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Challenges of Green Consumption in China: A Household Energy Use Perspective

1. INTRODUCTION

China's GDP grew at its slowest pace in six years at the start of 2015. Still, its rate of growth was tagged at an annualized rate of 7.0 percent. Such rates of GDP growth in China are largely supported by the continuing stream of rural-to-urban migration (Yang and Lahr, 2010). To support this growth, China's energy consumption has increased fivefold since 1980 (National Bureau of Statistics of China (NBS), 2014). In 2013, the nation consumed 21.3% of the world's energy, making it the world's largest energy consumer and top greenhouse gas emitter (International Energy Agency (IEA), 2015). Recently, China announced its national climate plan, which aims to achieve peak carbon dioxide emissions around 2030 by lowering carbon dioxide emission per unit of GDP by 60% to 65% from the 2005 level (*Xinhua News*, 2015). Green and Stern (2015) are high on this prospect for China, even going so far as to suggest that the nation's greenhouse gas emissions are likely to peak as early as 2025. After exploring matters via the perspective of household consumption, we suggest that such targets may be overly ambitious unless China moves hard and fast on green consumption initiatives.

China continues to rely heavily on capital investment and export production and, hence, on manufacturing, which itself feeds on energy resources (NBS, 2014). Undoubtedly due to these booming aspects of final demand, China has a very low share of household consumption in GDP. In 2013, household consumption accounted for only 36.2% of GDP in China, compared to 68.0% in USA and 60.4% in India (OECD, 2014).

This small share obscures the extent to which China's households have experienced lifestyle changes during the past three decades. While prior to the 1970s most of China's population lived in abject poverty, now household needs are general fulfilled such that many householders aspire toward ever higher living standards (Hubacek et al., 2011).

From 1980 to 2012, household incomes increased at an average annual rate of around 7.0 percent for both urban and rural residents. But, as noted earlier, growth of residential use of energy has lagged total energy use in China, so that residents' share of energy use declined from 16.5 percent in 1987 to 11.0 percent by 2012. It therefore should be no surprise that, to date, China's energy conservation policies have focused on industries and have largely neglected households.

Economic growth that primarily relies on capital investment is unsustainable. In this regard, the shift in China from high to medium-high growth has been expected. Thus, China is encouraging growth in domestic demand, predicated upon the burgeoning wealth of its households. That is, rather than embracing a policy of savings encouragement to sustain public investment, China is instead promoting a transition to Western-styled consumerism. Such an income-driven lifestyle change is expected to cause energy consumption by households to rise significantly. Indeed, direct residential energy use in China in 2012 was 274 kg oil equivalent per capita: This is 74.6% of the Japan's level and merely 33.9% of that in the U.S.A. It is natural to ask whether residential energy consumption growth in China will follow the Japanese model, the American model, or some other trajectory. The current rises in energy use appear to put Chinese households on a course to asymptotically approach energy use equivalents in the U.S.A. But, given its high population density, severe energy security problem, and environmental pressures, China should be cautious and pursue a model with deep energy savings, more akin to Japan's. In light of this, it seems prudent to gain a better understanding of recent trends and patterns in Chinese household energy use.

Most studies of household energy consumption in China focus on the direct energy consumption factors such as transitions within its fuel mix and changes in end use structures (Liu et al., 2005; Zhang et al., 2009a; Wang et al., 1999; Zheng et al., 2010). Wei et al. (2007) used a Consumer Lifestyle Approach to quantify the direct and indirect energy use and related CO_2 emissions by urban and rural residents in China from 1990 to 2002. Following Wei et al., Feng et al. (2011) compare household energy use and CO_2 emissions by income group across China's regions. Liu et al. (2009) quantify household indirect energy use in China from 1992 to 2005 to test how energy efficiency improvements and higher real electricity prices might affect prices of manufactured goods, real household incomes, and consumer prices. Interestingly, Ouyang et al. (2010) show that household-based energy efficiencies have altered the demand for energy by households in a perverse fashion. In fact, Liu et al. (2011) demonstrate rising urban and rural household consumption has been a main enabler of carbon emissions per capita from 1992 to 2007. Fan et al. (2012) explore in more detail how the embedded carbon footprints of Chinese urban households have evolved with rising related expenditures between 2003 and 2007.

Energy security, air pollution concern, and energy conservation are now listed high on China's political agenda. Policies that can enable or ameliorate these items are most likely to be effected via policies grounded in affecting energy use. Thus, a focus directly upon energy consumption is warranted. Herein, we explore the long-term trends of household energy use and related driving forces of changing household indirect energy use at a finer grain of sector detail than has been used previously. We do so using a new multiplicative structural decomposition to explore what is changing among Chinese households. Is it population rises, heightened urbanization, changes in preferences, or simply increased spending potential that is enabling the rise in household energy consumption? We support the analysis by digging deep into literature on certain aspects of Chinese households' lifestyles on four important aspects: housing quality, thermal comfort, use of home appliances, and personal mobility. As China's households move up the consumption ladder, our results indicate that household-based energy demand likely will continue to rise for some time. Growth prospects look especially high for rural China where energy use lags heavily. Based on our results, we also offer some valuable policy suggestions for China in guiding its residents' lifestyles toward greener consumption.

2. RESEARCH APPROACH

Household energy consumption is the sum of household direct energy use (E^{d}) and indirect energy use (E^{i}). Households use energy directly for cooking, heating, lighting, transportation, and other purposes, as well as indirectly through the production and delivery of their purchased goods (e.g., food, clothes, home appliances) and services (e.g., transit, dry cleaning, dining). In this paper, total household energy consumption (E) is the sum of both direct and indirect energy use by households.

Index decomposition analysis (IDA) and structural decomposition analysis (SDA) are both commonly used to understand the underlying economic causes of trends of energy consumption. IDA has been frequently used to analyze energy consumption and energy-related CO_2 emission (Ang et al., 2004; Wang et al., 2005; Liu et al., 2007; Feng et al., 2009; Hubacek et al., 2011; Zhang et al., 2009b). Less data-demanding, IDA decomposes proximate economic causes at a very aggregate level, ignoring sectoral interdependence.

