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Characteristics of residential energy consumption in China: Findings from a household survey

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HIGHLIGHTS

- We develop the first comprehensive survey of residential energy consumption in China.
- A typical Chinese household in 2012 consumed 1426 kilograms coal equivalent.
- Space heating accounts for half of energy demand.
- A large rural–urban gap exists in terms of energy sources and end-use activities.
- Results reveal challenges and opportunities for China's energy policy.

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ABSTRACT

A comprehensive survey of 1450 households in 26 Chinese provinces was undertaken in 2012 to identify the characteristics and potential driving forces of residential energy consumption in China. The survey covers six areas: household characteristics, dwelling characteristics, kitchen and home appliances, space heating and cooling, residential transportation, and electricity billing, metering, and pricing options. The results show that a typical Chinese household in 2012 consumed 1426 kilograms standard coal equivalent, which is approximately 44 percent of the 2009 level in the United States and 38 percent of the 2008 level in the EU-27. District heating, natural gas, and electricity are three major residential energy sources, while space heating, cooking, and water heating are three major end-use activities. Moreover, the results suggest a large urban–rural gap in terms of energy sources and purpose of usage. Commercial energy is used mainly for space heating in urban areas, while biomass dominates mainly for cooking purpose in rural areas. The survey results can help decision makers and scholars identify energy conservation opportunities, and evaluate the effectiveness of energy policies.

1. Introduction

With accelerating urbanization and rising income levels in China, residential energy consumption has grown rapidly over the last two decades, with an annual growth rate of 8 percent. The growth in demand for electricity, in particular, is even higher, with an annual average growth rate of 12.35 percent (NBS, 2012). This rapid increase mirrors the growth of major durable consumer goods, such as air conditioners, computers, shower heaters, and microwave ovens. In the near future of 2020, with 60 percent of the population expected to live in cities, residential energy consumption is likely to continue its rapid growth. The strong energy demand, on one hand, reflects the improvement of people's quality of life and the nation's development level (Niu et al., 2012). On the other hand, it may conflict with China's efforts toward energy conservation and greenhouse gas emissions abatement. As part of its national low-carbon plan, China is considering setting a cap on energy use (Reuters, 2011). Therefore, it is essential for decision makers and the public to understand the patterns, determinants, and implications of households' demand for energy and its consequences for climate change.

Surveys of household residential energy are conducted regularly by government agencies in many developed countries and some developing countries and have become a fundamental source of energy data. For example, the US Energy Information Administration started to survey US households' energy use in 1978, based on which several informative studies have been conducted. A similar and comprehensive survey of its kind, however, does not exist in China. Currently, only partial information about residential energy can be gleaned from the literature and national statistics. For example, Wang and Feng (2003)

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investigate the utilization ratio of energy as well as serious pollution caused by energy consumption in the Jiangsu province. Based on 200 randomly selected households in Xi'an, the capital of the Shaanxi province, Tonooka et al. (2006) clarify the status of energy consumption, and estimate emissions of greenhouse gases and air pollution from the residential sector. Feng et al. (2010) investigate the barriers to energy efficiency at the residential sector and explore patterns of household electricity consumption in Liaoning province. Zhou and Teng (2013) use annual household survey data from Sichuan province to estimate the income and price elasticities of residential electricity demand from 2007 to 2009. While all these local studies focus on residential household energy consumption, they do not capture regional differences in energy use.

To fill this gap, we developed a China Residential Energy Consumption Survey (CRECS) questionnaire and used it in 26 provinces of China. The survey is heavily based on the US Department of Energy and Energy Information Administration Residential Energy Consumption Survey. It covers six areas: household demographics, dwelling characteristics, household appliances, space heating and cooling, patterns of private transportation, and electricity billing, metering, and pricing options.

The survey makes three important contributions. First, to the best of our knowledge, this is the first attempt to develop a comprehensive survey and provide an overview of residential energy consumption in China. The information revealed from CRECS will inform policy makers and the public about changes in energy usage patterns in Chinese households. This also will help to develop more credible projections of energy demand through a better understanding of crucial determinants, such as significant changes in age structure, accelerating urbanization, and household income growth.

Second, our study provides the basis for evaluating the effectiveness of various efforts in China to promote energy efficiency, such as programs promoting efficient lighting and energy efficiency product labeling. The comprehensive data allows us to examine the degree to which households are actually participating in these programs and their attitudes and behavior in practice at a national level.

Third, surveys of this kind will form an important database for evaluating China's residential energy conservation policy. China implemented an increasing block electricity tariff on July 1, 2012, and will implement a progressive water pricing scheme before 2015 (Xinhua, 2012) and multitier household natural gas pricing by the end of 2015 (Reuters, 2014). To evaluate the effectiveness of these policies and understand how households respond to these pricing schemes will require detailed electricity and natural gas consumption and price data at a micro level.

The main objective of this survey is to understand the characteristics and possible driving forces of residential energy consumption and therefore identify the underlying challenges, opportunities, and possible policy measures. We have several major findings. First, a typical household consumed 1426 kgce in 2012 and annual per capita energy use was 612 kgce.[1] District heating[2] is the major fuel source, followed by natural gas and electricity. In both urban and rural households, most energy is used for space heating, followed by cooking and water heating.

Second, large urban–rural gaps exist in terms of fuel choice and end-use activities. An urban household consumed 1.4 times more energy than a rural household. Commercial energy is widely used in urban areas, while biomass still dominates in rural areas.

Third, household energy consumption in China is still lower than in developed countries. However, driven by a rich culinary culture, China's households consume 23 percent of their energy for cooking, which is generally higher than in other countries.

The remainder of this paper is organized as follows. In Section 2, we provide a detailed description of the survey. In Section 3, we present the main statistical results. Our energy flow chart analysis is described in Section 4. We discuss policy implications in our concluding remarks in Section 5.

2. Description of the survey

The CRECS survey was administrated by the Department of Energy Economics at Renmin University of China during February 2013. The questionnaire was designed with the aid of a few pilots and on the basis of the US Residential Energy Consumption Survey 2009. The questionnaire covered six main areas with 324 questions in total: household demographics, dwelling characteristics, household appliances, space heating and cooling, patterns of private transportation, and electricity billing, metering, and pricing options. To have a clear picture of household energy mix, for each section we collected detailed energy relevant information, such as appliance type, frequency and duration of appliance use, different types of energy costs, and electricity bill information.

