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Analysis

Rural Household Energy Use and Its Determinants in China: How Important Are Influences of Payment for Ecosystem Services vs. Other Factors?

Conghe Song[a,*], Richard Bilsborrow[a,c], Pamela Jagger[b], Qi Zhang[a], Xiaodong Chen[a], Qingfeng Huang[d]

[a] Department of Geography, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA
[b] Department of Public Policy, Curriculum for Environment and Ecology, and Carolina Population Center, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA
[c] Department of Biostatistics, Department of Geography and Curriculum for Environment and Ecology, and Carolina Population Center, University of North Carolina at Chapel Hill, Chapel Hill, NC 27599, USA
[d] School of Forestry and Landscape Architecture, Anhui Agricultural University, Hefei, Anhui 230036, PR China

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ABSTRACT

Fuelwood is an essential environmental good for livelihood in rural China. Heavy reliance on fuelwood is associated with numerous negative externalities. Due to decades of rapid economic growth in China, we hypothesize that the increase in rural household income would reduce reliance on fuelwood. Using data from a survey of 481 households conducted in 2014, we examined the effects of two payments for ecosystem services programs, the Conversion of Cropland to Forest Program (CCFP) and the Ecological Welfare Forest Program (EWFP), on energy use, along with other factors. We found that the CCFP did not significantly affect fuel choice nor the quantity of fuelwood used, but households with more forestland in EWFP were less likely to adopt modern fuels and likely to use more fuelwood. Household per capita annual income was the main factor promoting adoption of modern fuels, while household size was the most important factor determining the quantity of fuelwood used per capita. Overall, the gradually increasing adoption of modern fuels has thus far not resulted in any significant abandonment of fuelwood. Fuelwood remains the dominant fuel across all income groups, suggesting that households in the study area are in the early stages of the energy transition.

1. Introduction

Access to fuelwood and other affordable energy sources is essential to the livelihoods of rural households in developing countries. At present, roughly 2.7 billion people in the world use fuelwood to satisfy their basic energy needs (Bailis et al., 2015, IEA, 2016), the vast majority in developing countries. Reliance on fuelwood and other biomass fuels (e.g., crop residues, charcoal) has implications for the climate (Ramanathan and Carmichael, 2008), environmental sustainability (Bailis et al., 2015), and human health and well-being (Smith, 2000; Martin et al., 2014; Sovacool, 2012). Given this suite of negative externalities, it is socially desirable for fuelwood users to shift to cleaner energy, such as electricity or liquid petroleum gas (LPG). Shifting from fuelwood to modern fuels can also lead to ecosystem restoration due to reduced pressure on forest resources (Wang et al., 2012). Studies have been carried out to understand the factors that influence a rural household's fuelwood use in developing countries (Baland et al., 2010; Bandyopadhyay et al., 2011; Jumbe and Angelsen, 2011; Singh et al., 2010), and the factors that motivate switching from fuelwood to modern fuels. Because of both the environmental and health benefits associated with using modern fuels instead of fuelwood, many governments have policies to promote rural households to switch from biomass to modern fuels, but often with limited impacts (Arnold et al., 2006; Mahiri and Howorth, 2001; Madubansi and Shackleton, 2007). This may well be due to our lack of understanding of the factors determining rural household fuel use, which is a complex behavioral, cognitive and social process (Kowsari and Zerriffi, 2011), as well as a focus on demand side behavioral models which fail to take into account supply side constraints (Lewis and Pattanayak, 2012; Jagger and Perez-Heydrich, 2016).

1.1. Energy Ladder vs. Fuel Stacking Theories

Two competing theories exist in the literature with regard to the choice of fuels used by rural households in developing countries. One is the “energy ladder” theory (Leach, 1992), which differentiates energy

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[*] Corresponding author.
E-mail address: csong@email.unc.edu (C. Song).

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use into primitive (animal dung, stalks, and fuelwood), transitional (kerosene, coal) and modern (LPG and electricity) fuels. Under the energy ladder theory, household energy choice moves from primitive to transitional to modern fuels as incomes increase. Primitive fuels are dirtier and less efficient but cheaper, while modern fuels are more energy efficient and cleaner, but also more expensive. Poor households are constrained by income to use cheaper and dirtier fuels, while rich households can afford the more expensive and cleaner ones. Household income has been found to be the most important factor in determining fuel choices in several previous studies (Arnold et al., 2006; Cooke et al., 2008; Foster et al., 2000; Heltberg, 2005; Hiemstra-van der Horst and Hovorka, 2008). The *energy ladder theory* assumes a complete transition from primitive to more advanced fuels eventually occurs as income rises. A competing theory, the *fuel stacking theory*, states that rural households adopt new fuels as income rises without necessarily abandoning the old fuels. In other words, rural households do not simply switching fuels, but "expand" their fuel portfolio, using multiple fuels at the same time, taking advantage of the benefits each fuel provides with enhanced energy security (Masera and Navia, 1997; Masera et al., 2000; Gupta and Köhlin, 2006; Nansaior et al., 2011). Even advanced fuel users can continue to use traditional fuels such as fuelwood and charcoal.

Energy ladder theory captures the importance of income in determining rural household fuel choice. Strong evidence has been found at the macro-level on the effects of income growth in altering energy sources (DeFries and Pandey, 2010; Jiang and O'Neill, 2004; Zhang et al., 2009). At the core of the two theories is whether fuelwood would be *completely* replaced by modern fuels as income rises or only partially. The energy ladder theory makes two implicit assumptions: (1) Fuelwood is the "fuel of the poor" who uses it by necessity, not by choice, and (2) modern fuel is preferred universally. Therefore, once income rises sufficiently, fuelwood use will be completely replaced by modern fuels. However, there is growing evidence to show that the reality is much more complex than the energy ladder theory predicts. While income is one of the most important factors in determining rural household fuel choice, there are numerous other factors as well–geographic location, household demographic characteristics, availability and cost of fuelwood and other fuels, culture, and preferences, which collectively may encourage rural households to adopt multiple fuels at the same time (Masera and Navia, 1997; Rao and Reddy, 2007; Gundimeda and Köhlin, 2008; Pachauri and Jiang, 2008; Peng et al., 2010; Liu et al., 2013; Tang and Liao, 2014). Fuelwood has been found to be a key component of rural household fuel use across a wide range of the income spectrum (Cooke et al., 2008; Hiemstra-van der Horst and Hovorka, 2008), not an "inferior good" (Shi et al., 2009; van der Kroon et al., 2013), whose consumption declines with income. But this does not mean its use disappears as income rises. In places where fuelwood can be freely collected, its use is not well influenced by income (Hosier and Dowd, 1987; Heltberg, 2005).

