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Estimating the relationship between urban forms and energy consumption: A case study in the Pearl River Delta, 2005–2008

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ABSTRACT

Urban form, which refers to the spatial configuration of urban land use within a metropolitan area, has profound influences on energy consumption of a city. Landscape metrics are frequently used to quantify urban land use patterns, but there are limited studies reporting the implications of different urban land use patterns on energy consumption. In this study, we attempt to empirically estimate the relationships between urban land use patterns and energy consumption. Five cities of the Pearl River Delta (PRD) in south China, namely Guangzhou, Dongguan, Shenzhen, Foshan and Zhongshan, are selected as the study areas. PRD is becoming an emerging megalopolis and important manufacturing base in the world. However, the rapid and unregulated urbanization process as well as the extensive and inefficient use of energy has caused a series of problems. In this study, remote sensing images during 2005–2008 were used to reveal the dynamic distribution of urban land use based on land use classification. The urban land use patterns were then quantified using a set of landscape metrics, which further serve as explanatory variables in the estimation. The panel data analysis is implemented to estimate the relationship between urban land use patterns and energy consumption. Briefly, it is found that: (1) Urban size is positively correlated with energy consumption; (2) fragmentation/irregularity of urban land use patterns is positively correlated with energy consumption; (3) The dominance of the largest urban patch is negatively correlated with energy consumption.

1. Introduction

Urban form refers to the spatial configuration of urban land use within a metropolitan area (Anderson, 1996). Different urban forms may give rise to diverse social, ecological, and environmental consequences (Camagni, Gibelli, & Rigamonti, 2002; Holden, 2004; Wachs, 1993). Many studies revolve around the topic of sustainable urban forms (Breheny, 1992; Frey, 1999; Jabareen, 2006; Williams, Burton, & Jenks, 2000). Some researchers believe that compact urban forms (Jenks & Burgess, 2000), characterized by high density, mixed land use, pedestrian-oriented habitation and energy efficiency (Chen, Jia, & Lau, 2008), are more desirable for retaining the sustainability of development (Thomas & Cousins, 1996). Therefore, the compact urban forms become increasingly promoted by urban planners. Simulation techniques, such as cellular automata (CA), are adopted by researchers to illustrate the planning scenarios of compact development. For example, Li and Yeh (2000) proposed a constrained CA model to simulate compact urban forms of Dongguan; Ward, Murray, and Phinn (2003) integrated CA model with spatial optimization to generate the development scenario of high density and compact growth in south east Queensland, Australia. However, there are also evidences that challenge the superiority of compact urban forms. Holden and Norland (2005) indicated that lower energy consumption may be achieved by decentralized concentration. Whether the compact development policy is applicable for cities in developing countries like China, which inherently has a large population and high density, still needs further examination (Chen et al., 2008).

One important facet of the debate over sustainable urban forms is the relationship between urban forms and energy consumption. The influence of urban forms on energy consumption is profound, albeit not dominant (Anderson, 1996). Several aspects of urban forms can significantly affect urban energy consumption, such as the relationship between new developments and existing towns, the size, shape and function of new urban development, the mixing of land uses, travel patterns (Owens, 1986). Banister, Watson,

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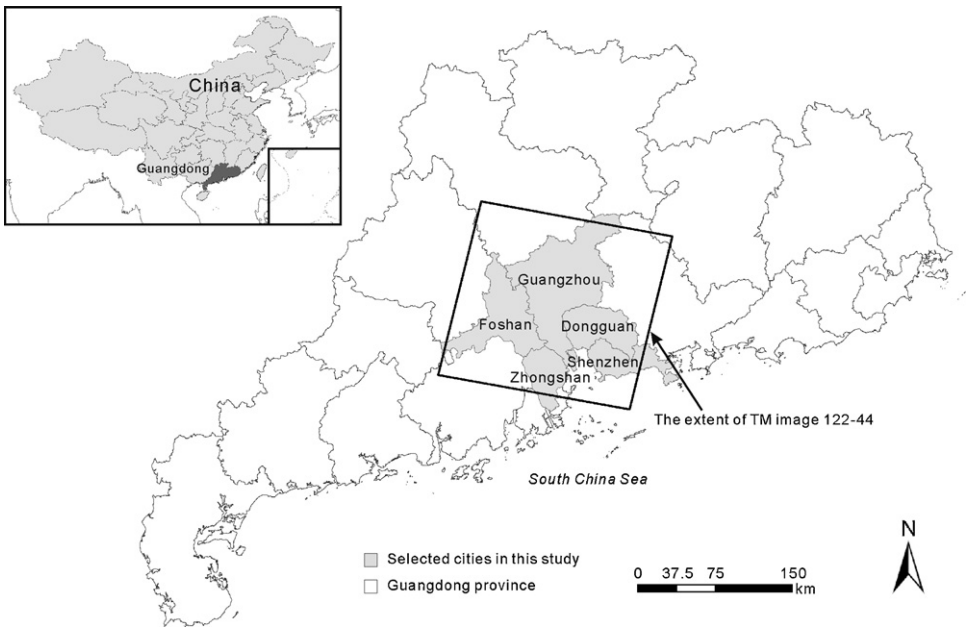