In December 2012, approximately 120 undergraduate and graduate students from Renmin University were recruited to administer the CRECS survey in their hometowns, representing 26 provinces, where they were going to spend their winter holiday in February 2013.[3] To guarantee the survey quality, all interviewers were required to attend a half-day training lecture. During the lecture they received intensive training regarding properly understanding each question, conducting interviews, and using smart phones or GPS services to locate household addresses.

Households that met four criteria were invited to participate in the survey. First, a household had to be able to provide its electricity bills or electricity consumption records for 2012. Second, a household had to have used energy only for consumption purposes, rather than for production purposes. Third, the respondents must have lived in their home for more than six months in 2012. Fourth, the household had to be the only one from a defined community to participate. To incentivize participation, each household would get a mobile phone prepaid card worth 50 RMB as a payoff after they finished the survey. A total of 1640 households[4] were initially invited to take the survey, while 1542 eventually enrolled in the study (a high response rate of 94 percent). After validity and consistency checks, 1450 total observations remained for the final analysis, with 80 percent from urban areas and 20 percent from rural areas.[5]

[1] Standard coal is a metric widely used in China. The heat value of 1 kilogram standard coal is 29,307 kJ, or 7000 kcal.

[2] District heating is a system for distributing heat for centralized residential and commercial buildings. Compared with traditional individual heating system, district heating systems consume less energy and emit less pollution (Keçebaş et al., 2013). Fuels used for various district heating systems include natural gas and coal in China. However, it is difficult to distinguish the source. Therefore, we treat district heating as one particular fuel source in our study.

[3] The distribution of the samples among province is based on household population in the 6th National Population Census in 2010. The official statistics show that the percentage of the population in eastern, middle, and western China is 40.61 percent, 31.7 percent, and 27.69 percent, respectively (NBS, 2010). Our samples' geographic distribution for eastern, middle, and western provinces is 38.28 percent, 43.24 percent, and 18.48 percent, respectively.

[4] Since this is the first attempt to conduct a comprehensive household energy survey, we focused more on questionnaire and questions design than on survey protocol. The interviewers were therefore allowed to randomly contact the families in their social networks and invite them for the survey, conditional on these families meeting the four criteria discussed above.

[5] According to the National Bureau of Statistics' definition, the urban area includes city and town (NBS (National Bureau of Statistics), 2006). There are 64 percent surveyed household in cities, 16 percent in towns and 20 percent in rural areas. To facilitate the comparison, we combine the city and town groups into the urban category.

3. Data description

3.1. Household characteristics

Table 1 provides brief profiles of the household characteristics of the surveyed observations. The average household size of our sample is 2.65 persons, with an average age of 40.6 years for all household members. Compared with the official National Bureau of Statistics number shown in the three right columns in Table 1, we find that our sample registers a smaller household size and lower male percentage. Among all household members, 65.3 percent are fully or partly employed. The urban–rural employment rate in our surveyed household is similar, while the urban–rural employment rate gap according to the National Bureau of Statistics is relatively large.

The education level for urban and rural residents is extremely unbalanced. On average, urban residents have 11.2 years of schooling, much higher than rural residents' 6.8 years. This is consistent with the official numbers, in which years of school for urban and rural residents are 10.4 and 7.6 years, respectively.

The average annual income of the surveyed household is 97.8 thousand Yuan, in which the urban household's income (109.8 thousand Yuan) is 2.2 times as much as that of a rural household (49 thousand Yuan). The average annual expenditure of the surveyed household is 52.8 thousand Yuan, in which the urban household's expenditure (55 thousand Yuan) is slightly higher than that of the rural household (43.3 thousand Yuan). For urban residents, our surveyed household seems to earn more and spend less than the official records, but, for rural residents, our income and expenditure data is slightly higher than that of the National Bureau of Statistics.

3.2. Dwelling characteristics

More than 80 percent of households live in apartments with less than six floors, built after 1998. As for ownership, 93 percent of dwellings are privately owned. The average gross area and net area are 117.6 meters (m^2) and 103.7 m^2, respectively. As shown in the last row in Table 1, urban residents occupy a smaller net dwelling area than rural residents, and the average of each is close to the official statistic. In general, a typical Chinese household owns 1.1 living rooms, 2.3 bedrooms and 0.4 study rooms. The average use area of these three rooms is 25.6 m^2, 16.6 m^2, and 14.8 m^2, respectively. More than half the living rooms and bedrooms are south facing. Approximately 82 percent of households are equipped with plastic or aluminum window frames. One-third of families installed double glazing.

On average, the surveyed household had lived in their present dwelling for 11 years at the end of 2012. During this period, 27 percent had replaced windows and 25 percent had sealed windows or doors. Only 7 percent and 2.5 percent, respectively, had insulated the external walls or heating pipes. The average reported daily maximum hours of sunlight are 5.7 h in winter and 7.1 h in summer.

3.3. Kitchen and home appliances

The rich Chinese culinary culture also is confirmed by the data, as shown in Table 2. In an average household, 1.5 stoves, 0.76 rice cookers, 0.41 microwave ovens, and 0.36 pressures cookers are used for cooking, as well as other cooking devices. The stoves mainly use natural gas (37 percent), electricity (26 percent), and liquefied petroleum gas (LPG, 21 percent) as fuel, while electricity dominates other types of kitchen facilities. The major purposes for such cooking devices are daily cooking and boiling drinking water.

Table 2 also displays an overview of home appliances in the surveyed households. The number of refrigerators, washing machines, televisions, and computers owned per 100 households is 89, 91, 120 and 89, respectively. This high penetration rate indicates the improved life quality associated with the popularity of home appliances. In addition to general questions about these appliances and their usage, we designed some questions related to energy policy. The responses show that 61 percent of refrigerators and 44 percent of washing machines in surveyed households are efficient, with grade 1–3 energy efficiency labels. By contrast, the percentage of efficient televisions (21 percent) and computers (15 percent) is relatively low.[6]

This energy-efficiency information is also an important parameter for estimating the associated energy consumption. Approximately 14–21 percent of households had obtained some subsidies when purchasing traditional durable appliances and about one-third of respondents agreed that subsidy policies have affected their purchase decisions.[7]

3.4. Space heating and cooling

Space heating and cooling patterns show a vast disparity in different climate zones. Since the 1950s, the urban areas in northern China have been supplied with central heating systems, but these were not available in southern China. As shown in Table 3, 40 percent of surveyed households use central heating systems. The heating sources for these systems are 63 percent from the municipal network and 21 percent from a local boiler. The average heating season is 3.9 months, during which heating is available for the whole day. Because individual heating meters are not widely used, 92 percent of centrally heated households pay in accordance with the heated area or the dwelling's construction area. Around one-quarter of users receive subsidies from their employers. In contrast, another 40 percent of households who cannot access the central heating system have to resort to distributed heating. Among the different devices, 35 percent are portable electric heaters, 28 percent are heatable air conditioners, and 28 percent are heating stoves.

