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Quantifying the spatial patterns of urban carbon metabolism: A case study of Hangzhou, China

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ABSTRACT

With rapid urbanization in China, there is an urgent need to better understand spatial patterns of cities' carbon transitions in urban metabolism processes and to explore ways to achieve low carbon cities through sustainable urban planning. In this study, we took Hangzhou City as an example, and firstly analyzed changes in carbon emission and sequestration based on land use types, using data with 5 years interval from 1995 to 2015. We then quantified both harmful and beneficial carbon transitions by land use changes spatially. Harmful carbon transitions are processes that cause carbon sequestration decreases or carbon emission increases and the beneficial ones are the opposite processes. Finally, we employed a panel data regression analysis to investigate how urban forms and road structures influence urban carbon emission at the district level. We found that carbon emissions experienced a nearly five times increase, while carbon sequestration decreased by 22.29%. And the land use change from cultivated land to industrial land accounted for 61.05% of the harmful carbon transitions. In addition, the spatial analysis of urban carbon transitions indicated harmful carbon transitions always sourced from the eastern parts of Hangzhou. Most beneficial carbon transitions were located in the urban central area and western mountainous areas. The panel data analysis demonstrated that urban expansion modes with high connectedness and a better coupling relationship between urban form and road structure could help to emission reduction, and a mononuclear urban expansion mode at the district-level exerted a positive influence in relation to carbon emissions increase. This study provided an approach to assess urban carbon metabolism and help to better understanding of low-carbon urban form.

1. Introduction

Carbon emissions has been recognized as the greatest known contributor to global climate change. Urban areas, which occupy only 2% of the overall land area in the world, accounts for approximately 75% of the global carbon emissions (Grimm et al., 2008; IPCC, 2006). In addition, urban carbon emissions are projected to grow significantly with rapid urban expansion (Bai et al., 2018). As a nation, China has had the highest carbon emissions since 2006 (Gregg et al., 2008) in the world and its rapid urbanization has been the greatest contributor to carbon emission growth. A nearly 6.5 times urban expansion was recorded in recent 35 years (Fang et al., 2017). While urbanization contributes greatly to national economic growth and poverty reduction, uncontrolled urban expansion, in particular the reduction of green lands and farmlands, has reshaped the process and distribution of urban carbon metabolism (Bai, 2016; Hutyra et al., 2011; Zhang et al., 2014). Curbing carbon emission while maintaining urban development constitutes a great challenge for Chinese governments. Optimizing urban planning and constructing a sustainable urban form (i.e., the spatial patterns and structural features of urban land use) have been proved to be efficient to reduce carbon emissions (Chen et al., 2011; Fang et al., 2015; Khan and Pinter, 2016; Madlener and Sunak, 2011; Marshall, 2008; Zhang et al., 2012a). Therefore, to achieve development of low carbon city by sustainable urban planning, there is an urgent need to better understand the spatial patterns of cities' carbon transitions in urban metabolism processes, and to investigate the relationships between carbon emission and urban forms.

Urban metabolism was defined as the process of materials and

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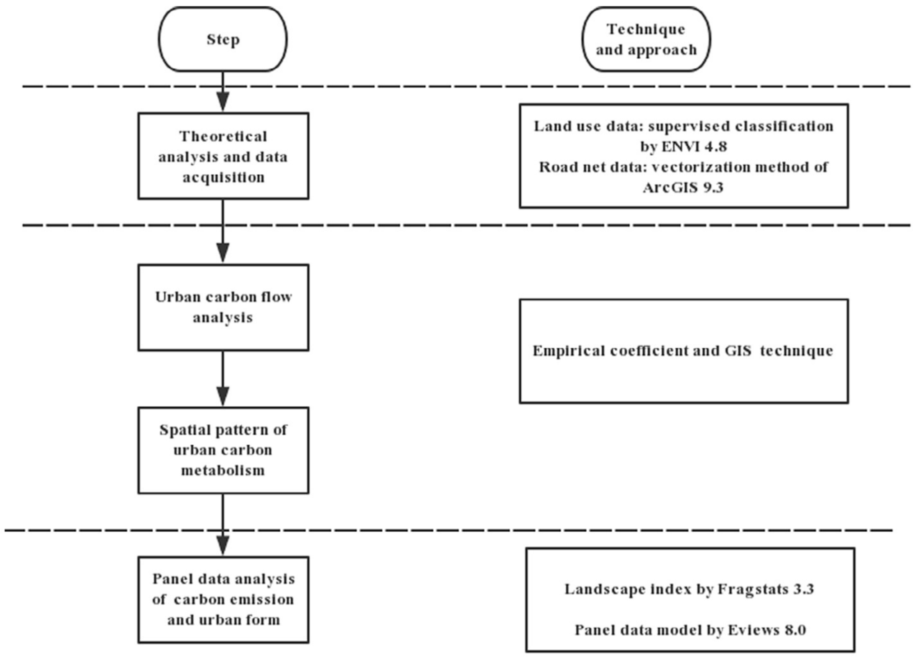

