Ecological Indicators 95 (2018) 841–850

Contents lists available at ScienceDirect

Ecological Indicators

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

Original Articles

Spatial correction of ecosystem service value and the evaluation of eco-efficiency: A case for China's provincial level

Lu Xing[a,*], Minggao Xue[a], Xiaoyan Wang[a,b]

[a] School of Management, Huazhong University of Science and Technology, Wuhan 430074, China
[b] School of Accounting, Nanjing University of Finance and Economics, Nanjing 210023, China

ARTICLE INFO

Keywords:
Ecosystem service value (ESV)
Dynamic evaluation model
Regional eco-efficiency
Super-efficiency slacks-based model (S-SBM)
China's provincial level

ABSTRACT

While bringing socio-economic prosperity, rapid urbanization exerts severely impacts on the ecosystem service functions, resulting in unsustainable development. However, the loss of ecosystem services resulting from urbanization are seldom considered in regional sustainable development assessment. This paper aims to apply a super-efficiency slacks-based model (S-SBM) to evaluate the eco-efficiency by considering regional ecosystem service value (ESV). Moreover, an improved dynamic evaluation model, including the adjustment coefficients of natural geographical characteristic, socio-economic development level and resource scarcity, is developed to evaluate China's provincial ESV in 2014. Based on the analysis of the evaluated dynamic ESV and eco-efficiency, our results show that (1) a total dynamic ESV of 88.60 trillion Yuan was provided in 2014, and the highest ESV provinces mainly distributed northwest and southeast coastal areas, while the lowest ESV provinces were mainly located in North China Plain and central areas; (2) the relationship between ESV and gross domestic product (GDP) was spatially negative, expect for some southeast coastal areas; (3) our evaluated results demonstrate that ESV is a necessary factor in eco-efficiency evaluation. After considering regional ESV, positive changes occurred in almost all northwestern provinces, while southeastern provinces declined; (4) at last, the optimization analysis emphasizes that ESV is an important factor for sustainable development. In sum, the results of this study remind policy makers that they should consider fully regional ecological conditions in the implementation of urban development policies, so as to realize sustainable development goals.

1. Introduction

Goods and services provided by ecosystems maintain the environmental conditions and material foundations for human survival (Costanza et al., 1997; Millennium Ecosystem Assessment, 2005; TEEB, 2010a,b). However, Millennium Ecosystem Assessment (MA, 2005; de Groot et al., 2010, 2012) gave the evidence that approximately 60% of the global ecosystems had degraded during the past five decades. More seriously, the trend of increasingly urbanization continues to bring enormous pressure on the supply of ecosystem services (ES) (Chen et al., 2016a). Costanza et al. (1997) emphasized that if the value of these services were not fully captured or adequately quantified, they would be paid little attention in policy decisions. This neglect may ultimately compromise the sustainability of humans in the biosphere. Therefore, the accurate evaluation of ecosystem service value (ESV) and how to use it in policy making are of great significance for sustainable urban development.

While bringing socio-economic prosperity, rapid urbanization exerts severely impacts on ecosystem service functions. Population agglomeration and dramatic land use changes resulting from urbanization are considered the most important reasons for the decline of regional ES (Manes et al., 2016). A large number of researchers and organizations analyzed and evaluated the impacts of urbanization on ESV at different spatial scales (Daily, 1997; Costanza et al., 1997; Li et al., 2010; IPBES, 2012; Su et al., 2012; Costanza et al., 2014; Long et al., 2014; Xie et al., 2015; Wang et al., 2016; Zang et al., 2017). These researches and projects greatly increase public awareness of ESV, and stimulate more scholars and groups to better evaluate, map and manage ES. However, most of them focus more on the evaluation and variation of ESV. There are lacks of researches on integrating regional ESV and socio-economic elements into a unified framework for sustainability analysis, this knowledge gap hinders the application of ESV in guiding appropriate policy making (Laurans et al., 2013).

