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Does Urbanization Increase Residential Energy Use?

Evidence from the Chinese Residential Energy Consumption Survey 2012

Lunyu Xie and Chu Wei

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Contents

1. Introduction **2**

2. Data **5**

3. Empirical Analysis **7**

4. Simulation **10**

5. Onsite and Offsite Urbanization **11**

6. Conclusion **12**

References **14**

Tables and Figures **18**

Does Urbanization Increase Residential Energy Use? Evidence from the Chinese Residential Energy Consumption Survey 2012

Lunyu Xie and Chu Wei*

Abstract

China's rapid urbanization and increasing energy use are accompanied by deteriorating environmental quality. Understanding the structure of energy use is necessary to address these environmental effects. We investigate how urbanization affects residential energy use, using data from the Chinese Residential Energy Consumption Survey 2012 (CRECS 2012) to compare the energy consumption of urban and rural households and identify the factors influencing the differences. We find that dwelling characteristics (e.g., building infrastructure, residential area), household characteristics (e.g., household size, income), and unobservable factors (e.g., the surrounding environment, living habits) all play roles in shaping residential energy consumption. Urbanization directly decreases energy consumption through differences in the environment outside the household (markets, infrastructure, etc.), while it indirectly increases consumption through the presence of central heating, decreased household size, and increased household income. We find a positive total effect — urbanization increases residential energy consumption in total. We also find that urbanization shifts energy consumption away from coal and toward electricity and gas. In addition, we distinguish between onsite urbanization (formation of towns based on rural markets) and offsite urbanization (movement to large cities). Compared to onsite urbanization, offsite urbanization shifts energy consumption toward electricity and gas by a larger magnitude. Finally, we project residential energy use in 2020.

Key Words: coal, electricity, gas, residential energy use, urbanization

JEL Codes: Q41, R22

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1. Introduction

Energy improves human welfare and promotes economic development. However, both the production and the use of energy cause environmental problems such as emissions of local pollutants and greenhouse gases. China is undergoing rapid growth and urbanization, along with a rapid increase in energy consumption and emissions of pollutants. In the last 35 years, more than 500 million rural residents in China migrated to urban areas. Figure 1 shows that the urbanization rate (the proportion of the population living in urban areas) increased from 36.2 percent to 56.1 percent from 2000 to 2015; the trend of per capita energy consumption is in line with the trend of urbanization; and the structure of energy consumption has shifted toward electricity and away from coal.[1] By 2030, China is expected to have over one billion urban residents (Normile, 2008) and urban areas are expected to consume 83% of the total energy consumption in China if urbanization continues on the current path (IEA, 2007). Realizing the urgency of the issue, the Chinese government has put forward an "intensive, intelligent, green, low-carbon" plan for urbanization.[2] To achieve this goal, it is critical to understand the mechanism through which urbanization affects energy use. Therefore, this paper investigates the factors that influence the differences in energy consumption between urban and rural households, and looks into the direct and indirect effects of urbanization on energy consumption.

This paper is rooted in two series of studies. One takes the angle of "top down". These studies start from the characteristics of urbanization, systematically state the impacts of urbanization on energy and environment, and investigate the mechanism of the impacts. The analytical tools include the theories of ecological modernization (e.g., Fudge and Rowe, 2001; Mol, 2006; Zhang et al., 2007), urban environmental evolution (e.g., Bai and Imura, 2000; Marcotullio, 2003; McGranahan and Satterthwaite, 2002), and compact cities (e.g., Burton, 2000; Capello and Camagni, 2000). Regarding whether urbanization increases energy consumption, empirical studies have mixed findings. Some studies find that

[1] Coal is primary energy and electricity is secondary energy. In China, about 60% of electricity is generated from coal. To avoid double counting, coal for electricity generation is not counted in when electricity is counted in energy consumption.

[2] Source: 2012 Central Economic Work Conference.
http://english.cntv.cn/special/2012economicmeeting/homepage/index.shtml

urbanization leads to an increase in urban energy demand through changing related production, transportation, infrastructure and other aspects of the living environment (e.g., Madlener and Sunak, 2011; Parikh and Shukla, 1995; Jones, 1991; Holtedahl and Joutz, 2004; York, 2007; Poumanyvong et al., 2012; Creutzig et al., 2015). In contrast, some other studies find that urbanization does not necessarily increase energy consumption due to the economies of scale and improvement of energy efficiency, resulting from the transition to modern energy (e.g., Pachauri and Jiang, 2008; Mishra et al., 2009; Pachauri, 2004).

The other strand of literature takes the angle of "bottom up". This research starts from micro-level decision makers – households or individuals – and analyzes the mechanism through which urbanization affects households' energy use behavior. Depending on the mechanism, this series of literature can be divided into three categories. One category focuses on household characteristics. Researchers find that urbanization increases household income through providing more job opportunities and better public services such as education. They also find that households in cities tend to have younger household heads, smaller household sizes and a smaller residential area. All these differences in the characteristics of the household affect their living habits and energy consumption behavior (Ironmonger et al., 1995; Sardianou, 2007; Song and Xiao, 2006). The second category focuses on the difference in the external environment in which individuals make decisions, such as markets, infrastructure, policies, etc. Urbanization provides better roads, communication and financial infrastructure, which leads to better access to markets and information. All of these changes in the environment affect residents' energy consumption behavior as well (Wang, 2010; Jiang and Zhi, 2011; Xia and Chen, 2004). The last category focuses on the direct impact of urbanization. Urbanization changes related infrastructural facilities and equipment, such as dwelling characteristics, energy-using appliances, etc. For instance, urbanization changes residents' energy choice set and increases the heat retention of homes, which directly changes residents' energy consumption (Dodman, 2009; Jiang and Zhi, 2011).

This paper fits into the second series of literature. Taking a "bottom-up" angle requires data at the household level. Due to the lack of comprehensive household-level data, previous studies in China mainly focus on regional differences in energy use or are limited to one type of energy or one category of factors that influence energy consumption (e.g., Tonooka et al., 2006; Wang and Feng, 2003; Zhou and Teng, 2013). Utilizing data from the Chinese Residential Energy Consumption Survey 2012 (CRECS 2012), this paper investigates energy consumption differences between urban and rural households nationwide — not only the difference in quantity, but also the difference in structure. This paper also identifies the factors that influence the energy consumption of households, and simulates spatial residential energy consumption trends under urbanization scenarios.

Urbanization in China includes both offsite and onsite urbanization (Men and Qi, 2017). Offsite urbanization refers to rural residents' migration to large cities. Onsite urbanization, unique to China, refers to the formation of small towns based on rural markets and driven by the industrialization of rural areas (Zhao, 2003). In China, offsite urbanization usually dominates in less-developed rural areas, while onsite urbanization dominates in more-developed rural areas (Lu, 2015).

Both offsite and onsite urbanization are expected to increase energy consumption in urban areas and decrease energy consumption in rural areas, because of the population change in these areas. However, the nationwide total effect is ambiguous, because urbanization could increase energy demand through increasing income and better access to energy, while it could also decrease energy demand through economies of scale or better energy efficiency.

