Ecological Indicators 93 (2018) 704–717

Contents lists available at ScienceDirect

Ecological Indicators

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

Review

How can cities support sustainability: A bibliometric analysis of urban metabolism

Xuezhu Cui

School of Management, Guangzhou University, Guangzhou 510000, China

ARTICLE INFO

Keywords:
Urban metabolism
Bibliometric analysis
Indicators
Cities
Sustainability
Recycling

ABSTRACT

Urban metabolism concerns the evaluation of how much urban ecosystems produce and consume resources. Such an assessment is now a critical perspective in understanding the manner in which city development affects local and regional environment. Research in urban metabolism is a relatively new and ever-evolving area that encompasses a multidisciplinary field and moves toward a combined natural and social science. This paper offers a verifiable and reproducible systematic literature review of sustainable urban metabolism, analyzing and scrutinizing 813 papers for co-occurrence of keywords. This review aims to answer two research questions: (i) what are the prevailing themes in urban metabolism and (ii) how have these themes measured the support of cities toward sustainability? Through clustering analysis based on bibliometric method, four different focuses and their main keywords were outlined. The four clusters are general concept, methodology, policy issue, and specific element clusters, and their core keywords are city, energy, relationship, network, sustainability, China, indicator, economy, country, recycling, disposal, and recovery. Urban metabolism themes have evolved from nutrient flows and individual element treatment concerning industrial ecology in the course of the past century to ecological views of complex urban networks. The taxonomy of themes and the analysis of their evolution lead to further research agenda on the general framework of urban metabolism toward sustainability.

1. Introduction

Since the 1950s, the global trend toward population urbanization has intensified. By the middle of 2009, the urban population (3.42 billion) has surpassed the rural population (3.41 billion) worldwide, implying that the amount of people living in the cities exceeds those living in rural areas (United Nations, 2010). Demographers have argued that this trend will continue beyond the following several decades (United Nations, 2012). The rural population will continue to migrate to cities, resulting in a series of problems in energy and resource use, and also urban development and environmental coordination. Counterbalancing the negative impact of human activities and meeting the challenges of global sustainable development are possible. To fulfill this goal, cities and human activities conducted within them, urban material resources and energy flows, waste discharge and resulting changes in urban operations, and urban functions have become research focus points in recent years (Inostroza, 2014).

1.1. Definition of urban metabolism

For over a century, scholars have studied sustainable urban development. Marx's "Capital: A Critique of Political Economy" (1887) was the first book on the subject. Wolman (1965) conducted a series of discussions on sustainable urban development and put forward the idea of urban metabolism to provide broad modeling, examination, and evaluation of the environmental impact of human activities. Urban metabolism analogizes urban systems to living organisms and adopts the metabolic thinking of living organisms to urban operations because they consume resources from the environment and excrete waste. Decker et al. (2000) stated that the material input of the system becomes energy for use, buildings and infrastructures, and many different kinds of waste. As cities are home to humans and other animals and plants, urban operations do not involve only single organisms. Research on the city as an ecosystem is now widely accepted, and the rules governing the function of natural ecosystems are, to some extent, the goal of sustainable urban development. In other words, cities are expected to be self-sufficient, similar to natural ecosystems. For example, feedback is received through scavenger cycles. If urban development were to possess such features, then it would become sustainable. However, the troubling fact is that the movement of resources and energy in modern metropolitan areas is largely linearly metabolic (Zhang et al., 2015) and is therefore unsustainable.

Kennedy et al. (2007) described urban metabolism as the new technology, changing industry and growing population that happens in

E-mail address: cuixuezhu_598@163.com.

https://doi.org/10.1016/j.ecolind.2018.05.056
Received 16 March 2018; Received in revised form 17 May 2018; Accepted 24 May 2018
1470-160X/

the city, accompanied by economic growth, material accumulation or storage, energy consumption, and disposal of waste. This definition clearly covers the components of urban systems that are used to perform urban metabolic analysis. From this perspective, urban metabolism as a systematic model integrates into cities various human activities, such as housing, work, and energy use with urban infrastructures, such as roads and houses, and land use (Cui and Wang, 2015). Due to the increasing number of elements considered in urban metabolic analysis, the quantitative analysis of urban metabolism in current studies does not completely follow the Kennedy definition. Nevertheless, this definition is still the clearest and most comprehensive description, and it lays the foundation for the further development of urban metabolism study.

1.2. Brief evolution of urban metabolism study

Since Wolman (1965) proposed the urban metabolism concept in the 1960s, extension of methods have promoted the continuous development of urban metabolism study. In the 1970s, the concept of urban metabolism was formed. After its decline in the 1980s, it again roused the interest of scholars in the 1990s with the acceleration of industrialization in developed countries and its resulting resource and environmental impacts. Since 2000, urban metabolism has become a research focus point of scholars all over the world. Two main schools of thought exist in urban metabolism. One school is an urban metabolism study that is based on energy equivalence, as represented by Odum (1983), and the second school is a metabolism analysis that is based on the flow of material resources, water, nutrients, and others, which is currently widely used (Shen and Ma, 2015). Urban metabolism studies further link urban metabolism with urban sustainability indicators (Leonardo and Taina, 2015; Huang et al., 2012; Huang et al., 2015a,b), urban greenhouse gas emissions (Zhang et al., 2014), urban metabolism mathematical modeling and policy analysis (Marull et al., 2010), and sustainable urban form design and landscape planning (Kennedy et al., 2011; Davoudi and Sturzaker, 2017; Thomson and Newman, 2017; Voskamp et al., 2018).

