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Research article

Drivers behind energy consumption by rural households in Shanxi

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Abstract: Biomass is widely used by households for cooking and heating in rural China. Along with rapid economic growth over the last three decades, increasing rural households tend to use less biomass and more commercial energy such as coal and electricity. In this paper, we analyzed the key drivers behind energy consumption and switching by rural households based on survey data of energy consumption by rural households in ten villages of Shanxi province in China. Our econometric results show that income growth can induce less use of biomass and more use of coal and modern fuels. However, no evidence shows that even wealthy households has abandoned biomass use in Shanxi, mainly due to the "free" access to land and agricultural resources in these villages. Previous wealth of a household represented by house value can lead to more time spent on biomass collection. Access to land resources has positive effects on biomass use and collection. Other key variables include education, household size, the number of elderly members, and coal price. We also find huge differences between villages, indicating the importance of access to agricultural resources and markets.

Keywords: Energy transition; Energy ladder; Energy stacking; Biomass; Rural households; China

1. Introduction

Although per capita consumption of energy in China is still relatively low, China overtook the U.S. in 2010 and is now the world's largest energy consumer [1]. In China, 32% of total population use some form of traditional biomass energy and most of them live in rural areas [2]. China has a rural population of about 750 million, of which, 377 million (50%) use traditional biomass. The widely used solid fuels such as coal and biomass can have environmental and health consequences. Will the rural households reduce the biomass use and increase commercial fuel use such as coal and electricity in the near future? What factors play a key role to drive the switching process? In the present paper, we provide new evidence to answer these questions by analyzing the key drivers behind energy consumption of rural households in Shanxi.

One of the major concerns pertaining to traditional biomass burning has been the increased deforestation resulting from fuelwood collection. However, fuelwood use in Shanxi is negligible and this should not be an issue. On the other hand, biomass in the form of crop residues and straw, as well as coal, are important energy sources for cooking and heating. Although deforestation is not an issue for these types of fuels, there are still reasons to be concerned with indoor burning of such fuels, as it has several additional negative effects. The use of biomass and coal for cooking and heating can have severe effects on environment, climate, agricultural production, productivity and health, to mention a few. By contrast, crop residues, such as corn stove and straw, help minimize soil erosion when left on the land, and the residues contain important elements that increase soil fertility. Hence, removing crop residues from the land can have detrimental effects on soil quality, such as reduced soil organic matter content, increased soil erosion, and increased land desertification [3].

Solid fuel burning has important health consequences due to the emission of health-damaging pollutants [4]. Almost 2 million people die prematurely from illness attributable to indoor air pollution from household solid fuel use every year [4]. Women and young children are particularly exposed as they spend more time indoors.

It is also worth mentioning that shifting to modern energy sources can improve the productivity of poor people. For instance, labor, biomass and land resources can be used for income-generating activities, and time will be saved if less time is used for collecting biomass, cooking and cleaning.

For these reasons, as well as the fact that China is the world largest energy user and CO_2 emitter, it is of utmost importance to understand the factors driving the growth of Chinese energy use. The energy transition of rural households in the coal-rich province is typical. Our study contributes to this understanding by exploring the determinants of fuel use and fuel switching in rural areas of Shanxi, a coal-rich Chinese province that possesses 260 billion metric tons of known coal deposits, about one third of China's total deposits. Rural households in the province tend to consume more coal and may transition slowly to modern energy. We collected survey data on energy used by rural households from 10 villages in the Shanxi province and estimated regression models for use of biomass, coal, and modern energy, as well as for labor input into biomass collection.

1.1. Theories of household energy use and energy transition

The "poverty-environment hypothesis" (PEH) was first proposed by the 1987 Brundtland Commission and the Asian Development Bank. According to this hypothesis, poor households rely more on environmental resources than non-poor do. Poor households have no option but to use local environmental resources such as biomass, and this hypothesis predicts that biomass use will be reduced when income grows [5]. This hypothesis is supported by Démurger and Fournier [5] who find that household economic wealth is a significant and negative determinant of firewood consumption in rural households in 10 villages in the Labagoumen township in northern China.

