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Scenarios of building energy demand for China with a detailed regional representation

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ABSTRACT

Building energy consumption currently accounts for 28% of China's total energy use and is expected to continue to grow induced by floorspace expansion, income growth, and population change. Fuel sources and building services are also evolving over time as well as across regions and building types. To understand sectoral and regional difference in building energy use and how socioeconomic, physical, and technological development influence the evolution of the Chinese building sector, this study developed a building energy use model for China downscaled into four climate regions under an integrated assessment framework. Three building types (rural residential, urban residential, and commercial) were modeled specifically in each climate region. Our study finds that the Cold and Hot Summer Cold Winter regions lead in total building energy use. The impact of climate change on heating energy use is more significant than that of cooling energy use in most climate regions. Both rural and urban households will experience fuel switch from fossil fuel to cleaner fuels. Commercial buildings will experience rapid growth in electrification and energy intensity. Improved understanding of Chinese buildings with climate change highlighted in this study will help policy makers develop targeted policies and prioritize building energy efficiency measures.

1. Introduction

China has experienced rapid economic growth in the past two decades with an annual GDP (Gross Domestic Product) growth rate of 10% [1,2]. China's buildings sector has also grown rapidly and Chinese building energy use has increased by 40% from 1990 to 2009. It demanded 443 Mtoe in 2009, accounting for about 28% of the country's total final energy demand [3]. China is the largest consumer in residential building energy use and the third in commercial building energy use [3]. This growth is not likely to wane anytime soon [4,5]. The consensus in the literature is that the shares of electricity and natural gas will continue to expand, displacing currently intensive use of traditional biomass [5,6].

Underlying the growth in the Chinese buildings sector is a continued expansion in building floorspace. Over the last several years, China has added 1.8–2.0 billion m^2 of floorspace annually, establishing the world's largest market for new construction [7,8]—urban and rural residential buildings expanded at the average annual rates of 7% and 2%, respectively, in the past decade [9]. In 2010, the size of building floorspace in China was about 59 billion m^2 with rural and urban residential buildings consisting of 41% and 35%, respectively [2]. Given the broad agreement that strong economic growth will continue in the foreseeable future, the trend in the Chinese buildings sector is likely to persist, putting upward pressure on building energy demand.

The trends and characteristics of building energy use in China were examined in many studies, which broadly fall into three groups. The first group focuses on the historical trends of building energy use in China. Tonooka et al. [10] and Nakagami et al. [11] attempted to decompose historical residential energy consumption into service and fuel types; they then estimated emissions based on these data. Chen et al. [12] split building energy demand into various services and estimated its monthly variation at the national level. These studies, however, did not consider possible differences in climate conditions across regions. The second group of studies specifically addresses the issue of regional heterogeneity by identifying the structure of building energy consumption based on the surveys of several cities or sectors in China (see Refs. [13–18]). A few studies provide a more comprehensive picture of the status of Chinese building energy demand at the regional level. Zhang [19] divided China into seven regions according to climatic characteristics and showed substantial differences in the demands

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for residential fuels (including district heat) across the regions between 1990 and 2000. Tsinghua University has been publishing the *Annual Report on China Building Energy Efficiency* since 2007, which details historical building energy use by building type and heating energy demand [20]. The last group of studies offers near-term projections for the development of the Chinese building sector, based on a set of assumptions on economic growth and end-use technologies [6,21–23]. However, none of these projection studies were conducted at the sub-national level, and they did not address the influence of regional heterogeneities in socioeconomic development and climate change, which we consider to be equally important.

This study builds on Eom et al. [5], which proposed a service-based building energy model for China, nested in the GCAM (Global Change Assessment Model) integrated assessment framework. The model captures key drivers of building energy demand, including urbanization, economic growth, the expansion of building floorspace and energy service demands. While our study employs essentially the same modeling framework, it distinguishes itself from the work of Eom et al. [5], contributing to the body of literature in two ways. First, we disaggregate China into four sub-regions with different socioeconomic and climate conditions to examine the long-term evolution of the buildings sector at the regional level. This is a major analytical and methodological advance as the process of constructing the model required us to consider regional differences in socioeconomic development and preferences for building energy services and fuels. In this way, the responses to socioeconomic development, energy efficiency improvement, and building energy policy would be better represented at the regional level, providing a better platform for analysis of the Chinese building sector in general. Second, we analyze the potential impacts of climate change on the Chinese building sector at the regional level. There is general agreement in the literature that climate change will increase cooling energy demand (mostly electricity) and decrease heating energy demand [24–30]. However, only a few studies provides analyses on the impact of climate change on the Chinese building sector, and they are national-level aggregated analysis [25], city-level statistical analysis [31], or short-term building simulation analysis [29,32]. Instead, we examine the responses of the Chinese buildings sector to long-term climate change, based on a detailed representation of heating and cooling requirement and its interaction with climate change at the regional level.

