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Urban land use change and its effect on social metabolism: An empirical study in Shanghai

Xuezhu Cui*, Xuetong Wang

School of Business Management, Guanghzou University, Guangzhou 510000, PR China

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ABSTRACT

Numerous breakthroughs in multiple areas concerning land use change have been introduced in recent years. This phenomenon indicates that people have begun to realize the high environmental costs of their actions and are beginning to address this situation. From the perspective of environmental economics, this research focused on urban land use and explored the relationship between land use change and social metabolism flow through canonical correlation analysis (CCA). An empirical study was conducted in Shanghai to prove that urban land management could be seen as a means of balancing the social metabolism flow. First, for urban land use quantity, increasing the warehousing and traffic land areas could significantly affect the metabolism amount; meanwhile, the cultivated land and urban green land had crucial roles in controlling metabolism amount. Second, for urban land use efficiency, the intensity and efficiency of social metabolism could be influenced by land use efficiency, which indicated that a highly efficient industrial estate and storage land use could decrease the intensity of material consumption. These findings provide the government with new ideas and methods for urban planning and land management.

1. Introduction

Rapid urbanization changes the land use structure along with a continuous “colonization” to nature, which expands the urban scope and diminishes rural areas (Lambin et al., 2011). The unlimited demand for limited land areas has spurred serious urbanization-related problems, such as urban sprawl, food security, and ecological damage (Wang, Shen, Tang, & Martin, 2013). The increasing urban population and social economic development in developing countries have also increased the need for housing and infrastructure, which may be satisfied at the expense of losing agriculture land and consuming natural resources and energy (Giuseppina, 2012). Urbanization also produces a large amount of wastes that damage the ecological environment and threaten the ecological system (Stephan & Friedrich, 2000). The amount of these wastes all over the world has rapidly increased in recent years and will continue to increase in the coming decades, particularly for developing countries such as China (United Nations, 2008). Therefore, if this land conversion trend continues, its negative externalities will seriously affect the sustainable development of humans (Hall, Perez, & Leclerc, 2000).

The International Geosphere–Biosphere Program (IGBP) and International Human Dimensions Programme on Global Environmental Change (IHDP) showed that the extant studies on global environmental change were primarily focused on land use/land cover change and served as mediums through which humans could address global change (IGBP & IHDP, 1999). Land provides people with the essential materials, such as biomass, thus increasing the dependence of humans on land area. Human activities, such as material and energy transportation, storage, conversion, consumption, and waste treatment, are all linked with land use (Giuseppina, 2012).

Previous studies have identified the negative effects of land use change on the world (Foley et al., 2005), environment (Alberti et al., 2007; Mark et al., 2012), ecosystem (Polasky, Nelson, Pennington & Johnson, 2011), climate (Chen, Zhao, Li, & Yin, 2006; Seto & Shepherd, 2009), and human health (Patz & Olson, 2008; Xu, Rita, Jing, & Xu, 2008). These studies indicate that most of the negative effects of land use change on the ecosystem and the environment can be addressed through ecological remediation or environmental governance, but the scarcity of non-renewable resources poses a more serious problem (Polasky, Nelson, Pennington & Johnson, 2011).

In the current research, social metabolism refers to the exchange and consumption of materials and energy between nature and

* Corresponding author.

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human society, and urban land use is considered the core problem from the social metabolism perspective. Such perspective aims to track the material flows among different social sectors and analyze their state and efficiency to understand how urban land use change influences social metabolism. In this manner, how the land use activities of humans affect the natural resources and the environment can be reflected. A theoretical analysis and empirical study were performed using Shanghai data to construct a method that could connect land use change with social metabolism and to propose several suggestions that could mitigate the negative effects of land use on the environment and natural resources.

2. Literature review

After global industrialization and urbanization have accelerated economic development during the 20th century and have induced environmental pollution and ecosystem risks all over the world, scholars have begun to investigate the effects of urbanization on the environment and natural resources (Yan et al., 2003). Most of these researchers have adopted the social metabolism perspective in their studies.