A related hypothesis to the PEH is the "energy ladder" hypothesis, which states that households switch from lower to higher quality fuels as their income increases [6–9]. According to Heltberg [8], the model conceptualizes fuel switching in three distinct phases, and transition takes place as a response to higher income, urbanization and scarcity of biomass. The first phase is characterized by full reliance on biomass. In the second phase, households switch to using "transition fuels" such as kerosene, coal and charcoal, while in the third and final phase, they switch to energy types such as LPG, natural gas or electricity. There may be several reasons why households would want to switch to fuel types higher up on the energy ladder, for instance higher efficiency and reduced indoor air pollution, but at the same time these fuel types are often more expensive than the lower quality fuels. According to Masera, Saatkamp and Kammen [10] the energy ladder model implicitly assumes that fuel types higher up on the ladder carries with them a certain status, and that households desire to move up the ladder to demonstrate an increase in socioeconomic status.

The energy ladder hypothesis predicts that low quality fuel types are replaced by fuel types higher up on the energy ladder as income increases, i.e. linear or unidirectional fuel switching, while in reality, we often see that multiple fuel types are used [8,10]. There may be several reasons why households choose to use multiple fuel types, for instance risk minimization (fuel security), or that the different fuels are not perfect substitutes such that using multiple fuels is advantageous to only using one type.

Masera, Saatkamp and Kammen [10] introduce an alternative fuel model, called the "energy stacking" model. Their model tries to account for the empirical observation that many households adopt new fuels without abandoning the old ones, and hence this model is an alternative to the "energy ladder" model. Their model also recognizes that there are several other factors than income, influencing fuel use.

Lastly, the Environmental Kuznets Curve (EKC) hypothesis postulates that there is an inverted U-shaped relationship between income and environmental degradation. This implies that initially, rising income or living standards increase pollution, while later on it decreases [11,12]. The EKC hypothesis has been proposed, and tested, for different pollutants, for instance CO2, SO2, CO, NOx and SPM[1]. Evidence of the existence of the EKC is mixed. Only some air quality indicators (especially local ones) show evidence of an EKC, and the turning points, i.e. when the emissions start decreasing, have been found to vary between the different pollutants [13].

Obviously, these theories of fuel use and fuel transition lead to different predictions of how energy use responds to an increase in income. According to the PEH and the "energy ladder" hypothesis, biomass use will decrease, and while the energy ladder hypothesis have clear predictions for which fuels biomass will be substituted for, the PEH does not. The "energy stacking" model suggested by Masera, Saatkamp and Kammen [10], on the other hand, predicts that households adopt new fuels without necessarily abandoning the old one, but its predictions of what will happen to biomass use are not clear. The EKC hypothesis predicts that emissions first will increase and later

[1]Carbon dioxide, sulphur dioxide, carbon monoxide, nitrous oxides, and suspended particulate matters.

decrease as a response to higher income, but it does not predict at which income level the turning point for emissions will occur. In addition, since its prediction is pollutant-specific, the implications for biomass and coal burning are not obvious as combustion of these results in several pollutants, and emissions may differ between coal and biomass. A theory of wave transition in household energy use has been proposed to capture the features described by the above models [14]. The wave transition theory assumes a bell-shaped curve for an energy type used by households and main energy use is changing over time and along with income.

After a review of previous studies on household energy use, Kowsari and Zerriffi [15] proposed a conceptual framework for studying the household energy use. In their framework, all economic, cultural, and behavioral factors affecting household energy use are organized and associated with three dimensions of energy services, devices and carriers. While this framework is useful to understand the causal relations between key factors affecting household energy use, it demands considerable data and multiscale approaches.

1.2. Empirical studies

The empirical literature on factors influencing fuel use is quite extensive. Still, evidence is mixed regarding which model best describes actual fuel use and fuel switching. We will concentrate on the part of the literature focusing on rural households, as rural households' energy use can differ considerably from urban households' energy use. Rural households often face additional constraints to their use of commercial energy as markets for energy and energy appliances can be limited or non-existing. Their fuel use is often to a larger extent determined by local availability as well as transaction and opportunity costs in collecting the fuel rather than budget constraints, prices and costs [16].