We distinguish between onsite and offsite urbanization, because they could have different effects on energy consumption, due to the differences between city (offsite urbanization) and town (onsite urbanization). They could also have different spatial effects on energy consumption, because offsite involves population change in the "sending" and "receiving" destinations, while onsite does not involve a change of local population.

Based on regression and simulation, we find that urbanization increases per capita energy consumption by 118 kilogram coal equivalent (kgce), increases electricity and gas by 21 kgce and 85 kgce, and decreases coal by 58 kgce. By looking into the factors that affect residential energy consumption, we find that household income, household size, education and unobservable factors (e.g., market environment) all have significant influence on residential energy consumption. We quantify their respective contributions to energy consumption change. Interestingly, we find that offsite urbanization increases energy consumption by 167 kgce while onsite urbanization decreases households' energy usage by 14 kgce. We also discuss the possible reasons behind the findings.

The remainder of this paper is organized as follows. Section 2 describes the survey data and compares the energy consumption between urban and rural households. Section 3 describes the empirical estimation strategy and presents the results. Section 4 simulates residential energy consumption change under urbanization scenarios. Section 5 repeats the empirical analysis with offsite and onsite urbanization distinguished. Section 6 concludes.

2. Data

The data used in this paper are from the Chinese Residential Energy Consumption Survey 2012 (CRECS 2012), conducted by the Department of Energy Economics at Renmin University of China. The sample covers 95 prefecture-level cities from 27 provinces in mainland China, except Jiangsu, Tibet, Qinghai and Shaanxi, giving a sample of 1450 households in total. The number of sampled counties is chosen based on the density of population, the percentage of non-agricultural population and the per capita gross regional product. The spatial distribution of the sampled households is depicted in Figure 2. It includes 928 households living in cities, 235 in towns and 283 in rural areas.[3]

The survey collects information on (1) the number of energy-using appliances owned by a sampled household (the power and the energy efficiency are also included for electric appliances); (2) the energy consumption habits of a household, including frequency and duration of all energy consumption activities, including cooking, heating, cooling, heating water, and other; (3) amounts of each type of energy consumed, including electricity, central heating,[4] coal, liquefied petroleum gas (LPG), natural gas, biomass energy (including firewood, agricultural residual, and manure), and solar energy; (4) household characteristics, including household income, each household member's education, employment, age, etc., and (5) characteristics of the residence, including size, age, infrastructure, etc.

To avoid recall error in energy consumption, we utilize the detailed information on energy consumption activities to first calculate the amount of each energy type consumed,

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[3] More information on the survey, including survey quality control and sampling criteria, can be found in the second section of Zheng et al. (2014).

[4] Central heating refers to the type of energy provided by a central heating system. For example, in Northern China, it is common for a community (hundreds or thousands of households) to be served by a central heating system. The system generates and transports heated water or steam from coal or gas boilers into households. Since no meter is installed on each household end, households do not know the quantity of central heating they consume. We therefore calculate the quantity based on equation (1).

and then add up all types of energy to get the total amount of energy consumption. The calculation formula is as follows:

$$Energy_i = \sum_{m=1}^{M} \sum_{n=1}^{N} Energy_{i,m,n} \times coef_n \tag{1}$$

where $Energy_i$ is the total amount of energy consumed by household i in the survey year, measured in kilogram coal equivalent (kgce); $Energy_{i,m,n}$ is the amount of energy type n consumed by household i in activity m, measured in energy type n's usual unit (e.g., electricity is measured in kwh, natural gas is measured in cubic meters, etc.); $coef_n$ is the conversion coefficient, which transforms physical quantity of energy type n into a standard quantity in kgce. The conversion coefficients are from the China Energy Statistical Yearbook.

Table 1 summarizes the conversion coefficient for each energy type, and the amount of consumption per capita in both physical quantity and standard quantity (kcge). It shows that the most-used energy types in China are central heating, natural gas, electricity, biomass and LPG. Surprisingly, coal is not among the most-used energy types. The possible reason is that urban areas in China no longer widely use coal for household activities.

We compare residential energy consumption between urban and rural areas. We distinguish between extensive and intensive margins of energy consumption. Extensive margin refers to whether a household uses a certain type of energy at all, measured as penetration rate. Intensive margin refers to the amount of energy consumed, conditional on the use of that energy type. Table 2 summarizes the penetration rates of energy types in urban and rural areas. It shows that all urban and rural households in the sample have access to electricity. This is expected, because the access to electricity in China reached 99.8% in 2012.[5] Penetration rates of central heating and natural gas are higher in urban areas, where infrastructure is better developed, than in rural areas. Compared to urban households, a larger portion of rural households use coal, LPG and biomass energy.

Figure 3 illustrates the distributions of per capita energy consumption quantity in urban and rural areas. It shows that per capita energy consumption is distributed log-

[5] http://www.nea.gov.cn/2015-12/24/c_134948340.htm

normally in both areas. The distribution of urban areas is to the right of the distribution of rural areas, indicating more energy consumption in urban areas. Table 3 compares the total energy consumption and the consumption of each type of energy in urban and rural areas. It shows that, besides electricity, the main energy types in urban areas are central heating and natural gas, while the main energy types in rural areas are biomass energy, LPG and coal.

There are many factors that affect residential energy consumption, including dwelling characteristics and household characteristics. We summarize these variables in Table 4. We compare these factors for rural and urban areas. Because urbanization in China is both offsite and onsite, we divide urban areas into cities and towns, corresponding to offsite and onsite urbanization respectively. Table 4 shows that, compared to rural households, urban households on average have newer and smaller dwelling spaces, higher income, smaller household size and more education. It also shows that, compared to town households, city households have newer and smaller residential spaces, are more likely to have central heating, and have higher income and more education. These differences confirm the importance of distinguishing onsite and offsite urbanization when simulating the effect of urbanization on energy consumption.

3. Empirical Analysis

In this section, we investigate the correlation between energy consumption and the influencing factors, including household and dwelling characteristics and unobserved differences between urban and rural areas in the external environment. The differences in the external environment may include energy prices, access to energy, energy-saving consciousness, consumers' willingness to pay for convenience, safety and cleanness, etc. We use a dummy variable of urban to capture these unobserved differences between urban and rural areas. We also include location dummies to capture the effects of additional unobserved differences in areas, such as differences in weather and energy price across provinces or counties.

The regression equation is as follows:

$$ln(Y_i) = \beta_0 + \beta_1 D_i + \boldsymbol{X_i}'\boldsymbol{\beta_2} + \boldsymbol{Z_i}'\boldsymbol{\beta_3} + \varepsilon_i \qquad (2)$$

where Y_i is the per capita energy consumption of household i; D_i is a dummy variable which equals one if household i lives in an urban area and zero otherwise; $\boldsymbol{X_i}$ is a vector of characteristics of the dwelling in which household i lives; $\boldsymbol{Z_i}$ is a vector of characteristics of household i; and ε_i is the error term.

