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Exploring the sensitivity of residential energy consumption in China: Implications from a micro-demographic analysis

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ABSTRACT

Energy consumption in the residential sector is one of the main parts of the total consumption in China, and demographic factors are the fundamental parameters affecting total energy use. Using residential energy consumption (REC) data from household surveys, demographic data from population censuses and macro-energy statistics, and the research assesses a theoretical model of the demographic sensitivity of REC in urban China. The method of population component is adopted to explore the demographic sensitivity on REC. Our research reveals different micro-demographic processes have different effects on REC, even when macro-demographic levels are identical or similar. Natural population change, urbanisation and aging are sensitive to REC. However, the population age structure is not sensitive to REC except for the 60+ age group. The scale effect plays a pivotal role in correlations between REC and demographic changes; decreasing per capita REC correlates with increasing family size. Because of the multiple sensitivities of population to REC, population size cannot be the exclusive demographic indicator with which to judge changes in REC. The effects of demographic structural factors surpass those of demographic quantitative factors. Finally, the findings of demographic sensitivity are used to simulate the scenarios of REC in 2015 under different assumed micro-demographic processes.

1. Introduction

This study examines the demographic sensitivity of residential energy consumption (REC) and evaluates how and to what extent demographic factors cause significant changes in REC in urban China from the perspectives of micro-demographic processes. We argue that different micro-demographic processes may cause various scenarios of REC even when macro-demographic levels are identical or similar. We expect that the findings of this study will improve forecasting (and adapting to) changes in REC through the consideration of detailed demographic insights.

What we talk about in the paper focuses on demographic processes which would change or influence individual and household interactions with urban residential energy system in China. REC in this paper refers to the energy directly consumed for human life in household, including cooking, heating, electricity, transportation and traffic. The sensitivities of urbanisation, age-structure change and natural population change on REC are detected through the method of population component. However, the energy consumption structure in residential sector is excluded from the analytic frame, in which the amount of REC is included only.

Global warming is one of the most important threats to the sustainable development of human beings. The primary cause of global warming is likely the emission of greenhouse gases as a result of human activities; this assertion is backed statistically at a confidence level greater than 90% [1]. According to data collected by the World Bank,[1] China surpassed the U.S.A. in 2006 to become the most prolific carbon dioxide (CO_2)-emitting country in the world. A combination of energy conservation and emissions reduction has become the national energy strategy of China; however, each component of this strategy poses complex challenges to policymakers across domains, from the economic to the social. Although the level

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[1] http://data.worldbank.org/indicator/EN.ATM.CO2(e).KT/countries/1W?display=default,2012-2-3.

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of REC in China accounts for only approximately 10% of total energy consumption [2], the huge population size and rapid demographic shift implies considerable growth in REC in the future as the population urbanises and lifestyles shift, as is occurring already.

Energy consumption is affected by a wider range of factors, such as levels of income, lifestyle, technology and other factors, but population is a fundamental parameter affecting total energy use. Whether micro-demographic changes alone (i.e., accompanied by little or no macro-demographic change) can result in different levels of REC is an important scientific issue in the domain of energy consumption research. Therefore, the composition of the population and micro-demographic changes that may induce changes in population structure should be studied scientifically to ensure that the understanding of REC is based on appropriate demographic principles in addition to considering population size in such an analysis.

The present study is organised as follows. Section 2 reviews the extant literature on the relationship between population and energy consumption and/or CO_2 emissions. Section 3 provides definitions for demographic sensitivity and the scale effect of REC and proposes a theoretical model that bridges the gap between micro-demographic processes and the macro-scale results of REC. Section 4 presents an empirical analysis that includes a description of the data, scale effects, demographic sensitivity and scenario analysis. Section 5 discusses the findings, offers suggestions for future research and concludes the study.

2. Literature review

Numerous studies have suggested that population plays a pivotal role in energy consumption, carbon emissions and/or climate change, although the specific mechanism through which population acts remains unclear. Almost all studies of energy consumption, CO_2 emissions and climate change utilise demographic factors as important parameters. Therefore, this section focuses on studies investigating population and REC; all analytical methodologies examining the relationship between population and energy consumption and/or CO_2 emissions will be taken into account.