Social metabolism has evolved from the concept of metabolism in life science. This concept is currently used to reflect the material and energy exchange between social and natural systems and to examine the exploitation, manufacturing, and application of natural resources as well as the emission of waste materials (Han, 2002). The social metabolism perspective considers the human society as a system that interacts with nature through the exchange of materials and energy as well as links the diminishing natural resources to the land use behaviors of humans (Heinz & Niels, 2002). Domestic scholars indicate that land use change is a consequence of human activities that can affect landscape conversion and metabolism change (Xie, 2008). Researchers from Austria perceive land use as a colonization process that continuously intervenes with the natural ecosystem (Helmut, Simon, & Emilio, 2001). Previous studies identify two features of social metabolism, namely, a continuous exchange between human society and nature and the storing or discharge of some materials and energy into the social system (Huang & Hsu, 2003). The changes in urban land use during industrialization have altered the throughput of energy, and the interrelations between social metabolism and land use change can be detected through material flow accounting (Krausmann & Haberl, 2002), which is a useful tool for tracking material and energy flows as well as for exploring the effect of land use change (Helmut, Marina, Fridolin, Helga, & Verena, 2004). A biomass flow model has been established to evaluate the relationship between land use and social metabolism, which depends on the land use type and its corresponding demands of biomass change (Krausmann et al., 2003). Another study demonstrates that the changes in land use and cover can influence the exchange of materials and energy between nature and humans, which can be evaluated using a metabolism frame (Fischer & Rotmans, 2009). Land use primarily changes the regional environment and influences the changes in the bio-geographical processes that are driven by the evolution of landscape structure (Stephanie, Paul, & Tisha, 2012). Urban development and planning must be connected with social metabolism in the cities to increase the ecological capacity and reduce the dependence of humans on the environment (Boyen, Millar, Newcombe, & O'Neill, 1981).

Studies on the metabolism response of land use change have also identified different forms of land use and their corresponding influence. A study from Austria reveals that land use/cover is closely related with social metabolism during the transition of lands from agricultural lands to industrial lands (Krausmann, 2001). Heinz and Niels (2002) investigated the relationship between land use and social metabolism in England from the 1850s to the present, provided a metabolism account of land use change, and analyzed different aggregates of inputs, such as domestic material extraction, foreign trade of materials, and energy input. Krausmann, Haberl, Erb, and Wackernagel (2004) analyzed the relationship among economic growth, socio-economic metabolism, and land use using four scenarios of land use pattern. They revealed a complex feedback mechanism between energy and land use policies as well as emphasized the usefulness of the socio-economic metabolism approach in examining land use. Given that the human appropriation of net primary production (HANPP) could be influenced by land use change, Wrbka et al. (2004) studied the relationship between social metabolism and land use intensity by calculating HANPP. They reported that strong monotonous correlations were also found between HANPP and urbanity, and land form could influence metabolism patterns, but not entirely. Lee, Huang, and Chan, 2009 used a spatial system modeling method to develop a socio-economic metabolism and land use change model that could simulate the spatial–temporal dynamics of socioeconomic metabolism and land use change. Chun asserted that material inflows could stimulate the accumulation of urban assets, and that some urban assets were out flowed to surrounding areas upon reaching the upper limit, thereby triggering land use change. Joan, Joan, Enric, and María (2010) used the Barcelona Metropolitan Region as an example to explore the synergies between socio-metabolic energy use and various landscape patterns. They concluded that the simultaneous loss of energy and land use efficiencies from the mid-19^{t}h century to present could be tracked by the changes in the functional landscape structure, thus revealing the importance of traditional rural landscapes in maintaining the ecological quality of non-built-up land. Erb (2012) reviewed the socio-ecological metabolism method for examining the changes in land use intensity and noted that material flow analysis can be used to study the vital aspects of land intensification by collecting, deriving, or modeling information on the stocks and flows of materials, energy, or substances between socioeconomic and natural systems.

Land use change has been recently investigated by Chinese scholars, and some regions in China have been used as research cases. By taking Jiangsu province as a case, Huang, Yu, and Ma (2006) studied the effect of land use change on social metabolism and reported that land use style, intensity, and pattern could directly affect the changes in the metabolism input and output of the socioeconomic system. A 10% increase in land use intention is accompanied by a 5.62% increase in social metabolism flux, whereas every 10% increase in land use intensity can induce a 5.03% increase in social metabolism efficiency. Through material flow analysis, Ma and Huang (2008) examined the responses of metabolism during the process of land use change in Jiangsu province from 1996 to 2005 and found a close relationship between these two variables. The changes in agricultural land did not increase the scale of output, whereas the changes in construction land increased the scale of input. Taiwanese scholars have analyzed the relationship between land use change and social metabolism using material flow accounting. By applying Geographic Information System (GIS) and its visualization in analyzing their data, these scholars argue that the development of Taipei was highly dependent on the flow of non-renewable energy; land use in Taiwan also demonstrated a significant layer structure that concerned the consumption of non-renewable energy (Chun et al. 2009). Wu, Yan, and Xu (2009) reviewed the sustainability aspect of energy-based urban metabolism and identified four points that should be further analyzed in the future. These points include (1) an integrated model for the ecological mechanism between urban metabolism and land use change, (2) government policies that are based on the