Physics and Chemistry of the Earth 101 (2017) 70–77

Contents lists available at ScienceDirect

Physics and Chemistry of the Earth

journal homepage: www.elsevier.com/locate/pce

# Optimization of land-use management for ecosystem service improvement: A review

Gui Jin [a], Xiangzheng Deng [b, c, d, *], Xi Chu [a], Zhihui Li [b, c, d], Yuan Wang [a]

[a] Faculty of Resources and Environmental Science, Hubei University, Wuhan, Hubei 430062, China
[b] Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China
[c] University of Chinese Academy of Sciences, Beijing 100049, China
[d] Center for Chinese Agricultural Policy, Chinese Academy of Sciences, Beijing 100101, China

ARTICLE INFO

*Article history:*
Received 19 August 2016
Received in revised form
22 January 2017
Accepted 2 March 2017
Available online 23 March 2017

*Keywords:*
Land-use management
Ecosystem service
Policy simulation
Computable General Equilibrium
System Dynamics

ABSTRACT

Land use is closely related to human activity, which affect ecosystem services by changing the types, patterns and ecological processes of ecosystem, and consequently impact the human well-being. Scientific simulation is needed to analyze the land use policy impacts on ecosystem services and socioeconomic development. Based on the reviews, the Computable General Equilibrium (CGE) model plays an important role in building simulation framework for land-use management optimization for ecosystem services improvement, which can be used to systematically analyze changes of ecosystem service driven by land use change as well as the consequent impacts on socioeconomic development. In addition, the similarities and differences between the CGE model and System Dynamics (SD) model are identified. CGE and SD models have their advantages and disadvantages, a suitable model can be select in the practice of policy simulation. In this sense, these simulation models are of great significance to decision-making on land-use management measures for ecosystem service conservation and socioeconomic development.



**Contents**



## 1. Introduction

Land system is an important component of the Earth terrestrial ecosystem (Verburg et al., 2015). Land use activities not only provided services such as the material products, but also brought profound land use/land cover changes (LUCC), which is an important part and one of the main reasons of global environment

* Corresponding author. Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, Beijing 100101, China.
*E-mail addresses:* jing_simlab@163.com (G. Jin), dengxz.ccap@igsnrr.ac.cn (X. Deng), chux_simlab@163.com (X. Chu), lizh.12b@igsnrr.ac.cn (Z. Li), wy_simlab@163.com (Y. Wang).

http://dx.doi.org/10.1016/j.pce.2017.03.003
1474-7065/

changes (Deng et al., 2014a). LUCC has been a hot issue in international geographic research field since the early 1990s, when the LUCC research plan was jointly put forward by International Geosphere-Biosphere Program (IGBP) and International Human Dimensions Program on Global Environmental Change (IHDP) in 1995. LUCC studies mainly focus on clarifying and analyzing the driving mechanisms and characteristics of land use/cover change, forecasting and simulating future land-use/cover change and spatial distribution (Li et al., 2013a, b; Xu et al., 2013; Deng et al., 2013a; Zhen et al., 2014).

Ecosystem service refers to all the benefits that humans derive from ecosystem, including provisioning services such as food and water supply, regulating services such as flood and disease control, supporting services such as the nutrients cycle maintenance of the Earth's living environment, and cultural services such as the benefits of spiritual, recreational and cultural.

Recently, the mechanisms of how the land use change affects ecosystem services and consequently affect the socioeconomic development has become a hot issue (Liu and Deng, 2010; Singh et al., 2014; Sutherland et al., 2014). Along with detailed research of land use, there is growing awareness that land-use management is one of the fundamental factors of ecosystem services improvement (Deng et al., 2016). Over the years, economists have already characterized the regulation and mechanisms of social economic system linked with land supply and land use. Accordingly, ecologists have also taken deep research on how the land use change affects the process of ecosystem services. However, on one hand, ecologists usually do not pay much attention to land-use management and policy impacts on land use. On the other hand, land-use management and policy affects the socioeconomic system via impacts on ecosystem services. Land-use management and policy are the main ways to alter the land use pattern. The ecosystem service function of different land use types is quite different, and have a different impact on the social economic system. Nevertheless, the economists usually do not hold the background knowledge of land ecology. Thus research on mechanisms of how land use change affects ecosystem services and consequently affect the socioeconomic development is quite fragmentary and unsystematic. Few studies explore more in depth in terms of combining land use, ecosystem services and social economic system to comprehensively analyze how to improve ecosystem services and promote social economic development through optimization of land use from the management level. There is no doubt that it is challengeable to quantitatively analyze the driving mechanism of land use changes on ecosystem service and socioeconomic development within a whole framework, which also incorporates the objectives about optimization of land-use management, ecosystem services conservation, and socioeconomic development (Deng et al., 2016; Jin et al., 2015a).

With considerable growth in national macro-economy, rapid increase in fixed investment and a strong demand for built-up land, China is facing the challenges of land conditions, such as a large population versus limited land area, limited cultivated land resources, etc. Due to the neglect of cultivated land protection and ecological conservation while in the process of urbanization, a series of land problems and environmental problems have occurred, including food shortages, environmental pollution, and extreme climatic conditions. Consequently, the ability to coordinate land use, national economic and social development has been weakened (Jin et al., 2015b). With a “Trinity” property of resources, assets and capital, land is the base resources and material guarantees for human survival and development. Reasonable and effective utilization of land resources is directly significant to deal with the socioeconomic, human, environmental, ecological, security and other key issues of sustainable development. Thus, reasonable management and control of land use, and improvement of ecosystem services are important guarantees for sustainable land resources utilization and human society development. The implication of this sentence is that the improvement of ecosystem service, such as promotion of provisioning, regulating, supporting and cultural services will have a positive impact on the sustainable use of land resources and socio-economic development, rather than a simple transformation between land use types. For example, taking the urban ecosystem as an example, increasing the green area in the built-up area will improve the regulating services of the ecosystem and utility pattern of land use, which is the embodiment of sustainable development.