1.2. Fuel Use in Rural China

China is the largest developing country in the world by population, and the number one contributor to greenhouse gases and global warming making energy use a major issue. Wang and Feng (2001) found that household energy consumption in rural China has evolved through three stages: the serious energy shortage stage before the 1970s; a stage of barely sufficient energy from the 1970s to the 1980s; and the sufficient stage from the late 1980s to present. The shortage of cooking fuel disappeared in the late 1980s as a result of rapid agricultural development, producing more straw and stalks that could be used as fuel. At the same time, commercial energy, such as coal and kerosene, became widely available. Biomass remains the primary fuel for rural households in China (Wang and Feng, 2005; Peng et al., 2010; Tang and Liao, 2014), although biomass energy as a share of total energy consumption is decreasing rapidly for the country as a whole (Zhang et al., 2009). Rural energy consumption is also highly variable across the country because of large variations in climate and natural resources endowments as well as the level of economic development (Zhang et al., 2009; Wang et al., 2015). For example, space heating accounts for the majority of household energy expenditures in northern China (Liu et al., 2013). Households use coal as the primary energy source in coal rich areas and fuelwood as the main source in forest-rich regions (Zhang et al., 2009; Sun et al., 2012). But as in other developing countries, household per capita income has been found to be a primary determining factor of household energy consumption in China (Zhang and Kotani, 2012; Sun et al., 2012; Liu et al., 2013).

1.3. The Conversion of Cropland to Forest Program and the Ecological Welfare Forest Program

Since the Chinese government adopted the open and reform policy in the late 1970s, China's economy has been growing at a double-digit rate until recently. Such an economic growth has provided unprecedented economic opportunities in the cities for rural residents. Through off-farm employment and remittances from migrants, rural household incomes have increased significantly. In fact, Song et al. (2014) found that nearly 92% of the household cash income in part of our study area came from off-farm employment. Off-farm employment almost always pays much better than farming, increasing the opportunity cost of fuelwood collection (Wang et al., 2012). According to the energy ladder theory, the significant increase in rural household income should promote use of modern fuels and reduce consumption of biomass fuels in rural China, presumably bringing in health benefits as well as environmental improvements.

Despite the rapid economic growth since the late 1970s, environmental conditions in China continued to deteriorate. In the wake of unprecedented natural disasters in the late 1990s, the Chinese government implemented a series of environmental restoration and conservation programs and new forest management practices intended to improve the ecological environment (Zhang et al., 2000; Zhang and Song, 2006; Song and Zhang, 2010; Zhang et al., 2015). Among them, the Conversion of Cropland to Forest Program (CCFP) is the most expensive and impactful program, involving 32 million households (Liu et al., 2013; Yin et al., 2010). CCFP is essentially a government-financed payment for ecosystem services (PES) program. Farmers converted croplands on steep slopes (> 25°) or otherwise ecologically sensitive croplands to forest. The central government compensated households based on the area of cropland reforested at a rate of RMB 3450 Yuan/ha/yr for eight years in the initial contract period for households located in the Yangtze River Basin or southern provinces, and RMB 2400 Yuan/ha/yr for households in the Yellow River Basin (China State Council, 2000). The central government renewed the CCFP program for another eight years in 2007, but at much reduced compensation rates for farmers of RMB 1875 Yuan/ha/yr and RMB 1350 Yuan/ha/yr, respectively (China State Council, 2007).

In addition to the forest conservation and restoration programs, China implemented sweeping changes in forest management. To clarify the goals of forest management, the Chinese government issued a series of new policies near the end of the 1990s (CSAF, 1996, 1999, 2001), in which forests that provide critical ecosystem services were designated as ecological welfare forests. Commercial logging was prohibited in these forests. The central government along with the provincial government jointly created the Ecological Welfare Forest Program (EWFP) that compensates forest owners for forfeiting their logging privilege. In our study area, the EWFP compensation for households was RMB 131.25 Yuan/ha/yr in 2014. However, the amount of land that farmers have in EWFP in these mountainous rural areas is usually many times that of their CCFP land, so most households receive more compensation from the EWFP land in the study area. Households enrolled in EWFP receive 417.5 Yuan/yr on average in the study area, compared with 142.5 Yuan/yr from CCFP. Although the direct compensations from these programs are low compared with average total household gross income in 2014, they were significant in the early 2000s when the PES programs were first implemented. Thus rural household income would have increased three times from the early 2000s to 2014, if it grew at the national rate of nearly 10% per annum.

The combination of the direct compensation from CCFP and the EWFP and the indirect income from other activities as a result of the implementation of the programs (such as remittances from migrants) could significantly raise rural household income over the time period observed, which could allow them to adopt more modern fuels and shift away from fuelwood. At the same time, these PES programs may also increase the availability of fuelwood, which may facilitate its use, partially offsetting the environmental benefits both programs bring. Therefore, we are particularly interested in understanding the roles of the CCFP and EWFP in rural household fuelwood use, providing valuable information for China's forest policy-makers.

1.4. *Hypothesis and Research Questions*

We hypothesize that the rising household incomes resulting from riding the tide of China's overall economic growth as well as the direct and indirect income as a result of enrollment in CCFP and EWFP will motivate households to shift from biomass fuels to modern fuels in the study area. Specifically, we address the following questions: (1) Do we find evidence supporting the energy ladder theory or the fuel stacking theory? (2) Has the implementation of CCFP and EWFP resulted in changes in fuel choices in the rural study area? (3) Have CCFP and EWFP influenced the quantity of fuelwood used in the households studied? To the best of our knowledge, no one studied the impacts of CCFP and EWFP on rural households' fuel use, and no one studied the fuel use situation in our study area before.

2. Methods

2.1. *The Study Area*

Our study uses data collected in Tiantangzhai Township, Jinzhai County in Anhui Province, China (Fig. 1) during the summer of 2014. The Township spanning 189 km^2 falls within the Tianma National Nature Reserve, which also includes five state-owned forest farms in the surrounding areas. The population of the Township, according to the 2012 household registration (*Hukou*), was 17,295 persons or 4369 households, living in seven administrative villages comprising 165 resident groups, the vast majority being rural clusters of 10–40 households with plots that include both forest and croplands. The study area is located in the Dabieshan Mountain Range, with elevations ranging from 363 m to 1729 m above sea level, and has a subtropical climate with a mean annual precipitation of 1350 mm and a mean annual temperature of 16.4 °C. Given the abundant water supply and warm climate, the area is lush with vegetation. Eighty percent of the Township is covered with forests, most of which are naturally occurring (vs. plantations or woodlots) (Zhang et al., 2016). Rice is the main crop; due to the relatively high elevation, only one rice crop per year is cultivated. Corn, sweet potatoes and other dryland crops are also grown in the relatively high elevations.

The CCFP was first implemented in Tiantangzhai Township in 2002, with 753 households participating. According to Song et al. (2014), households in this area were generally satisfied with the level of compensation they received from the central government in return for enrolling in the CCFP. Due to relatively high natural forest coverage, every household in the Township has some forests enrolled in EWFP, ranging in size from a fraction of a hectare to dozens of hectares.

