to Overall Planning of Urban Land Use in Chongqing (2006-2020), restricted size of built-up land is 7044 km^2. Since the irreversibility in development of built-up land makes it impossible for built-up land to convert to other utilization or shrink in a short period of time and to eliminate the negative effects of urban sprawl, such as irrational urban layout and environmental damage, we should attach more importance to the peak size of built-up land in scenarios, rather than subsequent decline. In scenario3 which simulates "business as usual" development of Chongqing, the peak size of built-up land is 7011 km^2 which is very close to the restricted size and vulerable to any uncertain change. So Chongqing is in an urgent need to take steps to control its urban expansion now.

5.2 Suggestion for Chongqing

At present, major cities in China are facing two contradictions in land use: the contradiction between hard constraints and extravagant utilization of land resources, as well as the one between constraint in urban land use and waste in rural land use. A large proportion of urban land supply was used to build industrial parks and commodity housing, where have a common phenomenon of inefficient utilization and vacancy. And in rural areas, large amount of scattered farmland is abandoned while built-up land is inefficiently used for developing inferior industries or underletting, resulting in countless waste of land.

In the past decade, built-up land in Chongqing have undergone rapid expansion. If this expansion continues, it may lead to tension in land use, deterioration of environment, lack of infrastructure and plight of urban development. So Chongqing urgently need to transform to a sustainable way of land use.

By implementing strict supply, land expansion can only be controlled in the short term. The existing adjustment policies on economic structure have played a positive role in slowing urban expansion. So government of Chongqing should continue to make reasonable planning for economic transformation that promotes development of high-efficiency, environment-friendly industries in replace of inefficient and pollutive ones.

And to better achieve the long-term goal of sustainable development, Chongqing should also seek all kinds of innovative ways, to enhance the utilization efficiency of regional built-up and agricultural land, which can fundamentally solve the contradiction between constraints of land and needs of economic development. Basically, adjusting economic structure has effect through improving land use efficiency by transferring land occupation from inefficient industries to efficient ones. Therefore, Chongqing's government should carry out land use policy that matched the plan of economic transformation. Chongqing can learn from other cities' experience of "smart growth" and focus on activating existing stock and redeveloping inefficiently-used or wasted land. Especially for the vast rural areas, agricultural mechanization and mass production can unlease potential value of agricultural land. Through land consolidation and redevelopment, large amount of underused agricultural and built-up land can be released for the use of restoring vegetation, developing diversified economy and constructing infrastructures. Relevant regulations should also be perfected, which should include standards, evaluation and supervision of sustainable and efficient land use.

6. CONCLUSION

The study have given a preliminary exploration on application of scenario planning on regional land use. Future scenarios of land use are simulated under comprehensive functions of uncertain push factors, providing a more forward-looking and flexible way for city planners. According to the case analysis of Chongqing, efficient land use and reasonable economic structure are important guarantee for sustainable development of the city.

Due to limitations of data, this study may be insufficient in accuracy and lack spatial analysis. If the study continues to combine scenario planning with spatial analysis in application to urban planning, more detailed and significant results may be achieved.

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Appendix 1. Land use efficiency (100 million yuan/km^2) and economic structure (%) of Chongqing in 2014 and 2020 under different scenarios

Scenario / Industry	Land Use Efficiency			Economic Structure			
	2014	2020		2014		2020	
		B1	B2	A1	A2	A1	A2
Primary Sector	0.01543	0.02291	0.02890	**7.44**	**7.44**	**5.89**	**5.89**
Secondary Sector				**45.78**	**45.78**	**44.69**	**44.69**
Construction	22.809	35.516	44.588	20.73	20.73	23.76	23.76
Manufacture				79.27	79.27	76.24	76.24
Processing of Food from Agricultural Products	1.684	2.622	3.292	4.51	4.18	5.31	3.63
Manufacture of Foods, Liquor, Beverage and Refined Tea	2.621	4.082	5.124	1.13	1.05	1.14	0.95
Manufacture of Textile	8.719	13.576	17.044	1.82	0.98	1.60	0.56
Manufacture of Textile Wearing Apparel, Footwear and Caps	8.033	12.508	15.703	0.61	0.65	0.94	1.14
Manufacture of Leather, Fur, Feather and Related Products	10.114	15.749	19.771	0.62	0.89	0.57	0.90
Manufacture of Wood, Bamboo, Rattan, Palm and Straw Products	9.854	15.345	19.264	0.17	0.32	0.18	0.34
Manufacture of Furniture	4.195	6.533	8.201	0.82	0.47	1.32	0.66
Manufacture of Paper and Paper Products	2.051	3.194	4.010	1.75	1.32	2.61	1.45
Printing, Reproduction of Recording Media	4.765	7.420	9.315	0.83	0.75	1.06	0.71
Manufacture of Culture, Education, Handicraft, Fine Arts, Sports and Entertainment Articles	5.111	7.958	9.991	0.01	0.45	0.01	1.65
Processing of Petroleum, Coking, Nuclear Fuel	6.190	9.638	12.100	0.71	0.33	0.91	0.31
Manufacture of Raw Chemical Materials, Chemical Products	5.628	8.763	11.002	5.15	4.45	4.00	3.35
Manufacture of Medicines	8.748	13.622	17.102	1.32	2.11	0.67	4.12
Manufacture of Chemical Fibers	6.017	9.369	11.762	0.11	0.03	0.14	0.03
Manufacture of Rubber and	9.055	14.099	17.701	2.25	2.47	3.10	3.71

Plastics							
Manufacture of Non-metallic Mineral Products	5.140	8.004	10.049	4.84	5.41	4.49	4.90
Smelting and Pressing of Ferrous Metals	3.659	5.697	7.153	5.07	4.04	4.54	2.59
Smelting and Pressing of Nonferrous Metals	4.331	6.744	8.466	4.54	3.54	3.42	1.77
Manufacture of Metal Products	3.333	5.189	6.515	2.06	2.50	2.48	3.40
Manufacture of General Purpose Machinery	6.775	10.550	13.245	5.08	3.23	5.22	2.31
Manufacture of Special Purpose Machinery	5.867	9.136	11.470	2.91	1.79	3.54	1.00
Manufacture of Transportation Equipment	7.630	11.881	14.916	28.85	27.94	22.17	21.45
Manufacture of Electrical Machinery and Equipment	13.014	20.265	25.441	6.90	5.15	8.45	5.90
Manufacture of Computers, Communication and Other Electronic Equipment	19.888	30.968	38.878	3.66	15.37	7.84	27.02
Manufacture of Measuring Instruments, Machinery for Cultural Activity, Office Work	7.141	11.119	13.959	0.55	0.85	0.23	0.43
Other Manufacture	1.820	2.833	3.557	0.19	0.46	0.19	0.86
Tertiary Sector				**46.78**	**46.78**	**49.42**	**49.42**
Financial Industry	28.474	41.430	55.008	12.92	18.36	12.18	21.30
Wholesale and Retail Trade	6.702	9.752	12.947	16.40	18.43	14.45	16.42
Real Estate	5.306	7.720	10.250	6.18	12.25	4.46	13.67
Hotels and Catering Trade	7.496	10.907	14.482	5.72	4.82	6.43	4.81
Other Services	1.703	2.479	3.291	58.78	46.14	62.48	43.80

Note: due to the lack of data of four industries (mining of ores, manufacture of tobacco, comprehensive utilization of waste resources, production and supply of electric power, heat power, gas and water) which take very small proportion, land occupied by these industries are not considered in this paper.