Land use policy is an important means for optimization of land-use management, which plays a significant role in ecosystem services regulation. Regional land use changes are influenced by natural, social, economic and other factors (Wu, 2008). Among them, natural factors plays a leading role, while the social, economic, technical and other human factors determine the types and structure of land use through operating mechanisms, price system, land ownership system, etc. Land use policy is a type of political and economic tasks that established by the government in a certain period. It can also be treated as the guidelines for the development, utilization, governance, protection and management of land resources. In this sense, it can clearly reflect the local economic development, industrial distribution and regional planning, which are important factors of economic operation (Jin et al., 2014). Currently, promoting optimization of land-use management through land use policies in China is still challengeable. On the one hand, cultivated land has serious non-agriculturalization trend. “Development zone” and infrastructure construction in the process of urbanization has greatly contributed to the regional economic growth, but also increased the pressure of food security and ecological environment (Seto and Satterthwaite, 2010; Zhang et al., 2014). On the other hand, the land ownership is still not clear, which leads to illegal land transactions and excessive land use. In addition, there have been excessive land acquisitions for built-up land construction from the government, resulting in uneven land price subsidy as well as cultivated land loss. Therefore, it is of great importance to evaluate the effect of land use policy with simulation and computation. Based on the mechanisms of how the land use change affects ecosystem services and consequently affect the socioeconomic development, scientific simulation of the policy impact on the socioeconomic development can be conducted. Subsequently, the proposed policy recommendation based on simulation results can assist and improve the efficiency of decision-making.

It is of great importance to theoretically study the mechanisms of how land use policies affect ecosystem services through land use changes and consequently impact the socioeconomic development, as well as to practically develop the techniques of computation and simulation of land use policies. As mentioned above, the mechanisms of how the land use change affects ecosystem services and consequently affect the socioeconomic development is linked with macroeconomics, land economics and land use policy, thus simulation of land use policy mechanisms based on mathematical modeling and computer simulation technology is a multidisciplinary field, which requires multidisciplinary knowledge, with the characteristics of intersectionality and complexity. This study will analyze the process that the land use change affects ecosystem services and consequently impacts on the socioeconomic development. Firstly, internal relations of land use policy conduction system will be sort out from flexible and complicated policies. Subsequently, model for land-use management optimization will be constructed for the investigation on the process that land use change affects ecosystem services and consequently impacts on the socioeconomic development. It is helpful to understand synergistic effect and trade-off effect caused by policy mechanisms and composite effects through market mechanisms. Then, land-use management measures and strategies will be proposed for ecosystem services conservation and socioeconomic development, which can improve the planning and implementation of land use policy.

## 2. Policy simulation of land use optimization

Policy simulation is generally defined as decision support system (DSS) for government services, whose goal is to seek appropriate policies responding to the future development and discover policies considering socioeconomic shock. Furthermore, policy simulation refers to virtual testing of policy problems based on mathematical modeling and computer simulation technology. This kind of simulation and experiment could be divided into two cases. One is to test a variety of policies to determine optimal policy. The other is to simulate a single policy role under complex policy environment to understand policy effectiveness. Policy simulation includes mathematical modeling, algorithms, computer modeling and simulation, decision support, etc. (Briassoulis, 2008; Deng and Wen, 2011; Zhang et al., 2013). With the advancement of computer science and technology, policy simulation has been widely utilized in the energy policy, agricultural and forestry policy, population policy, financial policy, innovation policy and other fields.

Land-use management activities are profoundly influenced by land use policy through the guidance, regulation and distribution functions (Hamblin, 2009), which is one of the most fundamental driving factors of ecosystem services change. Furthermore, ecosystem services are the carrier of human well-being (Deng et al., 2013b). Therefore, simulation of land use policy can realize more accurate forecasting and analysis of the policy implementation results. It is conducive for policy makers to formulate appropriate policies, reduce the risk and costs of policy implementation, and then help promote healthy and long-term socioeconomic development. Optimization of land use policy simulation in this paper is defined as virtual test involving land use policy scenarios and simulation. Based on computer technology and mathematical modeling, it is used for land use optimization and ecosystem services improvement.

### 2.1. *Analysis on land use policy*

Land use policies are laws or regulations in land resources development, utilization, governance, protection and management, whose aim is to fulfill the political and economic tasks in a certain future period. It involves with not only economic development, but also political, social and ecological civilization development (Song et al., 2015a). Among them, natural environment is the basic factor leading to the land cover change. Mostly, natural environmental factors such as climate, soil, hydrology, are relatively stable, which play cumulative effects on land use changes through land cover changes, rather than a direct influences. The social, economic, technical and other human factors are relatively active, affect the regional land use change by affecting people's decisions on land use. Land use is in a state of dynamic equilibrium under the joint action of natural, social and economic factors in a long time.

Policy factors are most influential factors of land use dynamic change. Land use policy plays a role in guidance, structure regulation, and distribution and intensity adjustment of land use (Brannstrom et al., 2008). The policy guides the method and objective of land use changes, directly influence the types and structure of land use through direct mechanisms including land property right, land allocation and land resources management, and indirect mechanisms which refer to the amount and structure of land supply, land prices, etc. (Du et al., 2011). These various land use policies change regional land use structure, distribution and intensity through balancing land supply and demand that is to adjust the competition between different land use types. In order to realize the economical and intensive utilization of land, with enhancing cultivated land protection and ensuring the amount of ecological area, China has implemented some policies such as grain for green, converting pastures to grasslands, natural forest protection, and cultivated land protection, etc.