2.2. *Sampling Design*

We selected Tiantangzhai Township due to its remoteness and historically high poverty rate. It is located in a county that was designated as a “county in poverty” by the Chinese government, suggesting that compensation from CCFP and EWFP would have a larger marginal impact on human well-being than that in a more affluent area. Our overall research strategy was to collect data for roughly equal numbers of households enrolled in the CCFP program and not enrolled in the CCFP, with a target of approximately 500 households altogether. Since every household in the study area has some forests enrolled in EWFP, ownership of ecological welfare forest (and receipt of EWFP payments) was not a factor in the sampling design.

We drew the sample using a list of all households in each of the 165 resident groups (RGs) provided by the Township Forest Station, and a roster of household heads by name participating in CCFP in each RG. This allowed us to calculate the proportion of households enrolled in CCFP for each resident group (Table A1). A total of 753 out of 4369 households were enrolled in the CCFP (17.2%). In order to select the desired sample size of about 500 households with approximately equal numbers enrolled and not-enrolled in the CCFP, we thus oversampled resident groups which had higher proportions of households in the CCFP, using a two-stage stratified disproportionate random sampling strategy, with the 165 resident groups as the first stage sampling units. We first formed strata based on the proportions of households enrolled in the CCFP for each RG. The 165 resident groups were classified into 5 strata, as shown in the Appendix Table A1.

Based on a previous smaller household survey in the study area (Song et al., 2014), and a pretest of the questionnaire for the present survey, we estimated that a field team of four interviewers and a supervisor could visit about 20 households per day. Given the costs of training, salaries, travel, hotels/lodging and food, plus insurance for fieldworkers, the budget available allowed for covering about 40 RGs in about 40 days of fieldwork. Allowing for nonresponse (most due to significant numbers of dwellings being closed during some or most parts of the year as household members were away working in cities), it was determined that the field team would be able to successfully interview about 12–13 households per day per sample RG selected, so that 40 RGs would yield around 500 completed households.

Table A1 shows the distribution of RGs in the five CCFP strata, and the numbers of RGs sampled using disproportionate sampling. We selected all 10 of the resident groups with the highest CCFP participation into the sample and only 4 out of the 86 resident groups listed as having no households in CCFP. The proportions selected from the five RG strata are 0.05, 0.29, 0.49, 0.79 and 1.0, respectively. Thus all resident groups in the same strata have the same probability of selection, but these probabilities vary across strata. Different strata therefore have different weights for representing the Township.

Following the selection of resident groups, in the second stage an average of 20 households per RG were selected from the two types of households, including those enrolled and those not enrolled in CCFP. Again a disproportionate sampling scheme was adopted in selecting the households. In strata with high proportions of CCFP households, a higher proportion of *non-CCFP* households were randomly selected to ensure *some* of each of the two types of households would be selected in all RGs in all strata, to the extent possible. The actual numbers of households selected are given in Appendix Table A2. Note this procedure means that the probabilities of selection of households with and without CCFP participation vary for each of the 40 sample resident groups. The inverse of these probabilities are the household weights from stage two of the sampling process.

To adjust for the unequal probabilities of selection of both RGs and households within RGs, the survey weights are used in all analyses. Since weights are the inverse of the probability of selection at both stages one and two, the overall weight for each household is the product of the two weights, the resident group weight for the stratum and the household weight for each of the two types of households in each sample RG. The final household weights also take into account nonresponse, so the actual weights used are based on the actual number of

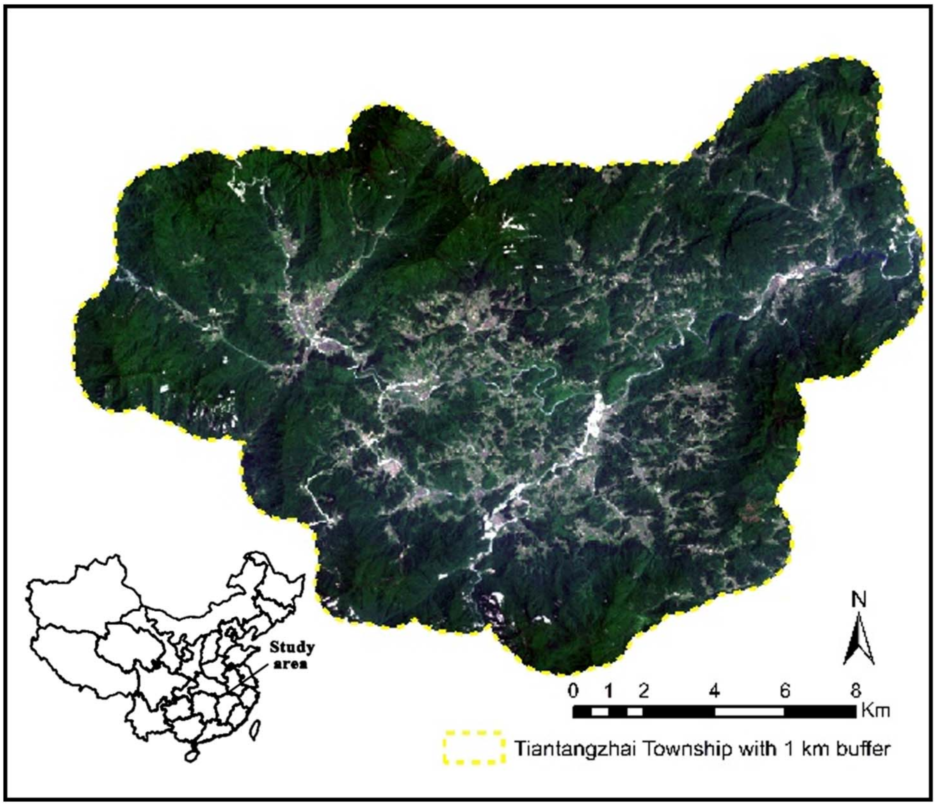

Fig. 1. Study area in Tiantangzhai Township, Jinzhai County, Anhui Province, China. Dark green areas are mostly forest. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

households successfully interviewed relative to the number of households of that type in that resident group available in the sample.

2.3. The Household Survey

A household-level questionnaire was designed to collect data on household demographics (e.g., age, gender, education, and marital status for every household member), agricultural activities, migration, CCFP participation and ecological welfare forest program area, sources of income (e.g., production and sales of crops, animals and animal products; business income, gifts, remittances, government subsidies, etc.), and household expenditures (e.g., food, clothing, transportation, medicines, gifts, etc.). Data for computing a household wealth index was developed based on the condition of the house, sanitary facility, access to electricity and transportation, means of communication, and types of farm tools available. Each category was assigned a score from 0 to 5. Table A3 shows a household wellness scoring scheme with 6 factors, as well as fuels used in the household. Since fuel choice is the variable of interest in this study, it was not included in calculating the overall household wellness index. In addition to the score for household fuel choice, we also asked the amount of fuelwood used by the household in the last 12 months. In order to more accurately estimate fuelwood use, we asked how much fuelwood was needed to cook on average each day; how much fuelwood was needed for heating each day in the winter and how many days of heating were needed; and how often they cooked food for pigs and how much fuelwood was needed each time. By disaggregating fuelwood into these three types of uses, and by using short recall periods, respondents appeared to generally be able to accurately respond to the questions. We evaluated a sample of respondents' estimates with a hand-held scale, and found their estimates generally accurate. Therefore, we believe that the accuracy of estimates for the total amount of fuelwood used is acceptable. The relatively high amount of fuelwood usage may be due to a couple of factors: (1) relatively high elevation with longer winter season for heating, and (2) plenty of fuelwood supply that is free.