Income (wealth or expenditures in some studies) has been found to be an important determinant of total energy demand in several studies [5,8,17–20], but as Jiang and O'Neill [18] points out, income may have to rise substantially in order for absolute biomass use to fall, and other determinants are also important. In fact, most studies recognize that there are several factors influencing fuel use in addition to income, however there is no consensus regarding which factors determine biomass and/or coal use and fuel switching. Examples of other factors that have been found to have an influence are geography/topography and climate, access to different fuel types, access to markets, infrastructure, fuel prices, household size, education level, size of land area, and distance to forest (in the case of fuelwood) [17,21–23]. According to Jiang and O'Neill [18], the consensus is limited to income and household size as almost all studies find that these are important determinants of fuel switching. For the other suggested factors, evidence is mixed. In the present paper, we will provide new empirical evidence on key determinants of energy used by rural households in China by taking Shanxi as an example.

2. Materials and Methods

2.1. Data

We use data from two surveys conducted in October 2010 in 10 villages of Shanxi: the 2010 Rural Household Survey and the Questionnaire on rural energy consumption in China. The Rural

Household Survey is a yearly survey carried out in all provinces in China by the Ministry of Agriculture[2]. In addition to demographic data, they collect data on employment and income, land situation, assets, agricultural production and sales as well as household expenditures. The Questionnaire on rural energy consumption was carried out for the first time in 2010, and only in the Shanxi province. Both surveys interviewed 954 rural households from Shanxi and were simultaneously conducted by the local office of the Ministry of Agriculture. The selected ten villages are evenly located in Shanxi to represent the overall rural households in the province.

Unfortunately, the data on rural energy consumption were not complete in all villages and we had to exclude three villages completely. In addition, we omitted households with no income information or zero household members. We ended up using a dataset of 571 households.

2.2. Shanxi province and the villages

The Shanxi Province is one out of five provinces that constitute the North China Region with area of 156,300 km^2. The province is bordered by the Yellow River (Huang He) in the west, Beijing and Heibei Province to the east and Inner Mongolia to the north. The province contains 119 counties with its capital set in Taiyuan City. The total population of Shanxi is 35.7 million in 2010, of which 54% live in rural areas [24]. Generally, the central axis of the province has the highest population density, the most populated counties being Taiyuan and Datong.

Shanxi is a major coal provider. The province possesses 260 billion metric tons of known coal deposits, about one third of China's total deposits. As a result, the coal production in Shanxi represents about a quarter of total coal production in China, two fifths of coke production and a seventeenth of total power generation [25]. Even though, Shanxi, together with other central and western provinces, has been lagging behind in the economic growth since the reforms in 1978. In 2010, income per capita in Shanxi was 81% of the average in China [24].

The province is largely mountainous and has a continental monsoon climate, which means that most of the precipitation falls in summer. Most of the province lies within the Loess Plateau. The fine texture of the loess soils makes the area highly susceptible to wind and water erosion [26], and high rates of erosion has caused problems for agricultural production for at least 3000 years [27]. The loess soil is still highly fertile and suitable for agricultural production [28]. Winter wheat and maize used to be the main agricultural crops in the region [29], but according to our data wheat is not commonly grown anymore. Today, the most important crops are maize, fruits and vegetables.

2.3. Income sources in rural Shanxi

Even in rural areas of Shanxi, agriculture is still a major income source, but its importance is declining and production systems vary from village to village. In villages close to urban centers more valuable, but perishable, products such as fruits and vegetables are becoming economically more important than staple grains. In our sample (Table 1), two villages (7 and 8) produce fruits as the economically most important agricultural product. Both villages are situated closer than 5 kilometers from urban centers. In these relatively urban areas, household incomes are also above the average for

[2]See http://www.rcre.moa.gov.cn/jizn/jgsz/ncgdgcd/ for a Chinese introduction of the survey office of the ministry.

all villages. The poorest villages (2, 6 and 9) are located in remote mountainous areas where transport is not convenient and the agricultural conditions are poor.

Table 1. Income in the villages.