In terms of land use structure adjustment, it obviously will directly or indirectly affect the conversion between the types of land use and land use structure in the process of realizing land use objectives. For instance, land use planning policies will clearly design the size, structure and layout of built-up land and the actual available adjustments, as well as of ecological land to guarantee different ecosystem services. Aimed to the protection and improvement of ecological environment, Grain for green was proposed and implemented in 2003. It aimed to prohibit farming on slope cropland where soil erosion is likely to happen, and afforest in harmony with local climatic conditions to recover forest and vegetation, thus increasing the proportion of forest land in land use structure and enhancing the protection of ecosystem services. Besides, the No.1 file from Chinese government again emphasized the importance of cultivated land protection. It come up with a series of tasks such as permanent primary cultivated land demarcated, implementation of a high standard cultivated land construction planning, cultivated land quality improvement actions, stripping topsoil recycling, land compensation and cultivated land dynamic balance system in national key water conservancy project. These policies directly motivated the speed of land utilization on cultivated land.

Land use layout is another important feature of land use, which refers to spatial configuration of various land types and reflect the basic situation of land use within a certain area. According to different regional development strategies, status, and potential, resources and environment carrying capacity, and land use suitability in a limited area, the region is divided into different functional areas which will be managed differently with diverse regulation indicators and measures. This will directly affect the spatial distribution of land use type, which contribute to reasonable, scientific, oriented land use development. Simultaneously, all types of land use policy would indirectly affect the spatial distribution of land use while adjusting the land use structure. Changes in the amount of land use types will eventually be reflected by the spatial distribution, and consequent impacts on ecosystem services. As for land use intensity, it refers to the efficiency of land resources utilization. In other words, it is the investment intensity per land unit. Extensive land use is usually a problem in the process of land utilization. Policy on land saving and intensive use can increase land use efficiency and the input-output ratio per land unit.

Land use policies has significant impact on regional land use and make corresponding structure, distribution and intensity change. According to collected recent national land policies in China, the land policies are divided into eight categories: cultivated land protection, land saving and intensive use, land reclamation, grain for green, converting pastures to grassland, primary cultivated land protection, built-up land management, and land circulation policy. Within comprehensive effect of various policies, land use is under dynamic changing process.

### 2.2. *Transmission mechanisms on land use optimization*

The land is the carrier of the terrestrial ecosystems, different land use types have different main ecosystem services. For example, cultivated land provides strong provisioning services of agricultural production, while weak supporting, regulating and cultural services. Natural forestry land can provide strong supporting services and regulating services while weak provisioning services. Meanwhile, grassland has strong supporting services while weak regulating services. Land use change will profoundly affect some ecological processes of ecosystem such as energy exchange, water cycling, soil erosion and deposition and biogeochemical cycling, etc., thus changing the provision of ecosystem services. (Geng et al., 2014; Singh and Shi, 2014; Deng et al., 2015; Jin et al., 2015b; Wu et al., 2015). Particularly, the change of ecosystem services caused by human activities under rapid socio-economic development has received considerable concern. Especially, as the core of global environmental change, LUCC plays a decisive role on ecosystem services through changing the structure and services of ecosystem (Polasky et al., 2011).

Human well-being is the valuable activity and status defined according to people's experience. Determinants of well-being sometimes are represented as inputs, which are mostly provided by ecosystem services, including food, fiber, fuel, clean water, housing materials, different types of crops, livestock, forestry products, mineral products in the market. In addition, the natural, environmental and social conditions, as well as access to resources and space are all related determinants of well-being (or means to acquire welfare). The United Nations "Millennium Ecosystem Assessment" report also defined the concepts of human well-being, including five main components: 1) the basic material needs for a good life, 2) health, 3) good social relations, 4) security, and 5) freedom of choice and action. These five components interacted with each other, and changes of each component will usually have a positive or negative impact on other components (MA, 2003). Human well-being is reflected by not only economic development and quality of people's livelihood, but also the environment. In this sense, the improvement of economic development as well as change of ecological environment should be taken into account in policy formulation. In other words, sustainable development is of high demand. Effects of ecosystem services for human well-being is divided into economic development, ecological environment and the quality of people's livelihood, according to the related literature and the report of Chinese People's Livelihood Index Research.

Changes of ecosystem services often affect regional economic development, which can be represented by GDP, directly and indirectly. Renewable resources (such as ecosystem services) and nonrenewable resources (such as mineral deposits, soil nutrients and fossil fuels) are both human capital assets. The degradation of ecosystem services represents a loss of a capital asset. Provisioning services such as food, fiber, water, and herb, are directly involved in economic production, and reflected in agricultural output of national economic accounts. Although regulating services such as the regulation of climate, floods, as well as disease, do not have a clear marketing price, they also play a huge role in protecting normal production and life in a country and take participate in economic production in an indirect way. For example, water purification helps increase fishery production. Flood regulation of wetlands helps to increase social capital and labor input. Cultural services contribute to economic development by education, scientific research, tourism, entertainment activities. Economic output of tourism and entertainment is directly reflected in national economic accounts, while education and scientific research usually indirectly represent as impact of science and technology on economic growth. Supporting services participate in economic production by guaranteeing the normal supplement of other services (Daily and Matson, 2008).

Regarding impacts of changes in ecosystem services on ecological environment, they have little influence on ecological surplus area (which can be divided into very rich area, relatively rich area, and rich area). It has sufficient capacity to mitigate those adverse effects. As for ecological balance area (which can be divided into surplus balance area and critical overload area), changes of ecosystem services would not affect the surplus balance area. But critical overload areas probably have the tendency to turn into ecological deficit areas. Changes of ecosystem services have higher impact on ecological deficit areas (which includes pretty overload area, relatively overload area, overload area). In ecological surplus area, biological diversity is pretty rich and ecosystem is complex with strong resistance. Although the regulating services such as the regulation of water, soil, and disease are weakened by the decrease of forest land and grassland, people are able to ease the negative impact of changes in ecosystem services through other alternative services. However, decline of ecosystem services would lead to irreversible loss in the ecological deficit areas due to its vulnerability and weak resistance. Human development should be in harmony with the carrying capacity of resources and environment. In this sense, land use regulation and control measures should be proposed based on ecosystem services. To keep human development be within the carrying capacity of the Earth, the environment protection need to be taken into action, including environmental pollution control, environmental quality improvement, life support systems protection and biological diversity conservation in the economy development.