In terms of the length of the questionnaire and duration of interviews in the fieldwork, the total questionnaire included 22 sections on a wide range of topics from household composition to fuelwood use, agricultural production and income from all sources, household receipt of PES payments, migration, attitudes, etc., and took 1–1.5 h to complete per household.

2.4. Analysis

We analyze two aspects of fuel use by rural households in the sample: fuel choice and the quantity of fuelwood used, taking into account the socio-economic and demographic factors that hypothesized to determine energy use as well as the supply of fuelwood. Forests in the study area are either created through the CCFP or (mostly) protected by EWFP. The forest area a household owns is considered a proxy measure for the fuelwood supply available to the household. Ten independent variables are selected for investigation in our analysis: the number of people in the household, the age of the oldest household member, distance in minutes from the house to the main road, the wellness index, years of education of the household head, household per capita income, area of paddy land planted, area of dryland planted, area of cropland enrolled in the CCFP, and area of forests enrolled in the EWFP. These are the factors identified as relevant based on our understanding from field interviews and the literature on rural fuelwood use in China (Rao and Reddy, 2007; Pachauri and Jiang, 2008; Peng et al., 2010; Kowsari and Zerriffi, 2011; Liu et al., 2013). Due to the large variation in per capita income, we used the natural logarithmic transformation of per capita income in the analysis.

The choice of fuel is a categorical variable, as shown in Table 1. Fuel choice provides evidence on whether rural households tend to follow the energy ladder theory or the fuel stacking theory. Although the question on fuel choice did not elicit the specific amounts of fuel used of each kind, it did ask what the primary fuel or fuels were for the household. The score for fuel choice was ordinal, starting from “traditional” fuels to “modern” ones. However, preliminary analysis found

Table 1

Comparison of fuel choice distribution of households enrolled in the Conversion of Cropland to Forest Program (CCFP) and those not enrolled. A Kolmogorov test indicates no significant difference in the fuel choice distributions between the two groups of households.

Fuel choice	Fuel description	CCFP		Non-CCFP	
		Count	Fractions	Count	Fractions
1	Fuelwood only	33	0.122	21	0.100
2	Primarily fuelwood complemented with modern fuels (e.g. coal, LPG and/or electricity)	193	0.712	156	0.743
3	Half and half fuelwood and modern fuels	20	0.074	18	0.086
4	Primarily modern fuel complemented with fuelwood	22	0.081	8	0.038
5	Modern fuels only	3	0.011	7	0.033

Note LPG = liquid petroleum gas.

that we could not conduct the ordinal logistic regression as the assumption of proportional odds was not satisfied (Kleinbaum and Klein, 2010). Instead, we conducted a multinomial logistic regression to understand how different factors influenced household fuel choice. Let the dependent variable Y = F_c, where F_c is the fuel choice as given in Table 1, and the predictor variables, X_i, are the ten variables identified above. The relative odds ratio with respect to a reference fuel, F_r, is modeled as.

$$\ln\left[\frac{P(Y = F_c|X)}{P(Y = F_r|X)}\right] = \alpha_{F_c} + \sum_{i=1}^{n} \beta_{Fc,i} X_i, \tag{1}$$

where α_{Fc} is the intercept for fuel F_c ($F_c \neq F_r$); $\beta_{Fc,i}$ are regression coefficients for predictor variables, X_i, for fuel F_c. The odds ratios so generated provide information on the extent to which predictor variables X_i affect the likelihood of using fuel F_c with respect to the reference fuel F_r.

The same 10 variables are also analyzed to understand the *quantity of fuelwood* used. In the second model, the dependent variable is per capita fuelwood use in kilograms by the household over the past 12 months. We conducted a weighted multiple regression analysis with the following standard multiple regression model:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots + b_nX_n, \tag{2}$$

where the b_i (i = 1, 2, …, 10) are the regression coefficients for the 10 independent variables.

3. Results

3.1. Descriptive Statistics

The fuel choices for CCFP and non-CCFP households are given in Table 1. First, we observed no statistically significant differences in fuel choices between CCFP and non-CCFP households. Also, there is no household that relies exclusively on crop residues for fuel, but nearly all households (98%) use fuelwood, 73% as the primary fuel regardless of whether they are enrolled in CCFP. Approximately 87% of the households use fuelwood in combination with LPG or electricity, providing evidence supporting the “fuel stacking” theory. These observations are consistent with Jiang and O'Neill (2004), who found that those using only fuelwood are rare in rural China, with > 97% of households using at least two types of fuels, with biomass (fuelwood) and electricity being the most common combination.

In the study area fuelwood is used for three main activities: cooking (46%), heating (42%) and preparing food for pigs (12%) (Fig. 2). Our estimates of the quantities of fuelwood used by rural households fall within in the ranges identified by Wang and Feng (2001), suggesting that households in this study area have not changed their patterns of fuelwood use much over time.

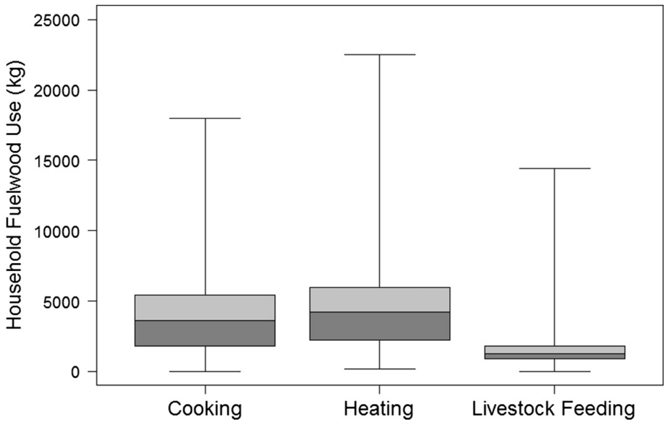

Fig. 2. Box plot showing minimum, 25%, median, 75% and maximum values for cooking, heating and preparing food for livestock.