We employ Fixed Effect Models to estimate equation (2) and present regression results in Table 5. The first three columns include province fixed effects and the last column includes county fixed effects. Column (1) includes only the dummy variable *urban*. The estimated coefficient of *urban* is 0.177 and is statistically significant at the 1% level. This shows that the energy consumption of urban households on average is 17.7% higher than rural households in the same province. Column (2) adds in dwelling characteristics. Column (3) further adds in household characteristics. Column (4) has the same specification as Column (3), but replaces province fixed effects with county fixed effects. The estimated coefficient of *urban* becomes negative as household and dwelling characteristics are added. This indicates that urban households consume less energy, compared to rural households with the same characteristics.

We use Column (4) in Table 5 as the main result, as it adopts a finer level of fixed effects and controls for all the observed characteristics. The estimated coefficients show that, as expected, older houses, larger living areas, and houses with central heating consume more energy. The coefficient of household size is negative and statistically significant, indicating the existence of economies of scale. The coefficient of household average age is positive, indicating that younger households use less energy than older households. The reasons could be that young households engage less in energy-consuming activities (e.g., cooking) or are more likely to use more energy-efficient devices.

In addition to total quantity of energy consumption, the structure of energy consumption is also important. Therefore, we also investigate how the consumption of main energy types change along with urbanization. According to Tables 2 and 3, the main energy types include electricity, gas (including natural gas and LPG) and coal. For each of the main energy types, we distinguish between extensive margin and intensive margin.

To investigate the extensive margin, we generate a dummy variable, which equals one if the main energy is consumed, and then regress the dummy variable on all the dwelling and household characteristics, the urban dummy, and the county fixed effects, the same specification as Column (4) in Table 5. For the extensive margins of gas and coal, we use both a Probability Linear Model (PLM) and a Logit model. We do not investigate the extensive margin of electricity, because all the households in the survey have access to electricity, as shown in Table 2.

The estimated marginal effects are reported in Table 6. It shows that urbanization improves gas accessibility and reduces the portion of households that use coal; older households are less likely to use gas and more likely to use coal; houses with a central heating system are less likely to use coal and more likely to use gas. The possible reason is that houses with central heating are those with better infrastructure, such as gas pipelines. The effect of annual income per capita on gas penetration has an inverted U-shape, with a turning point at 280 thousand yuan per year. Since the turning point is above most of the households in the sample, the quadratic to the right of the turning point can, for practical purposes, be ignored. To the left of the turning point we see that income increases the gas penetration rate at a decreasing speed. Furthermore, income has little influence on coal access, given all other conditions the same.

To investigate the intensive margin, we use as the dependent variable the consumption quantity of each main energy type, conditional on the use of that energy. We use the same specification as Column (4) in Table 5 and summarize the regression results in Table 7. For comparison, Column (1) replicates the regression results of total energy consumption, the same as Table 5, Column (4). Columns (2) through (4) are for electricity, gas, and coal, respectively. They show that the consumption of electricity is sensitive to almost all the household and dwelling characteristics, except the dummy variable of *urban.* In contrast, conditional on the use of coal, the quantity of coal consumed is sensitive to few factors, except for average age of members. Combining the estimated results for the extensive (Table 6) and intensive margins (Table 7), we see that urbanization changes coal consumption mainly through changing the access to coal; changes in total energy consumption include the changes in both quantity and structure.

To directly investigate the total effect of urbanization on energy consumption, combining both extensive and intensive margins, we include all the 1133 households, and use energy consumption, instead of logarithm of energy consumption, as the dependent variable. As many households do not use gas or coal, we employ a Tobit model to deal with the many zeros in the dependent variable of the gas and coal regressions. We report the marginal effects in Table 8.

Based on Table 8, we calculate the direct and indirect contributions of urbanization to energy consumption change. The calculation method is as follows. In previous sections, we have obtained the differences in influencing factors between urban and rural areas (Table 4), and the marginal effect of each factor on energy consumption (Table 8). By multiplying the differences and the marginal effects, we obtain the contribution of each factor to the energy consumption difference between urban and rural households. The results are presented in Table 9. It shows that urbanization decreases residential energy consumption directly through changing the external environment; urbanization also affects energy consumption indirectly through changing household and dwelling characteristics: newer houses in urban areas, smaller residential areas and younger household members reduce energy usage, while smaller household size and higher income increase energy consumption. Putting together the direct and indirect effects, urbanization results in a 118.15 kgce increase (a 27.60% increase) in energy consumption per capita, 21.14 kgce (32.18%) increase in electricity, 85.34 kgce (35.14%) increase in gas, and 58.05 kgce (96.80%) decrease in coal.

4. Simulation

In this section, we simulate the change of energy consumption from 2012 to 2020 that can be expected due to urbanization. We consider two scenarios: urbanization only, and urbanization plus population growth. Results are summarized in Table 10.

We first forecast the number of households that will migrate to urban areas from 2012 to 2020, using the goal of China's urbanization plans and population growth forecast. In 2012, the urbanization rate was 52.57% and the total population was 1.35 billion. The urbanization rate is expected to reach 60% in 2020, according to the "13th Five-Year Plan for Economic and Social Development of the People's Republic of China", and the total population is forecasted to be 1.42 billion in 2020.

We then put together the regression results from the previous section and the migration forecast, to simulate the change of energy consumption brought by urbanization. We multiply *Change in urbanization rate* with *population* and *energy change per capita*, and obtain 11.85 million tons of standard coal equivalent increase in total energy consumption. Using the same method, electricity, gas and coal consumption changes are forecasted to be 2.120 million, 8.560 million, and -5.823 million tons of standard coal. Given that total energy, electricity, gas and coal consumed by households in 2012 were 423.81 million, 76.61 million, 10.29 million and 124.26 million tons of standard coal, the consumption structure change brought by urbanization is significant.

Next, we simulate the energy consumption change considering both urbanization and population growth. Energy consumption change is forecasted to be 46.78, 7.61, 16.13, and -6.47 million tons of standard coal for total residential energy, electricity, gas and coal, respectively. This indicates that population growth is a strong force in increasing energy consumption – the increase in energy consumption due to urbanization is increased by fourfold when considering population growth.

We further simulate the spatial distribution of energy consumption changes brought by urbanization from 2012 to 2020, as provinces in China have much different population bases and growth rates, as well as urbanization rates. The results are depicted in Figure 4. The left upper figure shows that residential energy consumption will increase in most of the provinces except Heilongjiang and Jilin. Energy consumption in Shandong, Guangdong, and Hebei has the largest growth, followed by the provinces in eastern and central China. The right upper and left lower figures show that the spatial distributions of electricity and gas consumption changes are similar to that of total residential energy change. As for coal (shown in the right lower figure), most provinces will have a decrease in coal consumption. The area with the most decrease in coal consumption will be the region around the Bohai Sea (e.g., Hebei and Shandong provinces) and parts of central and western China (e.g., Henan and Sichuan provinces). These patterns are in line with the population distribution and migration pattern, as population and urbanization concentrate in these areas.

