ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Energy for 500 million Homes: Drivers and Outlook for Residential Energy Consumption in China

Nan Zhou, Michael A. McNeil, Mark Levine

Environmental Energy

Technologies Division

June 2009

This work was supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Energy for 500 million Homes:
Drivers and Outlook for Residential Energy Consumption in China

Nan Zhou*, Michael A. McNeil, Mark Levine

Keywords

China, residential building, urbanization, energy consumption, future outlook, end-use, bottom-up analysis

Abstract

China's rapid economic expansion has propelled it to the rank of the largest energy consuming nation in the world, with energy demand growth continuing at a pace commensurate with its economic growth. The urban population is expected to grow by 20 million every year, accompanied by construction of 2 billion square meters of buildings every year through 2020. Thus residential energy use is very likely to continue its very rapid growth. Understanding the underlying drivers of this growth helps to identify the key areas to analyze energy efficiency potential, appropriate policies to reduce energy use, as well as to understand future energy in the building sector.

This paper provides a detailed, bottom-up analysis of residential building energy consumption in China using data from a wide variety of sources and a modelling effort that relies on a very detailed characterization of China's energy demand. It assesses the current energy situation with consideration of end use, intensity, and efficiency etc, and forecast the future outlook for the critical period extending to 2020, based on assumptions of likely patterns of economic activity, availability of energy services, technology improvement and energy intensities.

From this analysis, we can conclude that Chinese residential energy consumption will more than double by 2020, from 6.6 EJ in 2000 to 15.9 EJ in 2020. This increase will be driven primarily by urbanization, in combination with increases in living standards. In the urban and higher income Chinese households of the future, most major appliances will be common, and heated and cooled areas will grow on average. These shifts will offset the relatively modest efficiency gains expected according to current government plans and policies already in place. Therefore, levelling and reduction of growth in residential energy demand in China will require a new set of more aggressive efficiency policies.

*This work was supported by the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Introduction

China's rapid economic expansion has propelled it into becoming one of the largest energy consuming nations in the world, with demand growth continuing at a high pace commensurate with its economic expansion. As the world's largest energy consumer, China's energy consumption has a growing impact on world energy markets, affecting the availability of energy resources and global market prices. At the same time, China's rapidly growing consumption, increasing imports, supply shortages, and difficulties integrating fully into global energy market are placing added pressures on the Chinese leadership to ensure that challenges in energy availability does not constraint its growing economy, which is critical to providing steady rates of employment and rising standards of living for the population. Moreover, because of China's increasing importance in the global energy scene, how Beijing chooses to deal with these energy security questions will not only affect the Chinese economy, but the global economy as well.

China's development over the next 15 years is being guided by a Medium- and Long-Term Development plan drafted by the central government and published in 2004 (NDRC,2005). This document laid out the broad guidelines of China's development from 2000 to 2020, central to which is a quadrupling of GDP with only a doubling of energy consumption. This goal is in essence to repeat the experience of the period from 1980 to 2000 when China did achieve a quadrupling of GDP while keeping energy consumption growth to only half that rate. The 2020 development goal is to be achieved for the most part through a steady increase in industrial, building, and transportation efficiency with the target of reaching international "leading levels" in each sector by 2020. The document is important in its consideration of the limits to China's extensive growth over the past 20 years and recognizing that even a doubling of energy consumption to 2020 is a serious challenge.

By 2005, however, it became apparent that China had substantially exceeded its energy consumption growth target for the first quarter of its 20-year development plan. Instead of maintaining the ratio of energy growth to economic growth at 0.5, China experienced a sharp rise in energy intensity between 2001 and 2005, This loss of momentum in continued efficiency gains and intensity reduction called into question China's ability to keep energy consumption growth at just half the rate of economic growth over the entire 20 year period and suggested that energy consumption in 2020—assuming success in quadrupling GDP over the period—would be significantly higher than forecast.

In an earlier study, we have undertaken a detailed analysis of recent energy intensity trends in China, revealing the dominant role of rampant growth in heavy industries as the leading cause of recent increases in China's energy intensity Lin, 2007) . Even though the rapid growth is largely attributable to heavy industry, this in turn is driven by rapid urbanization process, by construction materials and equipment produced for use in buildings.

Residential energy is mostly used in urban areas, where rising incomes have allowed acquisition of home appliances, as well as increased use of heating in southern China. The urban population is expected to grow by 20 million every year, accompanied by construction of 2 billion square meters of buildings every year through 2020. Thus residential energy use is very likely to continue its very rapid growth. Understanding the underlying drivers of this growth helps to identify the key areas to analyze energy efficiency potential, appropriate policies to reduce energy use, as well as to understand future energy in the building sector.

As a sequence of the research published early on commercial energy use in China (Zhou,2008), this paper provides a detailed, bottom-up analysis of residential building energy consumption in China using data from a wide variety of sources and a modelling effort that relies on a very detailed characterization of China's energy demand. The goal of the research is to characterize energy demand in a detailed manner, allowing for better insight into likely future trends in the absence of more aggressive efficiency policy, and suggesting opportunities for policy intervention that could significantly alter that future. Specific policies and their impacts are the subject of current research, and will be presented in an upcoming report.

China's current development plan forms the basis of our baseline scenario evaluation in the study. The baseline scenario incorporates the collective scope of technology choices, efficiency improvements, policy targets, fuel switching, production trends, equipment ownership and other elements of the development plan that China has proposed to shape its energy growth path to 2020. The primarily analytical tool used in this study was an accounting framework of China's energy and economic structure, built using the LEAP (Long-Range Energy Alternatives Planning) modelling software.

Methodology

In the early paper (Zhou,2008), a general methodology on *bottom-up approach* to develop an end-use model was described. The drivers for residential energy consumption are summarized in Table 1. Residential energy demand is shaped by a variety of factors, including location (in both geographic location and urban vs. rural) and climate. Within the locales, end uses were disaggregated into space heating, air conditioning, appliances, cooking and water heating, lighting, and a residual category. These end uses were further broken out by technologies; some appliances were broken out into classes by level of service, associated with different levels of efficiency. Space heating varies by climate type, so it is broken out by North, Transition and South zones. For all end uses, appropriate devices and fuels were assigned, with saturation (rates of penetration) and energy efficiencies based on statistical and survey data pertaining to the base year (2000) and future values based on analysis of government plans, trends, and comparisons to other countries. Changes in energy demand in the model are in part a function of driver variables, e.g., GDP, population, household size and urbanization rate, which were determined exogenously and included in the model. Table 1shows the breakouts.