Using I-O tables, SDA also has been frequently used by researchers to identify proximate driving forces of change in energy use and CO_2 emission by industries (Miller and Blair, 2009). Compared to IDA, SDA is able to account simultaneously for both the supply- and demand-side effects, as well as distinguishing between direct and indirect effects through the supply chain (Miller and Blair, 2009; Feng et al., 2012). For example, Peters et al. (2007) and Guan et al. (2009) use SDA to assess the effects of changes in technology, economic structure, urbanization, and lifestyles on CO_2 emissions in China for two time periods, 1992-2002 and 2002-2005. Both sets of authors find that rises in final demand have been a key growth driver, outweighing industrial and household energy efficiency gains that could otherwise have reduced CO_2 emissions. The rapid growth of infrastructure construction and urban household consumption that in turn was driven by urbanization and lifestyle changes contributed most of the increase in China's CO_2 emissions from 1997 to 2002. From 2002 to 2005, growing export demand was responsible for half of the increment in emission. Following up on this research with an analysis of the 2005-2007 period, Minx et al. (2011) found that capital investment had been a major driver of emissions in China. Focusing instead on energy use, Zhang and Lahr (2014) use SDA and also found that capital investment and exports have not only contributed most to the increase in energy use from 2002 to 2007, but also shifted that nation's production toward industries that required more energy inputs.

In the present analysis, we use SDA to explore the changes in household indirect energy use. The economywide energy burden stemming from household spending can be expressed mathematically as:

$$E^i = \mathbf{e}'(\mathbf{I} - \mathbf{A})^{-1}\mathbf{h} = \mathbf{e}'\mathbf{L}\mathbf{h} \quad (1)$$

where E^i is a scalar representing energy embodied in goods and services that are consumed by households; $\mathbf{e}'$ is a vector for which each element e^k is the total of all energy inputs per unit output for industry k (a vector of length n—the number of industrial sectors); the Leontief-inverse matrix $\mathbf{L} \equiv (\mathbf{I} - \mathbf{A})^{-1}$, which reports interindustry input requirements ($n \times n$ matrix); $\mathbf{I}$ is the identity matrix ($n \times n$ matrix); $\mathbf{A}$ is a $n \times n$ matrix that shows the intersectoral direct requirements of each sector's production; and $\mathbf{h}$ is an $n \times 1$ vector that denotes household consumption of production by industry.

Since total population changes over years, we decompose household spending $\mathbf{h}$ into per capita sectoral expenditures by urban and rural households $\mathbf{H}_\mathrm{p}$ ($n \times 2$ matrix) and the two-element vector representing the population of rural and urban households $\mathbf{p}_\mathrm{s}$, such that $\mathbf{h} = \mathbf{H}_\mathrm{p} \cdot \mathbf{p}_\mathrm{s}$. We further decompose $\mathbf{H}_\mathrm{p}$ and $\mathbf{p}_\mathrm{s}$ into structure and volume components with $\mathbf{H}_\mathbf{P} = \mathbf{H}_\mathrm{s} \cdot \hat{\boldsymbol{y}}$ and $\mathbf{p}_s = p \cdot \mathbf{u}$, where $\mathbf{H}_\mathrm{s}$ is household consumption preference by household type ($n \times 2$ matrix that bifurcates household consumption into that for urban and rural households), and $\hat{\boldsymbol{y}}$ is the level of per capita household consumption by household type (2×2 diagonal matrix that shows per capita household expenditure of urban and rural households).

Household indirect energy use can be decomposed into the six factors in *Equation* 2, which are related to changes in population levels (Δp), urbanization ($\Delta\mathbf{u}$), energy efficiency ($\Delta\mathbf{e}$), interindustry input mix ($\Delta\mathbf{L}$), household consumption preference ($\Delta\mathbf{H_s}$), and per capita household consumption level ($\Delta\hat{\mathbf{y}}$). Using a multiplicative structural decomposition analysis (SDA) framework, we can write changes in household indirect energy use as: [1]

$$\frac{E_1^i}{E_0^i} = \frac{\mathbf{e}_1'\mathbf{L}_1\mathbf{h}_1}{\mathbf{e}_0'\mathbf{L}_0\mathbf{h}_0} = (2a)\times(2b)\times(2c)\times(2d)\times(2e)\times(2f) \tag{2}$$

$$= \frac{\mathbf{e}_1'\mathbf{L}_1\mathbf{h}_1}{\mathbf{e}_0'\mathbf{L}_1\mathbf{h}_1} \tag{2a}$$

$$\times\frac{\mathbf{e}_0'\mathbf{L}_1\mathbf{h}_1}{\mathbf{e}_0'\mathbf{L}_0\mathbf{h}_1} \tag{2b}$$

$$\times\frac{\mathbf{e}_0'\mathbf{L}_0(\mathbf{H}_{s1}\hat{\mathbf{y}}_1)(p_{\mathbf{1}}\mathbf{u_1})}{\mathbf{e}_0'\mathbf{L}_0(\mathbf{H}_{s0}\hat{\mathbf{y}}_1)(p_{\mathbf{1}}\mathbf{u_1})} \tag{2c}$$

$$\times\frac{\mathbf{e}_0'\mathbf{L}_0(\mathbf{H}_{s0}\hat{\mathbf{y}}_1)(p_{\mathbf{1}}\mathbf{u_1})}{\mathbf{e}_0'\mathbf{L}_0(\mathbf{H}_{s0}\hat{\mathbf{y}}_0)(p_{\mathbf{1}}\mathbf{u_1})} \tag{2d}$$

$$\times\frac{\mathbf{e}_0'\mathbf{L}_0(\mathbf{H}_{s0}\hat{\mathbf{y}}_0)(p_{\mathbf{1}}\mathbf{u_1})}{\mathbf{e}_0'\mathbf{L}_0(\mathbf{H}_{s0}\hat{\mathbf{y}}_0)(p_{\mathbf{0}}\mathbf{u_1})} \tag{2e}$$

$$\times\frac{\mathbf{e}_0'\mathbf{L}_0(\mathbf{H}_{s0}\hat{\mathbf{y}}_0)(p_{\mathbf{0}}\mathbf{u_1})}{\mathbf{e}_0'\mathbf{L}_0(\mathbf{H}_{s0}\hat{\mathbf{y}}_0)(p_{\mathbf{0}}\mathbf{u_0})} \tag{2f}$$

Each component listed above (Eq. 2a – 2f) is a ratio that relates levels of the component in one period to the level of the same component in another period. The natural log of any one ratio identifies its percentage change over the period.

