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Research Article

District or distributed space heating in rural residential sector? Empirical evidence from a discrete choice experiment in South China

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ABSTRACT

Rural residential space heating is strongly linked to policy considerations related to the clean energy supply and rural sustainable development. As there has been a hot debate on whether to promote district heating in South China, this paper aims to investigate household heating choices with a particular focus on rural residential sector, using the survey data from Sichuan Province. In order to investigate the main influencing factors of household decision-making behaviors, a multinomial logit (MNL) model with sample selection correction and an alternative-specific conditional logit (ASCL) model were used to respectively analyze the actual and stated choices. The estimation results show that energy-specific attributes such as safety level and smoky level have statistically significant effects on household stated preferences for heating systems. Households prefer to adopt lower-cost heating system with high quality energy sources. Among household-specific characteristics, income level, educational level of the decision-maker, household demographic structure, and household location are important determinants of heating fuel choices. These findings suggest that future energy policy should pay more attention to its combined effect on both cost and quality of heating system as well as its different regional effects. Besides, enhancing household socio-economic status should also be attached importance in policy design.

1. Introduction

Globally, space heating occupies a very large proportion of overall residential energy demand (Michelsen and Madlener, 2012, 2013). In the case of China, the average amount of energy consumed for space heating by private households was around 400.7 kgsce[1] in 2014. This accounts for about 36.8% of the total residential energy consumption (Zheng et al., 2017). The current residential heat supply in China is composed of two parts. The centralized district heating system has been recognized as an efficient way of providing heating energy to urban homes, while the household-based distributed heating has been widely adopted by rural households who have no access to centralized heating system. According to the statistics, in 2014 about 54.2% of the total residential heating energy was supplied through district heating, whilst the rest (about 46.8%) was distributed via the decentralized heating system (Zheng et al., 2017).[2] In terms of the types of fuels used for space heating, traditional solid biomass energy (namely crop straw and firewood) is predominant in distributed heating system, constituting approximately 50.9% of total heating energy supply in rural areas (Zheng et al., 2017). Direct combustion of biomass (indoors or in open air) has brought many adverse impacts to rural livelihoods, for instance, resource waste, indoor air pollution, and social inequalities (Zhang et al., 2010). Moreover, rural residential space heating is regarded as a major contributor to greenhouse gas (GHG) emissions in China, because coal is another commonly used energy source for distributed heating system (Zheng et al., 2016). About 96.9% of the rural residential energy demand for coal can be attributed to this field of energy use (Wei et al., 2017). Due to these detrimental effects caused by the use of traditional solid biomass and coal, rural residential space heating is strongly linked to policy considerations related to clean energy supply and rural sustainable development. Additionally, recent policy goals for energy conservation and GHG emission reduction need to be achieved by taking specific policy measures to adjust rural heating energy consumption structure. Therefore, to develop effective policies for future energy construction in rural China, it is essential to understand household space heating energy choice behaviors and their key determinants.

In order to cope with the energy policy challenges, the Chinese government has initiated the ‘Rural Energy Revolution’ for the past few

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[1] In this paper, kgsce = kilogram(s) standard coal equivalent; tsce = ton(s) standard coal equivalent.

[2] According to Wei et al. (2016), centralized district heating accounted for 56% of total energy consumed in urban households, but only 2% in rural households.

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years. During this revolution, a range of policies targeting rural residential heating energy use have been implemented to promote the transition of the energy system towards a cleaner and more sustainable energy system. These policy measures include direct subsidies and rural 'coal-to-electricity/natural gas' construction programs, aiming at reducing the coal consumption of rural families for space heating and meeting their remaining energy demands with clean energy sources in Northern China[3] (Wu et al., 2018). Besides, a growing number of researchers have focused on the issue of energy supply for rural space heating (Nordqvist, 2000; Sun et al., 2013, 2014; Yuan and Zhao, 2014; Zhou et al., 2014; Liu, 2015; Zhang et al., 2017, 2018; Gao, 2017). From the interdisciplinary perspective, their studies have discussed the strengths and weaknesses of current heating systems in rural areas of North China. They have also proposed suggestions on the promotion of the high-efficiency and environmental-friendly heating system with clean energy sources (such as solar, biomass gasification gas, natural gas and electricity). However, for the rural areas in South China, such issue has not yet received wide public attention. At present, rural households in cold regions of Southern China still depend heavily on applying distributed stoves with solid fuels (such as firewood and coal) for space heating. This is probably because of the high installation cost of district heating equipment and the poor local conditions of weather and geography (Shi et al., 2016). Nonetheless, with the increasing demand for heating energy induced by increased concentration degree of rural residence and improved rural living standards, it has great potential to develop centralized heating system in some rural areas of the South. As there has been a long hot debate on whether and how district heating should be used, it is of great importance to clarify household heating fuel using behaviors in rural areas of South China.

In particular, Sichuan Province, located in Southwestern China, is a typical case to examine rural household heating energy choice behaviors due to four reasons. Firstly, the total amount of rural residential energy consumption was about 38 Million tsce in 2014, ranking first in China (Cong et al., 2017). Secondly, distributed solid biomass energy (i.e. crop straw and firewood) remains the principal type of energy for space heating in rural areas. Available official statistics reveal that the amount of traditional biomass energy consumed by rural households was about 26.4 Million tsce, accounting for approximately 69.4% of the total energy consumption by the end of 2014 (Cong et al., 2017). Thirdly, the local weather is rather cold and humid in winter. Especially in remote mountainous areas,[4] the average temperature was 0.42–1.12°C during the period from December to February in last decade (SPBS, 2007–2017). Under this circumstance, space heating is quite necessary for local rural households. Fourthly, cooking and space heating are two main purposes for rural residential energy use, especially in the backward mountainous areas (Zhai and Fu, 2016). Chen et al. (2016) had investigated household cooking fuel use patterns and determinants in the same region. Based on their findings, this paper intends to complement previous research by further analyzing household heating system choice behaviors and their influencing factors to give a clear picture of rural residential energy use. In short, taking inspiration from the main features of rural energy consumption in Sichuan Province, the main contribution of this paper is to find out empirical evidences on how a household makes its decision on adopting different heating systems in rural areas of South China and to provide references for future heating policy design.