Table 1 End-Use Structure of the Residential Sector

End use	Space heating		Air conditioning	Lighting	Cooking and water heating	Appliances		
Category	North	Transition				Clothes Washer	TV	Refrigerator Three sizes
Technologies	Electric heater gas boiler boiler stove district heating heat pump air conditioner		Ordinary efficient Highly efficient	Incandescent Florescent CFL	Electricity Natural gas LPG Coal Coal gas Other	Vertical Horizontal	Black TV Color TV	Ordinary efficient Highly efficient

The equation for energy consumption in residential buildings can be summarized as follows (some subscripts have been omitted for brevity of presentation):

Equation 1.

$$E_{RB} = \sum_{i}^{OPTION} \sum_{m}^{OPTION} \frac{P_{m,i}}{F_{m,i}} \times \left[\left(H_{m,i} \times \left(SH_{m,i} \right) \right) + \left(\sum_{j} p_{i,j,m} \times UEC_{i,j,m} \right) + C_{m,i} + W_{m,i} + L_m + R_m \right]$$

where, in addition to the variables listed above:

m	=	*locale type (urban, rural)*
Pm,i	=	*population in locale m in region i*
Fm,i	=	*number of persons per household (family) in locale m in region i,*
Hm,i	=	*average floor area per household in locale type m in region i in m2*
SHi	=	*space heating energy intensity in residential buildings in region i in kWh/m2-year,*
j	=	*type of appliance or end-use device,*
pi,j	=	*penetration of appliance or device j in region i in percent of households owning appliance (values in excess of 100% would indicate more than one device per household on average),*
UECi,j	=	*energy intensity of appliance j in region i in MJ or kWh/year,*
Ci	=	*cooking energy use per household in region i in MJ /household-year,*
Wi	=	*water heating energy use per household in region i in MJ /household-year,*
Lm	=	*average lighting energy use per square meter in locale type i in kWh /square meter-year, and*
Rm	=	*residual household energy use in locale type i in MJ /household-year.*

Air conditioner and refrigerator end uses are detailed with stock turnover modelling, which includes information on initial stocks by vintage, energy efficiencies by vintage (allowing explicit modelling of the impacts of standards), efficiency degradation profiles, and lifetime or survival profiles.

Current Residential Building Energy Consumption in China

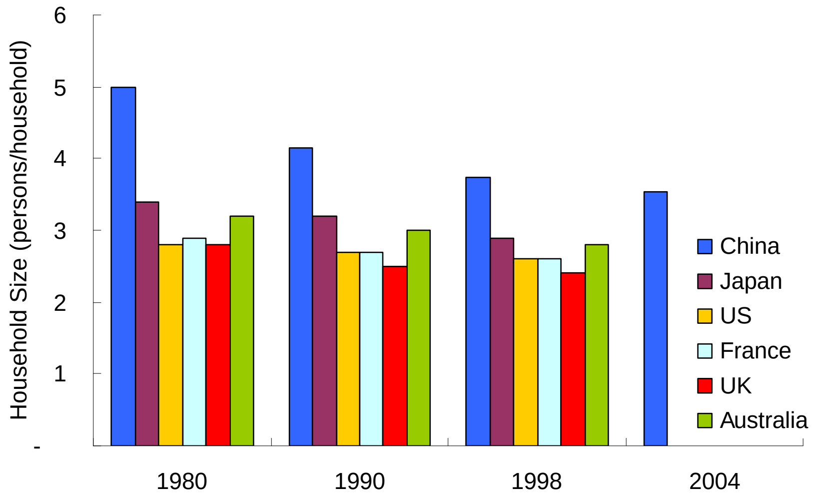
Assumptions of the Drivers

Along with population size, key activity drivers of energy and demand in residential buildings are rate of urbanization, number of households, per capita living area and persons per residence. As populations become more urbanized and areas become electrified, the demand for energy services such as refrigeration, lighting, heating, and cooling increases. In the residential buildings sector, the level of energy demand is further influenced by household income, number of households, size of households and the number of people per household. Although GDP is not a direct driver in our analysis, it is however used as reference to drive the increase of average household living area and saturation of appliances. Income and wealth effects have been strong generators of demand for durable and nondurable goods and services. In turn, the demand for inputs, including energy, to produce these goods and services would also rise strongly (Battles and Burns, 2000).

The key drivers used in our disaggregating effort are presented in Table 2. The population in 2000 was 1.27 billion and 34.3% of them lived in north China, 30% in the South, with the rest living in transitional areas. The regional split is used to estimate the energy demand in each region according to climate differences and determine the level of the space heating and space cooling needs. Urbanization rate is an important driver for developing countries, where the energy usage characteristics in rural households may be very different than that of urban ones. The number of people living in urban areas in China is 35.6% of the total, which is almost the level of the world average in 1970 (U.N. 2005). In general, higher levels of urbanization are associated with higher incomes and increased household energy use (Sathaye et al., 1989; Nadel et al., 1997). Historically, the average household size has been declining in most developing countries (Figure 1). China adopted a one child policy in 1979 which accelerated this decrease. Average household size declined from 5 persons in 1980 to 3.7 persons in 2004, and in urban China it has almost reached the level of developed countries. Change in household size is important because per capita energy use rises as household size decreases, since a small household have many of the same appliances as a large household and use same amount of energy for heating and cooling (Schipper and Meyers, 1992). Another important factor is the dwelling area. Existing research shows that dwelling area often increases even during recessions in many countries and the variations offer an important explanation of differences in per capita space heating needs among countries (IEA, 2004). Dwelling area in China has increased significantly over the past two decades with an AGR of 4.3% while it is only about 0.6% in other countries (**Error! Reference source not found.**Figure 2). In 2000, the average dwelling area in China was 94 m^2 per dwelling on average, which has already reached many of the developed countries level in 1998. For instance, France is 88 m^2, Japan is 93 m^2, UK is 85 $m^2$and Canada is 127 m^2 respectively in 1998 (IEA, 2004).

Table 2 Macro Drivers in Residential Sector

		2000
Population	billion	1.269
north	percentage	34.3%
transition	percentage	36.2%
south	percentage	29.5%
GDP	billion 2000 constant US$	1,198
GDP per capita	US$ /person	944
Urbanization rate	%	35.6
Household size		
urban	Person	3.19
rural	Person	4.35
Living area		
urban	m^2/capita	19.8
rural	m^2/capita	24.8



Source: IEA,2004; NBS,2004

Figure 1 Trends in Household size

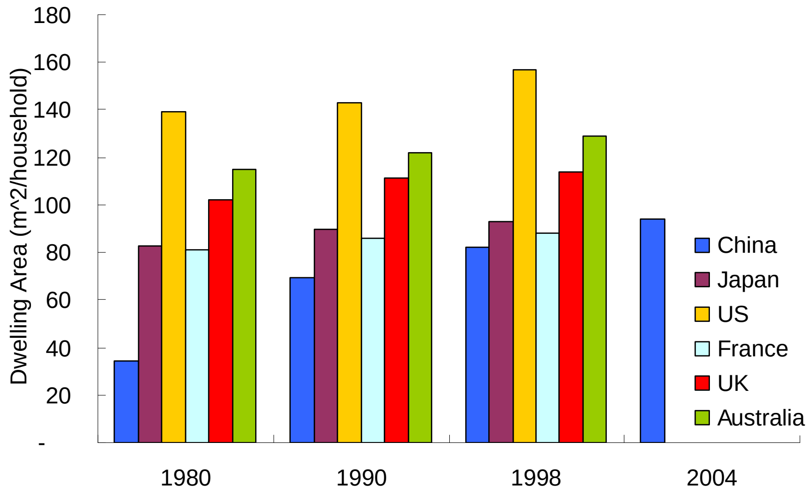


Figure 2 Trends in Dwelling Area

Source: IEA,2004; NBS,2004

Energy Use and Activity

Overall energy intensity in the buildings sector can be measured using energy consumption per capita values. We summarize the saturation and aggregated energy intensity on each of the main residential energy end uses in Table 3. Energy intensity trends in residential space conditioning are affected by climate, building thermal integrity, and the heating and cooling equipment used.