$\Delta\mathbf{e}$: effect of changes in energy requirements per unit of output (Eq. 2a);

$\Delta\mathbf{L}$: effect of changes in interindustry input mix (Eq. 2b);

[1] Above we only show one side of the two polar decompositions. We actually examine both polar decompositions and use Fisher indices—their geometric means—to analyze results as per Dietzenbacher et al. (2000).

$\Delta\mathbf{H_s}$: effect of changes in household consumption preferences (Eq. 2c);

$\Delta\hat{\boldsymbol{y}}$: effect of changes in per capita household consumption level (Eq. 2d);

Δp: effect of changes in total population (Eq. 2e);

$\Delta\mathbf{u}$: effect of changes in the share of urban and rural population of total (Eq. 2f).

This research is based on five types of data: household direct energy use data, national I-O tables, energy consumption data, demographic data and household income data. Household direct energy use data is from the *China Energy Databook* (LBNL, 2014). China's national input-output tables and economy-wide energy use data are used to calculate indirect energy use for urban and rural households. Here we use the I-O tables for 1987 (118 sectors), 1992 (119 sectors), 1997 (124 sectors), 2002 (122 sectors), 2007(135 sectors) and 2010 (65 sectors) from National Bureau of Statistics of China. For the sake of consistency, we aggregate all I-O tables to 53 industrial sectors. Also, all tables are adjusted to the 2007 constant prices to make them comparable.[2] The energy data were taken from *China's Energy Statistical Yearbook* (NBS, 1990; 1998; 2009; 2011a). The 1987 and 1992 energy data contain 23 industrial sectors, and energy data for other corresponding years use 44 industrial sectors. Similar to Peters et al. (2007), we map the energy data to 53 economic sectors used in the I-O tables through a coordinate matrix. The demographic data and household income data of urban and rural population is from *China Statistical Yearbook* (NBS, 2011b).

[2] As suggested by Yang and Lahr (2010), this paper uses agriculture's producer price index for the primary sector and the free-on-board price index for the secondary sector to adjust prices. For the tertiary and construction industries, an implicit GDP price index (Nominal GDP divided by real GDP of these industries) was used.

3. RESIDENTIAL ENERGY USE

3.1 Residential Direct Energy Use

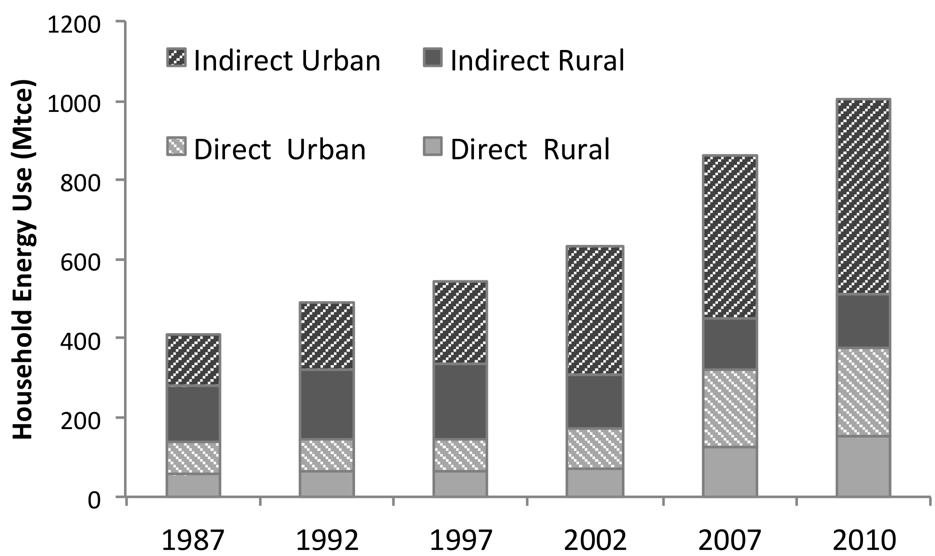
From 1987 to 2010, household direct energy use[3] rose gradually at an average annual rate of 4.5% from 138 Mtce in 1987 to 379 Mtce in 2010. Meanwhile household indirect energy use increased at an average annual rate of 3.7% from 271 Mtce in 1987 to 626 Mtce in 2010 (See *Figure* 1). Interestingly, this means that in 2010 energy use by Chinese households in aggregate was split about 38 **:** 62 between direct and indirect usage. Perhaps more critically, from 1987 to 2010, aggregate direct energy use rose 154% for rural households and 191% for urban households. Meanwhile over the same period, aggregated indirect energy use decreased 9% for total rural households but increased 296% for total urban households. These changes in levels were largely caused by the rapid urbanization in China. Indeed, between 1987 and 2010, the share of urban population in China had rose from 25.3% to 49.9%, with its total urban population increased 142%, while its total rural population decreased 18%.

Still, household energy consumption per capita has risen among both rural and urban China. In rural China, per household direct energy consumption was only 0.46 to 0.54 kg SCE per day in the 1960s and 1970s. Energy supplies available to households was barely sufficient to meet basic human needs, like cooking food. Starting in the 1980s, rural fuel shortages were resolved via this period's rapid agricultural development, which availed straw and other grain stalks for home-based combustion. The rising wealth of farmers and improving transportation and expanding electrical grid also enabled them to

[3] Here, direct energy use only refers to commercial energy. Non-commercial energy sources such as firewood, straw and biogas are also important energy sources for rural residents. In 2007, the average noncommercial energy use per capita for rural residents was 357 kg SCE. Thus, rural households consumed far more direct energy when non-commercial energy is considered.

purchase commercial energy resources—e.g., coal, gas, and electricity (Wang and Feng, 2001). Urban households experienced a parallel transition. Their higher relative wealth and more central locations, however, enabled them to spend much larger shares of their consumption baskets on commercial energy (Pachauri and Jiang, 2008).

