Urban Metabolism Based on Emergy and Slack Based Model: A Case Study of Beijing, China

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Abstract: The key to studying urban sustainable development depends on quantifying stores, efficiencies of urban metabolisms and capturing urban metabolisms’ mechanisms. This paper builds up the metabolic emergy account and quantifies some important concepts of emergy stores. Emphasis is placed on the urban metabolic model based on the slack based model (SBM) method to measure urban metabolic efficiencies. Urban metabolic mechanisms are discussed by using the regression method. By integrating these models, this paper analyzes the urban metabolic development in Beijing from 2001 to 2010. We conclude that the metabolic emergy stores of Beijing increased significantly from 2001 to 2010, with the emergy imported accounting for most of the increase. The metabolic efficiencies in Beijing have improved since the 2008 Olympic Games. The population, economic growth, industrial structures, and environmental governance positively affect the overall urban metabolism, while the land expansion, urbanization and environmentally technical levels hinder the improving of urban metabolic efficiencies. The SBM metabolic method and the regression model based on the emergy analysis provide insights into the urban metabolic efficiencies and the mechanism. They can promote to integrate such concepts into their sustainability analyses and policy decisions.

Keywords: emergy theory; urban metabolism; slack based model (SBM); Beijing Municipality; regression analysis

1 Introduction

The concept of urban metabolism came from a pioneering article on the metabolism of cities by Wolman (1965), in response to deteriorating air and water quality in American cities—issues still recognized today as threatening sustainable urban development (Kennedy et al., 2007). Wolman analyzed the metabolism of a hypothetical American city, quantifying the overall fluxes of energy, water, materials, and wastes into and out of an urban region of $1 \times 10^6$ people. Great deals of ambient particulate sampling studies have been conducted in a variety of cities by the research methods of material or energy flow analyses. These studies are typically of greater metropolitan areas, such as Sydney (Newman et al., 1996), Taiwan, China (Huang, 1998), Vienna (Hendricks et al., 2000), London (Chartered Institute of Wastes Management, 2002), Hamburg and a few other European cities (Hammer et al., 2003), Shanghai (Zhang et al., 2006a), Toronto (Forkes, 2007). In sun, an urban metabolism analysis is a means of quantifying the overall fluxes of energy, water, material, and wastes into and

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out of an urban region, somewhat analogous to human metabolism (Halla et al., 2003). It represents a holistic approach to urban planning, exploring the interactions among resource flows, urban transformation processes, waste streams and quality of life (Rotmans et al., 2000). Newman (1999) postulates that measuring urban material metabolism should include resource inputs/production and waste outputs, as well as other criteria such as livability, human amenity and health, employment, education, housing, accessibility and community. In an efficient urban metabolic system, resource consumption and waste generation are within the carrying capacity or assimilative capacity of the regional or global hinterland (Browne et al., 2009), as measured using material flow accounting (MFA), energy flows accounting or ecological footprint (EF) analysis (Zhang et al., 2009). By integrating the sum of all flows of available energy or material, the urban metabolic efficiency, ratio of output to input in urban metabolic systems can be calculated. The first comprehensive study on urban metabolism in Beijing was done in 2007 (Zhang and Yang, 2007a), and had analyzed Beijing’s urban metabolic system using emergy synthesis to evaluate its environmental resources, economy, and environmental and economic relations with the regions outside the city. The later studies by Zhang et al. (2009) also pointed out the significance of reducing the reliance on external inputs of sources, energy and services.

On the basis of these reviews, most of the work on urban metabolism focuses on the accounting of the inputs and outputs of materials or energy flows of a specified society (Huang et al., 2006). However, the urban metabolic relationship between cities and their environments can not simply be viewed from linear accumulations of materials (Fischer-Kowalski and Haberl, 1997). Especially the efficiency analysis of urban metabolism is still deficient, and most of the studies focus on the quantization of urban material or energy input-output (Zhang and Yang, 2007b). In addition, more often than not, analyses neglect consideration of metabolic efficiencies based on incorporating the input excesses and output shortfalls. Research on the issue of urban metabolic efficiencies would go a long way towards the framework for both natural and social scientists to study the interrelations between urban systems and their environments. Further studies on the driving forces of urban metabolic efficiencies’ differences would greatly enhance our understanding of urban metabolic system.

To address these issues, this paper creatively interprets urban metabolic efficiencies using ‘emergy’ (solar energy) and slack based model (SBM) analysis. It proposes to treat not only how a city’s metabolism be measured but also what drive the metabolism. For these purposes, an index of urban metabolic efficiency is proposed, which provides insight into the urban metabolisms of resource and energy acquisition and use. This study focuses on the measurement of the urban metabolic efficiencies of a typical metropolis Beijing over the last decade. Implications for the driving forces are also presented in this study.

2 Materials and Methods

2.1 Study area

Beijing (39°28′–41°05′N, 115°25′–117°35′E), is located in the northern part of the North China Plain and is the political, cultural and economic center of China. Beijing covers an area of 16 410.54 km² and consists of 14 districts and two counties (Yanqing and Miyun) (Fig. 1). As the second largest Chinese city by urban population after Shanghai, the total population in the study region is 1.96 × 10⁷ (2010), nearly 86% (1.69 × 10⁷) of which live in urban areas. During the past decades, Beijing has experienced rapid economic growth. Beijing’s gross domestic product (GDP) totaled 1.41 × 10¹² yuan (RMB) in 2010, being almost 4.4 times of that in 2001, with tertiary industry accounting for 75% of its GDP in 2010. Despite a great expansion of the tertiary industrial sectors in Beijing, more investments in urban infrastructure are needed for a better environment. Fog and haze conditions in Beijing serve as the best evidence of visibly metabolically unsustainable development due to the rampant urban growth. In addition, Beijing clearly belongs to the group of cities with a resource scarcity. The city has small reserves of coal, iron, and building materials. Most of the requirements for production and life depend on external inputs. Because of the city’s vulnerability to interruptions in these resource flows, it is important to clearly understand Beijing’s urban metabolism (Zhang et al., 2011).

2.2 Data sources

The data used in the analysis were derived from publicly accessible reports prepared by the National Bureau of Statistics of China and Statistical Bureau of Beijing, such as China Statistical Yearbook 2001–2011 (National Bureau of Statistics of China, 2001–2011), China Urban