From the perspective of the evolution of urban metabolism study, Wolman (1965) pioneered the use of data on national levels, such as fuels, water, and food, and incidences of waste, garbage, and air pollutants. Wolman (1965) based his work on the assumption of a United States city with a population of one million. He analyzed material inflows and outflows per unit of capital (Wolman, 1965). This proposed material flow method provided a new systematic perspective for the quantitative study of material consumption and waste discharge in the urban environment (Decker, 2000). Urban metabolism studies using real-life cases began in the 1976 in a study based in Tokyo (Hanya and Ambe, 1976). The empirical study of Hong Kong was completed in 1978 by Newcombe and his colleagues under UNESCO's Man and the Biosphere Program (Newcombe et al., 1978).

Emergy analysis methods originated in the same decade, which studied urban metabolism from the viewpoint of using solar energy to describe the amount of energy. These methods converted various forms of energy into a single unit, the solar energy joule. They also measured and analyzed energy and material flows in a system by a standard energy value, which was obtained by converting different kinds of incomparable energy in the system into the same unified energy standard. Zucchetto (1975) studied urban metabolism in Miami using the emergy method. Odum (1983) then used data provided by Stanhill (1977) to perform an empirical study of Paris using emergy analysis. Although Odum's emergy analysis has not yet become mainstream in urban metabolism studies, its application has continued for many years. Relevant research areas include the Chinese cities of Taipei and Beijing (Huang, 1998; Huang and Hsu, 2003; Zhang et al., 2009).

From the 1980s to the early 1990s, urban metabolism progressed relatively slowly. Girardet (1992) proposed the need for further research on the link between sustainable development and urban metabolism. Then Kobe, Japan hosted an international conference about urban metabolism on September 6, 1993. In this symposium, Bohle (1994) presented an analysis of urban food metabolism in developing economies, which was critical to urban metabolism study.

In the mid- and late-1990s, material flow analysis (MFA) made some progress and was applied to urban metabolism research. *Metabolism of the Anthroposphere* was first published in 1991 (Baccini and Brunner, 1991), and in 1996, Baccini analyzed regional material flow research methods and published significant textbooks (Baccini and Bader, 1996). Because the work of Baccini and Brunner (1991) was based on early-1970s urban metabolism studies, their energy flow was measured in joules. This measurement differs from the fossil fuel metric in kt or 1000 tons per year, which is provided in the Eurostat MFA guidelines. In contrast to Odum's focus on energy, MFA focuses on qualitative changes in the flow and storage of material resources. Although the Odum school has certain advantages from a sustainable development perspective, it is still not the mainstream school of thought. The Odum school applied biophysical value theory to evaluate the economic and ecological system (Huang, 1998). They also quantified the equivalence effect of different forms of energy (fuel, electricity, and solar energy), which is the direct or indirect application of a certain number of solar joules during the formation of a certain resource, product, or service. However, the Odum school neglected problems in practical applications, such as conversion and calculation, which limits its wide application and development. In contrast, the mainstream school of urban metabolism of MFA employs measurement units, which are easy to understand, especially for the government and policymakers. A unit of measurement that is based on weight is easy to understand, identify, and use. In fact, studies of the two schools are not far apart, except that they use different units of measurement to quantify the same subject. Research on the substance metabolism began gradually after 1995, with two of the key material elements being nitrogen and phosphorus. Nilson (1995) performed phosphorus metabolism calculations, with Gävle of Sweden as the subject. Meanwhile, Baker et al. (2001) performed a comprehensive nitrogen-accounting calculation that was based on the ecosystems of Phoenix and Central Arizona. Færge et al. (2001) performed metabolic calculations on Bangkok nitrogen fluxes from the perspective of food metabolism. Finally, Burstrom et al. (2003) studied the nitrogen and phosphorus metabolisms of Stockholm. All of these studies led to a general agreement that material elements in cities experience a cumulative and irreversible process (Burstrom et al., 2003).

In the late-1990s and the early twentieth century, the study of urban metabolism made rapid progress. Newman (1999) studied urban metabolism in the context of Sydney (Newman, 1999). Scholars applied MFA to urban metabolism studies on cities in Vienna and lowland Switzerland (Baccini, 1997; Hendriks et al., 2000). In addition, Warren-Rhodes and Koenig (2001) further enriched MFA research in Hong Kong. In Newman's (1999) research, he established an urban metabolism expansion model that includes various markers concerning income, entertainment, education, health, housing, employment, and social activities, which was included in the Australian State of the Environment report. Subsequently, Australian scholars Stimson et al. (1999) and Lennox and Turner (2004) further explored the impact of urban metabolism on the well-being of residents on this basis. An empirical study in Hong Kong that focused on its urban metabolism between 1971 and 1997 analyzed the relationships between urban development and the environmental impact as the country shifted from a manufacturing economy to a service economy (Warren-Rhodes and Koenig, 2001). During this shift, per capita consumption of raw material, food, and water increased by 149%, 20%, and 40%, respectively, and total atmospheric, sewage discharge, solid waste, and CO_2 grew by 30%, 153%, 245%, and 250%, respectively. Urban metabolism growth in Hong Kong may be related to the growth of urban material wealth and the growth of consumption. Although Warren-Rhodes and Koenig have not yet conducted further analyses on the causes of this rapid urban metabolism, their study from 2001 does show, to some extent,