In Energy Economics, there have been two main analytical frameworks developed to investigate the pathways and underlying drivers of household energy transition. One of them is the 'energy ladder' model and the other is the 'energy stacking' model. The basic assumptions of both models are similar: with an improvement in their socio-economic status, households will move up along an 'energy ladder' with modern and clean energy carriers (i.e. electricity) at the top and traditional solid biomass (such as crop straw and firewood) at the low end of it (Reddy, 1995; Masera et al., 2000; Gupta and Köhlin, 2006). In other words, the fuel switching process can be defined by household switching from the solid fuels (from traditional solid biomass to coal), through gaseous fuels (natural gas and LPG), to the advanced fuels (electricity and solar) for heating (Hoiser and Dowd, 1987; Masera et al., 2000; Van der Kroon et al., 2013; Chen et al., 2016). Although these two models provided different explanations for the determinants of energy transition, they formed the basic theoretical foundation for this paper to study household choices on different heating systems with corresponding energy sources. Hence, the basic hypothesis of this paper is that with an increasing socio-economic standing, household will choose the fuels which are better in terms of cost, cleanliness, efficiency and technological flexibility etc. The main purpose of this paper is to clarify how households make their choices on whether to adopt district or distributed heating as well as to examine the determinants of these choice behaviors. This research extends the existing studies applying choice modeling by considering relative impacts of the specific attributes of the residential heating systems (with corresponding energy sources) and differences in household revealed and stated preferences. The structure of the rest of this paper is as follows: a review on previous literature related to this study is presented in Section 2; Section 3 describes the data and methodology used in this study including the household survey design for data collection and the model specification for the empirical estimation. The results of empirical analysis are given in Section 4 and further discussed in Section 5. In Section 6, the main conclusions are obtained and the policy implications on future rural energy construction in South China are provided.

2. Literature review

Empirically, numerous researches have investigated the residential energy consumption for space heating and have identified the factors that could affect household heating fuel choice behaviors around the world. Most of them have focused on the cases of developed countries. Vaage (2000), Nesbakken (2001) applied different choice modeling approaches to test Norwegian household heating energy demand and suggested that energy prices and income have significant impact on the choice probability of electric heating. Couture et al. (2012) proposed an econometric analysis of household energy use for heating in France. The results of their studies showed that the choice of energy mix is determined by the income and the socio-economic characteristics of households. Braun (2010), Michelsen and Madlener (2012, 2013, 2016), and Decker and Menrad (2015) analyzed the factors affecting household choice of residential spacing heating systems in Germany, using the multinomial logit model and discrete choice analysis. They found that dwelling features, specific attributes of residential heating systems, household adoption motivations, heating habits and perceptions are more significant than income in determining household heating decisions. Mahapatra and Gustavsson (2008, 2009, 2010) investigated the adoption of different heating systems among Swedish households and its influencing factors. The findings of these studies implied that economic and system reliability factors are more important than environmental factors. Rouvinen and Matero and Rouvinen (2013) and Ruokamo (2016) designed discrete choice experiments to examine determinants of household heating system choices in Finland. They pointed out that household preferences for heating systems are affected by the

[3] Here, the term 'Northern China' refers to the areas of North China covered by the centralized district heating system. As it is illustrated in Guo et al. (2015), China is divided into northern and southern halves by the Qinling Mountains-Huaihe River boundary, named the North-South heating line. The district heating zones include the northern half where there are at least 90 days a year with daily average temperature less than or equal to 5 °C. At present, the centralized district heating system, which helps to maintain 20 °C indoors is widely used in northern cities.

[4] Here, the mountainous areas refer to those areas inhabited by Tibetan (namely Aba and Ganzi Prefectures).

investment cost of the heating system and household socio-demographic characteristics (age, living environment, education, etc.). Besides, Scarpa and Willis (2010) and Jeong et al. (2011) modeled household choices on heating energy, respectively using the household survey data from UK and Korea. They confirmed that the cost of the heating system is the most important determinant of household heating energy choice behaviors. However, few researches have been done to inspect household heating energy use in developing countries (Gassmann and Tsukada, 2014; Rahut et al., 2014). Notwithstanding the existing literature focusing on residential energy consumption in China has discussed household heating energy use patterns in rural areas (Nordqvist, 2000; Zheng et al., 2014; Wang and Jiang, 2017; Wu et al., 2017; Zhang et al., 2019), there has been a lack of comprehensive and quantitative studies on household heating energy choice and its determinants in rural areas of South China over recent years. This provides the motivation for this paper to fill such gap by providing an in-depth analysis of household choice on different heating systems (with corresponding energy sources), using a Chinese case study.