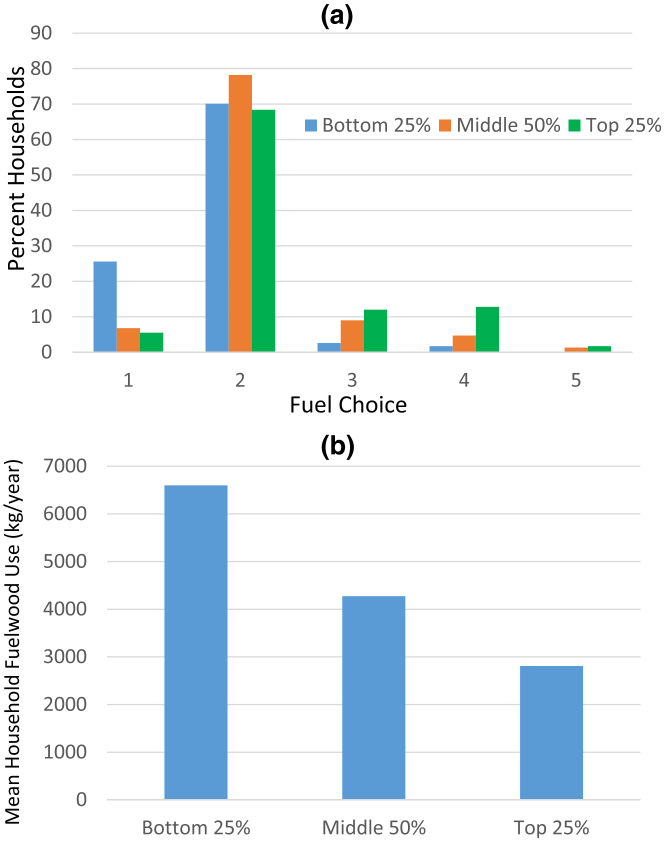

Fig. 3. Bar plot showing (a) fuel choice and (b) the mean fuelwood use for households in the bottom 25%, middle 50% and top 25% on total gross household income. Fuel choice: 1 = fuelwood only; 2 = primarily fuelwood with modern fuels as supplementary; 3 = half fuelwood and half modern fuels; 4 = primarily modern fuels with fuelwood as supplementary; 5 = modern fuels only.

Fig. 3 shows fuel choice and fuelwood use by income group, i.e. the bottom 25%, the middle 50% and the top 25% of households, based on total gross household income. Fuelwood is the dominant energy source among all income groups (Fig. 3a). The middle 50% income group has the highest percentage of households using fuelwood as the main source of energy. The bottom 25% income group has a lower percentage of household using fuelwood as the “main” source of energy because a significant proportion of these households use fuelwood as their *only* source of energy. No household in the bottom 25% income group used

Table 2
Basic statistics for dependent variable and the related social-economic and ecological factors for CCFP and non-CCFP households.

Variable	CCFP households			Non-CCFP households		
	Mean ± Std	Min	Max	Mean ± Std	Min	Max
Per capita annual fuelwood (kg)	4734 ± 4241	0.0	30,600	4146 ± 4276	0.0	36,750
Paddy land planted (mu)	2.0 ± 2.7	0.0	15.0	2.6 ± 2.5	0.0	17.0
Dry land planted (mu)	1.2 ± 1.5	0.0	10.5	1.2 ± 1.2	0.0	6.8
Minutes walking to main road	13.2 ± 15.7	1.0	80.0	10.5 ± 15.2	1.0	120.0
Wellness index (unitless)	20.3 ± 5.4	3.0	32.0	19.9 ± 5.3	5.0	33.0
Per capita income (Yuan)	16,973 ± 24,321	326.9	164,321	14,533 ± 15,307	151.9	98,679
Household head's education (years)	6.0 ± 2.9	0.0	12.0	5.8 ± 3.2	0.0	15.0
Oldest household member's age (years)	60.4 ± 12.5	39.0	95.0	59.2 ± 11.5	29.0	90.0
Household size (persons)	2.8 ± 1.4	1.0	9.0	2.9 ± 1.3	1.0	7.0
EWFP area (mu)	55.1 ± 67.5	2.0	530.0	39.1 ± 44.5	2.0	313.0
CCFP area (mu)	2.0 ± 1.6	0.1	9.0	–	–	–

Note: the unit used for land by farmers in China is mu (1 mu = 1/15 ha).

LPG or electricity as its sole sources of energy. Similarly, the top 25% income group has the lowest percentage of households using fuelwood as the main source of energy because a significant percentage of these households use modern fuels mainly or only. The total amount of fuelwood used also steadily decreases with income (Fig. 3b).

Table 2 presents descriptive statistics for the various socio-economic and ecological factors identified in this study that might influence the fuel choice and the quantity of fuelwood used by households. There are large variations in the quantities of fuelwood used by both CCFP and non-CCFP households, with CCFP households using slightly more fuelwood overall. The socio-economic and ecological factors between the two types of households are very similar because CCFP targeted land, not households. Thus the two types of households own roughly the same amount of dryland, but non-CCFP household have about 0.6 mu (1 mu = 1/15 ha) more paddy land on average than CCFP households. This suggests that CCFP households had slightly more dryland before participating in the CCFP program, and that non-CCFP households generally are located in lower elevation areas, thus having more paddy land. It thus takes a few minutes more time for CCFP households to get to the main road. CCFP households also have a slightly higher income than non-CCFP households. Non-CCFP households have a much larger maximum income compared to CCFP households because non-CCFP households are more likely located in the lower elevation closer to the town center, allowing better opportunities for business income. CCFP households have more ecological welfare forest because they are more likely to be located in the mountainous areas.

A correlation analysis found that there are some low to moderate but still statistically significant correlations among the predictor variables (Table 3), which is typical for socio-economic variables. The older the age of the oldest person in the household, the lower the education of the head (though they are not necessarily the same person) is. Older age of household head is correlated with larger household size, as is expected. Some large households have three generations living together. Finally, households with the oldest members are more likely to have lower incomes and wealth (wellness index). More educated household heads tend to have higher incomes and wealth. Households farther away from a main road earn lower incomes and less wealth but are more likely to participate in both CCFP and EWFP forests. Larger households earn higher incomes (not necessarily per capita, however) and have more wealth accumulation and more paddy land, which makes sense as the latter is the main source of farm income. A larger household tends to have more wage earners, and hence more opportunity for wealth accumulation. Income is directly correlated with wealth accumulation, as captured by the wellness index. Paddy land and dryland are positively correlated, both being farmland. Dryland area is significantly correlated with CCFP area, which reflects farmer's offering to give up farming on sloping lands rather than flat lands good for rice cultivation, and is also correlated with household income, mainly because it is a source of farm income. It also reflects that participation in CCFP does provide some small income subsidy. Finally, the area in the CCFP is correlated with EWFP forest area, indicating some tendency for farmers with larger total areas to also have larger farm areas, eligible for the CCFP and EWFP programs. Although the direct compensation from these programs is small for most households in 2014, it was likely still a significant source of income for many poor households (Song et al., 2014), and was of course larger in the early 2000s when the PES programs started.

3.2. Factors Determining Fuel Choice

Due to the small number households using only modern fuels (i.e., LPG and electricity), we first pooled these households with those that *primarily* used modern fuels for the multinomial, multivariate logistic regression, i.e., merged fuel category 5 and fuel category 4 in Table 1. We then selected fuelwood only (F = 1) as the reference fuel for the multinomial logistic analysis. The odds ratios for each of the

Table 3
Correlation matrix for the ten predictor variables.