	Village name	No. of households	Houshold income (Yuan)	Family business	Wages	Property rent	Transfers	Most important crop	% income from agriculture	Land area (Mu)
Total sample		571	25,521 (20,861)	59%	36%	2%	3%	Maize	37%	9.3 (7.3)
Village 1	Xiaolinhe	101	23,325 (13,954)	88%	8%	2%	2%	Maize	42%	9.4 (6.5)
Village 2	Daoba	104	17,866 (9571)	48%	45%		6%	Maize	41%	11.1 (8.3)
Village 3	Zhen'anzhai	88	29,200 (21,091)	40%	55%	3%	1%	Maize	35%	9.1 (8.5)
Village 6	Lijiawa	83	17,528 (10,931)	21%	70%	5%	4%	Maize	13%	11.8 (5.9)
Village 7	Xi'ao	95	43,765 (31,254)	74%	22%	1%	2%	Fruits	64%	10 (7.1)
Village 8	Huangdoujing	60	27,251 (20,510)	69%	29%	2%		Fruits	53%	4.9 (5.1)
Village 9	Xiaosai	40	13,537 (9312)	29%	60%	1%	10%	Maize	17%	4.3 (1.6)

Source: Household survey conducted by the authors. The last-year data were collected in October 2010. Standard deviations are reported in parentheses for household income and land area.

2.4. Energy use

Our data show that on average, a rural household in Shanxi consumes 1863 kg standard coal equivalents (kgce) energy sources. Since the household size is 3.72, one person consumes 500 kgce energy sources. This is almost 10% higher than the national average of 464 kgce per capita in rural China in 2008 [30]. Yao, et al (2012) found that biomass use decreased from 80% of residential energy use in rural China in 2001 to 70% of residential energy use in 2008. This picture is rather different in rural Shanxi where coal is the most important energy source and accounts for 60% of total energy use, while biomass accounts for only 21% according to our survey. Of the households using biomass, 55% use only straw, mainly from own land, and 36% use branches, while the others use a combination of branches and straw. Only 3% of households use solely biomass collected from public land. Households using biomass spend on average 18 days collecting biomass per year. Elderly household members collect close to 30% of the biomass, while other adult members in the household collect the rest.

Biomass is mainly used for cooking and only a small proportion is used for heating. In addition to biomass, people also use coal, electricity and gas for cooking to prepare food. Almost 80% of the households use biomass for cooking, 63% use coal, 54% use electricity and 26% use gas. Electricity is commonly used for cooking rice and 48% have an electric rice cooker, while 13% of the households own an electric stove. Almost 80% of the households use a combination of at least two of these energy sources for cooking and 40% use three or more energy sources for food preparation (Table 2).

Table 2. Energy sources used for cooking.

Mixed energy sources	% of households using	Energy used for cooking (kgce)						Total
Only 1	21	Biomass 85	Coal 22	Electricity 9		Gas 2		118
2	39	Biomass+Coal 68	Coal+Electricity 65	Biomass+Electricity 49	Biomass+Gas 26	Gas+Electricity 11	Coal+Gas 3	222
3	36	Biomass+Coal+ Electricity 119	Biomass+Coal+ Gas 55	Biomass+Electricity+Gas 24		Coal+Electricity+Gas 5		203
All 4	4	Biomass+Coal+Gas+Electricity 24						24

Source: Household survey conducted by the authors. The last-year data were collected in October 2010.

Our data indicate that domestic energy use per capita is stable at lower-income levels, but increases at high-income levels (see Table 3). Coal use per capita seems to increase in both absolute and proportional levels as income increases. The use of modern, more efficient energy sources such as electricity and gas is very low in all income categories, but it seems to increase in both absolute and proportional levels as income increases. In the lowest income quartile, electricity and gas accounts for 4% of all energy use, while it increases to 6% in the highest income quartile. Whereas the use of coal and modern energy sources increases with income, the use of biomass decreases in both absolute and relative terms. In the lowest income quartile, 32% of all domestic energy comes from biomass, while it is only 16% in the highest income quartile.

Table 3. Per capita use of yearly energy sources in income quartiles.

Income quartiles	Average income (Yuan)	Energy Use (Kgce)				
		Total	Biomass	Coal	Electricity	Gas
Lowest	2,579 (809)	480 (228)	155 (216)	305 (210)	17 (12)	2 (6)
Medium low	4,743 (544)	448 (287)	128 (194)	298 (180)	19 (12)	3 (8)
Medium high	6,950 (848)	485 (312)	104 (134)	356 (279)	21 (12)	4 (7)
Highest	15,135 (8,199)	665 (455)	112 (148)	512 (422)	34 (32)	7 (13)

Source: Household survey conducted by the authors. The last-year data were collected in October 2010. Standard deviations are reported in parentheses.