This diversification of heating devices leads to different fuel choices. Around 67 percent of households use electricity and 29 percent use wood or coal as heating fuel. On average, the households without central heating operate heating devices for 4.3 h per day and use them for 2.1 months. Their heating expenditure is based on fuel cost and heating time. None of them can get subsidies.

An air conditioner is an important home appliance for space cooling. Nearly all units in the surveyed households are split style and heatable. Nearly half are air conditioners with inverter technology. Fans are more common than air conditioners in terms of usage frequency and duration of use, partly due to their relatively cheap cost and durability.

With the improvement of living standards, the water heater also has become a necessity for daily use. On average, more than half of the surveyed households are equipped with a 75.4 l water tank, while the rest have instant water heaters. Around 42 percent of users do not unplug the water heater. The major fuel is electricity (43 percent), followed by gas fuels (31 percent). Solar water heaters occupy a one-quarter share of the surveyed samples,

[6] The energy-efficiency label in China has five categories, where 1 is the most efficient, 3 is the industry average level, and 5 is the lowest market admission standard. Our questionnaire prompted the investigator to check the labeled level for each home appliance.

[7] Currently, China offers three types of subsidies for home appliances: for trading in old appliances, purchasing energy-efficient products, and purchasing home appliances for use in rural homes.

Table 1
Profile of household characteristics.

Variables	Unit	CRECS-2012			NBS 2013[a]		
		Total	Urban	Rural	Total	Urban	Rural
Number of observations		1450	1167	283	–	–	–
Household size	Number of persons	2.65 (1.06)	2.57 (0.96)	2.95 (1.37)	3.02[b]	2.86	3.88
Male percentage	%	48.5	48.2	49.5	51.3[b]	50.6[b]	51.5[b]
Average age	Years	40.6 (17.99)	40.4 (17.30)	41.4 (20.22)	–	–	–
Proportion of employment per household	%	65.3	64.9	66.2	–	52.1	71.1
Schooling year	Years	10.2 (4.68)	11.2 (4.46)	6.8 (3.70)	8.8[b]	10.4[b]	7.6[b]
Income	10,000 Yuan	9.78 (15.70)	10.98 (17.16)	4.90 (4.98)	–	7.71	4.26
Expenditure	10,000 Yuan	5.28 (10.56)	5.50 (5.44)	4.33 (21.00)	–	6.39	3.73
Dwelling area	m^2	103.73 (48.68)	96.15 (41.77)	134.98 (61.19)	–	94.1	143.9

Notes: The mean value and standard deviation in parenthesis for each variable is displayed. CRECS=China Residential Energy Consumption Survey; NBS=National Bureau of Statistics; m^2=square meters.

[a] NBS, China Statistical Yearbook (2013).
[b] NBS, China Population and Employment Statistical Yearbook (2012).

Table 2
Profile of kitchen devices and home appliances.

	Kitchen device		**Home appliance**			
	Stove	Other kitchen devices	Refrigerator	Washing machine	Television	Computer
Number of goods owned per 100 households (unit)	150	76 (rice cooker) 41 (microwave) 36 (pressure cooker)	89	91	120	89
Capacity (size)	1196.5 W (406.15)	920.6 W (343.12)	155.3 l (54.37)	4.2 kg (0.99)	29.0 in. (13.07)	–
Fuel mix (%)	Natural gas—37 electricity—26 LPG—21	Electricity—83 natural gas—8 LPG—6	–	–	–	–
Daily frequency (times)	2.0 (1.00)	1.1 (0.98)	–	0.5 (0.48)	–	–
Daily usage hour (h)	0.5 (0.33)	0.5 (1.15)	24	0.8 (0.42)	3.3 (2.35)	3.0 (2.55)
Age (years)	–	–	12.6 (3.60)	6.7 (5.23)	6.5 (5.37)	4.3 (4.24)
Percentage with grade 1–3 energy efficiency label (%)	–	–	61	44	21	15
Percentage with purchase subsidy (%)	–	–	21	14	16	2.7
Subsidy will affect purchase (%)	–	–	34	33	33	28

Note: The mean value and standard deviation in parenthesis for each variable is displayed. W=watts; l=liters; kg=kilograms; LPG=liquefied petroleum gas.

Table 3
Profile of heating and cooling.

	Space heating		**Space cooling**		**Water heater**
	Central heating	Distributed heating	A/C	Fan	
Type (%)	City network—63 local boiler—21	E-heater—35 A/C—28 heating stove—28	Split—91 inverter—49 heated—85	Ceiling—29 desk—33 floor—36	Storage—56 tankless—44
Number of goods owned per 100 household (unit)	–	–	113	130	4
Capacity (size)	–	–	928.9 W (336.70)	–	75.4 l (46.82)
Fuel mix (%)	–	Electricity—67 wood/coal—29	–	–	Electricity—43 gas/LNG—31 solar—25
Frequency (month/year)	3.9 (1.10)	2.1 (1.19)	1.6 (0.99)	2.2 (1.08)	12
Daily usage hour (h)	24	4.3 (2.69)	3.8 (2.56)	4.0 (2.39)	0.5 (0.36)
Age (year)	–	–	5.8 (4.08)	8.0 (6.12)	5.0 (4.07)
Percentage with grade 1–3 energy efficiency label (%)	–	–	45	–	34
Percentage with purchase subsidy (%)	–	–	10	1	8
Subsidy will affect purchase (%)	–	–	29	24	31

Note: The mean value and standard deviation in parenthesis for each variable is displayed. W=watts; l=liters; LPG=liquefied petroleum gas.

Table 4
Profile of private transportation.