From the methodological perspective, previous studies concerning household heating energy using behaviors have studied the data of household actual choices obtained from direct observations or face-to-face interviews in field surveys (Sopha et al., 2010; Michelsen and Madlener, 2012, 2013; 2016; Decker and Menrad, 2015; Mahapatra and Gustavsson, 2008, 2009; 2010). Nevertheless, merely concentrating on actual choices has limitations on analyzing household real preferences for some alternative-specific attributes (e.g. energy prices, heating operation costs, environmental benefits etc.) or some government-led projects (Brownstone et al., 2000). Discrete choice experimental design, in this case, is an increasingly popular methodology for analyzing household stated choices (Vaage, 2000; Braun, 2010; Scarpa and Willis, 2010; Takama et al., 2012; Matero and Rouvinen, 2013; Ruokamo, 2016). The main advantage of this method is the ability to test the relative impacts of the attributes with non-use or non-market value (Whitehead et al., 2008), while the main limitation of it is that households might behave differently in response to hypothetic attributes than they would have when they were facing the same situation in real market (Brownstone et al., 2000). Thus, considering the strengths and weaknesses of both types of choice data, another contribution of this paper is to clarify the process of household choice making on space heating systems by examining and comparing household revealed and stated preferences.

3. Data and methodology

3.1. Data collection

The data analyzed in this paper were collected from a household survey conducted from August 2013 to February 2014 in rural areas of Sichuan Province.[5] All counties of the province were divided into three groups (i.e. high-, middle- and low-income groups) beforehand according to their average level of rural income per capita. The sampled households were then randomly selected from each group. More specifically, two counties were randomly selected from each income group at the first step. Three towns, each with two villages were randomly chosen from each county. In every village, 15–16 respondents were randomly interviewed. A total of 570 households were involved in the survey. After dropping out invalid questionnaires and outliers, a sample of 556 households was eventually obtained for analysis.

In addition to a questionnaire with some simple questions on household socio-economic characteristics and residential energy consumption status, a labeled discrete choice experiment (DCE) for space heating was included in the survey. Before the DCE, respondents were asked about their current energy use for space heating and which type of energy they prefer the most for space heating. The DCE was conducted by presenting 4 hypothetical choice sets to individual respondent. In each choice set, 3 residential heat supply system alternatives with 2 predetermined levels of 4 alternative-specific attributes were offered. These heating systems are: 1) distributed heating system with firewood; 2) distributed heating system with coal; and 3) district heating system with electricity, while the selected alternative-specific attributes are: 1) energy usage cost; 2) device usage cost; 3) smoky level; and 4) safety risk. The respondents were asked to choose from each choice set the heating system they would choose if they had to heat their home in this winter and if there were no other options available.

The generation of choice options and the identification of attributes were carried out on the basis of earlier studies (Lagarde and Blaauw, 2009; Takama et al., 2012; Matero and Rouvinen, 2013; Chen et al., 2016), on feedback from an informal interview with the local energy experts and on a pilot survey. For the two attributes of 'device usage cost' and 'energy usage cost', two levels were assigned corresponding to the minimum and maximum cost of each heating system option. Specifically, the device usage cost (CNY/Year) was calculated by allocating the cost of stove (represented by its price) or the device installation fee over its life span. Due to the data limitation, the costs of operation and maintenance were not included in this indicator. In regard to the energy usage cost, for coal and electricity, it refers to the product of energy consumption amount and energy price. Whereas for firewood, it can be measured by the opportunity cost of time spent on firewood collection, which equals to the product of total time spent on firewood collection and the market wage rate of household labor (Kanagawa and Nakata, 2007). Besides, the level of stove/device efficiency was also taken into account when calculating the energy usage cost. It was counted based on analyzing the data from the pilot survey and the official statistics. On the other hand, in order to make the attributes of 'smoky level' and 'safety risk' measurable, they were treated as pseudo-categorical variables (Takama et al., 2012; Chen et al., 2016).[6] Hence, for the 'smoky level': almost no smoke = 0, very little smoke = 1, little smoke = 2, relatively heavy smoke = 3, heavy smoke = 4, while for the "safety risk": safe = 0, little unsafe = 1, moderately unsafe = 2, unsafe = 3. The attribute levels and labels for the three heating energy supply system alternatives in DCE are listed in Table 1.

Having determined the 4 attributes and their 2 levels, 2^{12} hypothetic energy choice sets with different combinations of attributes and levels

Table 1
Assignment of levels and labels for attributes in cooking fuel choice experiments.

	Distributed heating system with firewood (A)	Distributed heating system with coal (B)	District heating system with electricity (C)
Device usage cost (CNY/Year)	{30, 50}	{6, 16}	{20, 60}
Energy usage cost (CNY/Year)	{58, 97}	{189,270}	{420, 1152}
Smoky level	{relatively heavy smoke, heavy smoke}	{little smoke, relatively heavy smoke}	{almost no smoke, very little smoke}
Safety risk	{moderately unsafe, little unsafe}	{little unsafe, safe}	{moderately unsafe, unsafe}

Note: CNY is abbreviation of Chinese Yuan; the average exchange rate in November 2013 was 6.09 CNY/USD.

[5] More detailed information can be seen in Chen et al. (2016).

[6] Based on Chen et al. (2016), the term 'smoky level' is defined as the amount of indoor smoke emitted by using heating stoves (or devices) with corresponding energy sources, while the term 'safety risk' refers to the risk of burn, explosion and poisoning associated with energy use.

can be constructed. After that, the orthogonal main effect design method was employed using the software SPSS 19.0 to reduce the number of choice sets to 20 (Hensher et al., 2005). To further reduce the cognitive burden of the respondent, all choice sets were randomized into 5 blocks, with 4 choice sets in each block to be shown to every respondent. An illustration of a choice set is given in Table 2.

