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Examining the impact factors of urban residential energy consumption and CO_2 emissions in China – Evidence from city-level data

Lu Miao

Graduate School of International Development, Nagoya University, Nagoya, Aichi 4648601, Japan

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ABSTRACT

Rapid urbanization has exerted substantial pressure on China's energy system and contributed to climate change. To find the key drivers of urban residential energy consumption and CO_2 emissions, this paper uses an extended Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model that employs city-level data to examine the influences of population scale, income level, population compactness and price on house-based residential energy consumption, energy-related CO_2 emissions and private vehicle ownership. The empirical results indicate that factors such as population scale, affluence, and population compactness can lead to increases in residential energy consumption and CO_2 emissions. In terms of transportation, income and population scale positively drive the growth of private vehicle ownership, while the fuel price negatively influences private vehicle ownership. Moreover, population scale is the most important factor in residential energy consumption and CO_2 emissions. Finally, policy recommendations are suggested for China's urban development strategy and urban design and to encourage technology innovations that reduce residential energy consumption and CO_2 emissions.

1. Introduction

There is a world consensus that global warming is a severe issue that threatens the living condition of human beings. Many studies have explored that the greenhouse gas emissions, especially carbon dioxide (CO_2) emissions from fossil fuel combustion, play a leading role in global warming. For recent decades, climate change has become the most important environmental issue as a result of the increase in energy-related CO_2 emissions (Wang and Zhao, 2015; Ye et al., 2015; Zhou et al., 2015). As the primary habitat for human beings, urban areas contribute 71% of global energy-related carbon emissions and in China this rate is approximate 73% (Rosenzweig et al., 2010; Zhou et al., 2013). It can be predicted that with the continuous process of world urbanization, the percentage of urban energy consumption will increase.

As the largest developing country in the world, China has experienced a rapid rate of economic growth and urbanization since implementing economic reform in 1978 (Li and Lin, 2015; Wang, 2014). During the 1995–2014 period, China's urbanization rate increased from 29.04% to 54.77%, with an average annual increase of 1.2%, which is still lower than the average urbanization level of developed countries, where approximate 70%-90% of people are living in urban areas (National Bureau of Statistics, 2015). The rural-urban transformation has become a dominant feature of socio-economic change in China, and urban areas are flooded by large numbers of rural migrants on an annual basis. However, these developments have been accompanied by a tremendous increase in energy consumption and CO_2 emissions and China has surpassed the United States to become the largest consumer and carbon emitter around the world (IEA, 2009). In China, energy consumption from the residential sector is the second largest energy consumption sector following the industrial sector, which contributes 10% of total energy consumption, and urban areas are responsible for 57% of this consumption (Lu and Liu, 2014; National Bureau of Statistics, 2014c). Triggered by accelerated urbanization, increase in income level, promotion of living standards and increases in private transportation, urban residential energy consumption increased from 84.05 million tons of standard coal in 1995 to 257.25 million tons of standard coal in 2013, with an average increase rate of 10.85% annually (National Bureau of Statistics, 2014c). According to the United Nations (2014), by 2050, approximately 80% of China's population will live in urban areas; thus, energy consumption will intensify, and residential energy consumption will account for a large proportion of the increase in future CO_2 emissions. Therefore, finding the key impact factors of urban residential energy consumption and

E-mail address: luoxiaoluoluo1988@gmail.com

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energy-related CO_2 emissions is an important aspect of sustainable urban development in China.

In recent decades, many theoretical attempts have been made to address the linkage between urbanization and urban energy consumption as well as energy-related CO_2 emissions. Poumanyvong and Kaneko (2010) presented three theories that describe the mechanisms that link urbanization and energy consumption and emissions. On a national level, ecological modernization theory focuses on the effects of modernization, including economic, social and institutional alterations to the environment. This theory argues that at low to medium levels of modernization, energy and other resource pressures may increase with economic and social development. However, such problems can be minimized once modernization has reached a certain scale and innovative technology and industrial structures become available (Mol and Spaargaren, 2000). At the city level, the theory of urban environmental transition argues that environmental pressures vary based on the level of affluence (Mcgranahan et al., 2001). As income levels rise, energy consumption-related issues become more prominent in affluent cities because of higher demand for electricity, heating, transportation and construction. Compact city theory, also at the city level, emphasizes the importance of urban design in realizing sustainable urban development. Sustainable urban design is high density, offers convenient public transportation as well as accessibility to local services and jobs and can be characterized as mixed use (Burton, 2002; OECD, 2012). The proponents of compact cities argue that they can increase energy efficiency by reducing motor vehicle dependency and travel distance (Burchell et al., 2000; Burton, 2001; Hillman, 1996; Thomas and Cousins, 1996). However, some critics insist that at extremely high densities, the advantages of compaction might prove to be disadvantages, i.e., congestion that leads to increased pollution, energy consumption, loss of amenity space and reduced privacy (Breheny, 1992; Knight, 1996).