	Automobile	Electric bicycle	Motorcycle
Type (%)	Passenger cars—84 Van—5 SUV—5	Battery portable—85	
Number of goods owned per 100 household (unit)	39.5	27	23
Age (year)	3.6 (2.85)	3.1 (2.72)	6.0 (4.39)
Engine capacity	1.8 l (0.58)	–	115 cm^3 (38.50)
Travel distance (km)	10,686 (year 2012) 51,569 (total)	–	–
Daily usage hour (h)	–	0.9 (0.62)	1.2 (0.93)
Fuel mix (%)	Gasoline—91 diesel—5 hybrid—3	Electricity—100	Gasoline—100
Fuel efficiency (l/100 km)	7.74 (nominal) 9.2 (actual)	–	–
Fuel cost (Yuan/l)	7.38 (0.95)	–	–
Maintain frequency (time/year)	2.3 (1.97)	–	–
Private ownership rate (%)	93	–	–
Fuel self-pay proportion (%)	74	–	–

Note: The mean value and standard deviation in parenthesis for each variable is displayed. l=liters; cm^3=cubic centimeters; km=kilometer.

indicating that this energy-saving product has been widely adopted.

3.5. Residential transportation

On average, the distance from a typical household to the nearest city or town center, shopping mall or market, and hospital or clinic is 2.4, 1.4, and 1.7 km, respectively. The average daily travel frequency of all surveyed household members is 1.2 trips. As a subset of those, 54 percent choose public transportation. For these households, the daily frequency is 2.3 workday and 1.4 weekend trips. It takes about 7.9 min to access the closest public transportation station by walking. Among all possible traffic modes, 74 percent of respondents take the public bus as their first choice, and 75 percent choose subway or taxi as their second choice.

Descriptive statistics of private vehicles are presented in Table 4. Around 40 percent of families had an automobile, of which 93 percent were privately owned and 84 percent were passenger cars equipped with a 1.8 l engine. In 2012, a typical private vehicle travelled 10,686 km. The reported fuel consumption per 100 km is 9.2 l, much higher than the nominal 7.74 l. Around 74 percent of car users pay for the fuel on their own at a cost of 7.38 Yuan per liter, and the rest receive subsidies from their employers. In addition to automobiles, electric bicycles and motorcycles are commonly used.

3.6. Electricity billing, metering, and pricing options

Information about monthly electricity consumption and associated expenditures was delivered to the users mainly through bills and meter readers. Around one-third of households paid for electricity in advance, while the rest paid after use. More than half of the users paid at the grid company's counter, while around 35 percent of users adopted a bank or internet transfer service. Most users paid the bill every one to three months.

The accessibility of information and the disclosure frequency may affect people's electricity consumption behavior. On average, 96 percent of surveyed households installed a separate electricity meter, of which 80 percent are located in a corridor that is visible to the user. The old mechanical meters are still used in more than one-third of the sample.

Awareness of policies aimed at reducing consumption also can affect one's electricity bill. A time-of-use pricing policy is an important economic instrument used in China and elsewhere to shift the electricity load in peak hours. Normally, the residential electricity price in off-peak hours (i.e., 22:00–06:00) is around half that in peak hours. However, the consumer must apply for time pricing from the grid company. Although 38 percent of respondents know about this policy through different channels, only 13 percent of users were directly informed by the grid company. In practice, only 14 percent of households had applied for it. After the investigator explained the benefit of time-pricing policy, 70 percent of respondents showed interest in applying for it. However, for the other 30 percent of users who were reluctant to make the change, most of them said their major concern was the difficulty of the application process; the next most common reason was that they were not sensitive to the expenditure.

Another policy instrument, block electricity tariffs, was launched nationwide in 2012. The tariffs are divided into three blocks and automatically implemented at the supply side. Tier one represents the basic demand and varies across provinces. We set up a hypothetical scenario that the tier-one electricity amount may be adjustable depending on household size. After the investigator told the respondents about this possibility, 75 percent of users expressed their willingness to adjust their basic electricity volume if the policy permits it. We also found that the complexity of the application process was the major obstacle preventing people from acting.

4. Residential energy consumption

How much energy do Chinese households consume? Who supplies their energy services? For what activities do they use energy? Based on our survey data, we can begin to answer these and other basic questions about the energy consumption of a "typical" Chinese household.

4.1. Measuring energy consumption

Suppose there are I surveyed households, M types of energy activities, and N types of energy. For the ith household, $e_{i,m,n}$ is the amount of the nth type of energy used for the mth purpose. One may convert it into standard coal equivalent (kgce) by multiplying by the conversion coefficient $coef_n$ for the nth energy. Then the annual energy consumption for the ith household can be measured as follows (Niu et al., 2012).

$$E_i = \sum_{m=1}^{M} \sum_{n=1}^{N} e_{i,m,n} \times coef_n \quad (1)$$

Also, the total energy consumption of nth energy is

$$E_{i,n} = \sum_{m=1}^{M} e_{i,m,n} \times coef_n \quad (2)$$

Similarly, the total energy consumption for mth activities is

$$E_{i,m} = \sum_{n=1}^{N} e_{i,m,n} \times coef_n \quad (3)$$

We set up seven fuel types: coal, natural gas, LPG, electricity, firewood, district heat, and solar power. Energy end-use activities are divided into five categories: cooking, space heating, space cooling, powering home appliances, and water heating. Personal transportation is excluded to make our results comparable with those of other studies.

For an electrical appliance, $e_{i,m,n}$ is determined by the output power, usage frequency, and duration. The energy-efficiency level and other technical characteristics (i.e., inverter air conditioner) are taken into account by multiplying by a coefficient that is adjusted according to various national energy-efficiency standards.[8] The calculation of energy for heating depends on the heating type. For the distributed heating systems, it is determined by two parameters. One is the heating period, which was collected from the questionnaires; the other is the average power or consumption rate, which can be obtained from the survey or related literature (Chen et al., 2013; Saidur et al., 2007). District heating is treated as one of the fuel sources for the central heating system user.[9] Because fuel and technology information about the heating source is not available, reference values (energy consumption per m^2 per heating season) are set up based on relevant energy-efficiency standards for residential construction.[10] This is adjusted in accordance with the age of the housing, window frame type, and insulation measures.

4.2. Residential energy flow chart in China

Based on Eq. (1), we estimated individual household energy consumption. We computed energy usage by various type and purpose from Eqs. (2) and (3), respectively. We apply e!Sankey pro 3.2 – a software tool for creating Sankey diagrams – to draw the energy flow chart, presented in Fig. 1.[11]

We find that the annual average energy consumption of a household is 1426 kgce, with a median value of 1230 kgce/year. Per capita household total energy consumption is 612 kgce/year, with a median value of 477 kgce/year.