The quality of people's livelihood is mainly reflected in income. Acquiring the basic materials for maintaining a high quality of life is one aspect of human well-being, which is strongly linked with provisioning services functions (such as food and fiber production) and regulating services functions (including water purification) of ecological system. Moreover, one of the most important reflection of basic material conditions is the income level.

Firstly, provisioning services of ecosystem can directly bring monetary income. Ecosystems can provide provisioning services functions such as food, fiber, fuel, wood, etc. All those products can directly enter the market and gain economic value. That land provides income source is one aspect of ecosystem impacts on earnings. Farmers cultivate land to get agricultural production, and gain income by exchanging agricultural surplus in the market after harvest season. People lived in the forestry ecosystems get income through gathering wild food, wood fuel, fodder, medicinal plants, and timber. For example, land is one of the major source of farmers ' income which consequently affects the consumption for the life improvement (Jin et al., 2015c).

Secondly, negative ecological utilization will reduce the value of ecosystem services. To mitigate the destruction of ecosystems, more money has to be invested leading to a decreased revenue ratio. According to the MA, three ecosystem services related to the crops, livestock and aquaculture production people have already improved through area extension or technical input. If these were all put into the market for equivalent currency trading, a very substantial revenue will occur. Although the average income of people in the world had increased, it did not grow with a high-speed and is in a state of volatility. Basically, the reason is that the cost has also been increasing. Many ecosystem services have been degraded, which increased the risk of nonlinear changes in ecosystems (including accelerating, abrupt, and potentially irreversible change). Ecosystem services that have been degraded over the past 50 years including fisheries, water supply, waste treatment and detoxification, water purification, natural hazard protection, regulation of air quality, regulation of regional and local climate, and regulation of erosion, spiritual fulfillment, and aesthetic enjoyment. In some counties with sufficient financial support on land investment, the degradation of ecosystems can be mitigated by taking remedial measures. For example, declining of soil fertility of the agricultural ecosystems can be mitigated with the application of chemical fertilizer. Regulating services and water purification services functions of basins and wetlands can be achieved with the water treatment equipment. However, rapid economic growth in many countries are burdened with increasing environmental costs. FULL NAME (RAND) Corporation point out that the costs of pollution in China are large, approaching 10% of GDP per year over the past decade (Crane and Mao, 2015). Degradation of ecosystem services can be compensated by technical means, but in general, the income will reduce along with continuously decreasing of costs inputs.

Changes in ecosystem services influence all components of human well-being, both directly and indirectly. The relationship between human well-being and ecosystem services is not linear. Generally speaking, when an ecosystem service is abundant relative to the demand, a marginal increase in ecosystem services contributes only slightly to human well-being (or may even diminish it). However, when the service is relatively scarce, a small amount of decreasing can substantially reduce human well-being.

Land use policies have a feedback relationship between different forms of human well-being. Study on optimization of land-use management for ecosystem service improvement has a very positive significance for ecosystem stability, ecological safety, human well-being, and sustainable development. On one hand, humans can obtain material products such as food, herbs and cultural products such as aesthetic and spiritual from land use. Reasonable land polices will promote the rational utilization of land resources, which can promote socioeconomic development, enhance the income level and strengthen ecosystem protection, thus forming a positive development of ecological environment and promoting the improvement of human well-being. On the contrary, unreasonable land use policies will result in less efficient use of land resources, causing land degradation and ecological environment destruction, declination of land output, excessive land uses, damage of ecosystem services, thus affecting the supply function of ecosystem services and human well-being, creating a vicious cycle (Li et al., 2013a, b). On the other hand, improvement of human well-being will increase land and ecosystem protection, and increase the demand for land production, which would cause intensive utilization of land resources and serious degradation of ecological environment. Therefore, a series of policies compliance with socioeconomic development need to be formulated for sustainable development.

## 3. Simulation on optimization of land-use management for ecosystem service improvement

### *3.1. Simulation mechanisms on optimization of land-use management*

The policy simulation is an important tool for policy decision making, and the simulation results can provide effective support for government policy decision. In the field of simulation research, scholars at home and abroad use computer technology to develop a variety of policy simulation system, to achieve the purpose of policy optimization, by using the computer optimization, and the SD model and CGE model is more popular.

Computable General Equilibrium (CGE) model is a powerful tool for policy analysis. Having three basic features: "computable", "general" and "equilibrium", which are corresponding with the name of CGE. CGE model is a system of equations that describe an economy as a whole and the interactions among its parts based on its clearly modeling theory (Burfisher, 2011; Deng et al., 2014b). A typical CGE model is to describe the relationship between supply, demand and balance by a set of equations, and solve those equations under constraint of optimal conditions (optimization of producers' profit, optimization of consumers' profit, optimization of import profits and optimization of the export costs), thus come to a group of the amounts and prices when the market reaches equilibrium (Lofgren et al., 2002). Combined with GDP and Input-Output tables, equations are analyzed from different perspective, and parameter estimation are made from the correlated equilibrium at baseline period. 64 production sectors and 12 groups of urban and rural households are contained in CGE model. And each production sector is assumed having the same structure.