	Age of oldest	Education	Distance	HH Size	Wellness	Paddy	Dryland	CCFP	EWFP
Education	− 0.177*								
Distance	0.021	− 0.015							
HH Size	0.163*	0.079	− 0.056						
Wellness	− 0.132*	0.212*	− 0.278*	0.342*					
Paddy	0.091	− 0.001	0.055	0.170*	0.069				
Dryland	0.033	− 0.041	− 0.022	0.093	0.196	0.269*			
CCFP	0.082	0.073	0.123*	0.014	− 0.028	0.080	0.159*		
EWFP	0.077	− 0.010	0.117*	0.077	0.016	− 0.103	− 0.012	0.227	
Income	− 0.133*	0.212*	− 0.139*	0.342*	0.465*	0.063	0.145*	0.023	0.050

Note. Due to space limits, variable names are abbreviated. See Table 2 for full descriptions.
* $p < 0.05$.

Table 4
Odds ratio for each variable on each fuel choice with respect to the reference fuel (F = 1), i.e. using fuelwood only as household energy source. The p-Values < 0.05 are shown in bold.

Variables	Fuel	Odds ratio	p-Value
Age of oldest household member	4	0.977	**0.0499**
Age of oldest household member	3	1.033	**0.0001**
Age of oldest household member	2	0.988	0.0529
Education of household head	4	1.027	0.4975
Education of household head	3	1.022	0.4961
Education of household head	2	0.977	0.3478
Wellness index	4	1.946	< **0.0001**
Wellness index	3	1.203	< **0.0001**
Wellness index	2	1.152	< **0.0001**
Natural log of household income	4	5.734	< **0.0001**
Natural log of household income	3	3.698	< **0.0001**
Natural log of household income	2	2.421	< **0.0001**
Minutes from home to main road	4	0.823	< **0.0001**
Minutes from home to main road	3	0.957	< **0.0001**
Minutes from home to main road	2	0.978	< **0.0001**
Household size	4	0.938	0.5254
Household size	3	0.698	< **0.0001**
Household size	2	0.610	< **0.0001**
CCFP area	4	0.920	0.5533
CCFP area	3	1.022	0.8400
CCFP area	2	1.108	0.101
EWFP area	4	0.990	< **0.0001**
EWFP area	3	0.974	< **0.0001**
EWFP area	2	0.992	< **0.0001**
Paddy land planted	4	0.757	< **0.0001**
Paddy land planted	3	0.907	**0.0251**
Paddy land planted	2	1.101	**0.0007**
Dryland planted	4	0.370	< **0.0001**
Dryland planted	3	0.558	< **0.0001**
Dryland planted	2	0.839	**0.0009**

explanatory variables for each (of the other three) fuel choice with respect to the reference fuel, along with their significance level, are given in Table 4. Because our reference fuel is the lowest in the fuel rank (F = 1), a higher than unity odds ratio signifies a positive effect of that factor in promoting the adoption of more modern fuels and shifting from fuelwood use. In general, the odds ratios (and resulting significance levels) should be increasingly divergent from 1.00 (no effect) moving from categories 2 (mixed) to 4 (most modern use). Thus, for example, the odds ratios for the household income move from 1.00 (implicitly, the reference category), to 2.4 for category 2 (compared to category 1), 3.7 for category 3, and 5.7 for category 4 (indicating households with higher incomes are almost 6 times as likely to use modern fuels). In cases where the odds ratios for categories 2–4 vary above and below 1.0 or do not move in consistently rising or falling ways, the results are weak or insignificant.

We first note that all predictor variables seem to have some effects on fuel choice, but three of these are not strong or are not consistent when we examine their odds ratios one by one: These include age of oldest household member, education of household head, and the area in CCFP. The age variable suggests that older age makes it more likely that the household uses mixed fuels vs. mainly fuelwood, or modern fuels vs. fuelwood, but in fact the ratios are all very close to 1.0, indicating no overall effect. For education, very similar findings are evident. While it is unexpected that household head's education does not make a difference in fuel choice, as one would expect better educated household heads to have a preference for using more modern fuels, and in any case, to earn higher incomes, facilitating shifting from fuelwood to modern fuels. This lack of much effect may thus be partly due to household per capita income capturing some effects of education, or due to the fact that those with more education in the study area still usually have very low levels of education—too low to affect income much. The lack of consistent effects of CCFP area and hence compensation on fuel choice, with the effect of choosing category 2 versus category 1 being the only marginally statistically significant effect, may be due to the compensation from CCFP not being big enough to stimulate a shift in fuel choice. According to Table 1, there are only ten out of the 481 households that completely rely on modern fuels, indicating few are willing to give up free fuelwood without a major income increase that leads to a life style change.

As anticipated from theory and previous studies, household income stands out as the most important variable for fuel choice, with the highest odds ratio for adopting modern fuels. Moreover, these odds ratios rise consistently for fuel categories 2 compared to 1, 3 compared to 1 and 4 compared to 1, with all three being the three highest in the table, indicating powerful effects of income on the choice of more modern fuel use. While income is the most important, there are other factors that influence fuel choice (Hosier and Dowd, 1987; Davis, 1998; Heltberg, 2005; Arnold et al., 2006). Another predictor capturing complementary effects is the wealth variable or wellness index, with odds ratios significantly higher than unity for fuel choice, especially for modern fuels (choice 4). Wellness index may be viewed as capturing long-term effects of household well-being, while income captures the short-term effects of the last 12 months. These two results strongly support the energy ladder theory.

Significant effects of several other factors should also be mentioned, with odds ratios consistently less than unity, viz., time (in minutes) from the home to the nearest main road, household size, EWFP area, and areas of dryland and paddy land planted. Dryland area has the strongest effect of these, with a larger area planted discouraging adoption of modern fuels. The more dryland a household cultivates, the more likely it is living in a remote, relatively high elevation. The time from the home to a main road also captures some of this effect of isolation and altitude. More isolated households in the mountains have better access to fuelwood, and less easy access to purchasing modern fuels at the same time, and are hence less likely to adopt modern fuels as a result of accessibility, affordability or both. EWFP area also has odds ratios that are consistently less than one, but close to one, meaning households with more EWFP area are reluctant to moving away from fuelwood, but the effect is small once the other factors are controlled for. Households living in more developed areas or close to roads are unlikely to have much EWFP area as most EWFP area is located in the mountains. Cai and Jiang (2010) found a similar positive effect on fuelwood use by local residents living in deep mountains in Jiangxi and Sichuan provinces. Therefore, EWFP area, dryland area, and minutes from home to the main road all have similar effects on fuel choice, although dryland area has the strongest effect, and overall trails only household income in its impact. A larger household size indicates more food to cook, and more rooms to heat and people to keep warm in the winter, and thus more energy needed. At the same time, more people in the household incur higher expenditures for other things as well. Given that fuelwood is free with the plentiful supply in the study area, sticking to fuelwood as the main energy source makes economic sense for bigger households.