Chinese residents obtain energy mainly from seven types of sources, including district heating, electricity, firewood, gas, LPG, coal, and solar. District heating supplies 45 percent of total energy needs, followed by natural gas and LPG. Electricity accounts for 15 percent of the total energy supply, used for diverse purposes, such as powering household appliances (including lights), cooking, cooling, and water heating. Firewood, solar, and coal are less important energy sources. Firewood is used for cooking and space heating. Solar is only used for water heating.[12]

Space heating is the most energy-intensive end use, followed by cooking. These account for 54 percent and 23 percent of total energy consumption, respectively. Residents employ various types of energy for cooking, including gas, LPG, electricity, and, to a lesser extent, firewood and coal. Water heating is the third-largest energy use, accounting for 14 percent of total energy consumption. Almost 70 percent of water heating relies on gas and LPG, while the rest comes from electricity and solar. The energy demand for household appliances and space cooling is not as large as expected, accounting for only 9 percent of total consumption. This comes exclusively from electricity.

4.3. The urban–rural gap

In 2013, 629.6 million people lived in rural areas in China, accounting for 46.3 percent of the total population (NBS, 2014)—but this number continues to drop as China experiences rapid urbanization. The State Council recently issued a "New National Urbanization Plan," with the ambition of encouraging approximately 100 million people to settle in urban areas. The implications of massive urbanization for energy demand require an understanding of the existing difference in energy consumption of urban and rural households. Based on our survey data, we depict the profiles of energy usage of typical urban and rural households.

The average household energy consumption in an urban household is 1503 kgce/year, and per capita consumption is 651 kgce/year. In rural households, the average total energy consumption is 1097 kgce/year, and per capita consumption is 445 kgce/year. In other words, energy consumption in urban households is about 1.4 times that of rural households (see Fig. 2).

As we may expect, the energy sources of urban and rural households are quite different. Urban households obtain more energy from district heating, gas, and electricity and less from firewood, coal, LPG, and solar than do rural households. District heating accounts for 56 percent of total energy consumed in urban households, but only 2 percent in rural households. In contrast, the most important fuel in rural households is firewood (used for space heating and cooking), accounting for as much as 59 percent in total energy consumption. The share of electricity consumption is similar in urban and rural households at approximately 15 percent. Natural gas is used much more in urban areas (20 percent versus 2 percent), reflecting the better network infrastructure, while LPG is used more in rural areas for cooking (5 percent versus 10 percent). Solar is used more often in rural households than in urban households (2 percent versus 6 percent), reflecting the higher adoption rate of solar water heaters in rural areas. Lastly, direct use of coal almost disappears in urban areas, while it still accounts for 5.6 percent of the consumption of rural households.

The profiles of end-use activities in urban and rural households differ, too, as shown in Fig. 3. In terms of absolute values, urban

[8] The energy-efficiency standard for refrigerators, washing machines, televisions, computers, air conditioners, and electrical water heaters refer to GB 12021.2-2008, GB 12021.4-2004, GB 24850-2010, GB28380-2012, GB 12021.3-2004, and GB 21519-2008, respectively.

[9] There are two major performance metrics for benchmarking building heating: source energy and site energy. Source energy is the total amount of raw fuel that is required to supply heat for the building. It accounts for all transmission, delivery, and production losses. Site energy is the amount of heat delivered by a building as reflected in the bills. In present paper, we use the site energy consumption indicator to measure residential district heating.

[10] The energy conservation program in the construction sector started in 1986. In the first stage, according to the energy conservation standard (heating residential buildings, JGJ 26-86), residential construction in the northern area was required to cut energy consumption by 30 percent of the 1980–1981 level. In the second stage, according to the energy conservation standard (heating residential buildings, JGJ 26-95), new construction had to cut energy consumption by 50 percent of the 1980s level. In the third stage, China announced an energy-efficiency standard for residential buildings in the hot summer and cold winter zones (JGJ134-2010) and other standards. The goal in this period was to cut energy by an additional 30 percent.

[11] More information on this software can be found at http://www.e-sankey.com/en/.

[12] The National Bureau of Statistics does not offer micro level statistics of household energy consumption, but macro level information can be found in the (*footnote continued*) energy balance sheet compiled in the yearly report *China Energy Statistics*. The major energy types in the residential sector include coal (23.9 percent), petroleum products (24.1 percent, including 10.1 percent LPG, 8.9 percent gasoline, and 5.1 percent diesel), natural gas (13.4 percent), electricity (27.4 percent), and heating (9.5 percent). These results are rather different from those of our survey, in which we have almost no gasoline and diesel consumption, much higher heating consumption, and much lower coal consumption. These differences lie in the different statistical scope and method of the energy balance sheet. First, residential energy consumption in the energy balance sheet includes the fuel consumption of private vehicles, while our calculation does not. Second, solar and firewood are included in our survey data but not in the energy balance sheet. Third, in the energy balance sheet, the energy consumption of district heating from city boilers is not included; rather, the input of coal to produce district heating is attributed to coal consumption. This may explain why the coal consumption in the energy balance sheet is much higher than that of our calculation.