CGE models have been applied to a wide range of land use structure simulation, resources utilization and energy consumption problems, and has become a standard tool for environmental policy analysis. It divides macro-economic system into a number of calculated parts. The impacts of price changes on economic system in a general equilibrium framework are analyzed by calculating simulation instead of parsing analysis. Taking the entire economic system as the study object, CGE model creates number connections between each component of socioeconomic systems, comprehensively investigating the supply and demand relationship between various goods and factors through one group equation. In the process of equation solving, this model highlights the price changes of goods and factors into the role of producer and consumer decisions. Hence, CGE model can be able to analyze the disturbance of one economic part on another economic part and even the whole economic system. Known as scientifically valid "test tools for policy" or "policy laboratories", CGE model is a multifunctional tool for policy analysis, which is quite ideal for simulation of macro-effects of policies implemented under the market economy system. By controlling a/some variable(s), any structural changes of the system will affect the entire economic system, leading to changes in price and quantity of goods and factors, and the economic system transition from one equilibrium state to another state. So that any shocks from the system both inside and outside impact on the whole socioeconomic system could be explored, which will give feedback to policy makers or decision makers, providing a reference for policy choices (Jiang et al., 2014a, b).

Terrestrial ecosystems provide human beings with a wealth of natural resources and a wide range of production and living space. However, in the process of land utilization, irrational utilization leads to serious challenges faced by terrestrial ecosystems (Su et al., 2012; Song et al., 2015b). In order to facilitate land-use management and enhance ecosystem services, CGE land use change (CGELUC) model built in this paper took both the natural resources and land information into consideration based on traditional CGE model. It takes land resources as the main content and analyzes the impacts of different land use policies on the land use change, and consequent impacts on the socioeconomic development. The CGELUC model consists of five parts: production systems, consumption demand, foreign trade, natural resources and the balance between supply and demand.

According to the actual needs, different types of production departments are incorporated into seven departments including farming, fishing, forestry, animal husbandry, industry, construction and services, which representing provisioning services, supporting services, regulating services and cultural services of ecological system respectively. Production factors include three categories: labor, economic capital and land natural resources. The subject of income distribution includes residents, businesses, governments, and the land. The surplus of the allocation will enter savings account, representing the human well-being. The incomes of residents come from labor endowments, economic capital income, as well as transfer payments of enterprises and government. Incomes of enterprises come from economic capital income. The government revenue comes from various taxes. Finally, the land revenues is a kind of virtual income, and it comes from land endowment, as well as protection of residents, businesses, and government.

Production activities is characterized by three layers with nested functions. The first layer is the synthesis of economic capital and land resources, using constant elasticity of substitution (CES) function. The second layer contains two content. One is the synthesis of labor and integrated economic capital-land natural resources using CES function, the other is the synthesis of intermediate inputs using Leontief production function. The third layer is the output. CES production function are adopt in labor-capital-land natural resources synthesis and synthesis of intermediate inputs. Export and domestic supply of products are represented by constant elasticity of transformation (CET), which can be divided into two layers: one is the substitutional relationship between export and domestic supply, the other is the substitution between exports and international exports. Residents' utility under constraints of budgetary will be maximized by Cobb-Douglas function. Government consumption and investment are described by function as fixed expenses share.

As a basis for running the CGELUC model, the Social Accounting Matrix (SAM) dataset we made based on Input-Output tables including the land natural resources with twelve sub accounts. It is quite different from traditional SAM tables that land natural resources are separated from the "capital" account in our study, which helps better analyze the impacts of economic activities on the land resources. Setting up "land" accounts in the main account reflects that the land ecosystem should have access to income sources and expense items. "Land" account refers to the earnings provided by provisioning services of land ecosystem, and those earnings will be a source of income to "land" accounts. Income of "land" accounts consists of two parts: one is the investment (transfer payments) paid by residents, businesses, and governments for optimization of land use, the other is the remuneration gained from production factors such as labor and economic capital of land ecosystem. The expensing items of "land" accounts refer to savings for maintaining the values of ecosystem services provided by land ecosystem. One the other hand, savings of "land" account can be considered as a reference value of compensation for land ecosystem. When the relevant variables (such as land transfer payments rate of residents, businesses and government) changes, land status will change correspondingly.

In terms of effect mechanisms of land-use management on ecosystem services, the conceptual framework can be built to model the impacts on ecosystem services (such as supporting services and regulating services) by human land use activities based on CGE model. In this sense, Qinghai Province can be selected as study case. It is the source of three major rivers (i.e., Yangtze River, Yellow River and Lancang River) in East Asia, and it has experienced severe grassland degradation in past decades. Based on the data from remote sensing satellites and meteorological stations, the regression and residual analysis were used to analyze the impacts of climate change and human activities on grassland ecosystem at different spatial and temporal scales. Results showed that the grassland degradation was strongly correlated with the climate factors (Yin et al., 2014). In addition, it showed that grassland ecosystem service has also changed, such as temporal and spatial heterogeneity in the quality of grassland, which was probably mainly because of the effects of human activities. These results are consistent with the currently status of grassland degradation in Qinghai Province, which could serve as a basis for the local grassland management and restoration programs (Yin et al., 2014). Furthermore, studies on North China plain is another good example. The analysis model was built for comprehensive quantitative analysis of land degradation affected by climate change and land use change. The results revealed the impacts of different land use type conversion on land quality, which will provide scientific information for ecosystem services improvement and sustainable land management (Li et al., 2015).