Space heating is an important end-use in the developed countries and in some developing countries. Buildings that are centrally heated consume almost twice as much energy as those heated by small room heaters. Heating equipment has been used throughout northern China, but only 30% of the urban area and 8% of the rural area in transition area has heating devices. In northern urban areas, stoves and boilers are the major heating equipment with a share of 40% respectively, followed by district heating of 22%, while in rural, biomass is the major heat source, with a share of 85%. In central China, electric heaters are the major heating with the share of 60% (Zhou, 2003). Buildings in North and Transition urban area are supposed to meet the 2001 building codes. Space heating intensity is 31.60 W/ m^2-degree day in north and 17.5 W/ m^2-degree day in transition region in 2000. Rural China has a much lower heating intensity because of the income gap with urban, which is 2.34 W/ m^2--degree day in north and 0.14 W/m^2-degree day in transition region in 2000.

Cooking and water heating intensity in urban areas is 1252 kWh/household per year and slightly more in rural areas. This is much lower than that of Japan in 2000 which was 4560 kWh/household (IEEJ, 2003). In developed countries, the energy consumption of water heating is approximately 5 times as much as that of cooking. Although no data exist to break the two end uses down, the trend in developed countries can serve as a reference. Water heating energy is 4.7 higher than cooking energy in the U.S. and UK, 3.5 times higher in Japan in 1998 (IEA, 2004), and 4.22 times higher for Japan in 2000 (IEEJ, 2003). We assume that a similar ratio also applies for China. LPG is a major energy source, while coal and electricity are also used in some parts of China. Biomass is the major energy in rural areas.

For lighting, an aggregated lighting intensity was used based on our previous research (Lin, 2003). The annual lighting energy intensity for 7 major cities in China is 213 kWh/household in 1999. The share for different bulbs is 55% for incandescent, 39% for fluorescent and 6% for CFL (compact fluorescent).

Energy use in appliances is determined by ownership or saturation rate and the unit energy consumption (UEC). Ownership rates often grow as a result of economic development. In 2000, refrigerators, TVs and clothes washers have already penetrated many of the households in urban areas, while the rates in rural areas are still much lower. The use of air conditioning is highly dependent on climate as well as income level; therefore on average the ownership is only about 30% in urban China, and very rare in rural. These numbers are much lower than those of developed countries such as 121% for refrigerators and 217.4% for air conditioners in Japan in 2000 (IEEJ, 2003). Unit energy consumption for a given type of appliance depends on not only the efficiency, but also on the usage pattern. In addition, change in the size and features of appliances plays a major role in determining the UECs. Increases in average size are most significant for refrigerators. Although our analysis on refrigerators was broken out into three sizes and three efficiency classes and stock turnover analysis is used, only aggregated and average numbers are presented here for comparison with other countries. Table 3 also shows that most of UECs of the appliances are higher those of Japan, indicating a large potential for energy efficiency improvement.

Table 3 End Use Saturations and Intensities

	Saturation, %		End use intensity/UEC				
	Urban	Rural	Unit	Urban	Rural	Japan	notes
Space Heating							
North	100	100	kWh/m^2-year	79	5.9	38.6	2000 average
Transition	30	8	kWh/m^2-year	26.6	0.24		
Refrigerator	80	12	kWh/year	460	460	380	2004 for 250L-300L
Clothes washer	91	29					
vertical	63	70	kWh/year	36	36	21.9 to 40.2	2004 for 4.2 kg
horizontal	27	30	kWh/year	61	61		
TV							
black	0	53	kWh/year	38	38		
color	117	49	kWh/year	150	150	79	2004 for 29 inch
Air Conditioner	31	1	kWh/year	388	375	229	2000 average
Cooking and water heating	-	-	MJ/household-year	4506	4986	16420	2000 average
Other use	-	-	kWh/year	280	100	16546	2000 average
lighting	-	-	kWh/household	283	253		

Energy consumption by fuel and end-use

Residential primary energy consumption was 6.6 EJ in 2000. This can be compared to the estimate from Chinese official statistics (NBS 2005), which was 4.7 EJ in that year. The likely reason for this disagreement between the bottom-up and statistics arises from a difference in building classification. Many residential buildings in China are built to house workers in large industrial complexes, and are located on the premises of the plant. In the Chinese statistics, energy use in these buildings is counted in within the industrial sector. This discrepancy is discussed in (Zhou, 2008). In terms of primary energy, not including biomass fuels which are mostly used for rural space heating and cooking, the residential sector accounts for 16% of primary energy in the bottom-up analysis, and 12% according to the Chinese official statistics. If biomass is included, the bottom-up analysis indicates a total primary energy share of 30.6% in the residential sector.

Residential building energy is mostly used in urban areas, where rising incomes have allowed acquisition of home appliances, in addition to the existing district heating system in northern China, which resulted in much larger share of electricity, coal and gas use. Despite the larger share of land area and more population (64.4%) in rural China, total rural primary energy use is only 1.84EJ, accounting for 28% of the total national residential energy use.

Besides biomass, coal is the dominant fuel within residential primary energy, accounting for 79% of non-biomass energy consumption in households (Figure 3and Figure 4). This includes the coal directly used for heating and coal used to generate electricity used for appliances. Oil use (principally kerosene) is mostly seen in rural lighting. Even though renewable energy has increased drastically, its share remains insignificant.

