Energy 46 (2012) 405–419

Contents lists available at SciVerse ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

China's building energy demand: Long-term implications from a detailed assessment☆

Jiyong Eom*, Leon Clarke, Son H. Kim, Page Kyle, Pralit Patel

Joint Global Change Research Institute, Pacific Northwest National Laboratory, College Park, MD 20740, USA

ARTICLE INFO

Article history:
Received 25 February 2012
Received in revised form
24 July 2012
Accepted 5 August 2012
Available online 1 September 2012

Keywords:
China buildings
Building energy modeling
Scenario analysis
Integrated assessment model
Electrification

ABSTRACT

Buildings are an important contributor to China's energy consumption and attendant CO_2 emissions. Measures to address energy consumption and associated emissions from the buildings sector will be an important part of strategy to reduce the country's CO_2 emissions. This study presents a detailed, service-based model of China's building energy demand, nested in the GCAM (Global Change Assessment Model) integrated assessment framework. Using the model, we explored long-term pathways of China's building energy demand and identified opportunities to reduce greenhouse gas emissions. A range of different scenarios was also developed to gain insights into how China's building sector might evolve and what the implications might be for improved building energy technology and carbon policies. The analysis suggests that China's building energy growth will not wane anytime soon, although technology improvement will put downward pressure on this growth: In the reference scenarios, the sector's final energy demand will increase by 110–150% by 2050 and 160–220% by 2095 from its 2005 level. Also, regardless of the scenarios represented, the growth will involve the continued, rapid electrification of the buildings sector throughout the century, and this transition will be accelerated by the implementation of carbon policy.

1. Introduction

It is widely recognized that any attempt to address climate change will ultimately have to include China. The Chinese economy has grown at a remarkable rate of 9–10% per year since 1990s, and expectations are that it will continue to grow rapidly. Energy consumption and associated CO_2 emissions have increased dramatically as a result of this growth. China consumed almost three times as much energy in 2006 as it did in 1990. China is now the largest energy consumer (followed by the U.S.) and is the biggest CO_2 emitter in the world [1,2].[1]

Buildings are an important contributor to China's energy consumption and CO_2 emissions. Measures to address energy consumption and associated emissions from the buildings sector will therefore be an important part of any strategy to reduce China's CO_2 emissions. In 2007, China's buildings sector consumed 31% of China's total final energy [1]. China is also the second largest building energy user in the world, ranked 1st in residential energy consumption and 3rd in commercial energy consumption [1]. In 2005, China's buildings sector emitted roughly 0.4 Gton of CO_2 for primary fuel uses; including indirect electricity emissions, the emissions amounted to about 1.1 Gton of CO_2, or 18% of China's total fossil and industrial CO_2 emissions.[2] As China continues its socio-economic transformation, energy consumption and associated emissions from the buildings sector will undoubtedly increase.

The topic of this paper is this evolution of the Chinese buildings sector through mid-century and beyond, and the potential influence of socioeconomic factors as well as climate and energy policies on this evolution. Understanding the potential nature and magnitude of this evolution is challenging. Indeed, there is indeed tremendous variation even in short-term projections of building energy consumption in China (see, for example, Li [3]). There are many factors that contribute to this uncertainty, including the rate of population and economic growth, the rate of transformation in China from a rural to

☆ This paper is a further development of the PNNL technical report, PNNL-21073. The report can be accessed at www.pnnl.gov/main/publications/.../technical_reports/PNNL-21073.

* Corresponding author. Tel.: +1 301 314 6783.
E-mail address: jiyong.eom@pnl.gov (J. Eom).

[1] There is some degree of recognition by the Chinese of their role in climate mitigation. As part of the 2009 Copenhagen Accord, China pledged to reduce its carbon intensity by 40–45% by 2020 relative to 2005. China's economic planning department has decided to develop a so-called "Low-Carbon Economy", which would require various measures ranging from expanding non-fossil renewable energy capacities to promoting end-use energy efficiencies throughout the economy.

[2] Throughout this study, we calculated estimates of CO_2 emissions by multiplying the amount of fuel consumed with its associated carbon emissions coefficient. This largely applies to electricity, for which the average CO_2 per kWh of electricity is applied.

0360-5442/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.energy.2012.08.009

urban economy, the increase in floorspace associated with economic growth, the nature of the building services (e.g., air conditioning, plug loads) that Chinese will demand in the future, and the technologies that will be available to provide these services.

This paper explores the long-term evolution of China's building sector based on a technologically detailed, service-based model of China's building sector, nested in the long-term, global, integrated assessment framework, the Global Change Assessment Model (GCAM). The China buildings model builds on previous technologically detailed analysis on the U.S. buildings sector in GCAM [4]. However, the construction of a model for China—and for a developing country more generally—provides a number of unique challenges associated with rapid economic development and associated shifts from rural to urban energy uses.