The concept of eco-efficiency has been widely used for sustainability analysis, which has been proposed as an indicator combining multiple information of environment, energy and economy. Schaltegger and

* Corresponding author.
E-mail addresses: shinglu1205@hust.edu.cn (L. Xing), xmgwt@hust.edu.cn (M. Xue), xiaoyanw@hust.edu.cn (X. Wang).

https://doi.org/10.1016/j.ecolind.2018.08.033
Received 11 December 2016; Received in revised form 11 August 2018; Accepted 16 August 2018

Sturm (1990) first proposed this concept in business world. Briefly, eco-efficiency refers to the production of more goods and services with less environmental impacts. Based on this concept, different methods and variables are built and used to measure eco-efficiency. Among all eco-efficiency evaluation methods (Korhonen and Luptacik, 2004; Park et al., 2007; Van Caneghem et al., 2010), Data Envelopment Analysis (DEA) is the most popular modeling method and has been widely applied. However, current eco-efficiency evaluation based on DEA mostly focus on energy consumption and pollutant emission related to urbanization (Yu et al., 2013; Beltrán-Esteve et al., 2014; Huang et al., 2014; Ren et al., 2016). In addition to the efficiency of energy and environment, the loss of natural land resulting from urbanization is scarcely considered in regional eco-efficiency evaluation. Natural land is the basis and carrier of multiple ES supply, such as carbon sequestration, hydrological regulation, climate regulation and entertainment supply (Costanza et al., 1997; de Groot et al., 2010). Thus, land use changes inevitably result in the variations of ESV by altering the processes and structures of ecosystems (Estoque and Murayama, 2013). That means if the deterioration of natural resource resulting from urbanization is not considered in eco-efficiency evaluation, it may lead to one-sided results. In fact, some scholars have found the puzzling result in their evaluations. Yin et al. (2014) used DEA to evaluate the eco-efficiency of 30 China's provincial capital cities in 2009, based on their results, they found that the higher the economic level of a city was, the higher its eco-efficiency but the truth was that it suffered more from haze and water pollution. Van den Bergh (2009) and He et al. (2016) considered that the reason for this is that GDP is the only selected desirable output in the evaluation, but GDP has been severely criticized as neglecting the value of some goods and services not sold in the market, especially the majority of ecosystem services. To address it, this paper re-evaluates the eco-efficiency by considering both regional ESV and GDP based on the data from China's provincial level. Further, to detect to what extent does ESV affect regional sustainable development.

In addition, as a cost-effective method, benefit transfer method has been widely applied to evaluate ESV (Costanza et al., 1997), although some limitations and restrictions still exist in this method. The great concern on this method is how to ensure the reliability of the evaluation results. Rosenberger and Loomis (2003) pointed out that if an unstudied "policy site" had the similar characteristics with an existing "studied site", and then the transfer was reliable. According to this guideline, the global value coefficients put up by Costanza et al. (1997) may not be suitable for China. To solve this problem, Xie et al. (2003) developed an equivalent factor table for China's terrestrial ecosystem and further improved it in 2008 and 2015 (Xie et al., 2008; Xie et al., 2015). Song and Deng (2017) compared the evaluation results based on the unit value tables of Xie et al. (2008) and Costanza et al. (2014). Results showed that national ESV ($756.15 billion) based on Xie et al. (2008) was much lower than that ($6174.05 billion) based on Costanza et al. (2014). It indicates that the adjustments of the value coefficients is necessary when benefit transfer method is applied.