3.2. Choice modeling

3.2.1. Theoretical background for choice modeling

In this paper, household heating energy system choices are empirically studied based on the random utility theory (RUT) in economics. According to the RUT, it can be assumed that individual household is a rational decision-maker, maximizing its utility relative to its choices (McFadden, 1973, 1974). Let C^i denote the choice set with J alternatives faced by household i , and let $U_j^i = U^i(X_j^i)$ denote its random utility function assigning a value to each potentially available alternative j (Herein, X_j^i is a vector of attributes related to alternative j and to household i), the probability that j will be chosen can thus be derived as:

$$P\left(j \middle| X_j^i\right) = Pr\left[U^i\left(X_j^i\right) > U^i\left(X_k^i\right),\ \ \forall j \neq k \in C^i\right] \tag{1}$$

Where the distribution of the utility function U_j^i is assumed to satisfy that the probability of ties is zero. Equation (1) proposes a basic interpretation for household's observed choice behaviors within the RUT framework. For a randomly selected household from the population of interest, the right-hand side of equation (1) indicates its probability of choosing an alternative j to maximize its utility (Manski, 2001). Besides, U_j^i can also represent attainable maximum utility for the sampled household, given its budget constraint and fixed alternatives (McFadden, 1980). Its randomness comes mainly from the unobserved variations in the perceived utility, which captures the combined effects of the various factors that introduce uncertainty into choice modeling (Cascetta, 2009).

3.2.2. Modeling household actual choices on heating energy

In order to investigate the factors determining households' actual choices on heating fuels, a multinomial logit (MNL) model is employed. Let Y_{im}^* denote the probability that individual household i chooses energy m, and let X represent a set of the characteristics of each household, the MNL is specified as follow:

Table 2
A sample of a choice set in DCE.

A	A	B	C
Device usage cost (CNY/Year)	50	16	60
Energy usage cost (CNY/Year)	97	270	420
smoky level	relatively heavy smoke	relatively heavy smoke	almost no smoke
safety risk	moderately unsafe	little unsafe	Unsafe
Your choice	☐	☐	☐
If you don't want choose any one from above set, please tick here. ☐			

Note: The names of heating energy supply system alternatives (distributed heating system with firewood, distributed system coal, and district heating system with electricity) were hidden behind the letter A, B and C.

$$Y_{im}^* = \frac{\exp\left(X_i\beta_m'\right)}{\sum_{k=1}^{m}\exp\left(X_i\beta_k'\right)} + \varepsilon_{im} \tag{2}$$

Where $\beta_1, \cdots, \beta_m$ are m vectors of unknown regression parameters to be estimated; ε is the vector of random error terms, which captures any influences on individual household choices that are omitted or unobserved.[7] However, in the household survey, quite a few interviewed households claimed that they do not need heating in winter (See Figs. 1 and 2). That is to say, the observed data can only reflect the situation of the households who had decided to heat their living spaces. Under this circumstance, a sample selection bias might be introduced. To eliminate this potential source of model misspecification, a two-step estimation procedure suggested by Heckman (1979) is employed. Following Fontana and Geuna (2010), a binary variable describing whether a household uses heating system is set first. Next, a latent variable Y_j^* associated with this binary variable is defined as:

$$Y_j^* = \gamma Z_j + \eta_j \tag{3}$$

Where Z is a set of determinants of the probability of adopting space heating for each household; γ are the coefficients to be estimated; and η is a random error term. Y_j^* is a variable which equals to 1 if the household decides to use heating energy, otherwise it equals to 0.

The selection equation ($Z_j\gamma + \eta_j > 0$) is then treated as a binary probit model and estimated by maximum likelihood (ML) method. The estimation results are used to calculate the Inverse Mills Ratio[8] ($\widehat{IMR}_j$) for each household j that decides to use heating system. In the second step, the parameter estimates of the multinomial logit model (1) are obtained by augmenting the regression with the $\widehat{IMR}_j$ using ML. Hence, the following equation will be estimated:

$$Y_{im}^* = \frac{\exp\left(X_i\beta_m'\right)}{\sum_{k=1}^{m}\exp\left(X_i\beta_k'\right)} + \lambda_j\widehat{IMR}_j + \varepsilon_{im} \tag{4}$$

for all households with $Y_j^* > 0$. While this is a standard estimation strategy for correcting sample selection bias (Mohnen and Hoareau, 2003), it has to be noted that the estimation results of both equations ((3) and (4)) are equally important. This is because the information on how households decide whether to use heating system and which types of energy sources they prefer to use in real situation are provided by the estimates of the two-step regression.

3.2.3. Modeling household choices in DCE

Following the choice modeling process outlined in McFadden (1973), an alternative-specific conditional logit (ASCL) model is applied to analyze the data collected from the discrete choice experiment. Firstly, it is assumed that Y_{in}^* denotes the probability of heating energy supply system choice n made by household i. X_{ij} is a matrix of alternative (energy)-specific variables for case (household) i, while z_{ij} is a matrix of case (household)-specific variables for case (household) i. Thus, the ASCL model can be expressed as:

$$Y_{in}^* = \frac{\exp\left(X_{in}'\beta\right)\exp\left(z_{in}'\gamma\right)}{\left[\sum_{n=1}^{N}\exp\left(X_{in}'\beta\right)\exp\left(z_{in}'\gamma\right)\right]} + \mu_{in} \tag{5}$$

Where β and γ are the matrices of regression coefficients; Similar to the MNL model, μ_{in} are the random disturbances assumed to be independent

[7] Conversion of the random utility model to a choice model needs to make certain assumptions on the joint distribution of the vector of random error terms (Matero and Rouvinen, 2013). In accordance with McFadden (1973), the random error terms are assumed to independently and identically distributed with a Type 1 extreme value (Gumbel) distribution.

[8] According to Heckman (1979), the formula for calculating the Inversed Mills Ratio is $\widehat{IMR}_j = \frac{\varphi(Z_j\hat{\gamma})}{\Phi(Z_j\hat{\gamma})}$.