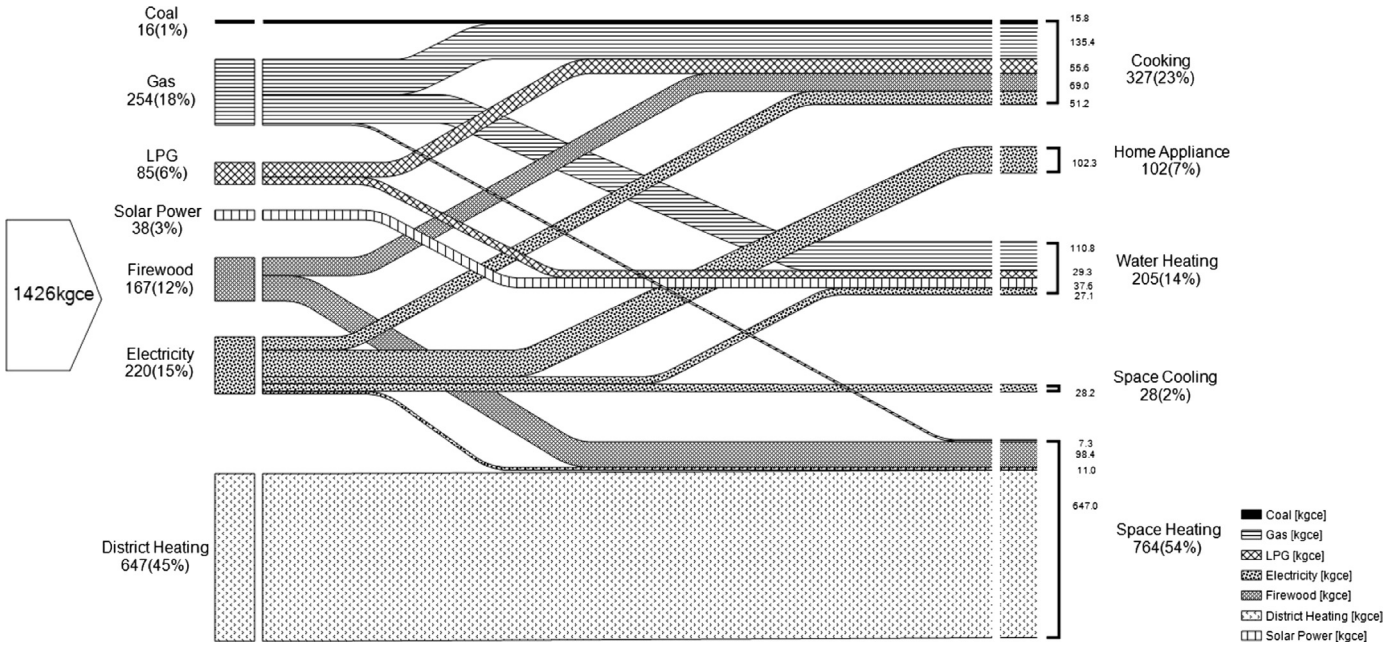

Fig. 1. Energy flow chart for a typical Chinese household in 2012, kilograms coal equivalent (kgce) per year per household.

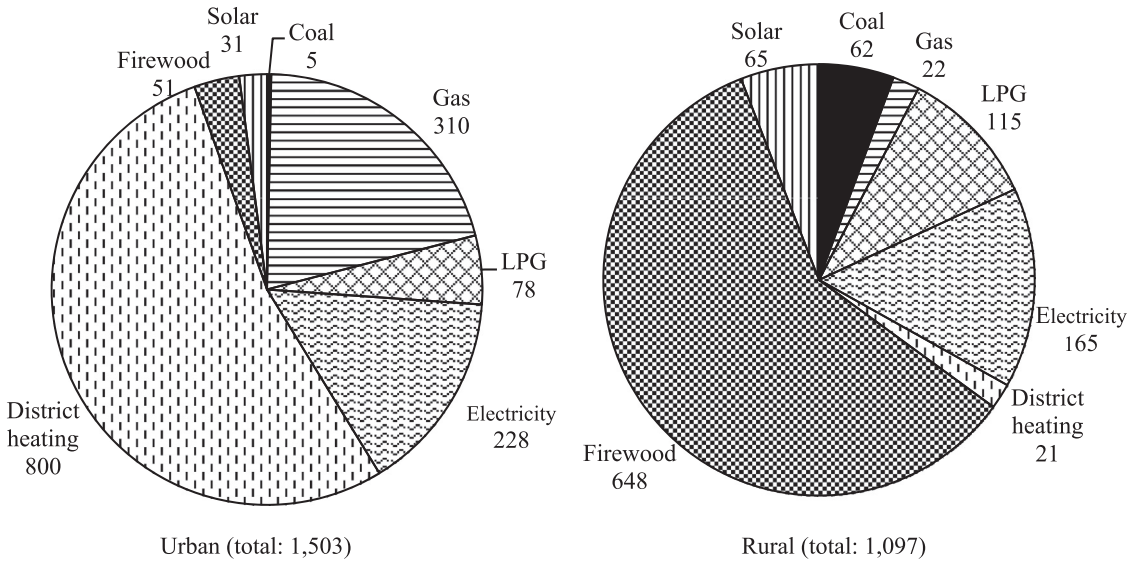

Fig. 2. Urban and rural household energy consumption by energy type in 2012, kilograms coal equivalent per year.

households consume more energy in every activity except cooking. Energy used for space heating in an urban household is almost as twice that in a rural household and explains most of the consumption gap. However, the shares of space heating in total energy consumption for urban and rural households do not differ much, at 56 percent and 40 percent, respectively. Cooking is the most energy-consuming activity in a rural household, accounting for 43 percent of total consumption, while this figure is only 19 percent in the urban counterpart. Urban households consume 15 percent of their total energy for water heating, while only 9 percent is consumed for water heating in rural households. The share of energy used for home appliances is very similar for urban and rural households, around 7 percent. Lastly, space cooling is the least energy-consuming activity in both urban and rural households, accounting for 2 percent and 1 percent, respectively.

Characteristics of energy use for urban and rural households have been examined in a few developing countries—for example, Zimbabwe (Hosier and Dowd, 1987), Tanzania (Hosier and Kipondya, 1993), and India (Pachauri, 2004). The energy ladder hypothesis proposed by Hosier and Dowd (1987) describes how households move toward more sophisticated fuels as their economic status improves. The theory has been tested by a few studies (Cai and Jiang, 2008; Pachauri and Jiang, 2008; Reddy and Reddy, 1994).