Although Xie et al. (2015) provided us with a value coefficient table for China, it may not be enough for all regional cases in China. Because as a static coefficient table, the evaluation based on it cannot reflect regional natural geographical and socio-economic characteristics (Yao et al., 2015). Specifically, on the one hand, People with different socio-economic backgrounds has discrepant preferences for the environment (Song et al., 2010; Zhang et al., 2010). Generally, people's willingness to pay (WTP) increases with the rise of socio-economic level. On the other hand, ecosystem service functions vary with natural geographical conditions (Hu et al., 2013; Wang et al., 2016). It is particularly the case for China, which has a vast land with a variety of topographical and natural characteristics. Above facts indicate that the dynamic adjustments to value coefficients should be made so as to reflect regional natural geographical and socio-economic characteristics. In order to make a reliable ESV evaluation of the study area, some scholars have begun to select some indicators to adjust the static coefficients (Fu et al., 2016; Zang et al., 2017; Li et al., 2017b; Li et al., 2017c). However, the selection of these adjustment indicators is still arbitrary and unsystematic. Some scholars have proposed some criteria and guidelines for the selection (Boyle and Bergstrom, 1992; Johnston and Duke, 2009; Plummer, 2009; Johnston and Rosenberger, 2010; Bateman et al., 2011). Recently, Richardson et al. (2015) summarized four vital criteria for valid evaluation: scope, societal preferences, geographic scale and substitutability. Based on previous literatures, this paper aims to provide an integrated framework of coefficient adjustment that can reflect both the natural geographical and socio-economic characteristics, and then apply it to evaluate China's provincial dynamic ESV.

At last, as the largest developing country, China's rapid urbanization has led to a dramatic conversion of natural or semi-natural land into construction land (Chen et al., 2016a). The total area of built-up land increases from 19,264 Km^2 to 47855.28 Km^2 with an annual growth rate of 5.21% from 1995 to 2013 (National Bureau of Statistics of China (NBSC), 2014). Meanwhile, the growing urban population continues to stimulate the huge demand for land resources. These factors have greatly influenced China's land use/land cover (LULC) (Chen et al., 2016b), accordingly, regional ESV also goes through declines to varying degrees. It indicates that the accurate evaluation of regional ESV and applying it to regional sustainability assessment are of vital significance for China to implement appropriate policy decisions.

In conclusion, our main work can be concluded in following three parts. Firstly, we construct an integrated ESV evaluation model that can reflect both natural geographical and socio-economic characteristics. Secondly, based on dynamic results, we further analyze the spatial relationship between provincial GDP and ESV. Thirdly, as an important ecological factor, provincial ESV is considered in the evaluation of eco-efficiency to provide an objective judgement on regional sustainability.

2. Methods and materials

2.1. An integrated framework of coefficient adjustment

According to the recent work of Xie et al. (2015), the value of standard equivalent factor can be calculated by the following formula:

$$D = S_r \times F_r + S_w \times F_w + S_c \times F_c \tag{1}$$

where D represents the static value of standard equivalent factor (Yuan/ha); S_r, S_w and S_c represent national percentages of sown area of rice, wheat and corn (%), respectively; F_r, F_w and F_c represent national average net profits per unit area of rice, wheat and corn (Yuan/ha), respectively.

2.1.1. Natural geographical adjustment coefficient

In formula (1), only rice, wheat and corn are included in the calculation for the value of standard equivalent factor. It cannot reflect regional differences of natural geographical conditions in China, grain crops are the main crops in Northeast China and North China Plain, such as Jilin (83.15%), Heilongjiang (74.30%) and Shanxi (71.71%), but vegetable, oilseed and sugar account for a larger portion in other regions. Thus, different major crops should be selected. Accordingly, natural geographical adjustment coefficient can be calculated as follows:

$$D_i = \frac{1}{5}\sum_{2010}^{2014} r_j \left(\sum_{1}^{n} P_{ij}^{n} \times F_{ij}^{n}\right) \tag{2}$$

where D_i is natural geographical adjustment coefficient in province i (Yuan/ha); P_{ij}^n is the percentage of sown area of main crops in province i and year j (%) (n is the number of main crops in each province); F_{ij}^n is average net profits per unit area of main crops in province i and year j (Yuan/ha); r_j is price index of farm products, which is used to convert net profit into constant price in 2014. Significantly, sown area and farm