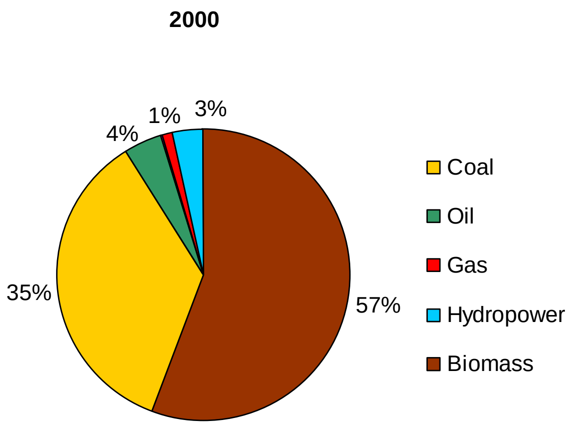


Figure 3 Residential Energy Consumption by Fuel (with Biomass)

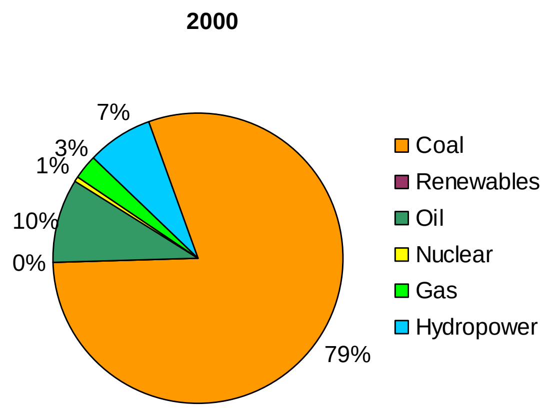


Figure 4 Residential Primay Energy Consumption by Fuel (without Biomass)

Most of the energy was used for space heating and water heating, accounting for 59% of the residential energy consumption (Figure 5). The four major appliances including air conditioners, refrigerators, clothes washers and TVs use about 21% of household energy, followed by lighting at 9% and cooking at 7%. Other uses which account for residual appliances such as computers, printers, etc.., used only 4% of energy in 2000. For comparison, according to IEA (2004) in 1998, the share of appliances in residential energy use had increased to between 10 and 15% in most European countries, with more than 20 % in the U.S. and Australia and 29% in Japan. Although its share has declined, space heating still accounts for more than half of total residential energy consumption in most of the IEA-11 countries[1]. While energy demand for space heating naturally varies with the climate, it is also determined by the household income level and other factors. Many households in China do not have sufficient heating due to poverty, and traditionally there has been no district heating system in Southern China, where the temperature can get very low in the winter. Also, a housing stock with high proportion of apartments (in contrast to single house) needs less space heat per unit area than one with a low proportion (Schipper and Meyers, 1992). These all possibly contributed to the lower share of space heating demand in China in 2000.

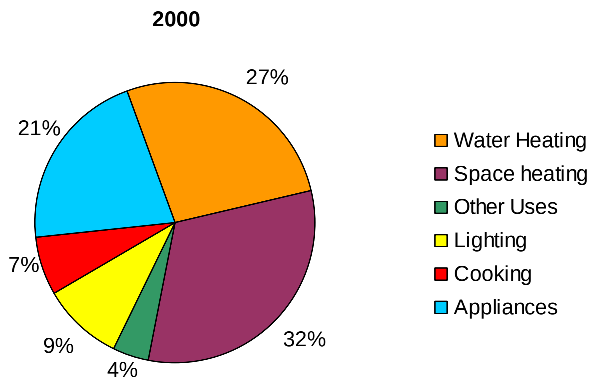


Figure 5 Residential Energy consumption by End-use

Future outlook for Energy Use in China

Activity and structural change

Population and Urbanization

The number of people living in urban areas in China increased between 1980 and 2000, growing from 193 million, or 19.5% of the total in 1970 to 451.8 million, or 35.6% of total in 2000 and is projected to increase to 55.8% in 2020 (UN, 2003) (see Figure 6). On the other hand, total population will continue to grow, but at a much slower pace compared with that of years before 2000, at 0.5% per year. Increasing urbanization leads to the increased use of commercial fuels, such as natural gas and liquefied petroleum gas, for cooking instead of traditional biomass fuels. Additional increases in energy use come with electrification, when appliances and lighting are adopted. In general, higher levels of urbanization are associated with higher incomes and increased household energy use (Sathaye et al., 1989; Nadel et al., 1997).

[1] The countries include: Australia, Denmark, Finland, France, Germany, Japan, Italy, Norway, Sweden, UK, and the U.S.

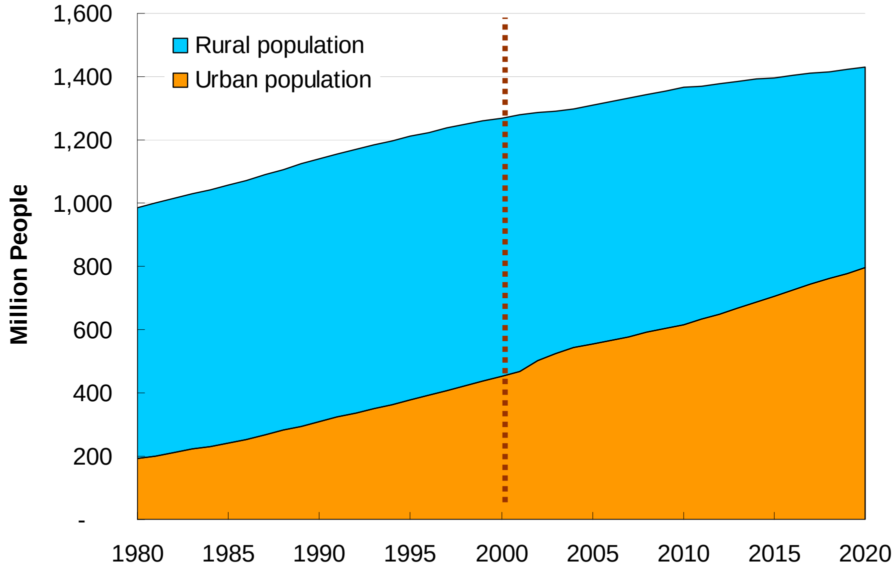


Figure 6 Population Trends and Projection

Residential Living Area and Household Size

Globally, the size of the household (number of persons per household) tends to decline with increasing income and urbanization of the population. In the case of China, the "one child policy" enforced such a decline particularly rigorously. Average household size in China dropped from 5.2 persons per household in 1981 to 3.04 persons per household in 2002 (Figure 7). This trend is expected to continue, with urban household size decreasing from 3.13 persons/household in 2000 to 2.88 persons/household in 2020, the level of Japanese household size today. It is also assumed that rural household size will be 3.9 persons/household in 2020.

In developed countries, the amount of household floor space per person has been gradually increasing since at least the early 1970s. In China, floor space per person increased from 9.9m^2 to 19.8 m^2 in urban and from 17.8m^2 to 24.8 m^2, from 1990 to 2000. In 2030, it is assumed to be equal to the current size in Japanese households (30 m^2/capita) while rural residences will have 34.8 m^2/capita).

The decline in household size leads to an increase in the total number of households in the region, which, together with the increase in living area will multiply the contribution of energy demand from households.