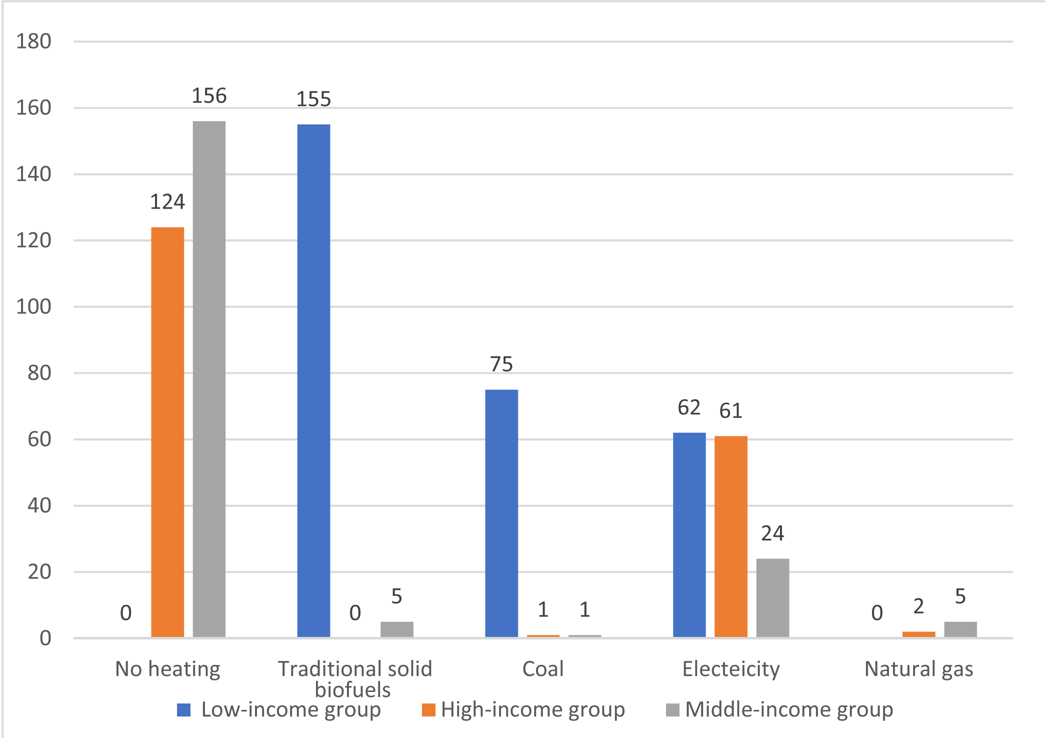

Fig. 1. Energy sources of space heating for the surveyed households (Unit: Households)
Data source: Author's own household survey.

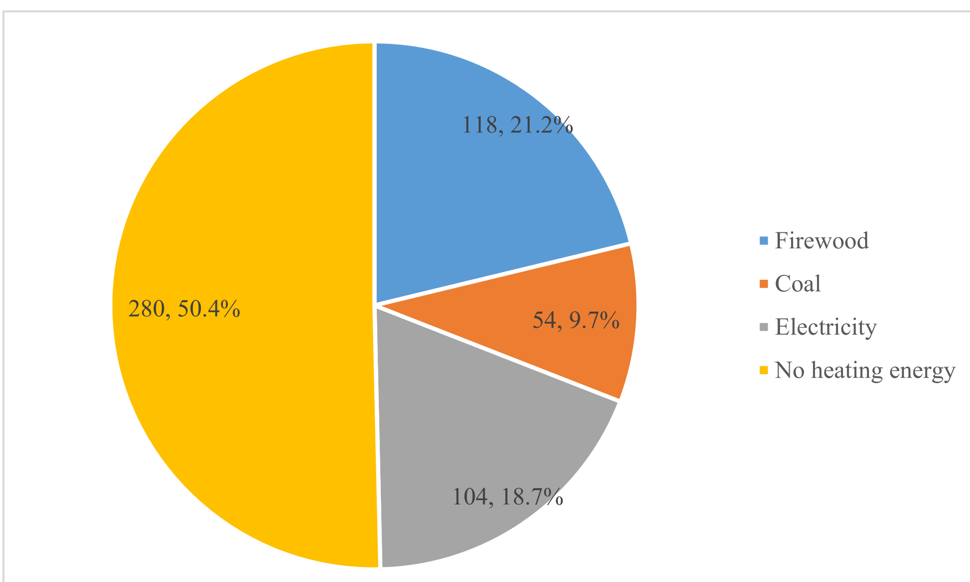

Fig. 2. Household actual heating energy choices (n = 556)
Data source: Author's own household survey.

and identically distributed according to a Gumbel distribution.

4. Empirical analysis

4.1. Household actual energy choice on space heating

Space heating energy sources for the surveyed households are presented in Fig. 1. According to the survey, currently in rural Sichuan Province, households still rely on decentralized stoves or devices for residential space heating in winter. Totally 107 households (19.2%) in the sample consume more than one type of energy. As it can be seen in Fig. 1, an obvious preference for traditional solid biomass energy is shown for the households selected from low-income group, as 155 (87.3%) of them use crop straws and firewood for space heating. 75 (40.5%) households use coal and 62 (33.5%) households use electricity. Considering middle-income and high-income households, the majority of them (84.3% and 66.7%, respectively) decide not to adopt any heating fuels. To be specific, in middle-income group, 24 (12.9%)

households use electricity. Only 1 household is still willing to use coal, accounting for a rather small share (0.5%), whilst merely 5 (2.7%) households select traditional biomass energy or natural gas. For the high-income group, electricity is applied for space heating by 61 (32.8%) households, while coal and natural gas are only adopted by 1 (0.5%) and 2 (1.1%) households respectively.