2.5. Methodology: Theoretical and empirical specification

In the previous section, we saw that people use biomass mainly for cooking. coal, electricity and gas are alternative sources of cooking energy. We therefore focus on biomass, coal and modern energy sources (electricity and gas). While coal and modern energy is traded in the market, there are no buying or selling of biomass in the villages. Households collect biomass only for own consumption and markets for biomass are missing. Thus, the joint production and consumption of non-commercial fuels suggests the use of a non-separable household model for analyzing household energy choices [31]. Chen, Heerink and van den Berg [17] show that optimal labor allocation leads to a specific amount of biomass collected and a certain monetary income from agriculture and wage employment. The biomass is used for consumption, while the money earned is spent on coal, modern energy and other goods.

We aim to investigate factors determining the use of biomass, coal, modern fuels and a possible switch from biomass to other energy sources in rural Shanxi. Therefore, we focus on four dependent variables: quantity of biomass used (*Qbm*), time spent on the biomass collection (*Tbm*), quantity of coal used (*Qc*) and the quantity of "modern fuels" (electricity and gas) used (*Qmf*). Each of these variables (represented by *Q*) can be expressed by a function of explanatory variables in a reduced form, $Q = f(xc, xf, Pco, \ldots)$.

In the function, household characteristics related to consumption (*xc*) are represented by household size, the share of labor-age members, the number of elderly members, mean education of adult household members and household wealth, which includes two indicators of income[3] and the value of the house owned by the household. Farming endowment (*xf*) is represented by the amount of land owned by the household. Coal price (*Pco*) is included in our model because households in a village can face different coal prices after selective subsidies from village collectives are deducted from the market coal prices. Prices of other goods are not included since they are assumed to be the same for all households living in a village and will be captured by village dummy variables. Table 4 shows the statistical description of these variables.

The specific functional form of the reduced-form equations cannot be derived analytically as long as the model is non-separable. Hence, we assume that the functions are linear and test for second-order effects of all the explanatory variables.

Table 5 shows the expected signs of all the explanatory variables used in the regression analysis. Household characteristics such as education, household size and wealth variables will have a direct effect on consumption preferences. They might have either positive or negative effects on consumption goods that require energy inputs.

Households with higher education levels are expected to lead a more modern lifestyle and therefore be using less biomass and more commercial energy sources. The same argument holds for more wealthy households. We believe they will have higher alternative value of their time and spend less time on collecting and consuming biomass, while they also have more money to spend on energy purchased from the market including as coal, gas and electricity.

[3]When making decisions on energy use, a household must consider its budget constraint for the whole household, i.e., total income of the household. This implies that total household income is a suitable independent variable.

Table 4. Summary statistics of the regression variables.

Variable	Definition	Mean	Variance
Dependent variables			
Biomass	Biomass use (kgce)	398.5	577.6
TimeBioCollection	Time for biomass collection (days)	13.2	23.5
Coal	Coal use (kgce)	1133.1	737.8
Modernfuel	Gas and electricity use (kgce)	87.9	72.4
Explanatory variables			
Hhincome	Household income (Yuan)	25,521.4	20,861.1
Housevalue	Vaue of owned houses (Yuan)	23,155.9	38,204.2
Landarea	Land area (Mu)	9.3	7.3
Coalprice	Coal price (Yuan per ton)	613.0	238.0
Meaneducation	Mean education of adults (years)	6.7	2.1
Hhsize	Household size	3.7	1.5
TotOlder	Number of elderly	0.33	0.64
Labourshare	Share of adult members	0.75	0.30

Source: Household survey conducted by the authors. The last-year data were collected in October 2010.

Table 5. Expected signs of explanatory variables used in the regression analysis.