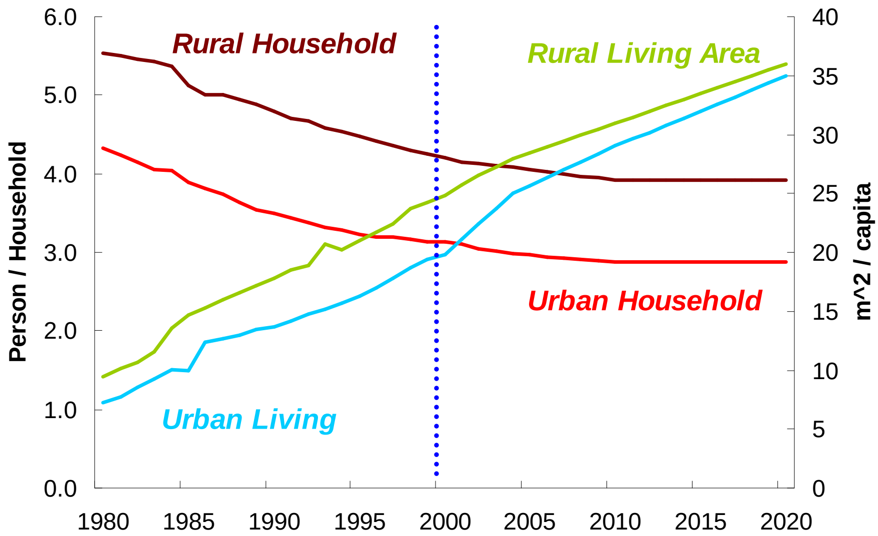


Figure 7 Floor area per Capita and Household Size Trend and Projection

Residential Appliance Penetration Change

Ownership of the four major electric appliances-refrigerators, air conditioners, clothes washers and TVs- increased significantly from 1981 to 2000 except for black & white TVs. For example, refrigerator ownership started at 1% in 1981 and increased to 80.1% in 2000 in urban China. Increased income levels and decreasing appliance prices drive the growth of the ownership of appliances, but will slow down when reaching a high saturation rate. In urban areas, colour TVs are already universal; clothes washer ownership is approaching saturation; and refrigerator rates are also growing. All of these will result in a much slower pace of growth of appliance ownership through 2020, and therefore will have much smaller relative impact on household electricity consumption in the future. Other factors such as air conditioning is an exception because it began to appear in early 90s, and is expected continue growing much faster. Japan is used as a proxy to project the development of China. The level of energy required for urban households in China in 2020 is assumed to be similar to that consumed in urban households in Japan today. For appliance saturation, it is assumed that urban Chinese households will reach the level of appliance ownership of Japan today by 2020. (Figure 8 and Figure 9).

End Use Intensities

For all end uses, appropriate devices and fuels were assigned, with saturation (rates of penetration) and energy efficiencies based on statistical and survey data pertaining to the base year (2000) (NBS,1985-2005; Zhou,2003, Brockett,2003) and future values based on analysis of government plans, trends, and comparisons to other countries. Table 4 shows the values for major driver variables that were used to obtain an outcome to 2020.

Energy intensity for cooking, water heating and lighting will increase in order to accommodate the demand for higher levels of comfort. These intensities are still low compared to other countries, whereas space heating stands out as an exception. Space heating in Northern urban China is predominately supplied through district heating systems that do not have meters or switches installed in individual houses, which result in imbalances and inability to control heat use, forcing consumers to commonly open windows as the only means to regulate overheating. In addition, current building codes are not stringent enough compared with other countries (Zhou, 2008), and the enforcement is far from adequate. In southern cities, the compliance rate in new buildings could be as low as 8 to 10%. Government at all levels should increase the capacity and resources for inspection and enforcement. With the adoption of the heat metering system and the building envelope improvement, we project that the efficiency of the heating utilization in northern urban region will significantly improve on both these fronts, therefore leading to a decline in heating intensity. On the other hand, the transition area (areas south of Yangzi river but north of the non-heating Southern China) and rural China, traditionally defined as "non-heating zone", is cold in the winter but historically has had no heating equipment, and will demand for more heating as their economy develops. This will result in growing intensity in space heating.

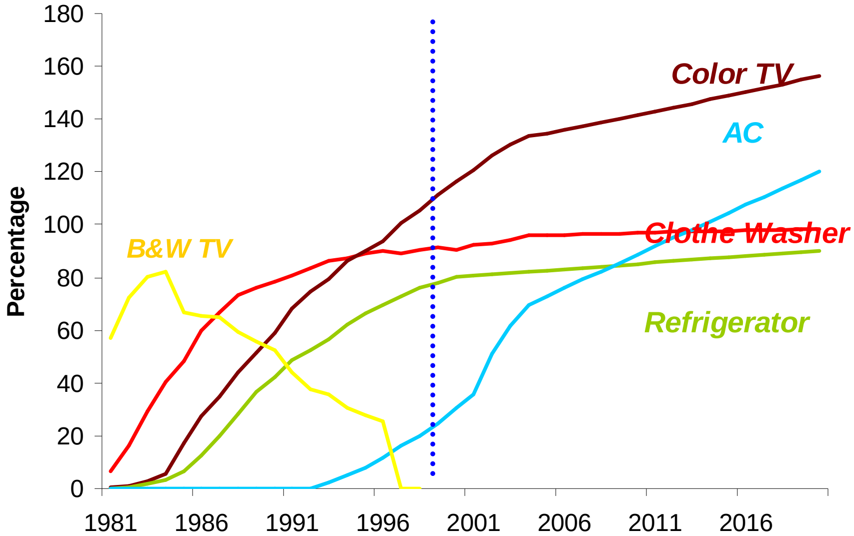


Figure 8 Urban Appliance Ownership

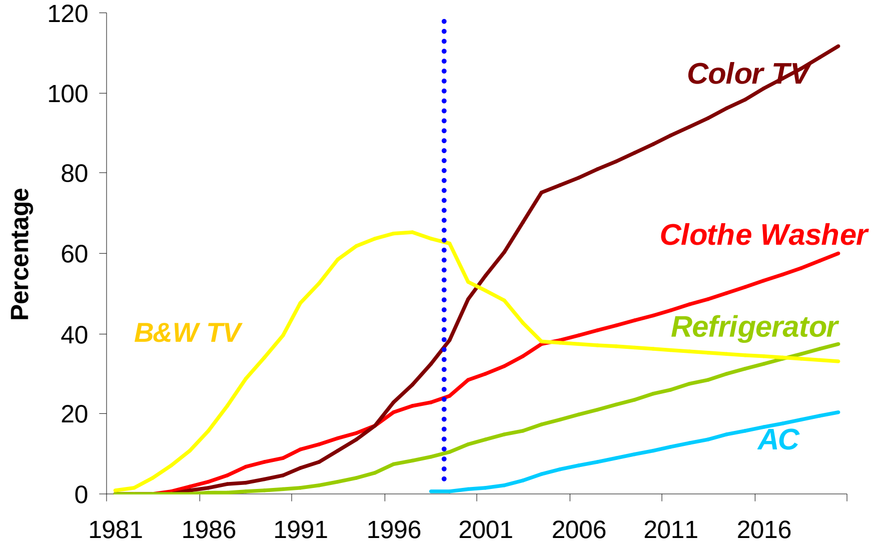


Figure 9 Rural Appliance Ownership

Table 4 Residential Energy Intensity by End-use

			Urban enduse intensity		Rural enduse intensity		Japanese 2004 most efficient technology	note
			2000	2020	2000	2020		
Space Heating								
	North	kWh/m^2-year	79	64	5.85	30.6		
	Transition	kWh/m^2-year	29.6	28.8	5	9.6		
Cooking		MJ/household-year	901.2	1421	997	1349		
water heating		MJ/household-year	3605	5685	3988	5396		
Other use		kWh/year	100	420	50	150		
lighting		kWh/m^2-year	3	4.5	1.5	2.2		
Refrigerator UEC		kWh/year	461.2	421.9	458.9	422.3	380	for 250L-300L
Clothes washer								
	vertical	kWh/year	35.88	32.9	23.9	28.1		
	horizontal	kWh/year	92.4	60.9	61.36	51.5	21.9 to 40.2	for 4.2 kg
TV								
	black& white	kWh/year	38	63.8	38	63.8		
	color	kWh/year	125	243	125	243	79	for 29 inch
Air Conditioner UEC		kWh/year	387.6	245.6	375	248.9	47 kWh/month for cooling, 116 kWh/month for heating	for capacity of 2.5 kW