For China's case, Chen et al. (2006) examine the driving factors of rural household's energy transition from biomass to modern sources using survey data conducted in Jiangxi province. However, very few studies focus on the comparison of the energy use of rural and urban households. Niu et al. (2012) conducted a household survey in Gansu province between 2009 and 2010. In order to compare the energy usage of rural and urban households, they sampled four types of regions, including the provincial capital, two medium-sized cities, county towns, and rural areas. The average per capita energy consumption is 323 kgce, 282 kgce, 250 kgce,

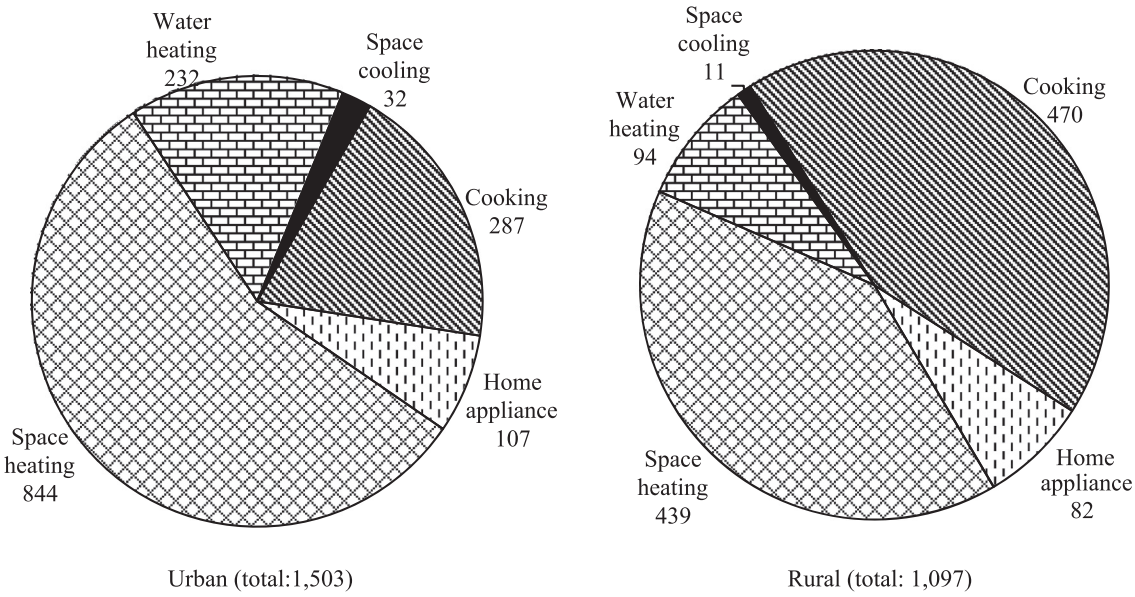

Fig. 3. Urban and rural household energy consumption by end-use activity in 2012, kilograms coal equivalent per year.

and 123 kgce, respectively, in the four types of regions. The estimates are much lower than our results, presumably because Gansu is a less-developed province in China. Because their categories of energy types and the purpose of energy use are quite different from ours, we cannot directly compare their quantitative results with ours. However, we do have some findings in common regarding rural households.

First, in rural areas, energy consumption is dominated by biomass energy, and energy used for cooking accounts for the largest proportion of total energy consumed. Both studies find that rural households consume much more biomass than natural gas and electricity, which can be seen as supportive evidence of the energy ladder hypothesis. They also find that space heating and cooling together account for a very large proportion of total energy consumed. This phenomenon implies the huge potential of energy saving in building efficiency improvement.

4.4. International comparison

This subsection provides some brief comparisons between China and other countries on household energy consumption. China's total household energy consumption was 1426 kgce in 2012, which was less than several OECD or economically developed countries (Table 5). For instance, the total household energy consumption in China in 2012 was approximately 44 percent of that in the United States in 2009, and 38 percent of that in the EU-27 in 2008.

Next, Fig. 4 compares the household energy consumption in detail by fuel type in different countries (regions). Households in China consumed more natural gas and electricity than firewood or LPG, and the least-common fuel was coal as a direct source. This pattern of energy consumption was quite similar to that of most other countries, with two notable exceptions: US and Canadian households do not use coal as a direct source of fuel in their houses. But in the United Kingdom and Germany, where households still use coal stoves as the main form of heating, coal consumption was twice that of China.

It is also worth mentioning that our coal finding for rural households in China is consistent with the finding by Brockett et al. (2002)[13] but inconsistent with Tonooka et al. (2006),

[13] Brockett et al. (2002) surveyed a total 251 city households in Shenyang, Beijing, Yixing, Shanghai, and Guangzhou in 1999.

Table 5
Country comparison of household energy consumption.

Country	Household energy consumption (kgce per household)
USA (2009)[a]	3227
Canada (2010)[b]	3287
EU-27 (2008)[c]	3717
Germany (2008)[c]	*2288*
France (2008)[c]	*2244*
United Kingdom (2008)[c]	*2353*
China (2012)[d]	1426

[a] US Energy Information Administration, 2009 Residential Energy Consumption Survey, http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption.

[b] Statistics Canada, 2010 Report on Energy Supply-Demand in Canada, http://data.gc.ca/data/en/dataset/27155507-0644-4077-9a97-7b268dfd8e58.

[c] EU-ODYSSEE: household energy consumption, http://www.indicators.odyssee-mure.eu/online-indicators.html.

[d] Estimated by authors.

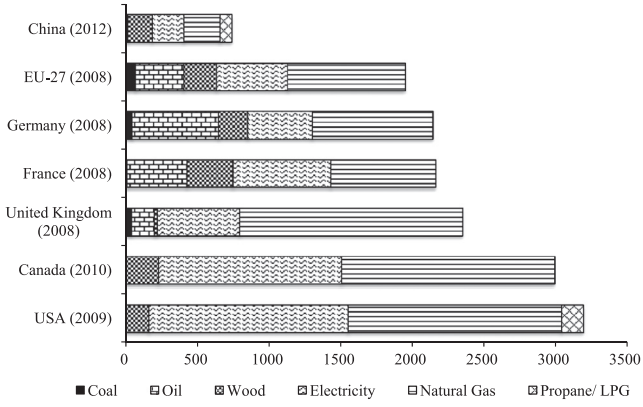

Fig. 4. Country comparison of energy consumption by source, kilograms coal equivalent per year. (a) Estimated by authors. (b) EU-ODYSSEE: household energy consumption, http://www.indicators.odyssee-mure.eu/online-indicators.html. (c) Statistics Canada, 2010 Report on Energy Supply-Demand in Canada, http://data.gc.ca/data/en/dataset/27155507-0644-4077-9a97-7b268dfd8e58. (d) US Energy Information Administration, 2009 Residential Energy Consumption Survey, http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption.