Figure 1: Resident's Direct and Indirect Energy Requirements

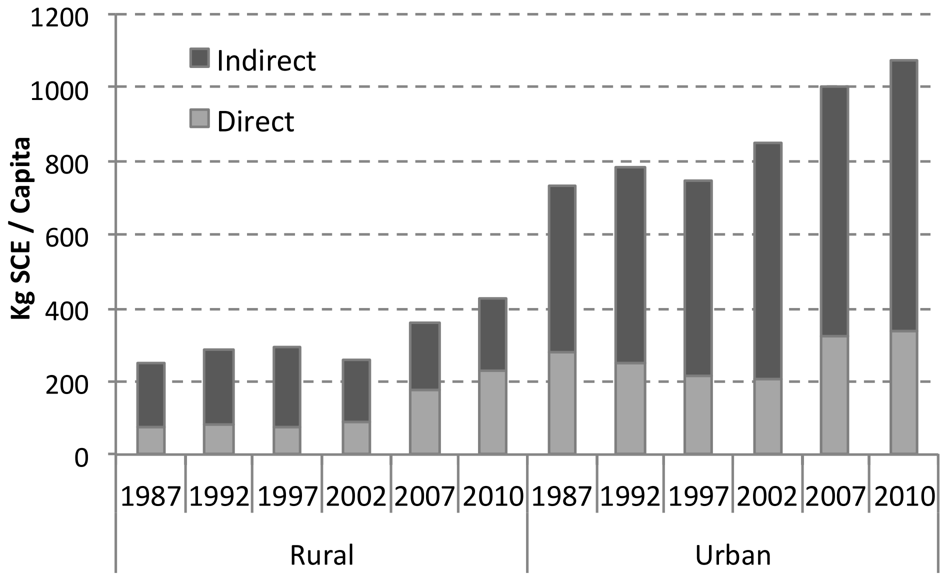


From 1987 to 2010, the fuel mix of Chinese households changed radically. Direct use of coal by households fell steadily; residents moved to units with central heating and, where/when available, switched to electricity for cooking and water heating. Coal's share decreased from 85.4% in 1987 to 17.3% by 2010. Within about 25 years, direct coal use per capita by urban households dropped precipitously from 234 kg to 20 kg, while it edged up slightly for rural households from 65 kg to 77 kg. The decreasing direct use of coal in homes significantly improved indoor air-quality.

As king coal abdicated from its home-based kingdom, the type of energy resources used directly by households became more diversified: electricity, municipally provided heating, liquefied petroleum gas (LPG), and natural gas became more widely used. Electricity's share rose most rapidly, from 8.4% in 1987 to 54.6% in 2010. The timing of the adoption of electricity (and concomitant non-use of coal) naturally differed between urban and rural areas. From 1987 to 2010, electricity usage per capita rose from 59 kWh to 446 kWh for urban residents and from 15 kWh to 318 kWh for rural residents.

China is a typical dualistic society. Compared to their rural counterparts, urban residents used greater shares of alternative fuels such as natural gas, heat and, LPG. Indeed, they have nearly fully replaced coal through the use of electricity, natural gas, and LPG. In this regard, rural households have more work ahead. In some poor rural areas that have limited access to electricity, coal continues to replace some non-commercial energy sources, such as firewood and other biomass (e.g., straw) as an important energy source for cooking and heating. These counteracting forces may explain why the direct coal use for rural residents fluctuated a bit prior to 2000. While the rural-urban gap in direct household energy use shrank, by 2010 a typical urban resident still used 50% more direct energy than did a typical rural resident. In fact, the direct energy used by urban residents rose rapidly from 2002 to 2010, and the growth showed no sign of relenting (See *Figure* 2). Rural residents showed even higher demand for direct energy use, converging on use rates of their urban counterparts. Hence, it would seem that residential direct energy use per capita should continue to rise in both urban and rural areas of China in the immediate future.

Figure 2: Per Capita Resident's Direct and Indirect Energy Requirements



3.2 Residential Indirect Energy Use

Over the course of the study period through 2010, energy use as embodied in goods and services consumed by a typical individual in a rural household experienced major changes. From 1987 to 1997, it rose at an average annual rate of 2.0%. During the subsequent five years indirect energy use per capita in a rural household decreased at an average annual rate of 5.3% to from 220 kg SCE in 1997 to 168 kg SCE in 2002. It then rose again through 2010; this time at an average annual rate of 2.1% to 199 kg SCE. From 1997 to 2002, per capita household consumption only rose 10.1%, while the average energy requirement per unit of output had decreased by 29.4%. Energy efficiency gains in production processes, changes in the consumption preferences of rural households and relative stagnant levels of rural household consumption all contributed to the annual 5.3% drop in per capita indirect energy use of rural households from 1997 to 2002.

A different story is told for urban households. Indirect energy use rose relatively steadily at an average annual rate of 2.2% during the study period, from 449 kg SCE in 1987 to 736 kg SCE in 2010. The net implication of this is that from 1987 to 2010 the gap of indirect energy use per capita between urban and rural households expanded. While a Chinese urban resident in 1987 consumed 150% more indirect energy through goods and services than her rural counterparts, by 2010 she consumed 270% more.

Urban households now consume more commercial energy indirectly than directly. During the study period, indirect energy varied somewhere between 61% to 76% of total energy used by urban households. Further they tend to consume more indirectly than do their rural compatriots. The greater purchasing power of urban households supports this phenomenon. Rural households also consumed more indirect energy than directly from 1987 to 2007. Indeed, due to rural fuel shortages, the share of indirect energy consumed by rural households rose from 71% in 1987 to 75% in 1997. The share subsequently slowly declined so that it reached 47% in 2010. This is largely because, as the supplies of energy resources loosened, the direct energy demanded by rural residents rose far more rapidly than did the use of energy in the other goods and services that they consumed.

Combining both direct and indirect energy use, households accounted for 47% of total energy use in China in 1987 and 31% in 2010. It is therefore fairly clear that it is important for China to give households a full examination when considering energy reduction options. Thus in the following we diagnose the trends behind forces that drive indirect energy use by households.