3.3. *Factors Affecting Quantity of Fuelwood Use*

The effects of predictor variables on the quantity of fuelwood per capita used by a household are analyzed with a multiple linear regression model, as given in Eq. (2), with results in Table 5. The overall model R^2 is 0.281 with significance level at $p < 0.0001$. Six out of the ten predictor variables have statistically significant effects on fuelwood quantity. Household head's education, income and household size all contribute negatively to the amount of per capita fuelwood a household uses, while age of oldest household member, EWFP area and dryland planted are positively associated with fuelwood quantity. The wellness index, minutes from home to the main road, and CCFP and paddy areas do not have significant effects. The negative effect of household size on per capita fuelwood use is due to economies of scale, as seen in other studies (Cline-Cole et al., 1990; Türker and Kaygusuz, 1995;

Table 5
Results from multiple regression of determinants of quantity of per capita fuelwood that a household used in a year. The model R^2 is 0.281, with significance level at $p < 0.0001$. The p-values < 0.05 are shown in bold.

Variable	Parameter estimate	Standard error	p- Value
Intercept	9495.2	2083.0	**< 0.0001**
Age of oldest household member	41.2	16.0	**0.0102**
Education of household head	− 138.3	58.2	**0.0180**
Wellness index	− 32.9	41.3	0.4267
Natural log of household income	− 386.2	192.0	**0.0450**
Minutes from home to main road	9.5	11.6	0.4163
Household size	− 1146.5	133.0	**< 0.0001**
CCFP area	120.4	165.4	0.4672
EWFP area	12.1	3.6	**0.0009**
Paddy land planted	− 54.1	57.2	0.3446
Dryland planted	260.5	126.6	**0.0404**

Gundimeda and Köhlin, 2008; Webb and Dhakal, 2011). Higher incomes are associated with reduced fuelwood use, which is consistent with the fuel choice results, as higher income promotes adoption of modern fuels, and hence less use of fuelwood.

Although the effect of the household head's education is not clear in fuel choice, it does have a significant negative effect on fuelwood quantity. Both EWFP area and dryland area are linked to higher fuelwood use, which is consistent with their effects on fuel choice for the reasons described previously. Chen et al. (2006) had a similar finding that an increase in the land area cultivated was associated with more fuelwood consumption in three villages in Jiangxi province, while Démurger and Fournier (2011) found that a 10% increase in farmland led to a 1.8% increase in fuelwood use in a rural township of Beijing. Finally, the older the oldest household member, the more he/she needs a heated home in the winter, and the more traditional the custom to use fuelwood, so age of the oldest household member is expected to be positively linked to fuelwood use. It is interesting that the wellness index is not statistically significantly associated with per capita fuelwood use, when other factors are controlled, although it does have a negative effect on fuel choice. Perhaps its effect here is already captured by household income and household head's education, which, on the other hand, was not significant in fuel choice analysis. Minutes from home to a main road had a positive effect on fuelwood quantity, but are not statistically significant once EWFP area and dryland effects are controlled for.

4. Discussion

It is important for environmental policy-makers in China to know whether the CCFP and the EWFP are contributing to help rural households shift away from using fuelwood because of both the environmental and health benefits of such a shift. The lack of effects of CCFP participation on either fuel choice or fuelwood quantity is likely partly due to the fact that both the direct and indirect economic benefits from CCFP are not large enough to stimulate households to shift away from the free fuelwood for energy. The fact that fuelwood can be easily collected for free in the study area also likely reduced the income effect on its use (Hosier and Dowd, 1987; Heltberg, 2005). Regarding EWFP, households received more compensation from the EWFP on average than that from the CCFP in the mountainous study region due to the large areas in the ecological welfare forests, despite the compensation rate per unit area of the EWFP being far lower than that of the CCFP. The key difference between the two programs is that the EWFP does not call for any change in land use while the CCFP does, thus the EWFP program has no effect on the allocation of farm labor for cropping or other uses, while the CCFP does by taking cropland out of cultivation. The lack of an effect from CCFP on fuelwood use in the study area is likely due in part to the small area enrolled by participating households. It may be useful to undertake new studies in areas where a bigger portion of farmer's cropland is enrolled in CCFP to better understand its effects on fuelwood use. Given the close linkage between EWFP area and mountainous residence and isolation and the prevalence of convenient fuelwood, it is understandable that EWFP households would not shift away from fuelwood as fuel. Fuel use in the study area is still in the early stages of transition, so neither the CCFP nor the EWFP payments are likely to help shift households away from using fuelwood or adopt more modern fuels.

It is interesting to note that the results of our analysis support *both* the energy ladder theory and the fuel stacking theory. Table 1 shows that the vast majority of households use multiple fuels simultaneously, supporting the fuel stacking theory, but there are a handful of households in our sample who reached the top of the “energy ladder”, using only modern fuels for energy. Our logistic regression analysis found that higher incomes strongly promote the adoption of more modern fuels, further supporting energy ladder theory. Many other studies in China and elsewhere also have found strong evidence for an energy transition as income rises (Jiang and O'Neill, 2004; Rao and Reddy, 2007; Pachauri and Jiang, 2008; van Ruijven et al., 2008; DeFries and Pandey, 2010; Tang and Liao, 2014). Therefore, we argue that both theories are useful for the understanding of fuel use and its likely evolution in the future in our study area. The two theories are thus not mutually exclusive: the fuel stacking theory describes fuel choices at a particular moment along the energy transition process; while the energy ladder theory characterizes the direction of fuel choice change as incomes rise. The most important feature in the energy ladder theory is the shifting from the biomass fuels to the modern fuels as income increases. However, a complete shift from biomass fuels to modern fuels requires major increase in household income that leads to a change in life style, which is so far rarely observed in our rural sample. The most common cases are a *partial* adoption of modern fuels without abandoning biomass fuels. This seems to be the rule in this part of rural China rather than the exception, which tends to be consistent with most existing studies in other parts of the developing world (Parikesit et al., 2001; Heltberg, 2004; Jiang and O'Neill, 2004; Madubansi and Shackleton, 2007; Nansaior et al., 2011).

Thus in general, what we observe in our study area is an expansion in types of fuel use as incomes rise, adopting new fuels without abandoning older ones. Fuel expansion may not reduce the absolute quantity of fuelwood use though, since as income increases, the *total amount* of energy use is likely to increase due to the pursuit of a higher quality of life (Liu et al., 2013), and so could overall use of fuelwood (Arnold et al., 2006; Cooke et al., 2008; Hiemstra-van der Horst and Hovorka, 2008; Shi et al., 2009). Foster et al. (2000) found that the relationship of energy consumption to household income follows an inverse U-shape. This may be part of the reason why income only explained a small percentage of variation in the amount of fuelwood used in this study. In a study conducted in the Labagoumen Township of Beijing, Démurger and Fournier (2011) found households substituted coal for fuelwood for heating as they became richer, supporting the energy ladder theory, although even households with higher living standards continued to use fuelwood for cooking, perhaps due to the perceived better taste of food cooked with fuelwood (Masera et al., 2000; Heltberg, 2005) or convenience/habit (Liu et al., 2013), supporting the fuel stacking theory.