This study highlights four major findings. First, relatively cold regions in China, such as the C (Cold) and HSCW (Hot Summer Cold Winter) regions, will continue to account for a major portion of building energy demand and floorspace in China. Second, climate change will help reduce total final energy consumption in Chinese buildings. The impact of climate change on heating energy demand will remain significant in China with the greatest impact in the C and HSCW regions. Climate change will influence cooling energy use as well with the impact most profound in the HSCW region. The combined effect is that the decrease in heating energy use offsets the increase in cooling energy use in most regions with the exception of the HSWW (Hot Summer Warm Winter) region. Third, due to continued rapid urbanization, rural households in China will have a rapid decrease in total energy consumption over the course of the century, as well as fuel substitutions from traditional biomass to coal and then to cleaner fuels such as electricity and gas. Fourth, urban residential buildings in the SC (Severe Cold) and Cold (C) regions will also experience significant fuel transition characterized by decreased coal use and increased electricity and gas use. Overall, EUI (energy use intensity) in urban residential and commercial buildings will continue to rise at least for the next several decades, taking a different path than its developed economy counterparts.

2. Methodology and data

2.1. Modeling framework

This study uses a detailed building energy model nested in the Global Change Assessment Model (GCAM) to analyze long-term building energy demands in China. GCAM is an energy sector focused partial equilibrium integrated assessment model capable of representing the development of the full energy system and its associated greenhouse gas emissions to the end of the century. The model is global in scale, and it comprises of 14 global regions and runs in 5-year time steps from 1990 to 2095. Details regarding GCAM can be found in the work of Edmonds and Reilly [33], Clarke and Edmonds [34], Clarke et al. [35], and Clarke et al. [36].

The building energy model used for this study is fully nested in GCAM, so that fuel prices in the buildings sector are cleared in the GCAM global or regional markets sharing the same set of socioeconomic assumptions. The model explicitly accounts for key forces that influence the evolution of the sector: (i) the increase in building floorspace with population and economic growth; (ii) the associated demand for building energy services (e.g., space heating, space cooling, and other services such as appliances and equipment); and (iii) the fuel and technology competition within the services. In particular, the model is capable of representing the changes in building energy services as a function of income, fuel prices, and climate change, while at the same time capturing regionally differentiated behavior of demand satiation. The model originally proposed by Eom et al. [5] consists of three distinct sectors—urban and rural residential buildings and commercial buildings—with detailed representation of energy services, fuels, and end-use technologies. Our study extends the model by disaggregating each of the three building sectors into four climate regions, so that in total twelve different building types are represented either separately or collectively under the influence of climate change.

2.2. Disaggregation of the Chinese building sector

To capture regionally differentiated responses to socioeconomic development, energy efficiency improvement, and climate change, we disaggregated the China region in GCAM to four distinct climate regions: SC, C, HSCW, and HSWW (Fig. 1). This is slightly different from Chinese official classification of SC, C, HSCW, HSWW, and temperate [37]. Because the temperate zone is small in geographic coverage and population size (less than 6% of China's total population), we collapsed the zone into the HSWW region, which shares the same building energy codes as the temperate zone and roughly similar building characteristics. This approach required one-to-one mapping between each of the 34 Chinese provinces,[1] from which regional socioeconomic and energy statistics are constructed, and the four climate regions. Those provinces geographically identified by multiple climate regions were placed into the associated climate region where the greatest portion of its population resides.

Building stock in each of the four climate regions are divided into urban and rural residential buildings and commercial buildings, so that twelve different building sectors are represented. All major assumptions, including socioeconomic development, floorspace

[1] Note that the China region in GCAM also includes former or current planned economies of Vietnam, Mongolia, Cambodia, and North Korea. The inclusion of these countries results in only a small deviation from national statistics, given that China accounted for more than 97% of the entire region's GDP in 2010. In this study, the contribution of these other countries is assumed to be evenly distributed across the four climate regions.