The distribution of the surveyed households with respect to their actual choice of a specific heating energy source is illustrated in Fig. 2. About 50.4% (280) of them do not use any fuels for space heating. Among the remaining 276 (49.6%) households, approximately 21.2% (118) of them choose firewood. There are 104 (18.7%) households who decide to use electricity, whereas 54 (9.7%) households who made their choices on consuming coal.

4.2. Variable selection and description

The variables used in this study are listed in Table 3. They can be classified into two categories: alternative-specific variables and case-specific variables. The alternative-specific variables are only included in the ASCL model for analyzing the DCE data, while the case-specific variables are selected for both of the two-step MNL and ASCL models.[9] The four energy attributes have been identified in choice experimental design are used as alternative-specific variables (See Table 1). It is hypothesized that households prefer to select the heating systems (with corresponding energy sources) with lower level of cost, smoke and safety risk.

For the case-specific variables used in model estimation (See Table 3), there are two basic assumptions about household preferences on heating systems. Within a household, it is assumed that all family members have the same preference for heating system adoption. It is also assumed that household head is the main decision-maker for its actual heating energy choices, while the respondent is the decision-maker for its hypothetical choices on different heating systems in the experiment. Thus, the characteristics (such as gender, age and educational level) of household head and the surveyed household member are respectively selected as independent variables in both of the two-step MNL and ASCL models. Particularly, in light of the findings of Yu et al. (2012) and Qu et al. (2013), it can be expected that the decision-maker with higher educational level simultaneously has lower probability of choosing firewood stove and higher probability of choosing electric heater for space heating.

Besides, variables of household demographic structure are added in the models as explanatory variables. The family size is supposed to positively affect household actual demand for energy (Wambua, 2011). This means that larger households usually consume more energy for their residential purposes. Other demographic characteristics such as fractions of adult male, adult female, children and elderly people are selected to measure the amount of available labor resources provided by a household from the perspectives of gender and age structure as well as to test the effect of demographic structure on household heating energy choices. It is conjectured that for a household, a higher proportion of adults is associated with a higher probability of choosing coal and electricity for heating, while the higher the proportions of children and elderly people the higher is the probability of using firewood for heating.

In addition, household location variables are incorporated in the models[10]. Firstly, distance from the nearest forest is used to reflect the accessibility and availability of firewood. It can be hypothesized that households living far away from the forest have to spend more time on firewood collection. That is to say that for these households, the usage costs of firewood are relatively high. As a result, they are less likely to choose firewood for space heating. In case that households did not participate in firewood collection, the values of this variable are missing. To deal with this problem, the regional sample means were substituted for the missing data assuming that those households face the average distance. Secondly, household location dummies (r_1 and r_2) are constructed to capture the regional effects. They take value 1 if the surveyed households are from mountainous areas or plain areas respectively, and 0 otherwise (See Table 3). According to the existing studies (Chen et al., 2016), it can be speculated that in comparison with households located in hilly areas, households living in mountainous areas are more likely to use firewood, whereas those from plain areas are more likely to choose electricity.

Finally, as suggested by previous studies (Vaage, 2000; Nesbakken, 2001; Couture et al., 2012; Mensah and Adu, 2013; Chen et al., 2016), income level is one of the most important determinants of household energy choice behaviors. Hence, the log-transformed value of income per capita is also included in both models to estimate the effects of income level on the choice of residential heating system. In line with the economic theory, household income level is expected to have a positive impact on choosing advanced energy sources such as coal and electricity.

Table 3
Description of case-specific explanatory variables used in empirical analysis.

Variables (Unit)	Mean	Std. Dev.
Household heads' characteristics (for the MNL model)		
Gender of household head (Male = 1, Female = 0)	0.928	0.259
Age of household head (Years)	51.673	11.679
Educational years of household head (Years)	6.424	3.478
Respondents' characteristics (for the ASCL model)		
Gender of the respondent (Male = 1, Female = 0)	0.664	0.473
Age of the respondent (Years)	51.552	12.470
Educational years of the respondent (Years)	6.072	3.605
Household demographic structure		
Family size (Number)	4.115	1.367
Fraction of adult females	0.414	0.149
Fraction of adult males	0.436	0.163
Fraction of children ($\leq$14)	0.112	0.156
Fraction of elderly member ($\geq$65)	0.121	0.233
Household location		
Distance from the nearest forest (Km)	2.335	4.387
Household is from mountainous areas ($r_1 = 1$)	0.333	0.471
Household is from plain areas ($r_2 = 1$)	0.333	0.471
Others		
Income per capita (CNY/Year)	14312.580	13754.380
Sample size		556

Note: CNY is abbreviation of Chinese currency Yuan. The missing dummy for region is "Hilly areas".
Source: Author's own field survey.

4.3. Model estimation results

The parameter estimates for the selection equation (treated as a probit model) are presented in Table 4, while those of the MNL model are reported in Table 5. The relative risk ratios (RRR) are also provided to make interpretations for the estimated coefficients of the MNL model easier. Apart from these, the marginal effects of the statistically significant variables in the MNL model at sample means are computed and shown in Table 6 to help better understand the substitution relationships

[9] The majority of the variables used in the selection equation (probit model) are the same as those selected in the MNL model (i.e. age, gender and educational level of household head, family size, and fractions of children, elderly people, adult males and adult females).

[10] As it is shown in Fig. 1, all households from mountainous areas are in low-income group. They all decided to use heating energy. This implies that when $r_1 = 1$, the probabilities of using space heating fuels for all households are equal to 1. Furthermore, all households choosing firewood for space heating are from mountainous areas. Thus, household location dummies are not included in neither the selection equation (probit model) nor the MNL model.

Table 4
Estimation results of the selection equation (probit model).