5. Onsite and Offsite Urbanization

In this section, we distinguish onsite and offsite urbanization. As discussed above, in offsite urbanization, rural residents migrate to cities; in onsite urbanization, rural areas convert to towns. Because the characteristics of households, dwellings and external environment are different between cities (offsite) and towns (onsite), rural households that migrated to cities may have different energy-using behavior and form different energy consumption habits than those who urbanize locally.

We replicate the regressions in Table 8, with the *urban* dummy replaced by *city* dummy and *town* dummy, and present the results in Table 11. It shows that, conditional on dwelling and household characteristics, both forms of urbanization increase the consumption of total energy, electricity and gas, and reduce the consumption of coal. However, the magnitudes of the estimated coefficients of the two dummies are different — offsite urbanization causes less decrease in energy consumption than onsite urbanization, conditional on the same dwelling and household characteristics. The possible reason could be that the external environment, such as energy-related markets and infrastructure, is more mature in large cities, which potentially induces more energy consumption and largely offsets the energy-saving effect of urbanization. Table 11 also shows that the structure of energy consumption change is also different between onsite and offsite urbanization. Compared to onsite urbanization, offsite urbanization shows a larger structural shift from coal to gas and electricity.

Table 12 simulates the energy consumption changes caused by the two forms of urbanization. It shows that onsite urbanization reduces per capita residential energy consumption by 14.65 kgce, while offsite urbanization increases per capita residential energy consumption by 167.13 kgce. The main difference comes from the contribution of the *urban* dummy to energy consumption, which is -91.84 and -8.71 for *town* dummy and *city* dummy respectively. Among the main energy types, the *urban* dummy differs significantly for gas; the *town* dummy is 77.33 and the *city* dummy is 144.7. This indicates that external environment change from rural to city increases consumption of gas more than that from rural to town. The possible reason is that the infrastructure for gas consumption is better in cities than in towns.

6. Conclusion

In this paper, we study the effect of urbanization on residential energy consumption. We find that the key driving factors behind the difference in energy consumption between urban and rural areas include both household and dwelling characteristic (e.g., dwelling age and size, household income, size and education, etc.) as well as unobservable factors (e.g., external environment, energy-saving consciousness and living habits). Urbanization could affect residential energy consumption directly through changing the external environment and indirectly through changing household and dwelling characteristics. Compared to rural households, urbanized households earn more, live in smaller spaces and make different choices in consumption and lifestyle.

We find that urbanization increases the quantity of residential energy consumption. We also find that urbanization improves gas accessibility and reduces the portion of households that use coal. Conditional on the use of coal, the intensive margin of urbanization on coal consumption is small. That is, urbanization also changes the structure of energy consumption by increasing the consumption of electricity and gas and decreasing the portion of households that use coal.

Putting together the direct and indirect effects, we find that urbanization leads to a 28% increase in per capita energy consumption, including a 32% increase in electricity, a 35% increase in gas and a 98% decrease in coal. By simulating the energy consumption change considering both urbanization and population growth, we forecast that from 2012 to 2020, consumption of residential energy, electricity and gas will increase by 47, 7.6 and 16 million tons of standard coal, respectively, while coal will decrease by 6.5 million tons of standard coal.

Looking into the spatial distribution of energy consumption changes, we find that most of the provinces will have an increase in the consumption of total residential energy, electricity and gas, and a decrease in the consumption of coal. The area with the most decrease in coal consumption will be the region around the Bohai Sea and parts of central and western China.

In the process of urbanization, either rural households migrate to cities (offsite urbanization) or rural areas become towns (onsite urbanization). We find that onsite urbanization (formation of towns) reduces energy consumption slightly, but offsite urbanization (moving to cities) increases energy consumption substantially. We also find that the structure of the energy consumption change will also be different between onsite and offsite urbanization. Compared to onsite urbanization, offsite urbanization will have a larger structural shift from coal to gas and electricity.