As for quantitative analysis of effects on ecosystem service caused by land-use management policies, land use efficiency has been improved in the process of land use conversion especially the expansion of built-up land. The types and structures of industries carried by land would also be further enhanced, which will play a much longer impact on regional ecosystem services. Another study of Qinghai province is good example for application of this methods. Based on CGE model, Input-Output Model was used to assess pollution risks of Qinghai province on the basis of the effect analysis of waste emission on environment. The results illustrated that the costs of environmental protection and recovery in China had a gradient distribution, of which the energy efficiency is lower while environmental costs are higher in Western China. Industrial structure adjustment has different impacts on the pollution of different sectors. Although the development of machinery and equipment, hotels and catering services, and real estate, leasing, and business services has increased the emission of pollutants, it is offset by the decreasing emissions caused by other industries such as construction and metal products (Jiang et al., 2014a, b). Therefore, although economic development would increase environmental pollution, industrial adjustments could effectively decrease waste water and waste gas emissions to reduce the pollution risk. It should be noted that there are still tremendous challenges for industrial transfer in Qinghai Province to coordinate the environment and industry development (Jiang et al., 2014a, b). In addition, based on a computable general equilibrium model of land use change with a social accounting matrix dataset, an equilibrium analysis of the land use structure was implemented in the Yunnan Province during the period of 2008–2020 under three scenarios, the baseline scenario, low total factor productivity (TFP) scenario, and high TFP scenario. The scenario-based simulation results are of important reference value for policy-makers in making land use decisions, balancing the fierce competition between the protection of cultivated land and the increasing demand for built-up area, and guaranteeing food security, ecological security, and the sustainable development of land resources (Luo et al., 2014).

### 3.2. Simulation for optimization policy of land-use management based on CGE model and SD model

From the point of principle and applications, CGE model clearly defined economic production functions and utility functions based on the Arrow-Debreu general equilibrium theory. As a consequence, it reflect the interdependence and interactions between multiple departments and multiple market, thus revealing the broader economic ties compared to partial equilibrium models and macro-econometric model (Pratt et al., 2013). Through CGE model, researchers can estimate the direct and indirect influence brought by a particular policy change and its overall impact on economic system, which is a reason that CGE model is widely used in policy simulation. Based on system theory, information theory and cybernetics ideas, System Dynamics (SD) starts from internal mechanisms and microstructure of a system, analyzes the relationship between internal structure and its dynamic behavior based on computer simulation technology, and then seek for problem-solving strategies. It emphasis the view of whole system and dynamic development, and is applied to analysis of dialectical relation of unity of opposites between structure, function and behavior of complex systems (Karnopp et al., 2012).

From the perspective of research scale, CGE model divides macro-economic system into a number of calculated parts, which analyze the impacts of price changes on economic system in a general equilibrium framework by calculating simulation instead of parsing analysis (O'Looney, 2002). SD model usually study the multi-part and multi-layered system from microstructure. It is used to solve economic, social and ecological environment and other system problems such as nonlinear, multivariable, higher-order, and multiple feedback.

In terms of the data dependence, CGE model contains plenty of information with its unique advantages compared with other methods or models. Nevertheless, the data availability will limit the application of CGE model. In the process of modeling, researchers often face the reality that special investigation and survey needs to be done to get the information due to the lack of available statistical data. The truth is that the investigations are often difficult to implement because of its high conditions demanding. Although sometimes the data is available, the format and the organization does not meet the needs of model. As a result, the cumbersome adjustment and preprocessing are needed. Anyway, data availability constrained the application of CGE model to a large extent. On the contrary, SD models, a structure-dependent model, can be applied without sufficient data. Reasoning analysis is used to give reliable results in the conditions of partial data lost according to causal relationships and feedback structure of various elements, as well as limited data (Hwang et al., 2013).

On the point of prediction function, CGE models simulates the effects of changes in policy to predict the aggregates and structure of macroeconomic. However, such predictions based on policy simulations have to be combined with predictions of trends of economic growth at the same time (Deng, 2008). And for macroeconomic forecasts, it still relies on underlying macro-econometric models. Therefore, the predictions function of CGE model is not strong. SD establishes system dynamic model on the basis of internal relations of reality system and historical data, fluidize social problems, seeks for optimal solutions by means of computer simulation, and quantitative analyzes the dynamic relationship between structure, function, and behavior of information feedback system. Developed from the system structure model, SD model analyze the features of system, track and model the real system. With incomparable advantages in complex nonlinear systems research, it is applied in qualitative and quantitative analysis of the history, present and future.

In short, the two policy simulation methods have their advantages and disadvantages. Both of them can realize policy simulations, analyze the influence of land use policies on land use structure, as well as the resulting ecosystem service change impacts on human well-being. With a complete modeling theory, CGE model has the advantage to build models and implement the simulation, while the accuracy of policy predictions will decline due to its idealized assumptions and data dependence. SD model also has a comprehensive set of theories as guidance, but deep analysis and data mining are needed for a reasonable model construction. To some extent, There is a more difficult to build the mode compared to CGE. It is a dynamic simulation model built based on actual observation information of the system instead of a deduction from mathematical logic. Furthermore, it describes future performance of the system based computer tests (Deng et al., 2013c; Jiang et al., 2015).

## 4. Conclusions and discussion

There is a conductive and interactional relationship between land use policies, land use change and human well-being. Land use policy influence land use decisions and the way people use and management ecosystems, and consequent to ecosystems impact on human well-being. Policies are basic means to control social and economic system, and control strategy is the specific performance of policy. Hence, studies on complex systems modeling, decision-making and policy optimization are of great theoretical and practical significance.

This paper first sorted land use policies and analyzed the transmission mechanisms of policy simulation for land use optimization. Based on these, we further reviewed the framework of policy simulation for land use optimization based on CGE model–CGELUC model, which has five components including production systems, consumption demand, foreign trade, natural resources and the balance between supply and demand, and incorporated the natural resources and land information on the basis of traditional CGE model, taking land resources as the main content to analyze the changes of human well-being caused by different land policies.

In addition, based on the comparison between CGE and SD model, it shows that both CGE model and SD model are effective tools for policy simulation. This paper compared both of their ability in policy simulation for land use optimization, analyzed their differences in transmission mechanisms and policy simulation mechanisms of land polices impact on land use, land use impacts on ecosystem services, and ecosystem services impact on human well-being. Then new ideas are sought from the management level to improve ecosystem services and promote socioeconomic development through optimization of land use. SD and CGE models have their advantages and disadvantages, a suitable model can be select in the practice of policy simulation.

In the follow-up study, the applicability in policy simulation of the SD and CGE model will be contrasted and analyzed in order to optimize the land use management and improve the ecosystem service.