Variables	Decide to use heating energy ()
Income per capita (log)	0.161* (0.088)
Gender of household head	−0.555** (0.227)
Age of household head	−0.022*** (0.006)
Educational level of household head	−0.044** (0.018)
Family size	0.093** (0.044)
Fraction of children	−0.591 (0.604)
Fraction of elderly people	−0.203 (0.278)
Fraction of adult female	−0.403 (0.599)
Fraction of adult male	−0.141 (0.588)
_cons	0.328 (1.040)
LR chi2 (9)	39.020***
Likelihood	−365.865
No. of cases	556

Note: The '(log)' means that the variables are in natural logarithm. The values in parentheses are standard deviations. This probit model was estimated using software STATA 15.0. *, **, *** denote significance at the 10%, 5% and 1% levels respectively.

Table 5
Estimation results of the MNL model with selection bias correction for actual choice data.

Variables	Coal		Electricity	
	Coef.	Relative risk ratios	Coef.	Relative risk ratios
Income per capita (log)	0.554* (0.318)	1.740	1.016*** (0.310)	2.761
Gender of household head	−0.665 (0.618)	0.514	−0.211 (0.654)	0.810
Age of household head	0.004 (0.021)	1.004	0.042** (0.020)	1.042
Educational level of household head	0.068 (0.065)	1.071	0.143** (0.065)	1.153
Family size	−0.034 (0.180)	0.967	−0.257 (0.176)	0.773
Fraction of children	1.953 (1.701)	7.052	4.129** (1.845)	6.212
Fraction of elderly people	−0.520 (1.416)	0.594	1.275 (1.127)	3.578
Fraction of adult female	1.271 (1.760)	3.563	3.958** (1.834)	5.236
Fraction of adult male	0.114 (1.678)	1.121	1.997 (1.746)	5.766
Distance from the nearest forest	−0.451*** (0.107)	0.637	−0.833*** (0.142)	0.435
	0.310* (1.039)	1.627	0.442** (1.249)	1.791
_cons	−5.245 (3.594)	0.005	−2.645*** (3.642)	0.003
LR chi2 (24)	171.239***			
Likelihood	−204.255			
No. of cases	276			

Note: The location dummies are not included in this multinomial logit model. The '(log)' means that the variables are in natural logarithm. "Firewood" is the base outcome. The values in parentheses are standard deviations. This multinomial logit model was estimated using software STATA 15.0. *, **, *** denote significance at the 10%, 5% and 1% levels respectively.

Table 6
Marginal effects of key influencing factors in the MNL model.

Variables	Firewood	Coal	Electricity
Income per capita (log)	−0.168***	0.062	0.105***
Educational level of household head	−0.022*	0.007	0.015**
Age of household head	−0.004	−0.001	0.005**
Fraction of children	−0.642*	0.204	0.438**
Fraction of adult female	−0.533	0.095	0.437**
Distance to the nearest forest	0.137***	−0.051***	−0.087***

Notes: For dummy variables (a), the marginal effects are obtained from probability differences. 'Pr' is the predicted probability that each type of heating system (associated with the corresponding fuel) is chosen by a household. The marginal effects were calculated using software STATA 15.0. *, **, *** denote significance at the 10%, 5% and 1% levels respectively.

among the three different types of heating fuels.

Considering the regression results of the selection equation in the first stage (See Table 4), income level can significantly affect household decision-making on whether to employ energy for space heating. The positive sign of its coefficient reveals that raising the income level leads to an increase in the likelihood that a household decides to use heating energy. Family size has a statistically significant estimated coefficient. This confirms that family size is directly related to household residential heating energy demand. The larger the family size is, the more likely a household is to heat its living space in winter. In other variables, household head characteristics have significant and negative impacts on household heating system adoption. Concretely speaking, male-headed households are less likely to use heating fuels than female-headed households. Moreover, the well-educated household head decreases the probability of adopting heating devices, whilst an increase in the age of the household head will decrease the probability of applying heating stoves.

Turning to the MNL model with selection bias correction, there are three fuel options of distributed heating stoves (or devices) for the sampled households, namely firewood, coal and electricity. Among them, 'firewood' is the omitted category (the base outcome), with which the estimated coefficients are to be compared. The Inverse Mills Ratio ($\widehat{IMR_j}$) is significant in both outcome equations (See Table 5), indicating that sample selection bias would happen if this MNL model was estimated without taking household decision-making on heating system adoption into account. According to the estimation results of the MNL model, income level is found to be statistically significant in both binary outcome models. This means that the relative probabilities of choosing coal and electricity increase as the income level increases. The marginal effects of income level suggest that a 10% increase in income per capita reduces the probability of choosing firewood by around 1.7%, while increasing the probabilities of adopting coal and electricity by approximately 0.6% and 1.1%. The age and the educational level of the decision-maker have significant effects on household actual heating choices. As the household head's age increases, the choice probability of electricity increases. Meanwhile, increasing the educational level of the household head significantly reduces the probability of selecting firewood, while increasing that of using electricity. Furthermore, it is noteworthy that demographic structure variables such as fractions of children and adult female are important in determining household heating energy choice behaviors. The estimated coefficients and the marginal effects of these variables in the MNL model demonstrate that households with larger fractions of children and women present higher preference for electricity over firewood. This finding is not consistent with the results of some previous studies (Mekonnen and Köhlin, 2009; Heltberg, 2004, 2005), since women and children, unlike those in some other developing and undeveloped areas, are not responsible for firewood collection. Instead, male adults engaged in farm work, in most cases, usually collect firewood on their way to and from the fields. Therefore, higher proportions of children and women in a household imply a lower likelihood of using firewood as well as a higher likelihood of choosing coal and electricity. Additionally, household location is another influencing factor. Households living farther from the forest are more likely to use firewood than the other two types of energy. This result is contrary to expectation, because most of the surveyed households who rely heavily on firewood for heating are living in mountainous areas, and their houses are often located far from the forest, compared with those from the other geographic areas.