Fig. 1. Flow diagram and approaches used.

energy flowed through the whole urban system (Wolman, 1965) and urban carbon metabolism therefore should concentrate on carbon flows, including both emissions and sequestration, between the different components of the urban system (Johnson and Gerhold, 2003; Xia et al., 2016; Zhang et al., 2016b). Quantifying urban carbon emission and sequestration of both natural and artificial components are an important step to understanding urban carbon metabolism comprehensively. The effects of natural components of the landscape on urban carbon budget has been widely discussed (Golubiewski, 2006; Ni, 2002; Zhao et al., 2007) and the global carbon cycle has been proven to be greatly affected by cultivation in temperate climates and tropical deforestation (Achard et al., 2014; Fearnside, 2016; Kaye et al., 2005; Schimel et al., 2015). In an urban area, human activities have a much stronger impact on urban carbon budget than natural components (Bai et al., 2017; Shi et al., 2016; Xia et al., 2017). Differing from those heavily industrialized cities, the main source of carbon emissions in a city is energy consumption of urban transportation (Baldasano et al., 1999; D'Avignon et al., 2010; Romero Lankao, 2007). Additionally, population aggregation in urban areas has been proven to promote carbon emissions by significantly increasing household energy consumption (Liddle, 2014; Pataki et al., 2006; Wang et al., 2017b; Zhang et al., 2016a). Moreover, modern farming methods and excessive fertilizer application play important roles in global carbon and planetary surface energy balance because these agricultural land management changes the physical land surface and biogeochemical cycles (Bondeau et al., 2007; Chen et al., 2017; Gurjar et al., 2004; Zafeiriou and Azam, 2017; Zhang et al., 2014).

Previous studies have showed that the impact of urban forms on carbon emissions in urban areas was significant and profound (Rickwood et al., 2008; Steemers, 2003; Wiedenhofer et al., 2013). Some researchers suggest that more compact, high-density urban areas and a mixture of land use can lead to lower carbon emissions (Anderson et al., 1996; Dhakal, 2009) through reducing the length of commutes (Chen and Zhu, 2013), while urban sprawl increases reliance on private automobile transportation (Ewing, 1997; Travisi et al., 2010). However, there have been several studies that found that dense urban areas had a higher urban heat island and thus led to a higher energy consumption for cooling (Makido et al., 2012; Morakinyo et al., 2017). Therefore, there needs a careful consideration of trade-off mechanism in sustainable urban planning in order to achieve the targets of emission reduction.

Previous studies have paid a less attention to analyzing urban carbon metabolism comprehensively, instead just analyzing isolated aspects of natural or artificial carbon sequestration and emission. Here we took Hangzhou city as an example, and analyzed the full picture of urban carbon metabolism by land use changes in order to better inform urban planning and management decisions. We analyzed carbon transitions (carbon flows) caused by land use changes from 1995 to 2015, divided these transitions into beneficial process and harmful processes. The panel data analysis was employed to explore how changes in urban forms and road structures affected urban carbon emissions at the district level. Based on these results, we presented suggestions for urban planning towards a low-carbon city.

2. Study area

Hangzhou, the capital of Zhejiang province, is one of the most developed metropolis cities in the Yangtze River Delta Region with a population of 9.02 million in 2015 (Hangzhou Bureau of Statistics, 2015). There has been a significant acceleration of Hangzhou's economic growth since the economic reform in China, especially in the 1990 s. From 1995 to 2015, Hangzhou's per-capita GDP increased from 4614 to 113,600 yuan (Hangzhou Bureau of Statistics, 1995, 2015) and currently ranks 8th of the 35 major cities across the country (Department of urban social economic survey, 2015).

The economic growth of Hangzhou, as well as rapid urban expansion, has converted a large amount of green lands and farm lands to roads, industrial and residential blocks, and has also led to a high consumption of energy. As a result, a series of environmental problems, including the greenhouse effect, have arisen in Hangzhou (Chen et al., 2014; Zhao et al., 2010).

3. Data and methods

Firstly, we derived land use data from Landsat TM images, and extracted road network data from transportation maps. Secondly, we