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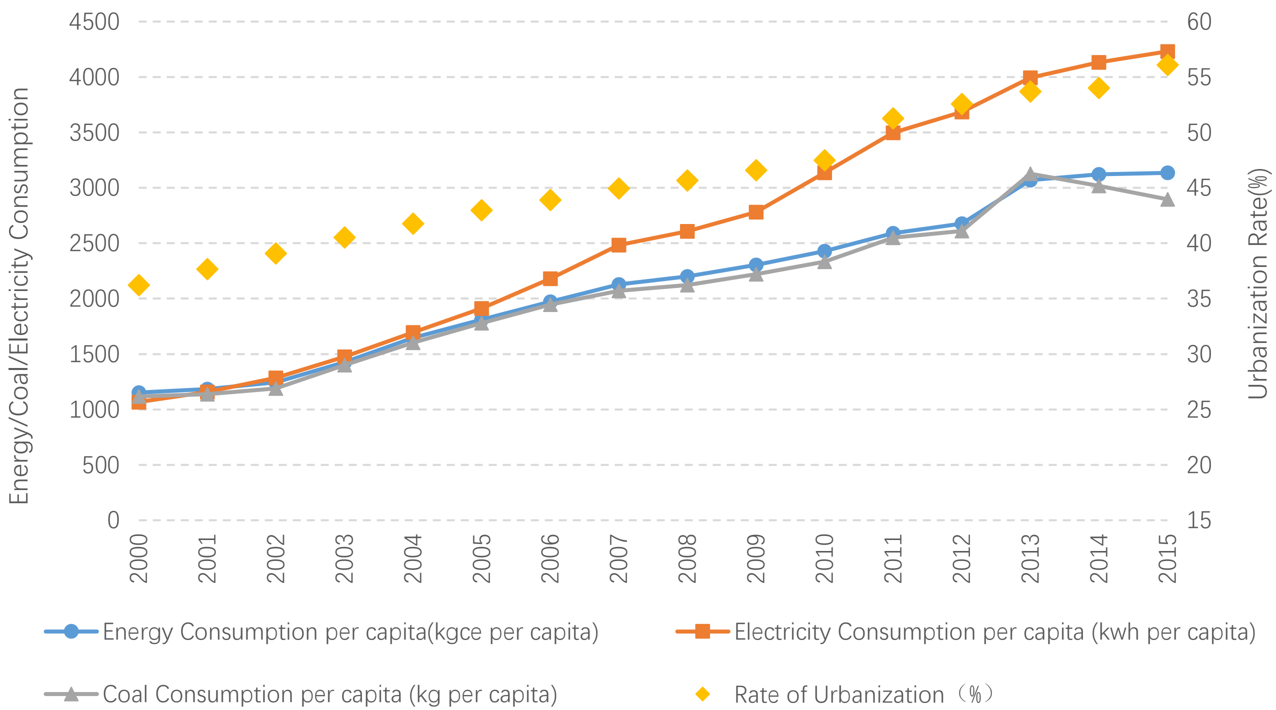
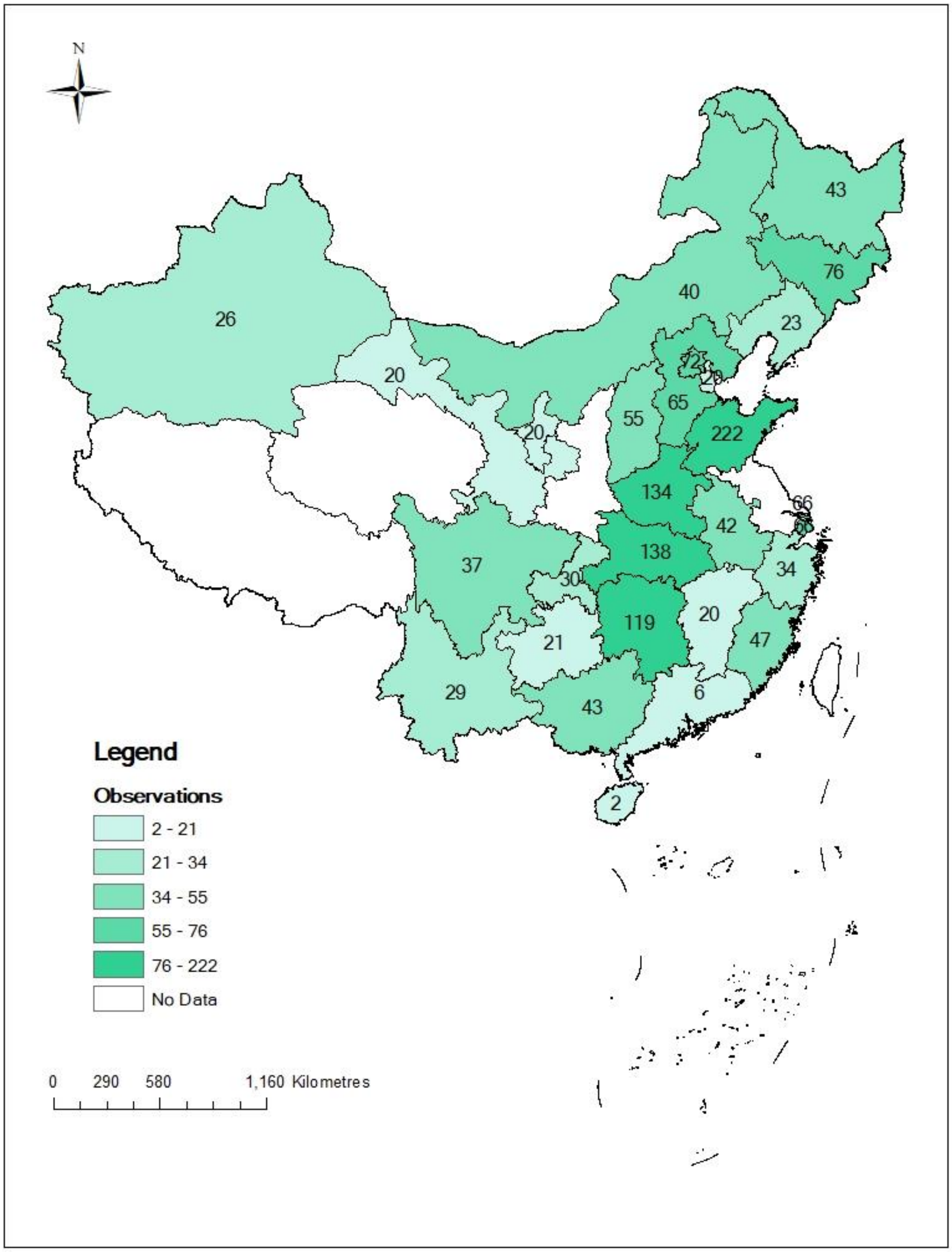
Figure 1. Urbanization and Energy Consumption in China since 2000



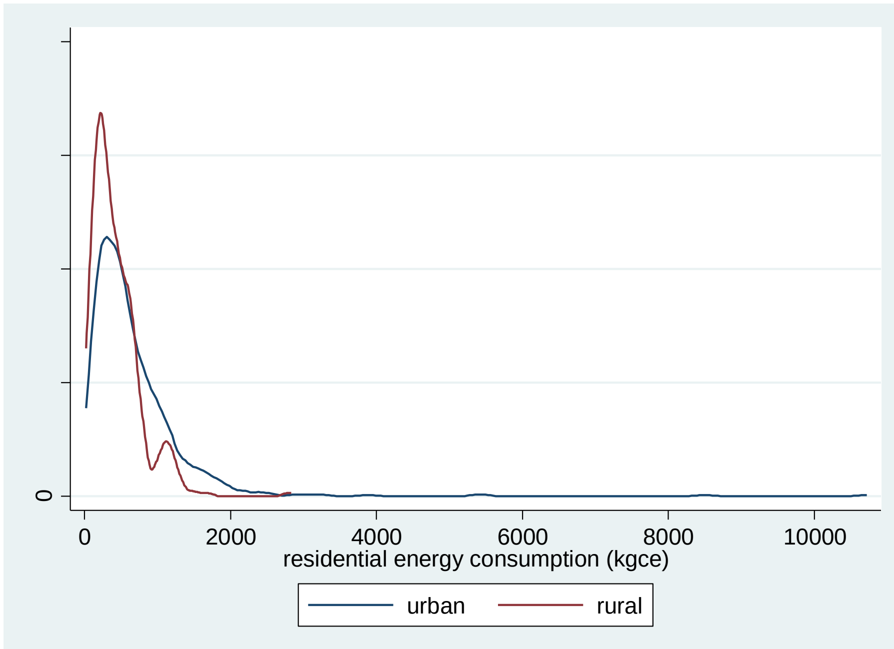
Notes: Data are from State Statistical Bureau from 2000 through 2015.

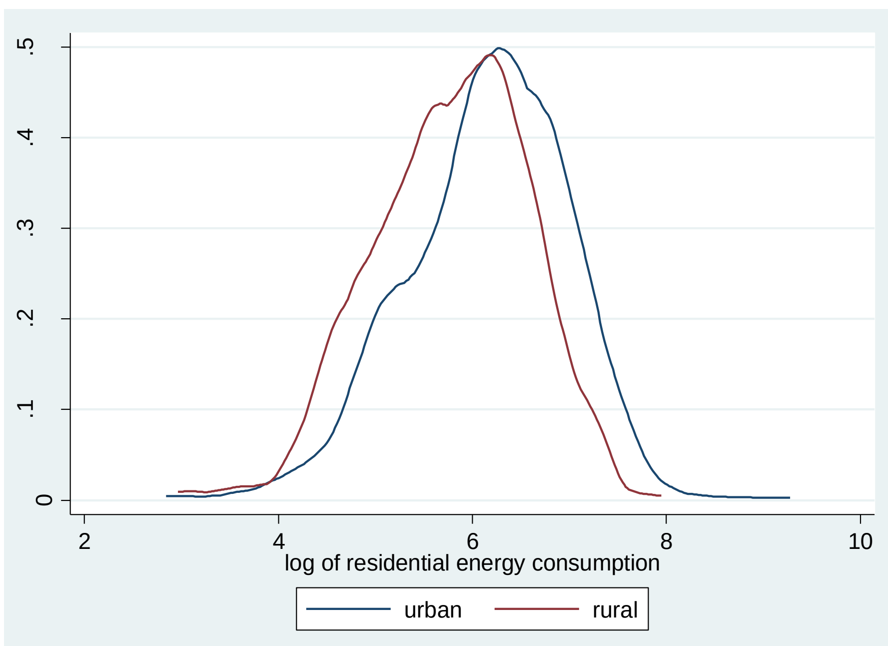
Figure 2. Spatial Distribution of Sampled Households in CRECS 2012