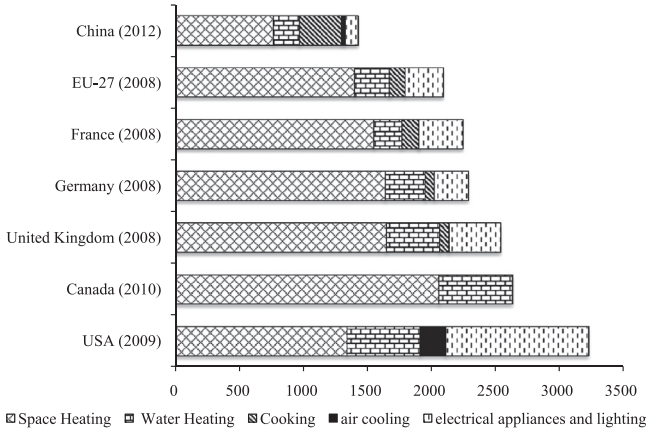

Fig. 5. Country comparison of energy consumption by end-use activities, kilograms coal equivalent per year. (a) Estimated by authors. (b) EU-ODYSSEE: household energy consumption, http://www.indicators.odyssee-mure.eu/online-indicators.html. (c) Statistics Canada, 2010 Report on Energy Supply-Demand in Canada, http://data.gc.ca/data/en/dataset/27155507-0644-4077-9a97-7b268dfd8e58. (d) US Energy Information Administration, 2009 Residential Energy Consumption Survey, http://www.eia.gov/consumption/residential/data/2009/index.cfm?view=consumption.

Nakagami et al. (2008), and Niu et al. (2012). The latter studies generally found a larger share of coal consumption in total energy consumption. The main reason for the discrepancy is that only 20 percent of our surveyed sample was rural households, while the other studies used a sample from mainly rural households. Also, residential gas consumption increased dramatically in the last decade, partially due to the rapid development of distribution infrastructure and the government's efforts in subsidizing changes in households' fuel choices to promote energy efficiency and the reduction of air pollution.

Fig. 5 presents the international comparison of energy consumption by end-use activities. Similar to most other countries, space heating for Chinese households accounted for the largest proportion of total household energy consumption, while household appliances and water heating used less energy, and the smallest share of energy was used for space cooling.

A striking difference between China and other countries is that Chinese households use a larger share of energy for cooking, accounting for 23 percent of household energy consumption versus 6 percent to nearly zero percent in other countries. There are several possible explanations for the relatively high proportion of energy use in cooking. Ordinary Chinese families use mainly gas fuels and coal products for cooking purposes but tend to use electricity frugally for non-cooking appliances, for example. In addition, living within the rich culinary culture of China, families form strong taste preferences and put relatively more time into cooking—hence using relatively more energy.

5. Conclusions

This paper presents a comprehensive overview of energy consumption in China's residential sector in 2012 based on the detailed CRECS 2012 dataset of 1450 surveyed households. The focus is on six particular types of data: household characteristics, dwelling characteristics, kitchen and home appliances, space heating and cooling, transportation, and electricity billing. Energy consumption is estimated by seven types of energy (district heating, electricity, firewood, gas, LPG, coal, solar) and five types of end-use activity (cooking, powering home appliances and lighting, space heating, space cooling, and water heating). All energy usage is converted into standard coal equivalents for aggregation and comparison. An energy flow chart for a typical Chinese household is then analyzed.

It is worth noting the shortcomings of the present survey. Due to financial limitations, the sample size is relatively small and rural households are under-represented. As a result, it may not fully capture the situation of the whole country or the urban–rural gap. We expect to improve these flaws in the future survey.

Overall, we find that average household energy consumption was 1426 kgce in 2012. The residential energy use per capita was 612 kgce per year. The major energy source for a typical household is district heating (45 percent), followed by natural gas (18 percent), electricity (15 percent) and firewood (12 percent). The main use is for space heating (54 percent), followed by cooking (23 percent), water heating (14 percent) and home appliances (7 percent).

Comparing urban and rural household energy consumption patterns reveals a large disparity. A typical urban household consumed 1503 kgce in 2012, 1.4 times that of a rural household, which consumed 1097 kgce. In terms of fuel sources, the urban household relies more on district heating, natural gas and electricity, while firewood is still the dominant fuel consumed in rural households. The main purpose of energy usage for an urban household is space heating, while in rural areas it is cooking.

In an international comparison, China has lower energy consumption than developed countries. The surveyed consumption in Chinese households in 2012 is approximately 44 percent of that in the United States in 2009 and 38 percent of that in the EU-27 in 2008. China consumes more commercial energy (i.e., natural gas, LPG and electricity) than noncommercial energy (i.e., firewood and coal), exhibiting a similar pattern to most developed countries. China is also similar to other countries in that space heating is the largest end use, while China's rich cuisine culture drives a higher percentage of energy consumption for cooking activity than in other countries.

Our results have three important policy implications. First, our data and analysis demonstrate an overall picture to help policymakers understand the current residential energy consumption pattern and the vast urban–rural gaps in terms of fuel types and end-use activities. Especially in the context of the accelerating urbanization process, the energy demand of the residential sector is anticipated to increase continuously. In addition, people who migrate from rural to urban areas are expected to transit from traditional biomass fuel to modern commercial energy. If policymakers are fully aware of these possible changes, they can better forecast energy demand and make science-based decisions on energy-related infrastructure investment.

Second, our results identify key opportunities for energy conservation management. For example, the energy flow chart shows that space heating occupied half of energy demand and that its major fuel source is district heating. Because most district heating is operated by municipal heating stations, this creates great opportunities to save energy through more efficient thermal generation, lower thermal loss rates from pipelines, more building insulation measures, individual heat metering systems, and other measures. However, this raises an equity issue in terms of energy utilization and payment. Central space heating only exists in northern cities. As a result, these proposed infrastructure improvements (as well as the existing central heating subsidy) may damage the welfare of rural and southern households that use electricity to heat space and have to pay the tiered electricity price. The reform of heat metering and pricing system may lead to elimination of this inequity.

Third, our dataset provide a basis for evaluating the effectiveness of various energy policies, especially the electricity policy. The energy-efficiency label system, for instance, was launched in 2005 and applies to most home appliances. To promote the widespread use of energy-efficient appliances, the government implemented

another energy-efficiency program in 2007. Our data collected information on whether households purchased energy-efficient appliances and received subsidies for doing so, as well as their attitudes toward conservation. A further examination can identify the determinants of purchase choice and investigate whether there exists a rebound effect (Yu et al., 2013). In addition, because the block electricity tariff was implemented in July 2012 and our survey collects electricity quantity and expenditure on a monthly basis, we will be able to conduct a pre- and post-analysis. However, household response to this price change is determined by the degree of information disclosure, household characteristics, and other social and economic factors, which require more detailed study in the future.

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