4. THE CONTRIBUTION OF DRIVERS TO HOUSEHOLD ENERGY USE

4.1 Driving Forces of Household Indirect Energy Use

Our structural decomposition analysis shows that changes in household consumption per capita ($\Delta\hat{\boldsymbol{y}}$) had been the main driving force of household indirect energy use. Increasing per capita household consumption level drove energy use to rise at an average annual rate of 5.2% during the 1987–1992 period. Its effect surged to 7.0% annually in the 1992–1997 period. It decreased gradually to 4.6% annually in the 2002–2007 period and then bounced back up to 7.8% annually in the 2007–2010 period.

Energy efficiency improvements ($\Delta\mathbf{e}$) had largely offset increments in household consumption per capita from 1987 to 2010. In fact, for 1987–1992 as well as 1997–2007, energy efficiency improvements fully offset the increments in energy use due to household consumption per capita (see *Table* 1). Indeed, energy efficiencies ($\Delta\mathbf{e}$) helped reduce households' indirect energy use by 5.3% to 7.3% annually during the 1987–1997 and 1997–2002 periods. Since 2002, they edged downward a little bit to about 7% annually.

Table 1: Average Annual Changing Rates of Driving Forces of Household Indirect Energy Use

	$\Delta\mathbf{e}$	$\Delta\mathbf{L}$	$\Delta\mathbf{H_s}$	$\Delta\hat{\boldsymbol{y}}$	$\Delta\mathbf{u}$	Δp	Total
1987-1992	-5.3%	2.1%	0.2%	5.2%	0.5%	1.5%	5.0%
1992-1997	-5.3%	-2.3%	-0.3%	6.9%	1.0%	1.1%	2.7%
1997-2002	-7.3%	-0.6%	-0.7%	7.0%	1.8%	0.8%	2.9%
2002-2007	-7.1%	1.7%	0.5%	4.6%	1.8%	0.6%	3.5%
2007-2010	-7.0%	0.5%	0.6%	7.8%	1.7%	0.5%	5.0%

Changes in the interindustry input mix ($\Delta\mathbf{L}$) and in the household consumption preferences ($\Delta\mathbf{H}_s$) lead to relatively small changes in household indirect energy use. From 1987 to 1992, changes in these two factors enhanced household indirect energy use. But from 1992 to 2002, changes in the interindustry input mix and household consumption preferences helped reduce household indirect energy use (at an average annual rate of 1.4% and 0.5%, respectively). Nevertheless since 2002 these they returned to enhancing household indirect energy use. Changes in the interindustry input mix ($\Delta\mathbf{L}$) had increased household indirect energy use by 1.7% annually in the 2002–2007 period, and its effect decreased to 0.5% annually in the 2007–2010 period. Changes in household consumption preferences ($\Delta\mathbf{H}_s$) drove up household indirect energy use by 0.5% annually in the 2002–2007 period, and its effect rose slight to 0.6% annually in the 2007–2010 period.

Population growth (Δp) and urbanization ($\Delta\mathbf{u}$) both caused household indirect energy use to rise from 1987 to 2010. Population growth moderated as the one-child law was enforced, so its effect decreased gradually from 1.5% annually in the 1987–1992 period to 0.5% in the 2007–2010 period. Meanwhile, urbanization's effect strengthened, rising from 0.5% annually from 1987 to 1992 to 1.9% annually in the 1997–2002 period. Its effect has been relatively constant since. Demographic factors, especially urbanization, had become important factors driving household indirect energy use in China. By focusing on the most recent periods (2002–2007 and 2007–2010), we further explore the contributions of demographic changes, household consumption levels and household consumption preferences by following three sections.

4.2 Demographic Changes

From 1987 to 2010, China's total population rose 0.9% annually from 1.09 billion to 1.34 billion. This growth was outpaced by the number of households, which increased 2.0% annually from 248.4 million to 367.3 million. A decrease in average household size was the clear culprit: it declined from 4.23 people in 1987 to 3.10 in 2010. Urban areas increased their share of China's total population from 25.3% in 1987 to 49.9% in 2010. Such demographic changes have manifested in household consumption levels and preferences through several different pathways. First, with rapid urbanization, the geographical expansion of large cities and newly formed polycentric urban zones has dramatically increased the demand for transportation infrastructure (Fernández, 2007). Second, due to the huge gap between urban and rural residents in energy usage per capita by households, urbanization should continue to intensify total household energy demand considerably in the foreseeable future. Third, smaller households consume more energy and resources per capita than larger ones do. Thus China's shift to smaller households would pose a serious challenge to energy conservation (Liu et al., 2003; Liu and Diamond, 2005).

4.3 Household Consumption Preferences

From 1987 to 2010, per capita annual spending by urban residents rose at an average annual rate of 7.3% from 2,946 Yuan to 15,015 Yuan (in constant 2007 prices). For rural residents, it rose 5.4% annually from 1,306 Yuan to 4,333 Yuan. The share of spending on core necessities—food and clothing—by all households, decreased from around 54% in 1987 to about 34% in 2007. Meanwhile, the share of household expenditures on health care, transportation and communication services increased from 1987 to 2010. Chinese households clearly pursued a more comfortable style of living that required a developed service sector.

Households' lifestyle changes affected their pattern of indirect energy consumption. Changes in household consumption preferences ($\mathbf{\Delta H}_s$) helped reduced household indirect energy use from 1992 to 2002 (see *Table* 1). Rising spending shares on services partly explains why the changes in households' consumption preferences reduced indirect energy use from 1992 to 2002. For both urban and rural households, the share of household spending on *Finance, Insurance & Real State* and *Commercial, Catering, Hotel & Other Services* rose significantly from 1992 to 2002, while the share of household spending on *Agriculture* decreased largely during the same period.