Energy efficiency

China's government plan calls for efficiency improvement through a tightening of standards, incentives and subsidies as well as moderate measures to accelerate the adoption of higher-efficiency technologies (RNECSPC, 2005). The energy efficiency in our model is a combination of the efficiency and market shares of different types of technologies. Our analysis reveals that the efficiency of the different technologies will be improved over time due to the revision of minimum energy efficiency standard as well as technology development. **Figure 10** illustrates an example of the efficiency change of space heating technology. For instance, the average efficiency of district heating will increase by 23 percent, whereas a heat pump shows a 80 percent efficiency-improvement potential.

At the same time, the market share of efficient and cleaner technology also rises according to the current government policy (**Figure 11**). Technologies such as conventional coal boilers and district heating will gradually shift to cleaner gas boilers and more efficient heat pumps. The projection is based on assumption that both the efficiency and market shares of the different technologies used in the Chinese residential sector will converge to their current level in Japan by 2020.

Because of their large share in household energy use, refrigerators and air conditioners were modelled in some detail. They were broken out into efficiency classes (and also, in the case of refrigerators, size classes) and simple stock turnover modelling was implemented. The case of refrigerators in urban households provides an example of how the efficiency changes over time.

Current data for actual refrigerators on the Chinese market and information on possible future efficiency standards (China National Institute of Standardization, 2003) are used to determine efficiency levels for these three efficiency classes in each of three typical refrigerator sizes (170 liters, 220 liters, and 270 liters). Average intensity levels for the three efficiency classes, which are assumed to decline over the 2000 to 2030 period are shown in Figure 12. Figure 13 shows that, over the period of the scenario, the average size of new refrigerator is assume to rise. The increased capacity of Chinese offsets the effects of efficiency gains, limiting the reduction in energy consumption shown in Table 4.