Explanatory variables	Dependent variables			
	Biomass	TimeBioCollection	Coal	Modernfuel
Hhincome	–	–	+	+
Housevalue	–	–	+	+
Landarea	+	+	?	?
Coalprice	+	+	–	+
Meaneducation	–	–	+	+
Hhsize	+	+	+	+
TotOlder	+	+	–	–
Labourshare	+	+	+	+

We assume that larger households consume more food and therefore need more energy for preparing food. Since biomass is mainly used for cooking, we assume that bigger households will tend to use more biomass. Bigger households will also demand more use of appliances using electricity and therefore we expect a positive effect on modern fuel consumption. Coal is used for both cooking and heating, and we expect a positive correlation between coal consumption and household size.

Forests are more or less absent in our study area and people mainly use biomass from their own land. We therefore expect to find a positive correlation between access to land and both consumption of biomass and time used to collect biomass. On the other hand, we do not believe we will find any correlation between access to land and use of commercial fuels other than biomass.

The elderly members in a household may prefer a more traditional lifestyle, meaning that a household with one additional elderly member may use more traditional biomass and have more time for biomass collection, and use less commercial energy. Hence, we expect positive effects of the number of elderly members on biomass use and its collection time, but negative effects on coal use and modern fuel use.

Household labor endowment should have a positive effect on the use of labor (and leisure), including labor for biomass collection. We therefore expect a positive effect on biomass consumption of the share of labor-age members in a household.

In all villages, households could choose between several energy sources. Biomass is the most commonly used fuel for cooking, but 25% of the households do not use biomass at all. Coal is used (both for cooking and heating) by almost 90% of the households and gas is also frequently used. Electricity is the only energy source that is used by all households and hence, the modern fuel model will be estimated by the OLS regression method. Possible heteroscedasticity in the regression will be dealt with by the robust version with the regress command in Stata[4]. Because many households do not use biomass and coal, meaning zero values for coal and biomass consumption and the time for biomass collection. Thus, Tobit (truncated) regression methods are applied to the three models other than the modern fuel model.

We have considered squared terms of all the explanatory variables listed in Table 5. We found that only squared income and land area show statistically significant in the regressions of biomass and total labor. All other squared terms did not improved the regression results and were removed from the regressions.

3. Results and Discussion

Table 6 reports the regression results for biomass consumption, time used to collect biomass in the survey households, coal consumption and modern fuel consumption.

Household income has significant effects in all of the regressions. As expected, higher household income leads to reduced use of biomass and increased use of both coal and modern fuels. The same income can induce higher rates of increase in coal and modern fuel use than rates of decrease in biomass use for the rural households. This shows that wealthier households increase total energy use and switch from biomass to coal and modern fuels, which is in line with the "energy-ladder" theory of fuel-switching away from biomass as income increases. The reduction in biomass use can be explained by the increasing labor cost associated with income growth. This is confirmed by negative coefficient of income in the regression of time used for biomass collection, indicating that higher income reduces the time for biomass collection used by a household. Furthermore, the reduction in biomass use and time for its collection are diminishing with income growth as shown by the positive coefficients of the squared income. This may indicate that biomass may not be abandoned for a long period until household income reaches a considerable high level.

[4]A explanation on how the robust regression solves the heteroscedasticity problem can be found at http://www.stata.com/meeting/germany12/abstracts/desug12_jann.pdf

This phenomenon is consistent with the energy stack theory and was called a “floor effect” by Démurger and Fournier [5]. Based on a larger dataset on energy use of three provinces of Shanxi, Zhejiang and Guizhou, Zhang, Wei, Glomsrød, et al. [20] have found similar evidence on the “floor effect.”

House value is the other wealth variable we use in our regressions. Surprisingly, this wealth variable was only positively and significantly correlated with the time for biomass collection. Moreover, the house value seems positively correlated with the use of all the three energy types even though the correlations are not statistically significant. This makes us doubt if the house value is a suitable indicator of wealth owned by the households. A regression shows that the house value can only explain 10% of variations in income based on the same dataset. If income is taken an indicator of current and potential ability to increase wealth of a household, then the house value can be taken as an indicator of previous wealth owned by the household. When a household owns a high value house, the household may spend a large share of its savings to buy the house and become short of current savings, implying a stricter cash constraint for current consumption. Hence, the household may use more time for biomass collection, and use more biomass as well, to reduce current cash spending to some extent. This can be an explanation for the unexpected positive effects of the house value on the time for biomass collection and biomass use.