Table 2: Per Capita Household Indirect Energy Use in China from 2002 to 2010

Sector	**Urban**			**Rural**		
	2002	2010	02-10	2002	2010	02-10
Agriculture	32.9	37.8	4.8	15.3	18.4	3.1
Mining	53.1	45.2	-8.0	13.5	12.1	-1.3
Food & Tobacco products	39.6	42.0	2.4	13.2	15.5	2.4
Textile Products	22.7	26.3	3.6	4.4	6.8	2.4
Sawmill, Paper, Printing & Recreation Goods	19.4	19.4	0.1	4.4	5.1	0.7
Petro-, Chemical & Non-metal Mineral Products	180.1	187.0	6.8	47.9	48.5	0.6
Metal Smelting, Pressing & Metal Products	63.0	89.7	26.7	14.8	21.2	6.4
Machinery & Transportation Equipment	11.0	13.3	2.3	2.8	2.9	0.1
Electric & Electronic Products	5.9	7.4	1.5	1.1	1.9	0.8
Other Manufacturing	7.4	5.4	-1.9	1.4	1.3	-0.1
Utilities	88.5	89.5	1.0	18.0	22.1	4.0
Construction	1.0	1.7	0.7	0.3	0.1	-0.2
Transportation & Wholesale	63.3	76.6	13.3	16.1	20.6	4.6
Postal, Information & Software Services	4.4	7.7	3.3	0.9	1.9	1.1
Finance, Insurance & Real Estate	13.5	26.7	13.2	5.9	6.2	0.3
Commercial, Catering & Hotel	22.7	31.3	8.6	4.9	8.5	3.6
Other Service	17.8	28.5	10.7	3.3	5.7	2.4
Total	646.2	735.6	89.4	168.0	199.0	31.0

But changes in household consumption preferences ($\mathbf{\Delta H}_s$) increased household indirect energy use at an average annual rate of 0.5% from 2002 to 2010. During this period, *Metal Smelting, Pressing and Metal Products* accounted for 30% of the rise in per capita indirect annual energy use of urban residents and 21% for rural residents. Clearly, households' rising consumption of living space and ownership of home appliances, which are discussed in a following section, explains much of such indirect use. *Utilities* accounted for 13% of the rise in per capita indirect energy use of rural households and about 1% for urban households. As mentioned before, the contribution of electricity to rural households' direct energy use increased from 38% in 2002 to 58% in 2010. Rural households' rising consumption of electricity partly explains the rapid rise in indirect energy use among rural households. From 2002 to 2010, service sectors accounted for about 55% of the rise in indirect energy use by households in urban China and 38% in rural China. Most of increase was due to rises in the consumption of services by energy-intensive *Transportation and Wholesale Service* sector and *Commercial, Catering, and Hotel* sector, accounting for 15% and 10% of per capita household indirect energy use of both rural and urban households, respectively. This rising indirect energy use of the *Transportation and Wholesale Service* sector reflected the increased personal mobility of both rural and urban households. Urban households' indirect energy spent on the *Finance, Insurance, & Real Estate Sector* nearly doubled from 13.5 kg SCE in 2002 to 26.7 kg SCE in 2010. This accounted for 15% of the rise in indirect energy use by urban households. Meanwhile, rural household's indirect energy use via *Finance, Insurance, & Real Estate Sector* increased by just 0.3 kg SCE from 2002 to 2010.

Household indirect energy use per capita of products from the *Petroleum, Chemical and Non-Chemical Mineral* sector rose 6.5 kg SCE for urban residents from 2002 to 2010. A large part of this increment was undoubtedly caused by the rising use of privately owned cars, which concentrated in urban China. The *Food and Tobacco*

Products sector accounted for 5% of increment of per capita indirect energy use of urban residents and 10% of the rural residents. This increment likely reflects the increasing demand for processed food, particularly meat, especially in rural China. Fundamentally, recent trends in indirect energy use suggest that households have been increasingly shifting their consumption toward more energy- and material-intensive goods and services.

4.4 Household Consumption Level

With rapid economic growth, China's household incomes have increased steadily in both urban and rural areas. Average income per capita in constant 2007 prices rose at an average annual rate of 7.5% from 3,400 Yuan in 1987 to 17,682 Yuan in 2010 in urban China but just 5.5% annually from 1,570 Yuan to 5,381 Yuan in rural China. Clearly, huge urban and rural disparities in average income per capita persist. In 2010, average income per capita in urban China was 229% higher than in rural China. With rapid income growth, Chinese households experienced significant lifestyle changes that led them to demand more energy both directly and indirectly. Chinese lifestyles had changed from fulfilling basic needs toward pursuing both higher living standards and higher qualities of life. Golley and Meng (2012) found that both China's per capita indirect energy usage and carbon emissions increase over all income ranges.

As household incomes continue to rise, Chinese households are highly likely to adopt more energy-intensive and carbon-intensive lifestyles. In the following, we demonstrate the lifestyle changes in China by examining four aspects: housing, ownership of home appliances, space heating and cooling, and personal mobility.

4.4.1 Housing

Since the early 1980s, China's housing reform successfully transformed urban China's housing from a public-sector dominated system to a market-oriented housing industry (Deng et al., 2011). As a result, urban housing shortages have greatly diminished, and urban residents' living conditions have greatly improved. Average living space per capita expanded radically from 1987 to 2010, from 12.7 m^2 to 31.6 m^2 in urban China and from 16 m^2 to 34.1 m^2 in rural China. In rural areas, homes were rebuilt or expanded, using more material- and energy-intensive building materials in the process. The share of brick and wood structure buildings among new rural residential housing declined from 65% in 1987 to 26% in 2010, and the share of reinforced steel and concrete rose from 8% to 70%. The ability to improve living conditions drove China's construction boom. From late the 1990s to 2004, China added about 1.5 to 2.0 billion m^2 of space annually to its residential stock. This trend is expected to continue through 2020 (Fernández, 2007). Residences are expected to account for about 80% of all new constructed spaces in the near term.

