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The influence of urban structure on individual transport energy consumption in China's growing cities

Pengjun Zhao [a, b, *], Jingjing Diao [a, b], Shengxiao Li [a, b]

[a] Department of Urban and Regional Planning, College of Urban and Environmental Sciences, Peking University, PR China
[b] Center for Urban and Transport Planning Research, Peking University, PR China

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ABSTRACT

The energy consumed by urban transportation systems has implications for local environmental protection and greenhouse gas emission reductions. It is widely claimed that in growing cities, individuals' transport energy use could be made more efficient by planning to control urban sprawl and create polycentric urban structures. However, existing conclusions are mixed. This paper contributes to this issue with an in-depth analysis of China's cities. Interestingly, polycentric cities demonstrated lower travel energy efficiency than monocentric ones. This is mainly because urban sub-center developments have failed to combine employment and residential land use. In these planned sub-centers, land use is usually dominated by either housing or industrial park developments, requiring people to commute long distances between home and work, and use cars at high rates. Increasing fragmentation of development management due to political decentralization has apparently worsened the job-housing imbalance. Though a significant effect of urban structure on transport energy consumption was observed, car use control policies had no effect, while a high level of metro services was associated with lower energy consumption.

1. Introduction

Nowadays, urban residents consume most fossil fuel of all residents in the world. Rapid industrialization and lifestyle transitions, especially changes in travel behavior, may contribute to this phenomenon. It was reported that although only about 60% of people lived in cities in 2006, they consumed about two-thirds of global fossil fuel-produced energy, and produced over 70% of anthropogenic CO_2 emissions (IEA, 2008). At the same time, the world has experienced rapid urbanization over the past century, a trend which will continue. By 2050, the world's population is predicted to reach approximately 9 billion, 75% of which will be living in cities (UN, 2014), mostly in developing countries. In this sense, more energy is expected to be consumed in cities than in all other areas combined. It should be noted that the energy used by transport systems, which are vital for urbanization, comprises 25%–60% of households' energy consumption (Pacione, 2009). The construction of transport infrastructure and increasing rates of private automobile use are both important sources of increased energy consumption.

Developing countries are, and will, continue to play the main role in global urbanization. In China for example, from 1978 to 2008, the number of cities increased from 193 to 661, and the urban population soared from 170 million to over 600 million (Liu, 2009). It is predicted that by the year 2030, more than 60% of Chinese people will live in urban areas (UN, 2014). Studies show that during the urbanization process in China, the aggregate energy demand has increased 5.6% annually, on average, from 1980 to 2008 (Liu, 2009). Increasing motorization and population growth contribute to the high energy demands of contemporary China. As a result of extensive and increasing energy use, energy security has become one of the major challenges faced by China.

The transportation sector is an important and increasing user of energy in China. According to Wang, Zhang, and Zhou (2011), the growth rate in fossil fuel demand for the transport sectors has reached 10.56% per year. Transport has become the biggest CO_2 emitter in China. In particular, the energy used by urban individual road transport has been growing at an unexpected scale and speed.

* Corresponding author. Department of Urban and Regional Planning, College of Urban and Environmental Sciences, Peking University, Room 3267, Yifu 2 Building, 5 Yiheyuan Road, Haidian District, Beijing 100871, PR China.
E-mail addresses: pengjun.zhao@pku.edu.cn (P. Zhao), junedjj@pku.edu.cn (J. Diao), lishengxiao@pku.edu.cn (S. Li).

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It now comprises 60% of transport energy use and causes an enormous amount of pollution. In Beijing, it was reported that vehicle exhaust contributed to more than 60% of air pollutants. To be more specific, vehicle exhausts compromise 22% of total $PM_{2.5}$, 85.9% CO_x, 56.9% NO_x, and 25.1% CH_x (Zhang, 2013).

A variety of policies have been discussed to reduce individual energy use. In the transport planning field, the supply of public transport infrastructure and services has been addressed (Hu, Chang, Li, & Qin, 2010; Nakamura & Hayashi, 2013; Vuchic, 2007; Wu et al., 2010). In the transport management field, car use control policies have been implemented, such as vehicle license controls, parking pricing, and congestion charges. In the urban planning field, spatial policies which emphasize the control of urban sprawl and development of suburban subcenters have the potential to reduce individual energy use (e.g. Dai, Zhang, & Rao, 2014; Newman & Kenworthy, 1992; Wegener, 2013). However, conclusions remain mixed. Some researchers have found that individual transport energy consumption is lower in monocentric cities with better public infrastructure (Hu et al., 2010; Nurhadi, Borén, & Ny, 2014). Individual transport energy consumption can actually increase when public transportation systems are poorly managed (Lo, 2014; Wang, Li, Xu, & Zhang, 2014). Therefore, transportation policies, rather than spatial policies, could be the most effective way to reduce energy consumption (Newman & Kenworthy, 1989).