Table 6. Tobit regression output of key energy variables used by rural households in Shanxi.

	Biomass	Time Bio Collection	Coal	Modernfuel
Hhincome	−0.0172***	−0.000790***	0.00633***	0.000567***
	(0.00360)	(0.000131)	(0.00169)	(0.000200)
Hhincome squared	8.67e-08***	4.04e-09***		
	(2.60e-08)	(9.26e-10)		
Housevalue	0.000745	0.000103***	0.00144	0.0000238
	(0.000796)	(0.0000276)	(0.000875)	(0.0000840)
Landarea	39.58***	1.804***	−2.113	0.000149
	(9.266)	(0.339)	(4.360)	(0.410)
Landarea squared	−0.279	−0.0295***		
	(0.263)	(0.00932)		
Coalprice	0.397*	0.0108	−0.183	0.0853***
	(0.207)	(0.00757)	(0.219)	(0.0259)
Meaneducation	−5.087	−1.042*	−0.869	2.559*
	(14.79)	(0.548)	(15.96)	(1.502)
Hhsize	32.62	0.878	59.57***	7.408***
	(19.88)	(0.758)	(20.35)	(1.956)
TotOlder	111.5*	7.193***	139.2**	−0.938
	(61.93)	(2.308)	(67.09)	(5.862)
Labourshare	60.96	11.99**	431.9***	1.762
	(141.3)	(5.360)	(149.4)	(12.00)
Village dummies				
_Ivillage_1	−479.4***	−35.69***	560.6***	2.526
	(91.17)	(6.232)	(94.65)	(4.205)
_Ivillage_3	−247.5*	3.365	632.3***	71.25***

	(96.74)	(3.509)	(102.7)	(11.31)
_Ivillage_6	−487.2***	6.480	285.6**	26.93*
	(119.0)	(4.304)	(124.8)	(14.22)
_Ivillage_7	462.6***	20.17***	−693.9***	27.45**
	(133.7)	(4.917)	(147.5)	(12.93)
_Ivillage_8	542.8***	58.05***	−417.3***	95.83***
	(114.6)	(4.156)	(124.9)	(11.53)
_Ivillage_9	−71.84	44.94***	−96.88	−47.15***
	(132.5)	(4.745)	(145.0)	(10.27)
_cons	−76.34	−19.36***	364.6	−51.59**
	(214.1)	(7.963)	(226.9)	(25.48)
Sigma				
_cons	582.8***	20.00***	661.4***	
	(20.84)	(0.784)	(21.54)	
Regression method	Tobit	Tobit	Tobit	OLS
pseudo R^2 / adj. R^2	0.031	0.138	0.025	0.371
chi2 / F	212.7***	508.2***	207.7***	26.26***
Log Likelihood	−3313.8	−1583.2	−3998.3	−3026.6
N	554	554	554	554

Source: Household survey conducted by the authors. The last-year data were collected in October 2010. Standard errors in parentheses $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Access to land is a highly significant factor when it comes to consumption of biomass and collecting time. Households with more land also use more time for biomass collection and tend to use more biomass as most of the biomass is either straw or branches collected in their own fields. Forests and other public fuelwood sources are almost nonexistent in this area. Moreover, the positive effect of land on biomass use and time for its collection seems diminishing with larger land area owned by the households since the coefficients of squared land area are negative in both regression models. Zhang, Wei, Glomsrød et al. [20] also found a positive effect of land area on biomass use, but did not find evidence on the diminishing effect with larger land area. On the other hand, access to land does not significantly affect the consumption of coal and modern fuels.

As expected, the estimated coefficient of coal price is negative in the coal use model and positive in the other three models, even though it is not statistically significant for the models of coal use and time for biomass collection. When coal price becomes higher, the households would use more alternative energy sources including modern fuel and biomass rather than coal to reduce energy costs. The substitution of energy sources may indicate that the price of an energy source can have considerable effects on energy transition of the rural households. Given the low costs of biomass collection, we would expect that rural households will continue to use biomass for a long period in the future.