4.4.2 Home Appliances

Increasing income and larger residences room allow Chinese households to buy more home appliances. During the past three decades, increased access to the electric grid facilitated the market penetration of home appliances in both urban and rural China. From 1985 to 2010, the ownership rates of durable goods increased rapidly everywhere (see *Table* 3 and 4). Color televisions have saturated homes in both urban and rural China: In fact, many households have more than one. Household ownership of washing machines, refrigerators, and air conditioners is close to full saturation in urban China. In rural area, ownership rates of these appliances are much lower. In 2010, about 112 air conditioners existed per every 100 urban households, only 16 were owned per every 100 rural households. Compared with traditional electrical appliances, information technology such as computers and mobile phones penetrated Chinese households more rapidly during the past decade. In 2000, only a small share of Chinese households had mobile phone. Now, mobile phones dominate communications even in rural China. From 2000 to 2010, ownership of computers rose from 9.7 to 71.2 per 100 households in urban China and from 0.5 to 10.4 per 100 rural households. Previously a luxury, home appliances became every-day items in Chinese households. The collective surge in home appliance ownership has driven household electricity usage (Glicksman et al., 2001). Continued enhancements in the purchase and use of home appliances will place upward pressure on per capita electricity demand in China.

Table 3: Average Durable Goods Ownership per 100 Families in Urban China

Year	**1985**	**1990**	**1995**	**2000**	**2005**	**2010**
Color television	17.2	59.0	89.8	116.6	134.8	137.4
Washing machine	48.3	78.4	89.0	90.5	95.5	96.9
Refrigerator	6.6	42.3	66.2	80.1	90.7	96.6
Air conditioner	-	0.3	8.1	30.8	80.7	112.1
Mobile phone	-	-	-	19.5	137.0	188.9
Personal computer	-	-	-	9.7	41.5	71.2
Car	-	-	-	0.5	3.4	13.1

Table 4: Average Durable Goods Ownership per 100 Families in Rural China

Year	1985	1990	1995	2000	2005	2010
Color television	0.8	4.7	16.9	48.7	84.1	111.8
Washing machine	1.9	9.1	16.9	28.6	40.2	57.3
Refrigerator	0.1	1.2	5.2	12.3	20.1	45.2
Air conditioner	-	-	0.2	1.3	6.4	16.0
Mobile phone	-	-	-	4.3	50.2	136.5
Personal computer	-	-	-	0.5	2.1	10.4
Motorcycle	-	0.9	4.9	21.9	40.7	59.0

4.4.3 Heating and Cooling

Energy used in buildings accounted for 27.8% of all energy used in China in 1999. Continued urbanization should cause this share to grow to about 35% by 2030, a share more typical of developed countries (Zhu and Lin, 2004). Energy for space heating and cooling accounted for most residential energy use. As a spacious country, China has different needs for heating and cooling across its regions. In the northern heating zone, urban households have access to the central heating system.[4] The transition zone, with cold winters and hot summers, demands a significant amount of space heating in winter and cooling in summer. In the southern zone, the demand for cooling is significant (Glicksman et al., 2001). As Chinese residents getting richer, households throughout the nation will demand ever more comfortable indoor temperatures. Presently, highly subsidized, municipal central heating is available only to urban residents in the northern heating zones. Households in transition zones, which maintain 37% of China's residential floor area, are soon expected to cause a spike in the demand for space heating (China Green Buildings Blog, 2009). The transition zone's households use heater or air

[4] During China's planned regime of 1950 to 1980, China had established its central heating system. China's heating line is defined by the Huai River and Qinling Mountain. Places above the line is defined as the northern heating zone and can enjoy the central heating system with subsidies from the government, whereas no central heating would be provided to places below the heating line. Homes in the non-heating zone should install their own heating facilities.

conditioners sparingly in the winter, and use air conditioners in hot, humid weather. In 2004, more than 60% of cities in China experienced an electricity shortage during summer peaks when air conditioning was in highest demand (Aldhous, 2005). Clearly more potential for electricity exists for home heating and cooling in urban China. From 2000 to 2010, household ownership of air conditioners rose from 30.8 to 112.1 units per 100 households in urban China and from 1.3 to 16.0 units per 100 rural households. As the electric grid and the ownership of both air conditioners and home heaters penetrate rural China, the demand for electricity will continue to cause electricity demand in China to surge.

Most buildings in China are not very energy efficient. Although China's Ministry of Construction has been actively engaged in the design and dissemination of energy conservation building codes, enforcement of the codes has remained fairly lax. That is, many new Chinese buildings do not meet energy standards established by the Ministry of Construction. In north China, residential space built after the implementation of energy efficiency standards still manage to consume 50% to 100% more energy directly compared with buildings in similar climate zones of Western Europe or North America. This is despite the fact that China's new buildings provide far less thermal comfort (Li and Yao, 2009). In most of China's heating zone, heating is billed based on floor space rather than on actual usage. In many existing buildings of the heating zone, households have little control over their housing temperature and heat usage. Perhaps worst of all, residential heating is largely subsidized by the national and local government in the heating zone. So incentives are perverse or absent. On the production side, central heating systems are not very energy efficient, especially from distributional perspectives. As a result, low building energy efficiency and heating provision system have lead to enormous energy inefficiencies in China.

Starting in 2007, China implemented an energy-efficiency program to retrofit existing residential buildings in its northern heating zone with insulation, door and window seals, and heating systems with improved fuel-efficiency (Yu, Evans, and Shi, 2014). It includes the installation of heat metering in individual dwelling units to measure achievements in building energy efficiency (Lu et al., 2014). China plans to retrofit 35% of old existing buildings in the northern heating zone at the end of the 2015 and expects to finish retrofitting all existing buildings by 2020 (Ministry of Finance, 2011).

4.4.4 Personal Mobility

Over the past three decades, personal mobility in China has risen rapidly. From 1987 to 2010, total motorized passenger-kilometers increased at an average annual rate of 7.4% from 541 billion kilometer (km) to 2,789 billion km. Motorized km per capita more than tripled, rising from 495 km/year in 1987 to 2,080 km/year in 2010. The use of civil aviation and highways increased even more rapidly. Rising disposable income has boosted the rapid penetration of cars among Chinese households. Per household private car ownership in urban China surged from 0.50 units per 100 households in 2000 to 13.07 units per 100 urban households in 2010. Through 2013 it jumped to 21.54 units per 100 households. Car ownership in China has become a sign of wealth and higher social status. But it also has lead to skyrocketing demand for petroleum products. In China, raw petroleum is largely imported. Imports account for about 70% of the nation's total oil consumption in 2012 (NBS, 2014). Rising demand for petroleum-based fuel are likely to cause an energy-security crisis for China. Assuming the rising trend of car ownership continues, Han and Hayashi (2008) estimate that the emissions of CO_2, CH_4, CO, NMVOC, NOx, and SO_2 produced by cars in 2020 will be 16 to 20 times greater than their 2000 levels. Consequently, China should be very concerned about the rising use of private vehicles and be firmer in enforcing policies pertaining to fuel consumption.

