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Review of spatial analysis of urban carbon metabolism

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ABSTRACT

Urban areas have contributed 75% of the global CO_2 emissions. Therefore, seeking global carbon reduction solutions from the perspective of city has become a focus of decision-makers in charge of environmental protection. The carbon emission reduction potential in land management and spatial adjustment has become an important mean for achieving regional and global sustainable development. In this paper, we systematically review and synthesize four main aspects of urban carbon metabolism spatial analysis, namely: (1) advances in urban carbon metabolism, (2) carbon accounting based on land use and cover change, (3) spatial distribution of urban carbon metabolism and influencing factors, and (4) forecasting based on land use change (Land Use and Cover Change – LUCC). In addition, we point out current deficiencies in the study of urban carbon metabolism, such as incomplete process analysis and lack of spatial display. Based on previous research, we propose a spatial-analysis-centric outlook on urban carbon metabolism, including the following key approaches: (1) future researchers should simultaneously consider natural and socioeconomic components, as well as vertical (flows from land to atmosphere) and horizontal (flows among different land use types) carbon flows, to obtain a more complete picture of the entire urban carbon metabolism system; (2) carbon metabolic spatial mapping can be implemented in patches to better serve government's goals for optimal regulation and spatial planning; (3) researchers should refine current urban-scale research, also expanding it to the metropolitan (i.e., urban agglomeration) scale, to establish multi-scale, multi-level, and organic network structures, and study the spatial distribution pattern of carbon metabolism within and among cities and metropolitan areas, which will lay a scientific foundation for urban, regional, and national sustainable development.

1. Introduction

In recent years, significant pressure to reduce CO_2 emissions has attracted more and more attention of government policy makers. In spite of efforts to reduce fossil fuel combustion, studies have shown that CO_2 emissions caused by global energy consumption have remained relatively stable for two consecutive years (about 321Gt in 2016). Therefore, transforming carbon emissions patterns and seeking more effective ways of reducing carbon emissions are necessary. The 2007 IPCC report pointed out that about 80% of anthropogenic carbon emissions were from urban areas, within which approximately one-third are from land use and cover change (LUCC). Thus, land management and spatial adjustment have become every country's key task to reduce urban and even global carbon emissions. Previous urban carbon cycle and carbon metabolism research has been reviewed from the viewpoint of industrial ecology and sociology, and also through studies that use carbon accounting process analysis inside and outside cities (Zhao and Huang, 2013). These studies assess the content (including energy consumption, industry production, agriculture production, solid waste, forest, grassland water, and external flows) and methods (including greenhouse gas inventory method, field observation, model construction and RS-based method) of carbon accounting (Zhang et al., 2015b), and factors influencing carbon emissions (Li et al., 2013). This represents a shift in the research focus from macroscopic mode to microscopic mechanisms (Zhao and Huang, 2013), and from a single process of either a natural or anthropogenic process to a combined anthropogenic-natural process. However, previous studies did not consider carbon flows among urban components from the perspective of spatial adjustment. Spatial analysis more intuitively demonstrates the distribution and spatial transfer of carbon metabolism. It can provide a scientific foundation for land planning, industrial distribution change, and spatial adjustment of carbon management