All the estimated coefficients of education have the expected signs expect for the coal use model. Households with a higher mean education level spend less time collecting biomass and consume less biomass and coal, but more modern fuel. Even though the coefficient on education were significant only in the modern fuel and the time collecting biomass models, our results indicate that educated households switch to modern clean fuel from “dirty” coal and traditional biomass in recent years with serious air pollution problems in North China. Interestingly, Chen, Heerink and van den Berg [17] found the same result for the biomass collection time, but the opposite result for the use of biomass and coal in two villages of Jiangxi province in South China where it was possible to switch between fuelwood and coal consumption. In their study, it seemed educated households were more efficient in the biomass collection and still used more coal. This was around 2000, when air pollution was still not a big issue in China, particularly not in South China.

Household size has positive effects on the use of all the three energy sources and biomass collection time, statistically significant for the cases of coal and modern fuel use. Bigger households seem to use more energy, particularly coal and modern fuels, than smaller households do. Furthermore, households with more labor relative to the household size use significantly more coal and spend more time for biomass collection than households with more dependents do. This could indicate that available time, or the cost of labor, could be a limiting factor when it comes to collecting and using biomass in 2010, after three decades of family plan policy implemented in China. This result was not found in Chen, et al. (2006)'s study based on biomass data of around 2000 in three villages of Jiangxi.

Our results show that the composition of the households, particularly the number of elderly members, may also affect the choice of energy use. More elderly members in a household have positive effects on coal and biomass use and the time for biomass collection. It seems that the elderly in the households prefer to use traditional biomass and coal rather than modern fuel. In the villages, the elderly may spend significantly more time for biomass collection to continue their traditional life style of energy use and help the households reduce their spending on commercial energy sources. We also checked if the number of children had effects on our dependent variables, but the estimated coefficients were not statistically significant even at the 10% confidence level.

Finally, we find big, systematic and significant differences between the villages when it comes to the use of different energy sources. Villages 1, 3 and 6 use significantly less biomass and more coal than Village 2, while Villages 7 and 8 use more biomass and less coal after controlling for other key determinants such as access to land resources and income. These differences could be due to differences in relative prices between the villages. Another important difference in this regard might arise from the fact that the households in Villages 7 and 8 are fruit producers, and have a higher share of income from agriculture than households have in all other villages. Having access to branches from trees, compared to straw from maize as in the other villages, probably gives more secure and plentiful access to biomass. Households in these two villages also spend more time collecting biomass. We also found that in Village 9, households spend significantly more time collecting biomass than in Village 2, even though they do not consume more, to some extent because Village 9 is a very poor, remote village in the mountains where land is dry and barren. In this village, it requires more labor to collect the same amount of biomass as in productive areas.

4. Conclusion

In this paper, we have reported results of a survey on household energy use in ten villages of Shanxi conducted in the fall 2010 and analyzed the key determinants of their energy use and transition. Our findings support that energy use of these households switches from traditional biomass, via coal, to modern fuels including gas and electricity along with income growth. During the energy transition, biomass is not abandoned as coal and other fuels are adopted, supporting the "energy stack" model. Hence, people do not necessarily abandon biomass use when their income increases, or when they gain access to modern fuel types.

Households with high house value may spend more time on biomass collection as indicated by our results. This may implies that house value as a previous wealth indicator plays a different role from a current wealth indicator such as income. Coal price is also an important positive factor for biomass use and modern fuel use. Higher coal price can promote more use of biomass and modern fuels.

Another key determinant of the biomass use is access to land. Our results show that labor cost can be a constraint to collecting biomass. This has probably changed over the last 10–15 years as an increasing number of working-age members in the households have migrated to the cities. However, the households may still consider biomass a "free" by-product from agriculture and even the wealthy households continue to use biomass in the villages.

We also found significant effects on energy use of several household characteristics such as education, household size, and the number of elderly members. Educated households tend to use more modern fuels and less traditional biomass and coal, while more elderly members in a household have the opposite effects. Larger households tend to use more coal and modern fuels.

Finally, we noticed considerable differences between villages. This may indicate the importance of access to agricultural resources and markets. Hence, we probably require place- and context-specific knowledge to design optimal policies for reducing indoor burning of biomass and coal.

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Conflict of interest

The authors have no conflict of interest.

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