Fig. 1. Location of the study area.

and Wood (1997) tried to reflect the links between energy use in transport and urban forms, based on six case studies in United Kingdom and Netherland. Factors significantly affecting urban energy consumption were identified, such as density, employment and car ownership. But the data involved were coarse and the inconsistency of variables prevented the comparative analysis of different cities. In another empirical study on three cities in Netherland, Dieleman, Dijst, and Burghouwt (2002) found that the dependency of private cars related to factors of car ownership, household type, abundance of public transport and local residential environments. Ratti, Baker, and Steemers (2005) devised several algorithms to reflect the effects of urban texture on the energy consumption of buildings, using digital elevation models (DEMs).

Different from the studies mentioned above, we attempt to empirically estimate the relationship between urban forms and energy consumption from the perspective of spatial patterns of urban land use. With the advances in remote sensing and geographical information systems (GIS), extensive studies have demonstrated the use of landscape metrics to quantify the spatial characteristics (Alberti & Waddell, 2000; Luck & Wu, 2002; Seto & Fragkias, 2005; Xie, Yu, Bai, & Xing, 2006) and the change of urban land use patterns (Dietzel, Oguz, Hemphill, Clarke, & Gazulis, 2005; Herold, Scepan, & Clarke, 2002; Liu et al., 2010). Landscape metrics are also considered very useful in assisting urban planning. Botequilha Leitão and Ahern (2002) developed a conceptual framework for sustainable landscape planning, and the landscape metrics were utilized in order to address the ecological concerns. To our knowledge, less attention has been paid to the link between urban landscape and energy consumption. Especially, such studies have not been reported for the rapidly growing cities in China.

In this study, five cities of the Pearl River Delta (PRD) in south China, namely Guangzhou, Dongguan, Shenzhen, Foshan and Zhongshan, are selected as the study area. As an emerging megalopolis, PRD becomes an important economic region and manufacturing base in the world. Despite its economic success, the rapid and unregulated process of urban growth has resulted in a series of environmental problems (Li & Yeh, 2004; Seto et al., 2002). Meanwhile, the extensive and inefficient use of energy causes a serious degradation of environment (Fang, Chan, & Yao, 2009; Guo et al., 2006). This study attempts to reveal the relationship between urban land use patterns and energy consumption in PRD. Urban land use patterns are retrieved from multi-temporal images during 2005–2008. Afterward the spatial patterns of urban land use are quantified by a set of landscape metrics, which are further taken as the explanatory variables for energy consumption. The panel data analysis is then implemented to estimate the relationship between urban land use patterns and energy consumption.

2. Study area and data

2.1. The Pearl River Delta

The Pearl River Delta is situated in the central part of Guangdong province in south China. This region is mainly dedicated to agricultural production until the economic reform started in 1978. Since then the region has attracted large amounts of foreign direct investments (FDI), which is the critical support to the take-off of regional economy. The continuing development of manufacturing plants and joint ventures demands a large quantity of land. As a result, a lot of land was converted from agricultural use to infrastructure, real property or industrial uses. The unregulated urbanization process gave rise to a series of problems, e.g. the loss of large amount of fertile agricultural land (Li & Yeh, 2004; Seto et al., 2002). Many researchers were therefore devoted to developing effective methods for monitoring and quantifying the fast changing landscapes of the PRD (Seto & Fragkias, 2005; Sui & Zeng, 2001).

The economic growth of the region requires a vast volume of natural resources, especially energy. Although the Pearl River Delta only occupies 20% of the territory of Guangdong province, it consumes 67% of the coal and 85% of the oil that are consumed by the entire province (Shao, Tang, Zhang, & Li, 2006). Moreover, the efficiency of energy consumption is very low compared with other developed regions in China (like the Yangtze River Delta), not to mention the industrialized countries like US or Japan (Fang et al., 2009). The air quality here seriously deteriorates as a result of such extensive and inefficient use of energy (Fang et al., 2009; Guo et al., 2006). Thus, substantial efforts should be paid to reduce the energy consumption and improve the environmental quality.

In this study, we attempt to analyze the relationship between spatial patterns of urban land use and energy consumption. Five