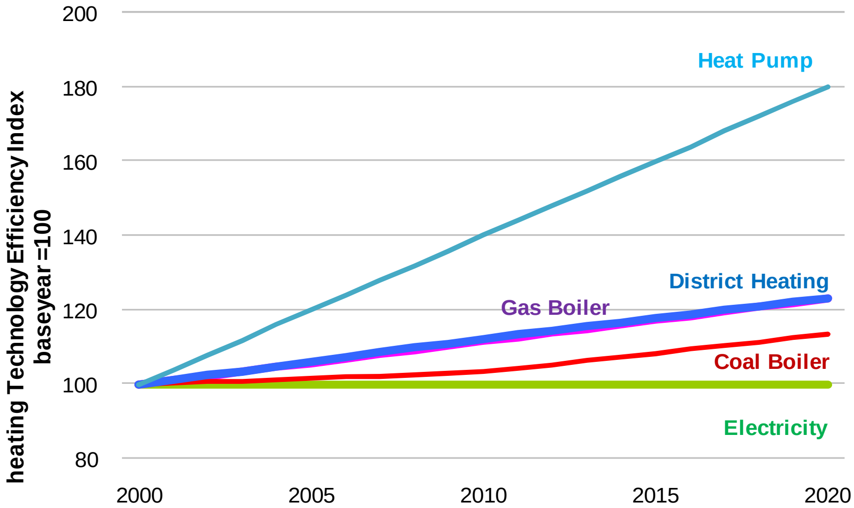


Figure 10 Efficiency of the Space Heating Technologies

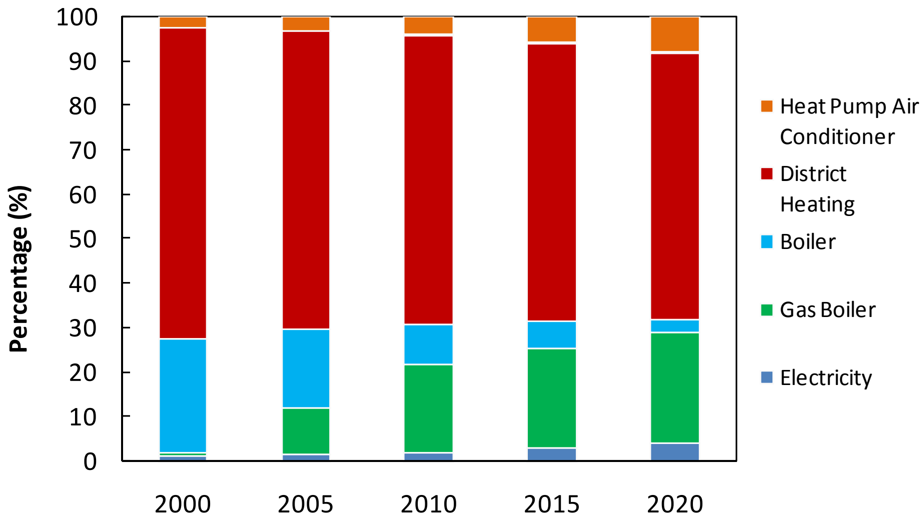


Figure 11 Space Heating Technology Shift in Residential Building

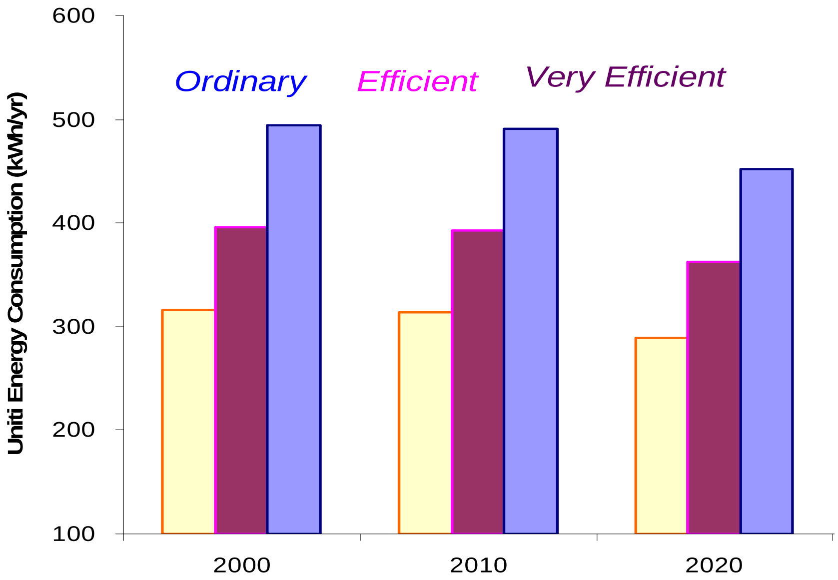


Figure 12 Refrigerator UECs by Efficiency Class

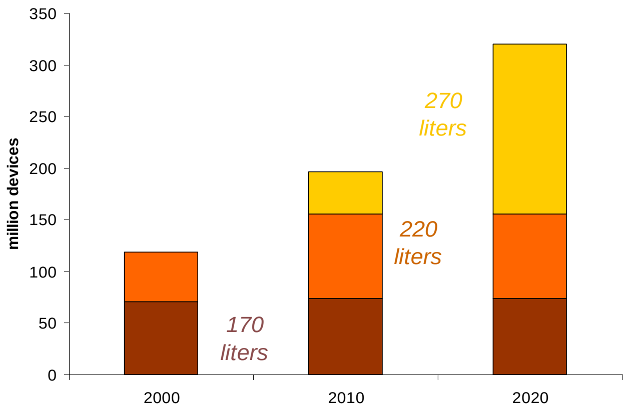


Figure 13 Refrigerator Stock by Size

Future Energy Outlook in Residential Buildings

The bottom-up analysis presented in the previous sections allows for a credible projection of future residential energy consumption in China. We project energy consumption by end use to 2020 by combining forecasts of equipment uptake with likely evolution in use patterns and efficiency. The resulting energy consumption predictions are displayed in terms of primary energy. Primary energy consumption includes final consumption plus the energy that was necessary to produce secondary energy, such as energy transformation losses in electricity production. Final to primary conversion factors are a function of the projected installation of new power plants, by plant type and efficiency, which are taken from a recent analysis of the Chinese government's Energy Policy Strategy (RNECSPC, 2005).

Growth in residential energy consumption is driven both by an increase in total floor space devoted to these uses and by the increase in appliance, lighting, and heating and cooling usage in these areas Figure 14, *a*nd Figure 15?). As urbanization increases, growing from the current 40% to 56% in 2020, and household wealth continues to rise, demand in households for refrigerators, air conditioners, lighting products, clothes washers, consumer electronics, space heating, water heating and other functions will increase substantially. For example, the average efficiency of an "efficient" split-type room air conditioner in urban households is expected to improve by nearly 40% by 2020 over the 2004 level, but owing to continued high rates of sales, total electricity consumption by "efficient" room air conditioners is expected to more than triple, from 12 TWh in 2004 to 38 TWh in 2020.

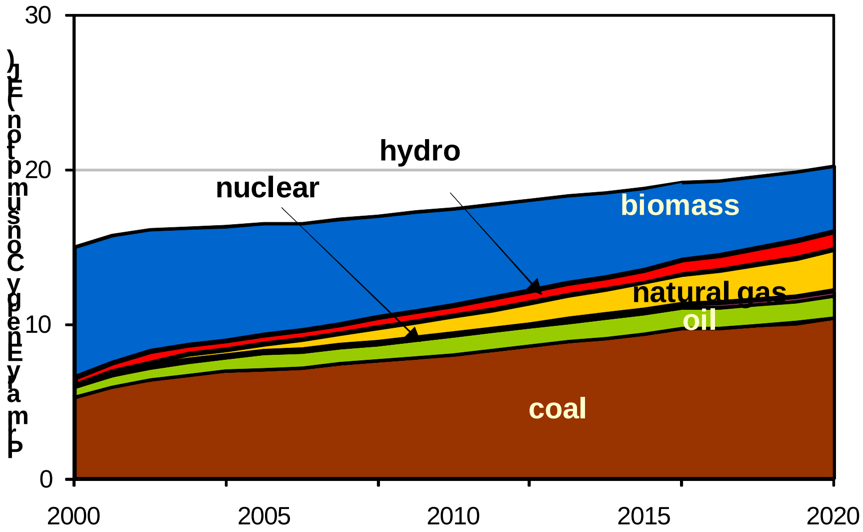


Figure 14 Residential Primary Energy Consumption by Fuel (with biomass)

In terms of fuels, the residential sector will experience a significant fuel-mix shift between 2000 and 2020. Biomass, the leading energy source in the rural economy with a share of 56% in 2000, will decline to 21% in 2020. On the other hand, coal use in rural areas will increase from 36% to 51%. Without counting biomass, the share of coal would be much more dominant throughout this period, even with the aggressive plans for development of renewable energy, and for increasing the share of natural gas and nuclear power. From a share of 80% of total primary energy supply in 2000, coal will drop to about 65% by 2020, while natural gas will increase from 2.8% to 17%, and nuclear power from 0.6% to 2%. By 2012, the total energy consumption of China's 650 million urban residents will surpass that of the 728 million rural residents, even considering the 5.8 EJ consumed in rural households in the form of biomass. In terms of commercial energy only, urban household consumption will be three times that of rural areas. This continued high reliance on biomass for rural energy consumption as discussed above shows the potential challenge to the coal, oil, gas and electricity sectors of fully displacing biomass usage in rural households.

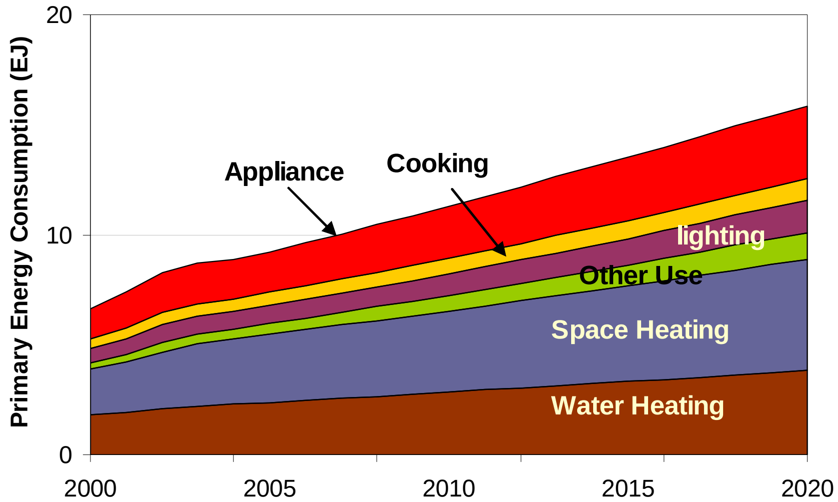


Figure 15 Residential Primary Energy Consumption by End-use (without biomass)

Conclusions

Several important conclusions can be drawn from a bottom-up study such as this one. First of all, we find that as living standards in China rise, energy efficiency improvements in the residential sector are likely to be offset by the growing demand for higher levels of energy services: more space heating and cooling, improved lighting, more hot water, and larger appliances. These responses to higher living standards make it difficult to reduce energy intensity in building sector. We find that in 2020, residential primary building energy consumption may reach 15.9 EJ from 6.6 EJ in 2000, with a 4.5% growth rate per year, unless stronger policies encouraging efficiency are implemented. Figure 16 shows the different components of annual energy growth. The figure shows that the largest contributions to the growth rate are: refrigerator and air conditioner saturation (1.0%), increased floor area per capita (0.9%) and urbanization (0,9%), which together more than offset the trends of efficiency (-0.6%) and (-0.1%) each for regional migration and reductions in heating intensity from improved construction. Urban energy use accounts for 72% of the total residential primary energy. Most residential energy consumption is consumed by space heating and water heating, accounting for 59% of the total. The four major appliances including air conditioner, refrigerator, clothes washer and TV use about 21% of household energy, followed by lighting at 9% and cooking at 7%.