Utilizing national-, regional- and city-level data, the empirical study of the relationships between urbanization and energy consumption and emissions has become the focus of considerable scholarly concern in recent years. At the national level, most of the existing studies have found that urbanization has a positive influence on energy consumption and consequential carbon emissions. Wang (2014) performed a time-series analysis to study the impacts of urbanization on residential energy consumption in China. The results showed that economic growth triggered by urbanization is the most important contributor to an increase in residential energy consumption. Liddle and Lung (2010) found that urbanization substantially influenced residential energy and electricity consumption, but the effect of urbanization on CO_2 emissions from the transportation sector was not significant. Sun et al. (2014) explored that urbanization drived the increase energy demand in China and household consumption pattern had a long-term influence on China's energy demand. Zhao et al. (2012) analysed the effects of energy price, population, and consumption structure on urban residential energy consumption, which is divided into four catogories: private transportation, electrical appliances, central heating and activities utilizing fuels (coal, natural gas, coal gas and liquefied petroleum gas). They found that the price of energy helps to reduce urban residential energy use, while urban population scale and income level significantly contribute to growth in residential energy consumption. In addition, some scholars compared the impacts of urbanization on energy consumption among different development stages. Poumanyvong et al. (2012) conducted a cross-national study to examine the relationship between the rate of urbanization and national residential energy consumption and CO_2 emissions, taking into account three income groups. They found that urbanization promotes residential energy consumption in a low- and middle-income countries, while in high-income countries, residential energy consumption reached a turning point when the rate of urbanization reached a certain point (66%). Lin and Ouyang (2014) compared the characteristics of energy consumption in the process of rapid urbanization between the United States and China and they concluded that energy demand has a rigid characteristics of increase in the rapid urbanization stage in both countries. Pachauri and Jiang (2008) compared the variation in residential energy use between India and China and verified that energy efficiency is higher in urban areas because of the transition from fuel energy to electricity and kerosene, which are more efficient and cleaner.

For the case of China, most of the research are conducted at the regional level since China has a vast territory with different patterns of economic growth and urbanization level. Wang et al. (2016) and Wang and Zhao (2014) compared regional economic growth, energy consumption, and CO_2 emissions through econometrical approaches and their results showed that the energy intensity, total and per capita CO_2 emissions are higher in eastern regions and economic growth and consequential urbanization showed a long-run positive impacts on energy consumption and CO_2 emissions. Zhang (2004) separated China into seven areas according to climate and analysed residential energy use, including electricity, coal gas, liquefied petroleum gas, natural gas and coal. The results showed that heating energy consumption significantly contributes to annual energy consumption per household and that compact building structures (apartments) were more energy efficient than detached houses. Based on provincial data, Lin and Du (2015) discussed the influence of urbanization and income disparity on transport energy consumption in China. They suggested that urbanization positively influences transportation energy consumption and that this impact was higher in high-income provinces than in a low-income provinces. Ji and Chen (2015) found that the relationship between urbanization level and energy-saving potential in China followed a U-shape and the energy-saving effects increase with the promotion of income level.

At the city level, Wang et al. (2015) studied the relationship between urban development intensity and CO_2 emissions of the five major cities utilizing panel data between 1995 and 2011. The results showed that urban development intensity positively influence CO_2 emissions and land-use intensity is the most important factor that contributes to the increase of CO_2 emissions. Wang et al. (2012) applied STIRPAT model to analyze the driving factors of carbon emissions in Beijing. Their results showed that urbanization is the main driver of the increase of carbon emissions and suggested that Beijing should focus more on residential energy consumption. Liddle (2013) examined the correlation between urban density and climate change associated with the consumption of private passenger transportation in developed and developing cities. They addressed whether urban density negatively influenced the energy consumption of private transportation. Chen et al. (2008) studied the relationship between urban compactness and domestic electricity consumption as well as public transport in 45 Chinese cities, including 41 mega-cities. They found that the impact of urban compaction on public transport was not significant and that the relationship between population density and domestic electricity consumption was negative. In addition, they argued that urban density in China was already high and that the impact of further compaction was unclear.

The empirical analyses of previous research enrich our knowledge on the driving factors of CO_2 emissions and energy consumption under rapid urbanization and economic growth. However, due to the nature of the available data, the majority of studies are based on macro-statistics (national or provincial) and the research with evidence from different sizes of Chinese cities are scarce. In addition, in China, not all cities can be defined as urban areas since the 'cities' are politico-administrative units that include both urban and rural areas. Although some of the previous