## Acknowledgement

This research was supported by the National Natural Science Foundation of China (Grant No. 71225005, 41501593), the Key Project in the National Research Council of Science and Technology Pillar Program of China (Grant No. 2013BACO3B00) and the National Key Research and Development Plan (Grant No. 2016YFA0602500). The authors wish to thank the editors and the anonymous reviewers for their insightful contributions to this manuscript.

## References

Assessment, M.E., 2003. Ecosystems and Human Well-being. Island Press, Washington, DC.

Brannstrom, C., Jepson, W., Filippi, A.M., Redo, D., Xu, Z., Ganesh, S., 2008. Land change in the Brazilian Savanna (Cerrado), 1986–2002: comparative analysis and implications for land-use policy. Land Use Policy 25 (4), 579–595.

Briassoulis, H., 2008. Land-use policy and planning, theorizing, and modeling: lost in translation, found in complexity? Environ. Plan. B Plan. Des. 35 (1), 16–33.

Burfisher, M.E., 2011. Introduction to Computable General Equilibrium Models. Cambridge University Press.

Crane, K., Mao, Z., 2015. Costs of Selected Policies to Address Air Pollution in China. RAND Corporation, Santa Monica, CA, USA.

Daily, G.C., Matson, P.A., 2008. Ecosystem services: from theory to implementation. Proc. Natl. Acad. Sci. 105 (28), 9455–9456.

Deng, X.Z., 2008. Simulation of Land System Dynamics. The land of China Publishing House, Beijing.

Deng, X., Wen, X., 2011. Research on computer-based simulation for the dynamics of land system. In: Advances in Computer Science, Intelligent System and Environment. Springer Berlin Heidelberg, pp. 251–255.

Deng, X., Liu, J., Lin, Y., Shi, C., 2013a. A framework for the land use change dynamics model compatible with RCMs. Adv. Meteorol. 2013, 1–7. http://dx.doi.org/10.1155/2013/658941. Article ID 658941.

Deng, X., Li, Z., Huang, J., Shi, Q., Li, Y., 2013b. A revisit to the impacts of land use changes on the human wellbeing via altering the ecosystem provisioning services. Adv. Meteorol. 2013, 1–8. http://dx.doi.org/10.1155/2013/907367. Article ID 907367.

Deng, X., Huang, J., Lin, Y., Shi, Q., 2013c. Interactions between climate, socioeconomics, and land dynamics in Qinghai Province, China: a LUCD model-based numerical experiment. Adv. Meteorol. 2013, 1–9. http://dx.doi.org/10.1155/2013/297926. Article ID 297926.

Deng, X., Zhao, C., Lin, Y., Zhang, T., Qu, Y., Zhang, F., Wang, Z., Wu, F., 2014a. Downscaling the impacts of large-scale LUCC on surface temperature along