Energy consumption in the residential sector is one of the main parts of the total consumption in China [3]. REC is the second largest energy use category (10%) in China and urban residents account for 63% of the REC. Although the increasing of productive energy consumption would slow down, or even the amount tend to be stable, the total energy consumption will tend to grow significantly thanking for the fast increase of residential energy consumption [4]. Scale factors including increased urban population and income levels have played a key role in the rapid growth of REC [5]. In order to promote energy conservation in the residential sector, and to predict the CO_2 emission, it is important to examine the residential energy consumption so that policy makers and energy experts in different countries can learn from each other in the policy-making of residential energy standards [3].

The basic theoretical framework of the relevant studies is derived from the Impact of Population, Affluence and Technology (I-PAT) model [6] and its extended model [7], in which methods of factor decomposition or regression are applied generally. Because the I-PAT model has important advantages in terms of data availability and application convenience, many statistical studies have been conducted to explore the net effects of population on energy consumption and carbon emissions. However, this type of model also has obvious disadvantages, including limitations in the compatibility of demographic factors and the comparability of findings, among other issues. Therefore, Dietz et al. [8–10] proposed the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) model to test elasticity with respect to coefficients for population, affluence and technology; STIRPAT may account for more demographic indicators and is more sophisticated than I-PAT.

With the development of insights into correlations between population and energy consumption and/or CO_2 emissions, the research community has recognised that population size might not account for the complex correlations completely because a wide range of demographic factors may be associated with energy consumption and/or CO_2 emissions. For example, the Intergovernmental Panel on Climate Change examined 40 demographic scenarios in its fourth report [11], but it is believed that the effects of population on climate change were underestimated because the demographic component of the IPCC report included only changes in population size, whereas important factors of population structure were excluded [12].

Recent studies integrate indicators of population structure into models to reflect the complex effects of demographic structural factors on energy consumption [13–17]. However, although there are many such studies, their theoretical frameworks do not break through the domain of the STIRPAT model; indeed, these studies also belong to the linear model based on macro-demographic indicators. For example, there are methodological limitations to addressing age structures in 1-year groups, family patterns and urban-rural distributions simultaneously.

In recent years, efforts have been made to analyse linkages between population and energy consumption, in which systematic models commonly used by climate change researchers are employed. Models of this type may contain more detailed parameters of demographic dynamics, technological change and economic development than linear models. In addition to population size, population composition (e.g., age, urban–rural residence, household structure, etc.) can be analysed in detail. Dalton et al. [18] adopted a population, environment and technology (PET) model to analyse CO_2 emissions in China and India, in which the urban-rural distribution, family size and age structure were considered. Including the age of the householder, family size and urban-rural distribution in the demographic component, O'Neill et al. [19] explored the effects of global demographic trends on future carbon emissions. However, the systematic model addresses most demographic composition factors indirectly, which seems to be unsuited for a study of REC. For instance, in systematic models, the labour supply is taken as an intermediate variable to transfer the impact of population aging on energy consumption or carbon emissions.

Generally, in addition to population size, age, urban–rural residence and household structure—all of which are factors that influence energy consumption directly or indirectly—demographic compositional factors are also closely related to energy consumption [20]. Because households are the basic units of energy consumption (particularly REC), the scale effect of energy consumption is the theoretical basis for how households affect energy consumption [21]. Because of the loss of economies of scale, the per capita energy consumption of smaller households is significantly higher than that of larger households [20], which has been shown empirically [22,23]. Similarly, it is necessary to consider the impact of urbanisation if there are obvious differences in energy consumption or patterns of carbon emissions between rural and urban populations [24,25]. Conclusions from the analyses of the effects of urbanisation on energy consumption and/or carbon emissions are mixed. In developed countries, the level of CO_2 emissions in urban areas is lower than in rural areas, but this pattern is reversed for developing countries [26,27]. In addition, populations worldwide are aging, and the impact of such older populations on energy demand should be considered. Because the income level and consumption behaviours of the elderly vary regionally and over