Notes: The surveyed households are randomly sampled, covering 95 prefecture-level cities from 27 provinces in mainland China, except Jiangsu, Tibet, Qinghai and Shaanxi.

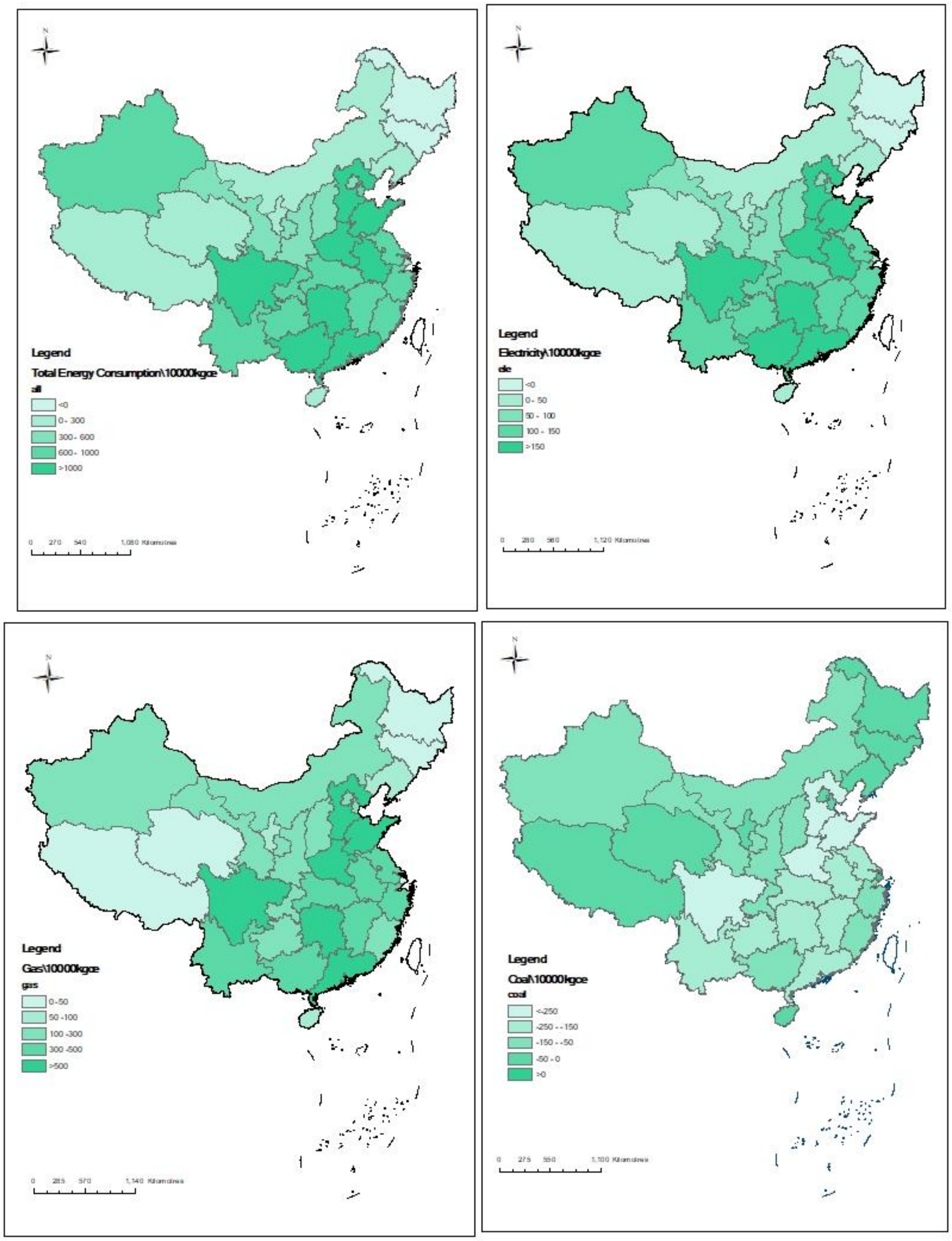
Figure 3. Distribution of Residential Energy Consumption in Urban and Rural Areas





Notes: Total energy consumption per capita and the natural logarithm of the total energy consumption per capita are depicted, respectively.

Figure 4. Spatial Distribution of Residential Energy Consumption Changes from 2012 to 2020 Induced by Urbanization



Notes: Based on the regression results and the changes of population and urbanization in each province in mainland China, we simulate the spatial distribution of the change of residential energy consumption as well as electricity, gas and coal in each province.

Table 1. Conversion Coefficients and Energy Consumption per Capita

Energy	No. of Obs.	Conversion Coefficient	Physical Quantity		Standard Quantity (unit: kgce)		
			Mean	Unit	Mean	Min	Max
Electricity	1,425	0.123	771.626	kWh	94.91	2.219	1016
Central heating	1,425	1	289.2	kgce	289.2	0	10432
Coal	1,425	1.33	4.881955	kg	6.493	0	489.7
LPG	1,425	0.357	108.0952	m3	38.59	0	1238
Natural gas	1,425	0.357	294.6779	m3	105.2	0	2731
Biomass energy	1,425	0.714	100.6162	m3	71.84	0	2398
Solar energy	1,425	1	0.0452	kgce	0.0452	0	0.903

Notes: The physical quantities are collected from CRECS 2012. The standard quantities are calculated using conversion coefficients from the China Energy Statistical Yearbooks.

Table 2. Penetration Rates of Energy Types in Urban and Rural Areas

	Urban	Rural	Difference
Electricity	100.00%	100.00%	0.00%
Central heating	49.00%	1.77%	47.23%***
Coal	4.71%	43.10%	-38.39%***
LPG	25.50%	58.00%	-32.50%***
Natural gas	64.00%	7.07%	56.93%***
Biomass energy	8.48%	78.10%	-69.62%***
Solar energy	18.10%	33.60%	-15.50%**
No. of obs.	1,144	281	-

Notes: The first two columns summarize the penetration rates of energy types in urban and rural areas, respectively. The last column shows the differences. The significance level is indicated by stars: *** indicates 1% significance level, ** 5%, and * 10%.