In China, urban sprawl and car dependence has emerged in many large cities. This trend is associated with problems such as traffic congestion, air pollution and ineffective urban land use (Zhao, 2010; Zhao P., 2013). In this context, the reduction of transport energy consumption has become a key issue for energy-saving policies designed to achieve the sustainable development of Chinese cities. In order to make Chinese cities more sustainable, many city planning policies have been designed to change cities from monocentric structures to being polycentric. Cities such as Shanghai, Tianjin, and Chongqing have all had polycentric designs included in their urban plans in recent decades (Sun, Shi, & Ning, 2010). However, whether or not polycentric urban structures are beneficial to energy saving and pollution reduction remains unclear.

The goal of this paper is to examine the effects of polycentric urban structures on energy use and discuss the performance of other urban policies in saving transport energy. The paper is organized as follows. Section 2 reviews the interactions between urban spatial structure and transport energy use reported by previous studies. Section 3 outlines the methods, while Section 4 presents the results of the data analysis. Section 5 discusses the results and their policy implications. Section 6 draws conclusions.

2. Literature review: urban structure and transport energy use

Previous studies show that urbanization has great impacts on energy consumption. Economic activity, transport costs, geographic factors, and urban spatial structure explain 37% of overall energy use and 88% of transport energy use in urban areas (Creutzig, Baiocchi, Bierkandt, Pichler, & Seto, 2015). Among the above factors, urban spatial structure has a firm association with energy consumption (Holden & Norland, 2005; Newman & Kenworthy, 1989; Stead & Marshall, 2001), especially with that of the transport sector (Zhao, 2010).

The types of urban spatial structures that are more or less energy efficient than others, in terms of transport, is still debatable. Some researchers found that polycentric designs can help reduce travel pressure (Newman & Kenworthy, 1992) and, therefore, transport energy consumption. Wegener (2013) found that polycentric countries use less energy for transport per unit of GDP than monocentric countries after examining the histories and theoretical backgrounds of polycentric cities. Dai et al. (2014) concluded that the polycentric urban system of Shenzhen may be an effective way to reduce pressure on transport to the city center. One important reason for this may be attributed to the positive effect of polycentric structures in reducing travel distances. New city subcenters can satisfy people's daily needs for employment, education and leisure activities, without needing to travel to the main city center (Giuliano & Small, 1993; Gordon & Richardson, 1989; Rickaby, 1987).

However, many other researchers have claimed that polycentric urban structures are not effective in reducing transport energy consumption. This is because the new city subcenters do not always provide the same degree of urban opportunities (such as culture, leisure and sports amenities) as the original city center (Meijers, 2008). As a result, residents of polycentric cities depend more on automobiles, and the share rate of public transportation in polycentric cities is much less than that of monocentric cities (Sun & Pan, 2008). Therefore, monocentric cities with highly compact urban cores are considered to be the most energy-efficient urban structure (Rickaby, 1987). In conclusion, in polycentric cities, if the urban opportunities in the various city subcenters have distinctive differences, residents living in underdeveloped subcenters must travel to other subcenters to obtain better services and products, leading to higher transport energy consumption. This is made even worse when subcenters are far away from each other.

At the individual level, the impact of urban spatial structure on energy consumption acts through its influence on travel behavior. Previous studies have focused on the impacts of urban spatial structure on travel frequency, average trip length and travel mode choice (Frank & Pivo, 1994). The transformation of urban spatial structure changes individual travel behavior mainly in two ways: changes of travel distance and travel mode.

First of all, structural transformation, led by the decentralization of jobs along with polycentric development, has a significant impact on individual travel distance. Some researchers believe that transformation of the city towards a polycentric structure contributes to excessive travel between suburbs, causing automobile vehicle miles travelled (VMT) to soar (Aguilera, 2005; Levine, 1992; Van der Laan, 1998). Meanwhile, agglomerated monocentric cities have easier access to major activity destinations and the total travel distances per capita are smaller (Newman & Kenworthy, 1992; Rickaby, 1987). For example, Meijers (2008) insisted that residents in poly-center cities travelled long distances for better services and thus caused more traffic. Aguilera (2005) investigated the development of commuting distance associated with employment location in three French cities. He found that most people worked outside their subcenter of residence, which caused increased average commuting distances. A survey conducted in Singapore by Zhong, Huang, Arisona, and Schmitt (2013) showed that travel distance per capita became greater as the city transformed towards polycentricism, because residents preferred to go to the most developed center instead of the subcenters.

Conversely, some researchers believe that polycentric cities help reduce transport distances by allowing people to reside close to their employment location (Giuliano & Small, 1993; Gordon & Richardson, 1989). Holden and Norland (2005) discovered that total travel distances in monocentric cities were longer, as people in compact monocentric cities tended to take longer leisure trips. Muñiz and García-López (2012) confirmed that subcenters have positive impacts on density patterns and reduce commuting distance per capita in Barcelona Metropolitan Region.

Secondly, urban structure also influences the travel mode choice of individuals. On the one hand, researchers believe that