Our understanding of the factors influencing the quantity of fuelwood used and fuel choice in this study depend also on the particular local context, where there is little limit to fuelwood supply due to mountainous area with plentiful forest cover. The study area is located in a remote region of a county designated as “a county in poverty” by the Chinese government. Heavy reliance on the generally freely available fuelwood as an energy source is thus a rational livelihood option, which is not easily changed by external factors, such as CCFP or EWFP subsidies. This may not be the situation in other contexts where fuelwood use has been investigated and where it is not plentiful and even free (for example, Cooke et al., 2008; Bandyopadhyay et al., 2011; Jagger and Perez-Heydrich, 2016; Jagger and Shively, 2014).

5. Conclusions

Our study found that energy consumption in rural households is a complex phenomenon, affected by a variety of socio-economic as well as ecological factors. Ninety eight percent of households in the study area use fuelwood, 73% as their primary fuel. Nevertheless, 87% of households used at least two kinds of fuels, fuelwood and some modern fuel, supporting the fuel stacking theory for fuel choices at the time of this study. We also found strong evidence that higher incomes lead to the adoption of more modern fuels, with a few households completing the transition to rely on modern fuels only, the latter supporting the energy ladder theory. Thus the vast majority of households that have adopted advanced fuels have so far not abandoned fuelwood in the study area, but rather are making a gradual transition through expanding fuel choices. The most important factor determining fuel choice is household income, while household size is the dominant factor influencing the quantity of per capita fuelwood used. In contrast, CCFP and EWFP play much minor roles in fuel use in the study area. CCFP has little direct influence on either fuel choice or the quantity of fuelwood used possibly due to the small areas enrolled on average, but households with more EWFP area tend to rely more on fuelwood as their fuel choice. EWFP area also significantly increases the quantity of per capita fuelwood use, which may be considered a proxy for access to mountainous forestland. These findings indicate the study area study is still in the early stage of energy transition, and fuelwood is likely to remain the dominant fuel in the rural study area in the foreseeable future, even if significant economic growth continues. The intrinsic dependence on a vital livelihood resource like fuelwood can hardly be expected to shift quickly due to external policies with other main goals, such as CCFP and EWFP. If reduced fuelwood use is desired, new policies are needed that specifically promote or facilitate the use of modern fuels by rural households.

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Appendix A

Table A1
Sampling strata showing fractions of households enrolled in the Conversion of Cropland to Forest Program for resident groups (RG) in the study area.

Sampling stratum	RG proportion of households in CCFP	# Of RG in stratum	# Of resident groups sampled	Sampling fraction	Stratum weight
I	1.00–0.80	10	10	1.0	1.0
II	0.79–0.50	13	9	0.69	1.44
III	0.49–0.30	18	7	0.39	2.57
IV	0.29–0.01	38	10	0.26	3.80
V	0	86	4	0.05	21.5
Total		165	40	0.24	–

Table A2
Detailed information on the number of households (HH) in each resident group (RG) sampled from each stratum participating in the Conversion of Cropland to Forest Program (CCFP) and not participating and corresponding sampling weights.

Village ID	RG ID	# Of HH	# Of CCFP HH	# Of non-CCFP HH	# Of CCFP HH sampled	# Of non-CCFP HH sampled
RG stratum I: 0.8–1						
1	26	26	22	4	16	4
1	28	29	25	4	16	4
1	27	31	30	1	19	1
1	29	27	24	3	17	3
1	30	28	27	1	19	1
1	31	13	12	1	12	1
2	54	19	18	3	18	1
2	53	19	17	2	17	2
2	52	11	9	2	9	2
7	165	30	24	6	14	6
Subtotal		233	208	27	157	25
RG stratum II: 0.5–0.79						
1	25	13	8	5	8	5
1	24	24	13	11	12	8
2	51	34	20	14	13	7
3	78	17	12	5	12	5
5	127	9	5	4	5	4
5	128	15	11	4	11	4

6	148	24	14	10	12	8
6	147	11	6	5	6	5
6	149	20	15	5	15	5
Subtotal		167	104	63	94	51
RG stratum III: 0.3–0.49						
1	23	23	10	13	10	10
1	16	41	13	28	12	8
1	20	19	8	11	8	11
1	18	34	12	22	12	8
2	49	16	6	10	6	10
3	76	36	16	20	13	7
6	143	36	11	25	10	10
Subtotal		205	76	129	71	64
RG stratum IV: 0.01–0.29						
2	46	23	6	17	5	15
2	45	31	6	25	4	16
3	71	35	6	29	3	17
3	68	26	2	24	2	19
4	107	42	7	35	4	16
4	108	35	7	28	5	15
6	139	31	5	26	4	16
6	138	17	3	14	3	12
6	141	29	8	21	5	15
6	140	38	7	31	6	14
Subtotal		307	57	250	41	155
RG stratum V: 0–0						
7	163	26	0	26	0	20
6	131	31	0	31	0	20
4	81	34	0	34	0	20
1	9	15	0	15	0	15
Subtotal		106	0	106	0	75
Total		1018	445	575	363	370

Table A3
Indicators of household wellness. The sum of the highest scores in each category is used to construct the household wellness index, except for fuel choice, since it is the dependent variable in this study.

Category	Item	Points
What type of house do you have?	Three story concrete	5
	Two story concrete with indoor bathroom	4
	Two story concrete without indoor bathroom	3
	Single story brick house	2
	Adobe house	1
	No house	0
What kind of water and sanitation facilities do you have?	Piped water and flush toilet	5
	Piped water and outdoor latrine	4
	Pressure well and outdoor latrine	3
	Natural spring and outdoor latrine	2
	Open water and outdoor latrine	1
	Harvest rain and outdoor latrine	0
What are fuels the household uses?	Advanced fuels only	5
	Primarily advance fuels complemented with fuelwood	4
	About half/half for advanced fuels/fuelwood	3
	Primarily fuelwood complement with advanced fuels	2
	Fuelwood only	1
	Crop residual only	0
What kind of the electrical appliances do you have?	A/C	5
	Solar panel	4
	Refrigerator	3
	Washing/dry machine	2
	Electric cooking pot/microwave	1
	None	0

What communications and entertainment equipment do you have?	Computer	5
	Cell phone	4
	Fixed line phone	3
	TV/stereo	2
	Radio	1
	None	0
What farming tools and equipment do you have?	Tractor/transporting tractor (> ¥2000 Yuan)	5
	Thrasher machine/other small process machine	4
	Electric pump	3
	Ox	2
	Hoes, other farming tools	1
	None	0
What do you use for transportation?	Sedan or minivan	5
	Mini-truck	4
	Motor cycle/motorized tricycle	3
	Electric bike	2
	Bike or human-powered tricycle	1
	None	0

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