Table 3. Energy Consumption per Capita in Urban and Rural Areas

Panel A: Full sample

	Urban	Rural	Difference
Total	650.1	428.1	222.01***
Electricity	102.1	65.70	36.39***
Central heating	358.0	9.173	348.86***
Coal	1.798	25.61	- 23.81***
LPG	36.97	45.20	-8.24***
Natural gas	128.2	11.71	116.52***
Biomass energy	23.00	270.7	- 247.68***
Solar energy	0.0398	0.0672	-0.027
No. of obs.	1,144	281	

Panel B: Non-zero Sample

	Urban		Rural		Difference
	Mean	obs.	Mean	obs.	
Total	650.15	1,144	428.14	281	222.01***

Electricity	102.09	1,144	65.70	281	36.39***
Central heating	724.94	565	515.52	5	209.42***
Coal	38.80	53	59.97	120	- 21.16***
LPG	143.84	294	78.40	162	65.43***
Natural gas	201.21	729	164.46	20	36.75***
Biomass energy	265.78	99	347.32	219	- 81.54***
Solar energy	0.201	206	0.220	94	0.02

Notes: This table shows the standard quantity of residential energy consumption per capita in urban and rural areas for both full and non-zero samples. The significance level is indicated by stars: *** indicates 1% significance level, ** indicates 5% significance level, and * indicates 10% significance level.

Table 4. Comparison of Factors that Influence Energy Consumption between Urban and Rural Households

	Urban			Rural
	Urban (town and city)	Town only	City only	
Dwelling Characteristics				
Age of residence	13.56	14.27	13.38	17.84
Living area (square meters)	101.09	115.47	97.71	135.37
Central heating (yes = 1, no = 0)	0.49	0.226	0.558	0.0177
Household Characteristics				
Household size (number of residents)	2.541	2.523	2.546	2.936
Annual income per capita (million yuan)	0.048	0.046	0.049	0.019
Average age of members	42	41	42	44
Education level				
Not educated	0.0155	0.0383	0.00974	0.0461
Primary to middle school	0.196	0.366	0.154	0.748
High school	0.282	0.289	0.28	0.167

Bachelor or above	0.506	0.306	0.556	0.039
Observations	1144	235	905	281

Table 5. Residential Energy Consumption and Urbanization

	(1)	(2)	(3)	(4)
Urban dummy	0.177***	-0.086	-0.184***	-0.264***
	(0.055)	(0.064)	(0.062)	(0.081)
Age of residence		0.007***	0.007***	0.004*
		(0.002)	(0.002)	(0.002)
Log of residential area		0.186***	0.253***	0.263***
		(0.052)	(0.049)	(0.059)
Central heating		0.971***	0.969***	0.841***
		(0.068)	(0.064)	(0.084)
Household size			-0.242***	-0.231***
			(0.017)	(0.019)
Average age of members			0.006***	0.006***
			(0.001)	(0.002)
Annual income per capita			1.228***	0.649
			(0.454)	(0.558)
Squared income			-0.807***	-0.548
			(0.302)	(0.372)
Primary or middle school			-0.242***	-0.117
			(0.017)	(0.110)
High school			-0.154	-0.154
			(0.112)	(0.110)

Bachelor or above			-0.198*	-0.083
			(0.114)	(0.112)
Constant	5.632***	4.936***	5.243***	3.850***
	(0.110)	(0.296)	(0.302)	(0.324)
Observations	1,425	1,415	1,400	1,133
R-squared	0.317	0.422	0.550	0.707

Notes: Fixed Effect Models. The dependent variable is the logarithm of the total energy consumption. The first three columns include province dummies, and the last column includes county dummies instead. Robust standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table 6. Penetration of Main Energy Types and Urbanization (Extensive Margin)

	Gas		Coal	
	PLM	Logit	PLM	Logit
Urban dummy	0.239***	0.293 ***	-0.065	-0.009
	(0.048)	(0.053)	(0.051)	(0.044)
Age of residence	-0.004***	-0.005***	0.004***	0.005***
	(0.001)	(0.002)	(0.001)	(0.001)
Log of residential area	-0.016	-0.011	0.043	0.041
	(0.033)	(0.042)	(0.032)	(0.043)
Central heating	0.107**	0.096*	-0.104**	-0.201***
	(0.051)	(0.050)	(0.045)	(0.070)
Household size	0.009	0.012	0.002	0.005
	(0.011)	(0.016)	(0.011)	(0.014)
Average age of members	-0.001	-0.002	0.001	0.001
	(0.001)	(0.001)	(0.001)	(0.001)
Annual income per capita	1.506***	22.356***	-0.377*	3.954
	(0.395)	(6.070)	(0.224)	(20.415)
Squared income	-1.072***	-36.270**	0.199	-120.794
	(0.237)	(14.652)	(0.134)	(172.638)
Primary or middle school	0.015	-0.054	-0.048	0.222 ***
	(0.057)	(0.098)	(0.071)	(0.082)
High school	0.069	-0.047	-0.086	0.199 ***
	(0.061)	(0.037)	(0.073)	(0.057)
Bachelor or above	0.073	0.012	-0.114	0.153***
	(0.062)	(0.032)	(0.072)	(0.056)

Constant	0.217	-1.560	-0.273	-7.742***
	(0.174)	(2.433)	(0.170)	(2.325)
Observations	1,133	845	1,133	622
R-squared	0.631	0.465	0.484	0.394

Notes: Probability Linear Model (PLM) and Logit model. The dependent variable is a dummy variable, which equals one if the main energy is consumed. County dummies are included in all columns. Robust standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.1.

Table 7. Consumption of Main Energy Types and Urbanization (Intensive Margin)

	Total	Electricity	Gas	Coal
Urban dummy	-0.264***	0.126	0.164	-0.506
	(0.081)	(0.083)	(0.219)	(0.465)
Age of residence	0.004*	-0.004**	-0.002	-0.024
	(0.002)	(0.002)	(0.006)	(0.020)
Log of residential area	0.263***	0.154**	-0.058	-0.791*
	(0.059)	(0.060)	(0.133)	(0.461)
Central heating	0.841***	-0.047	0.044	1.364
	(0.084)	(0.098)	(0.255)	(1.765)
Household size	-0.231***	-0.268***	-0.166***	-0.072
	(0.019)	(0.021)	(0.054)	(0.100)
Average age of members	0.006***	-0.003	0.005	0.027***
	(0.002)	(0.002)	(0.005)	(0.010)
Annual income per capita	0.649	1.954***	1.533	-2.225
	(0.558)	(0.659)	(1.205)	(22.585)
Squared income	-0.548	-1.200***	-1.003	109.306
	(0.372)	(0.393)	(0.766)	(197.809)
Primary or middle school	-0.117	0.288**	-0.551**	-0.314
	(0.110)	(0.112)	(0.215)	(0.281)
High school	-0.154	0.322***	-0.597**	-0.534

	(0.110)	(0.118)	(0.261)	(0.370)
Bachelor or above	-0.083	0.398***	-0.640***	-2.073
	(0.112)	(0.117)	(0.222)	(1.856)
Constant	3.850***	3.329***	5.039***	5.052
	(0.324)	(0.321)	(0.870)	(3.333)
Observations	1,133	1,133	922	159
R-squared	0.707	0.492	0.327	0.740

Notes: County Fixed Effect Models. Dependent variable is the logarithm of electricity/gas/coal consumption. Taking logarithm automatically drops households with zero consumption. The regressions in this table, therefore, investigate the intensive margin of urbanization on energy type. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, * p<0.