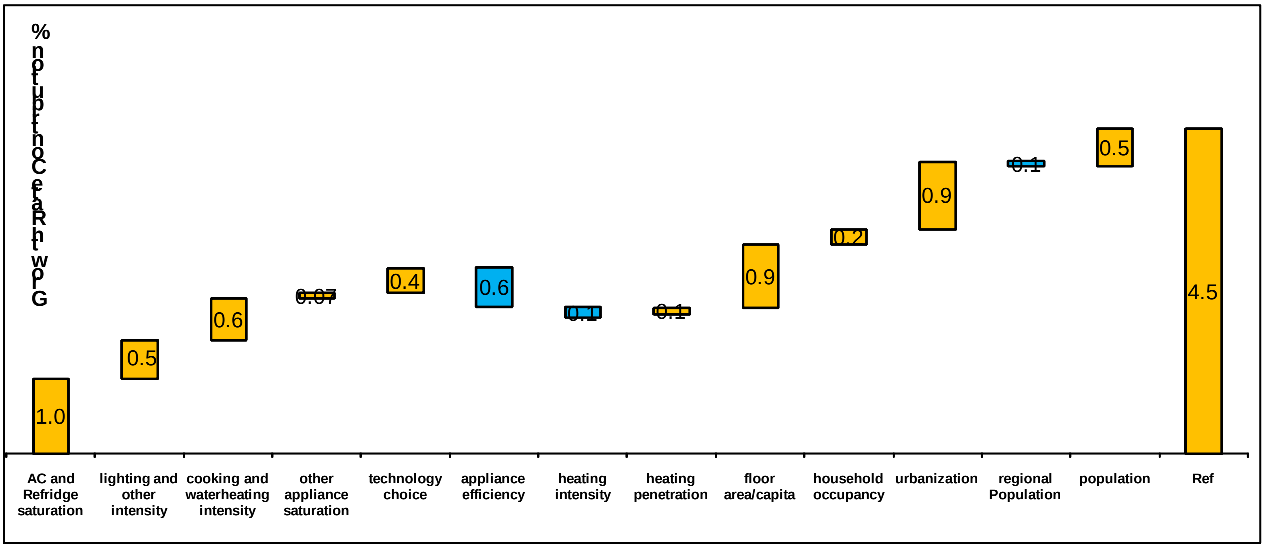


Figure 16 Contributions to Annual Growth Rate in Residential Primary Energy Consumption

The assumptions used to make this projection are based on polices and plans that have been undertaken or are under development by the Chinese government. However, the implication of this paper suggests that without more aggressive policies calling for further improvement in energy efficiency and behavioural change, the trend of increasing energy consumption in the residential sector and reliance on coal is unlikely to change. Possible options for improvement include: implementation and better enforcement of stricter building codes and appliance standards; better enforcement; heating use metering and pricing reform; adoption of fiscal policies that could promote cleaner and more efficient products; construction of energy-saving buildings and retrofit of existing buildings, in addition to initiatives to improve the efficiency of the electricity supply sector and an increase in renewable energy sources.

An advantage of the bottom-up methodology is that it allows for precise and accurate assessment of what the impacts of more aggressive policies are likely to be. Currently, research is underway at LBNL to provide a detailed set of efficiency scenarios for China. The results of this assessment will be provided in an upcoming report.

References

Battles, S., and Burns, E., 2000. Trends in Building-Related Energy and Carbon Emissions: Actual and Alternate Scenarios, Summer Study on Energy Efficiency in Buildings, August 21, Washington, DC: American Council for an Energy-Efficient Economy.

Brockett, D., Fridley, D., Lin, J. M, and Lin, J 2003. A Tale of Five Cities: The China Residential Energy Consumption Survey, Human and Social Dimension of Energy Use: Understanding Markets and Demand

Committee of RNECSPC, 2005. Research on National Energy Comprehensive Strategy and Policy of China (RENESPEC), Economic Science Press

Institute of Energy Economics, Japan (IEEJ), 2003. Handbook of Energy & Economic Statistics in Japan, he Energy Data and Modeling Center, The Institute of Energy Economics, Tokyo, Japan

International Energy Agency (IEA),2004. 30 Years of Energy Use in IEA Countries, Paris: IEA/OECD.

Lin, J, 2003. A Light Diet for a Giant Appetite: An Assessment of China's Fluorescent Lamp Standard, Energy, No.30, pp8-35

Lin, Jiang, Zhou, Nan, Levine, Mark, and Fridley, David. Taking out one billion tons of CO2: the magic of China's 11th five year plan? Energy Policy, No. 26. 2008, December 2007. LBNL-757E.

Nadel, S.M., Fridley, D., Sinton, J., Zhirong, Y., Hong, L., 1997. Energy Efficiency Opportunities in the Chinese Building Sector. Washington, DC: American Council for an Energy-Efficient Economy.

National Bureau of Statistics of China (NBS), 1981-2005. China Statistical Yearbooks. Beijing: Info Press. http://www.stats.gov.cn/english/statisticaldata/yearlydata/

National Development and Reform Commission (NDRC), 2005. Medium- and Long-term Conservation Plan, China Environmental Science Press, Beijing.

Sathaye, J., Ketoff, A., Schipper, L., and Lele, S., 1989. An End-Use Approach to Development of Long-Term Energy Demand Scenarios for Developing Countries, Berkeley, CA, LBNL (LBL-25611).

Schipper, L., Meyers, S., Howarth, R., and Steiner, R., 1992. Energy Efficiency and Human Activity, Cambridge University Press, Cambridge: UK

United Nations (UN), 2003. World Population Prospects: The 2002 Revision, United Nations Population Division. www.unpopulation.org.

United Nations, 2005. World Population Prospects: The 2005 Revision. Department of Economic and Social Affairs. Population Division.

Zhou, D., Dai,Y., Yu, C., Guo, Y. and Zhu,Y., 2003. China's Sustainable Energy Scenarios in 2020, China Environmental Science Publishing Company.

Zhou, Nan and Lin, Jiang. 2008, The Reality and Future Scenarios of Commercial Building Energy Consumption in China, 2008, Energy& Buildings, June Volume 40, Issue 12, Pages 2121-2127