This paper makes two primary contributions to our understanding of buildings in China. The first contribution is methodological: the inclusion of a detailed, service-based China building energy model within an integrated assessment framework. Integrated assessment models are some of the primary tools for exploring the long-term interactions between human and earth systems and the possible implications of long-term policy structures and options for greenhouse gas mitigation (see, for example, Clarke et al. [5,6]). These models have historically focused far more heavily on the supply and conversion side of the energy system than the demand side. The inclusion of the buildings module within an integrated assessment framework, as opposed to a stand-alone version, provides the advantage of integration. It allows for consideration of how the Chinese buildings sector might interact with the remainder of both the Chinese and global energy systems, particularly in the context of climate mitigation. Moreover, the integrated assessment modeling allows for a comprehensive analysis of the effects of policy instruments, such as a price on carbon, tradable emissions permits, or technology-focused policies such as buildings standards.

The second contribution of this paper is to enhance our understanding of the possible evolution of China's building sector, the interaction with emissions mitigation policies, and the potential implications over the long term of building regulatory policies. The process of constructing any model forces the model developer to grapple with and understand the key forces that shape its behavior, and this process provides many insights in and of itself. Using the model to produce scenarios provides additional understanding about how these forces interact. In particular, we focused our efforts in constructing the model on five key issues:(1) the rate of urbanization in China and its relationship to overall economic growth, (2) the demand for building floorspace associated with this growth and urbanization, (3) the associated demand for building energy services, (4) the technologies that might be available and deployed in the future, and (5) urban-to-rural differences in energy services and fuels. Various policy scenarios presented in this study also provide a sense of the tradeoffs between economy-wide carbon prices and energy efficiency measures such as building codes and standards in China.[3]

A few technologically detailed analyses have focused on a subset of these key forces in the context of household energy consumption in developing countries. For example, van Ruijven et al. explored the consequences of household income distribution and electrification in India based on a detailed, service-based model [9] and of rural electrification in developing countries using econometric analysis [10]. van Vliet et al. also analyzed future energy access to clean cooking fuels and electrification in developing countries [11]. O'Neill et al. explored the effect of urbanization on energy consumption in India and China, based on the general equilibrium model, iPETS [12]. Krey et al. [13] compared the scenario results of four integrated assessment models capable of representing urban and rural residential energy consumption in China and India [9–12]. Our study distinguishes itself from these previous works, in that we present longer-term scenarios for the Chinese building sector (residential and commercial combined), employing a detailed, behaviorally consistent energy model that represents all of the key drivers of building energy consumption: urbanization, income growth, expansion of floorspace and energy services, service preferences, and technology choices. In addition, full integration of the model within GCAM allowed us to explore the implications that a global carbon policy may have for the decarbonization of the Chinese building sector.[4]

In general, the research confirms intuition. The exercise suggests a dramatic expansion in building energy consumption in China, associated with rapid economic growth and urbanization. This holds for all the scenarios presented in this paper. In the reference scenarios, the sector's final energy demand will increase by 110–150% by 2050 and 160–220% by 2095 from its 2005 level. Within this larger context, the model also suggests that the Chinese buildings sector will undergo rapid electrification, and a carbon policy would lead to more rapid electrification, reducing its dependence on traditional biomass, coal, and oil. The model also suggests that while rural income growth would gradually phase out the use of traditional biomass, a climate policy may result in a prolonged use of traditional biomass. Looking forward, the newly constructed model offers a means to explore not only the interaction between the Chinese buildings sector and efforts to mitigate climate change, but also the impact of a changing climate on building energy consumption in any part of the world.

The remainder of the paper is structured as follows. Section 2 provides background. It describes the characteristics of building energy use in China in comparison with developed countries' historical building energy use. Section 3 briefly introduces the GCAM integrated assessment model and then presents the structure of the building energy model with the discussion of a variety of methodological issues associated with modeling buildings in a rapidly growing economy like China's. Section 4 discusses the results emerging from the scenarios explored using the model. Concluding remarks are presented in Section 5.

2. Background

2.1. Current building energy use in China[5]

The rural population plays an outsized role in China's building sector today. In 2005, rural energy consumption accounted for roughly two-thirds of total building final energy consumption

[3] For detailed information about building codes and standards in China and barriers to improving building energy efficiency, see Lang [7] and Hong [8].

[4] Note that the effect of long-term climate change on heating and cooling service demands is not taken into account in this paper. However, the model is flexible enough to utilize the changes in heating and cooling degree days that can be calculated based on spatially explicit climate simulation models. This climatic interaction will be addressed in future work. There is some previous work on the influence of climate change on building energy in China. For example, based on a non-structural statistical analysis of climatic variables, Wan et al. [14] proposed a climate impact model for heating and cooling loads and energy consumption of generic office buildings in five major cities in China. However, the long-term simulation model does not account for non-climatic socioeconomic drivers.

[5] Because of reliability and consistency problems with the sectoral energy breakdown provided by China's National Bureau of Statistics, as pointed out by Sinton [17], we instead used IEA's energy balances to characterize China's residential and commercial building energy consumption in 2005 [1][6] and used the China Energy Databook to split the residential energy consumption into urban and rural uses [2]. Regarding service-level energy consumption, due to the absence of comprehensive national energy consumption survey, we have applied reasoned judgments based on several detailed energy use analyses and local surveys [18–21].