with IPCC RCPs: a global perspective. Energies 7 (4), 2720–2739.
Deng, X., Wang, Y., Wu, F., Zhang, T., Li, Z., 2014b. Integrated River Basin Management: Practice Guideline for the IO Table Compilation and CGE Modeling. Springer.
Deng, X., Shi, Q., Zhang, Q., Shi, C., Yin, F., 2015. Impacts of land use and land cover changes on surface energy and water balance in the Heihe River Basin of China, 2000–2010. Phys. Chem. Earth Parts A/B/C 79, 2–10.
Deng, X., Li, Z., Gibson, J., 2016. A review on trade-off analysis of ecosystem services for sustainable land-use management. J. Geogr. Sci. 26 (7), 953–968.
Du, H., Ma, Y., An, Y., 2011. The impact of land policy on the relation between housing and land prices: evidence from China. Q. Rev. Econ. Finance 51 (1), 19–27.
Geng, X., Wang, X., Yan, H., Zhang, Q., Jin, G., 2014. Land use/land cover change induced impacts on water supply service in the upper reach of Heihe River Basin. Sustainability 7 (1), 366–383.
Hamblin, A., 2009. Policy directions for agricultural land use in Australia and other post-industrial economies. Land use policy 26 (4), 1195–1204.
Hwang, S., Park, M., Lee, H.S., 2013. Dynamic analysis of the effects of mortgage-lending policies in a real estate market. Math. Comput. Model. 57 (9), 2106–2120.
Jiang, L., Wu, F., Liu, Y., Deng, X., 2014a. Modeling the impacts of urbanization and industrial transformation on water resources in China: an integrated hydro-economic CGE analysis. Sustainability 6 (11), 7586–7600.
Jiang, Q.O., Tang, C., Zhan, J., Zhang, W., Wu, F., 2014b. Environmental cost and pollution risk caused by the industrial transfer in Qinghai Province. Front. earth Sci. 8 (3), 362–374.
Jiang, Q., Cheng, Y., Jin, Q., Deng, X., Qi, Y., 2015. Simulation of forestland dynamics in a typical deforestation and afforestation area under climate scenarios. Energies 8 (10), 10558–10583.
Jin, G., Wang, P., Zhao, T., Bai, Y., Zhao, C., Chen, D., 2015a. Reviews on land use change induced effects on regional hydrological ecosystem services for integrated water resources management. Phys. Chem. Earth Parts A/B/C 89, 33–39.
Jin, G., Li, Z., Lin, Q., Shi, C., Liu, B., Yao, L., 2015b. Land use suitability assessment in low-slope hilly regions under the impact of urbanization in Yunnan, China. Adv. Meteorol. 2015.
Jin, G., Li, Z., Wang, Z., Chu, X., Li, Z., 2015c. Impact of land-use induced changes on agricultural productivity in the Huang-Huai-Hai River Basin. Phys. Chem. Earth, Parts A/B/C 79, 86–92.
Jin, Q., Deng, X., Wang, Z., Shi, C., Li, X., 2014. Analysis and projection of the relationship between industrial structure and land use structure in China. Sustainability 6 (12), 9343–9370.
Karnopp, D.C., Margolis, D.L., Rosenberg, R.C., 2012. System Dynamics: Modeling, Simulation, and Control of Mechatronic Systems. John Wiley & Sons.
Li, M., Wu, J., Deng, X., 2013a. Identifying drivers of land use change in China: a spatial multinomial logit model analysis. Land Econ. 89 (4), 632–654.
Li, Z., Deng, X., Huang, J., Zhang, R., Huang, J., 2013b. Critical studies on integrating land-use induced effects on climate regulation services into impact assessment for human well-being. Adv. Meteorol. 2013, 1–14. http://dx.doi.org/10.1155/2013/831250. Article ID 831250.
Li, Z., Deng, X., Yin, F., Yang, C., 2015. Analysis of climate and land use changes impacts on land degradation in the North China Plain. Adv. Meteorol. 2015.
Liu, J., Deng, X., 2010. Progress of the research methodologies on the temporal and spatial process of LUCC. Chin. Sci. Bull. 55 (14), 1354–1362.
Lofgren, H., Harris, R.L., Robinson, S., 2002. A Standard Computable General Equilibrium (CGE) Model in GAMS, vol. 5. Intl Food Policy Res Inst.
Luo, J., Zhan, J., Lin, Y., Zhao, C., 2014. An equilibrium analysis of the land use structure in the Yunnan Province, China. Front. earth Sci. 8 (3), 393–404.
O'Looney, J., 2002. Sprawl decisions: a simulation and decision support tool for citizens and policy makers. Gov. Inf. Q. 18 (4), 309–327.
Polasky, S., Nelson, E., Pennington, D., Johnson, K.A., 2011. The impact of land-use change on ecosystem services, biodiversity and returns to landowners: a case study in the State of Minnesota. Environ. Resour. Econ. 48 (2), 219–242.
Pratt, S., Blake, A., Swann, P., 2013. Dynamic general equilibrium model with uncertainty: uncertainty regarding the future path of the economy. Econ. Model. 32, 429–439.
Seto, K.C., Satterthwaite, D., 2010. Interactions between urbanization and global environmental change. Curr. Opin. Environ. Sustain. 2 (3), 127–128.
Singh, R.B., Grover, A., Zhan, J., 2014. Inter-seasonal variations of surface temperature in the urbanized environment of Delhi using Landsat thermal data. Energies 7 (3), 1811–1828.
Singh, R.B., Shi, C., 2014, http://dx.doi.org/. Advances in observation and estimation of land use impacts on climate changes: improved data, upgraded models, and case studies. Adv. Meteorol. 2014, 1–7. http://dx.doi.org/10.1155/2014/748169. Article ID 748169.
Song, W., Deng, X., Liu, B., Li, Z., Jin, G., 2015a. Impacts of grain-for-green and grain-for-blue policies on valued ecosystem services in Shandong Province, China. Adv. Meteorol. 2015.
Song, W., Deng, X., Yuan, Y., Wang, Z., Li, Z., 2015b. Impacts of land-use change on valued ecosystem service in rapidly urbanized North China Plain. Ecol. Model. 318, 245–253.
Su, S., Xiao, R., Jiang, Z., Zhang, Y., 2012. Characterizing landscape pattern and ecosystem service value changes for urbanization impacts at an eco-regional scale. Appl. Geogr. 34, 295–305.
Sutherland, W.J., Gardner, T., Bogich, T.L., Bradbury, R.B., Clothier, B., Jonsson, M., Kapos, V., Lane, S.N., Möller, I., Schroeder, M., Spalding, M., Spencer, T., White, P.C.L., Dicks, L.V., 2014. Solution scanning as a key policy tool: identifying management interventions to help maintain and enhance regulating ecosystem services. Ecol. Soc. 19 (2), 1–22.
Verburg, P.H., Crossman, N., Ellis, E.C., Heinimann, A., Hostert, P., Mertz, O., Nagendra, H., Sikor, T., Erb, K., Golubiewski, N., Grau, R., Grove, M., Konaté, S., Meyfroidt, P., Parker, D., Chowdhur, R., Shibata, H., Thomson, A., Zhen, L., 2015. Land system science and sustainable development of the earth system: a global land project perspective. Anthropocene 12, 29–41.
Wu, J., 2008. Land use changes: economic, social, and environmental impacts. Agric. Appl. Econ. Assoc. 23 (4), 6–10.
Wu, F., Zhan, J., Su, H., Yan, H., Ma, E., 2015. Scenario-based impact assessment of land use/cover and climate changes on watershed hydrology in Heihe River Basin of northwest China. Adv. Meteorol. 2015, 1–11. http://dx.doi.org/10.1155/2015/410198. Article ID 410198.
Xu, Q., Jiang, Q., Cao, K., Li, X., Deng, X., 2013. Scenario-based analysis on the structural change of land uses in China. Adv. Meteorol. 2013.
Yin, F., Deng, X., Jin, Q., Yuan, Y., Zhao, C., 2014. The impacts of climate change and human activities on grassland productivity in Qinghai Province, China. Front. Earth Sci. 8 (1), 93–103.
Zhang, P., Liu, Y., Pan, Y., Yu, Z., 2013. Land use pattern optimization based on CLUE-S and SWAT models for agricultural non-point source pollution control. Math. Comput. Model. 58 (3), 588–595.
Zhang, Q., Wallace, J., Deng, X., Seto, K., 2014. Central versus local states: which matters more in affecting China's urban growth. Land Use Policy 38, 487–496.
Zhen, L., Deng, X., Wei, Y., Jiang, Q., Lin, Y., Helming, K., Wang, C., Hu, J., 2014. Future land use and food security scenarios for the Guyuan district of remote western China. IForest-Biogeosci. For. 7 (6), 372.