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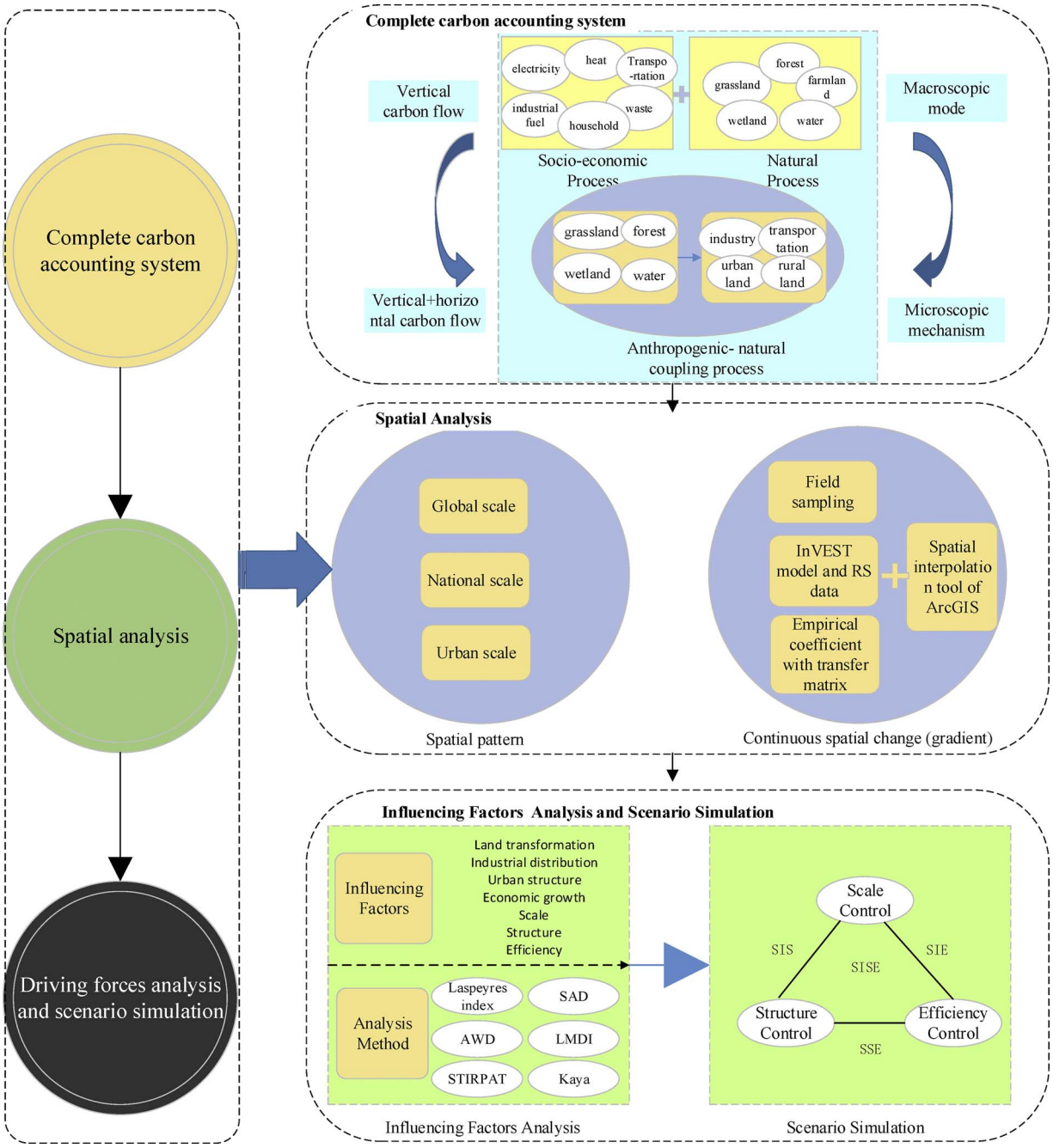

Fig. 1. Research Framework of urban carbon metabolism spatial analysis.

activity. In this paper, we review the research literature on: urban carbon metabolism, carbon accounting based on land use and cover change, the spatial analysis of urban carbon metabolism, and the main driving forces and scenario simulation (Fig. 1). This study provides a scientific basis for future spatial planning and designs of low-carbon cities.

2. Urban carbon metabolic process

The concept of "urban metabolism" was first put forward by Wolman (1965) who, similar to describing a natural metabolic process, described the complete process of material and energy input to and output from a city. As a key ecological factor in urban metabolism, carbon's metabolic process has received extensive attention from researchers (Sovacool and Brown, 2009). Baccini (1996) first advanced the concept of "urban carbon metabolism," and considered carbon emissions caused by food processing, industrial trade, energy conversion, residential consumption, waste management, and other social and economic activities as well as carbon sequestration owing to natural components such as farmland and forest. This provided a conceptual framework for understanding urban horizontal carbon flows (Churkina, 2008). Urban carbon metabolism research firstly focused on metabolic process accounting, and opened the 'black box' of the city through the analysis of its material flows while exploring its internal metabolic mechanism. The early research focused on the social and economic components of carbon emissions (e.g., carbon emissions caused by electricity, heat, and industrial fuel, surface transportation fuel, industrial processes and waste of ten megacities (Kennedy et al., 2010), household energy use in Xiamen, China (Ye et al., 2011), and port city transportation activities in Barcelona, Spain (Villalba and Gemechu,