With increasing household income, more and more households in both rural and urban areas are climbing the consumption ladder. Lifestyle changes lead Chinese households to demand more energy both directly and indirectly. Households' higher demand for housing has largely increased indirect energy use through *Construction* sector, *Metal Smelting, Pressing & Metal Products* sector, and a range of related sectors. The popularization of home appliances has boost energy use both directly through the use of electricity as well as indirectly through the production of these appliances. Rising demand of personal mobility has also largely increase energy use directly through the use of petrol and indirectly through the upstream production process of vehicles, the construction process of transportation infrastructures and so on. Chinese households' rising demand for more convenient life (with improved personal mobility, interior climate control, and time-saving appliances and goods) is likely to drive household consumption to become even more energy-intensive in the future.

5. Conclusions

Chinese households' energy use had risen 146% from 409 Mtce in 1987 to 1005 Mtce in 2010. Per capita household energy use rose from 253 kg SCE in 1987 to 425 kg SCE in 2010 for rural households and from 731 kg SCE to 1075 kg SCE for urban households. The gap in energy use between urban and rural households has risen too. Moreover, Chinese households severely lag equivalents in Japan and the United States in their energy consumption. The speed with which Chinese household are increasing their living spaces, electric appliance ownership, their demands for heating and cooling, and personal mobility displays a propensity for energy consumption that is more Western styled. Such lifestyle changes amplify energy use by inducing changes in China's production structure. Since 2002, changes in interindustry input mix and household consumption preferences have elevated household indirect energy use. China's economy has shifted toward more energy-intensive sectors like *Primary Iron and Steel Manufacturing*. Households have been increasingly shifting their consumption towards more energy- and material-intensive goods. Fortunately, industrial energy efficiency gains have largely offset household consumption rises. Meanwhile, capital investment, which could enable efficiency gains, is waning.

Since China's household energy consumption is now compared to western standards, its potential for growth looms large on the horizon. The potential for energy use by Chinese rural households is particularly high. In this vein, a focus on household energy consumption is paramount in any policy developments or further research on future carbon emissions in China. Our research suggests some key policy insights as well.

First, housing is a prime driver of household energy use. Buildings with low energy efficiency in China have lead to the waste of much energy. The enforcement of energy conservation through building codes is fairly low in China. China's government must play a stronger role in the regulation, and more importantly, the enforcement of such codes. For existing building stock, Glicksman et al. (2001) suggest increasing insulation levels in walls and roofs, as well as installing double glass windows as a means of improving energy efficiency. Since buildings last for decades, renovations of this sort will pay back via energy savings during their lifecycle. The Chinese government should deliver this sort of information to its citizens and provide incentives, such as low-interest loans, subsidies, or information counseling to homeowners. The combined actions suggested above could improve the overall energy efficiency of China's residential building stock.

Second, Chinese households' increasing demand for thermal comfort has induced more energy use both directly and indirectly. In the northern heating zone, highly subsidized heating undermine producers' and consumers' incentives to save energy. Thus, government should adjust the price of heating to better reflect real costs to more households. In doing so, China could also consider social equity for a subset of low-income households. Current billing systems based on the amount of living space does not always actually reflect the real heating consumption. In the 11^{th} Five-Year Plan period (2005-2010), China retrofitted 0.15 billion m^2 of existing residential buildings with thermostats in northern heating zone (Zhao et al., 2009). Future expansion of this program in the northern heating zone could enable a market of central heating by billing households for the actual amount of heat that they consume. Pricing heat at something at or close to the costs underwritten by the government to produce it could improve the overall energy efficiency of housing heating in the northern heating zone.

Third, fuel substitution significantly improved China households' indoor air quality. Still, coal remains the dominant resource for generating electricity and central heating (Aldhous, 2005). Rising power and space heating demand is likely to cause coal demand to rise. China's continued reliance on coal threatens to worsen the already notorious air quality in many of its cities. Thus, China should further encourage renewable energy and promote clean-coal technologies in power generation. Also, China should gradually switch from coal to more clean and efficient gas for space heating to help clear the wintertime air.

Fourth, Chinese households "moved up" the consumption ladder as their income increased. China's newly formed middle class has been emulating energy-addicted Western lifestyle with the purchase of cars, bigger homes, and more labor-saving appliances. Rural households have been lagging their urban counterparts. Still, this also means they have more potential to increase energy demand if they continue a desire to emulate their urban counterparts. According to China's New Urbanization Plan (2014 - 2020), the share of urban population in China is expected to rise to 60% in 2020. Urbanization is expected to narrow the urban-rural income gap and provide large sources of domestic demand and services. With increasing urbanization and income-induced lifestyle change, household energy consumption has great potential to rise for many years to come.

Last, but not the least, China is now encouraging private consumption to boost its economy growth. In the *Report on the Work of the Government*, Premier Li Keqiang (2015) announced that China plans to raise consumer spending on education, culture, sports, and tourism and to give impetus to green consumption. Thus, guiding Chinese residents' lifestyles toward greener consumption will be a critical strategy for future energy conservation in China. Green consumption requires the united effort of government, households, and civil society. The government should take an active, central role in promoting green consumption by implementing regulations, like stricter building codes and energy efficiency standards for electric appliances. The Chinese government should also coordinate cross-sector policies that may have potential environmental impacts on household decisions (e.g., land-use, infrastructure investment on public transit, and renewable energy technologies) to give consumers a stronger and more consistent set of signals and incentives to engage in green consumption. Households' demand for environmentally green products will concomitantly stimulate the supply of these products. Thus, China should enhance credibility and independence of China's green product certification system. If eco-labeling of buildings and home appliances and public awareness campaigns in energy conservation were highly promoted in China, households would become more aware of how to attain a more sustainable lifestyle. China also needs to become a civil society by encouraging NGOs to become information brokers for both corporations and households.

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