Table 8. Consumption of Total Residential Energy and Main Energy Types

	Total	Electricity	Gas	Coal
Urban dummy	-48.991	16.902**	116.378***	-10.930***
	(41.437)	(6.798)	(34.267)	(3.229)
Age of residence	2.469**	-0.137	-1.259*	0.833***
	(1.208)	(0.221)	(0.663)	(0.097)
Log of residential area	224.790***	21.402***	46.580*	10.477***
	(46.274)	(6.700)	(25.468)	(0.615)
Central heating	389.535***	-9.228	-74.439	-61.014***
	(53.573)	(8.944)	(45.415)	(4.014)
Household size	-130.045***	-23.415***	-25.639***	-2.303***
	(15.794)	(2.424)	(8.270)	(0.783)
Average age of members	4.565***	-0.246	0.350	0.967***
	(1.051)	(0.176)	(0.655)	(0.059)
Annual income per capita	827.663*	200.660**	165.571	207.579***
	(456.282)	(93.206)	(213.640)	(70.387)
Squared income	-675.698**	-134.999**	-192.543	-1,716.57***
	(305.358)	(54.731)	(173.151)	(335.955)
Primary or middle school	-11.689	24.637**	-36.987	-11.855***
	(66.782)	(10.124)	(27.555)	(2.449)
High school	-110.922	30.693***	-38.253	-31.070***

	(72.546)	(11.193)	(26.983)	(2.662)
Bachelor or above	-67.956	29.164***	-30.782	-79.975***
	(70.329)	(10.830)	(27.912)	(3.462)
Constant	548.909**	2.994	-162.699	-396.127***
	(252.087)	(39.849)	(152.451)	(3.063)
Observations	1,133	1,133	1,133	1,133

Notes: Tobit model with county fixed effects. The dependent variable is the quantity of energy consumed. Robust standard errors are in parentheses: *** p<0.01, ** p<0.05, * p<0.01.

Table 9. Direct and Indirect Contributions of Urbanization to Residential Energy Consumption Change

	Total Energy (kgce)	Electricity (kgce)	Gas (kgce)	Coal (kgce)
Urban dummy	-48.991	16.902	116.378	-10.930
Age of residence	-10.567	0.586	5.389	-3.565
Residential area	-65.815	-6.266	-13.638	-3.067
Central heating	183.977	-4.358	-35.158	-28.817
Household size	51.368	9.249	10.127	0.910
Average age of members	-9.130	0.492	-0.700	-1.934
Annual income per capita	17.309	4.535	2.941	-10.648
Total change	118.151	21.139	85.340	-58.052
Percent change	27.60%	32.18%	35.14%	-96.80%

Notes: Energy consumption change is obtained by multiplying the difference in the factor between urban and rural households and the effect of the factor on energy consumption. Because the number of years of education is not likely to change with urbanization in a short run, education is not included in the calculation of contribution of influencing factors.

Table 10. Forecasted Change of Residential Energy Consumption from 2012 to 2020

	Considering urbanization only （million tons of standard coal）	Considering both urbanization and population growth （million tons of standard coal）
Total Energy	11.851	46.780
Electricity	2.120	7.607
Gas	8.560	16.128
Coal	-5.823	-6.468

Table 11. Onsite and Offsite Urbanization and Energy Consumption

	Total	Electricity	Gas	Coal
Town dummy	-91.843**	12.690	77.333*	-3.991
(onsite urbanization)	(44.473)	(7.945)	(39.694)	(3.256)
City dummy	-8.708	20.861**	144.702***	-23.147***
(offsite urbanization)	(46.667)	(8.317)	(35.045)	(3.867)
Age of residence	2.487**	-0.136	-1.239*	0.832***
	(1.205)	(0.220)	(0.660)	(0.098)
Log (residential area)	229.685***	21.883***	49.695*	8.704***
	(46.397)	(6.671)	(25.371)	(0.617)
Central heating	371.640***	-10.986	-86.656*	-54.421***
	(54.081)	(9.143)	(46.577)	(4.441)
Household size	-130.505***	-23.460***	-26.161***	-2.322***
	(15.856)	(2.425)	(8.327)	(0.786)
Average age of members	4.567***	-0.245	0.336	0.943***
	(1.052)	(0.176)	(0.651)	(0.059)
Annual income per capita	779.493*	195.924**	127.707	214.983***

	(451.014)	(92.970)	(211.286)	(71.091)
Squared income	-640.180**	-131.507**	-164.292	-1,735.63***
	(303.616)	(54.645)	(173.663)	(342.774)
Constant	-20.495	23.771**	-42.343	-10.828***
	(66.346)	(10.098)	(27.675)	(2.456)
Observations	1,132	1,132	1,132	1,132

Notes: Tobit Model. County dummies are included. Education dummies are included but not reported. Robust standard errors are in parentheses *** p<0.01, ** p<0.05, * p<0.

Table 12. Energy Consumption Change Caused by Onsite and Offsite Urbanizations

	Onsite Urbanization				Offsite Urbanization			
	Total (kgce)	Electricity (kgce)	Gas (kgce)	Coal (kgce)	Total (kgce)	Electricity (kgce)	Gas (kgce)	Coal (kgce)
Urban dummy	-91.843	12.690	77.333	-3.991	-8.708	20.861	144.702	-23.147
Age of residence	-8.879	0.486	4.423	-2.970	-11.092	0.607	5.526	-3.711
Residential area	-36.520	-3.479	-7.902	-1.384	-74.877	-7.134	-16.201	-2.838
Central heating	77.413	-2.288	-18.050	-11.336	200.797	-5.936	-46.820	-29.404
Household size	53.899	9.689	10.804	0.959	50.897	9.149	10.203	0.906
Average age of members	-13.701	0.735	-1.008	-2.829	-9.134	0.490	-0.672	-1.886
Annual income per capita	4.979	2.006	-0.534	-36.889	19.245	5.017	2.830	-3.853
Total change	-14.653	19.838	65.067	-58.440	167.128	23.055	99.568	-63.932
Percentage change	-3.42%	30.19%	26.79%	-97.45%	39.04%	35.09%	41.00%	-106.61%

Notes: Energy consumption change is obtained by multiplying the difference in the factor between urban (city for offsite urbanization and town for onsite urbanization) and rural households and the effect of the factor on energy consumption.

Because the number of years of education is not likely to change with urbanization, education is not included in the calculation of contribution of influencing factors.