On the other hand, the estimated coefficients of the variables and the odds ratios in the ASCL model are reported in Table 7. Similarly, in the ASCL model, 'firewood' is selected as the omitted basic alternative for

Table 7
Estimation results of the ASCL model for the DCE data.

Alternative-specific variables (energy)	Coef.	Odds ratios		
Energy usage cost (log)	−0.103 (0.069)	0.903		
Device usage cost (log)	−0.112 (0.096)	0.894		
Smoky level	−0.137** (0.058)	0.872		
Safety risk	0.260*** (0.059)	1.297		
Case-specific variables (household)	Distributed heating (coal)		District heating (electricity)	
	Coef.	Odds ratios	Coef.	Odds ratios
Income per capita (log)	0.141* (0.08)	1.152	0.505*** (0.115)	1.656
Gender of the respondent	0.161 (0.115)	1.174	0.127 (0.159)	1.135
Age of the respondent	−0.001 (0.006)	1.000	0.013 (0.008)	1.013
Educational level of the respondent	0.091*** (0.017)	1.095	0.080 *** (0.023)	1.084
Family size	−0.034 (0.041)	0.966	0.030 (0.058)	1.030
Fraction of children	−0.914 (0.588)	0.401	−2.556*** (0.793)	0.078
Fraction of elderly people	−0.598** (0.272)	0.550	−0.655* (0.366)	0.519
Fraction of adult female	−0.444 (0.593)	0.641	−2.115*** (0.770)	0.121
Fraction of adult male	−0.383 (0.576)	0.682	−1.792** (0.751)	0.167
Distance to the nearest forest	0.008 (0.013)	1.008	0.058*** (0.019)	1.059
Mountainous areas	0.290** (0.136)	1.336	−0.791*** (0.214)	0.453
Plain areas	1.135*** (0.146)	3.111	1.106*** (0.181)	3.023
_cons	−1.412 (0.979)	0.244	−4.780*** (1.355)	0.011
No. of cases	2220			
Wald Chi2(28)	231.020***			
Log likelihood	−2023.235			

Note: The missing dummy for region is "Hilly areas". The basic alternative for this ASCL model is 'Distributed heating supply system with firewood'. The '(log)' means that the variables are in natural logarithm. The values in parentheses are standard deviations. This asclogit model was estimated using software STATA 15.0. *, **, *** denote significance at the 10%, 5% and 1% levels respectively.

Table 8
Marginal effects of key influencing factors in the ASCL model.

Alternative-specific variables	Distributed heating (firewood)	Distributed heating (coal)	District heating (electricity)
	Pr = 0.261	Pr = 0.591	Pr = 0.149
Smoky level			
Distributed heating (firewood)	−0.026**		
Distributed heating (coal)	0.021**	−0.033**	
District heating (electricity)	0.005**	0.012**	−0.017**
Safety risk			
Distributed heating (firewood))	0.050***		
Distributed heating (coal)	−0.040***	0.063***	
District heating (electricity)	−0.010***	−0.023***	0.033***
Case-specific variables			
Income per capita (log)	−0.041***	−0.010	0.052***
Educational level of the respondent	−0.017***	0.015***	0.002
Fraction of children	0.240**	0.004	−0.244***
Fraction of elderly people	0.118**	−0.087	−0.031
Fraction of adult female	0.151	0.079	−0.229***
Fraction of adult male	0.129	0.065	−0.193**
Distance to the nearest forest	−0.004	−0.003	0.007***
Mountainous areas[a]	−0.014	0.140***	−0.126***
Plain areas[a]	−0.218***	0.177***	0.040***

Notes: For dummy variables (a), the marginal effects are obtained from probability differences. 'Pr' is the probability that each type of heating system (associated with the corresponding fuel) is chosen by a household. The marginal effects were calculated using software STATA 15.0. *, **, *** denote significance at the 10%, 5% and 1% levels respectively.

comparing estimated coefficients. For the statistically significant variables in the ASCL model, their marginal effects calculated at sample means are given in Table 8. And the values of the predicted probabilities that each type of heating system is chosen by a household are also listed in Table 8.

In the DCE, only 4 respondents stated that they do not need heating. Compared with the data of household actual choices (presented in Section 4.1.1),[11] this implies that the surveyed households have potential energy demand for heating. The predicted probabilities (See Table 8) demonstrate that on average, the sampled households have the highest probability (59.1%) to choose the distributed heating with coal, implying that they have the highest potential preference for decentralized coal stoves over other types of heating systems. Meanwhile, the surveyed households have the lowest propensity (14.9%) to adopt the centralized district heating with electricity, while they have a probability of 26.1% to choose the distributed traditional firewood stoves.

According to the estimation results of the ASCL model (See Table 7), all the signs of the alternative-specific variables are consistent with theoretical expectations. Although the estimated coefficients of energy and device usage costs are not statistically significant, their negative signs show that the heating systems with lower costs are probably preferred by the respondents. Nevertheless, the statistically significant coefficient estimates in the ASCL model clearly reflect that smoky level and safety risk are major determinants of household heating energy choice behaviors. The opposite signs of the coefficients on these two variables indicate that households prefer to use the safer energy carriers which could generate less smoke.

Regarding the case-specific variables, income level is one of the key determinants of household stated preferences on different heating systems. The coefficients on income level are statistically significant and positive in both choice models of distributed heating with coal and district heating with electricity. These results indicate that relative to distributed firewood stove, the probability of choosing heating systems with advanced energy sources such as coal and electricity increase as the household's income level increases. The marginal effects of income level suggest that a 10% increase in income per capita leads to about 0.5% increase in the choice probability of district heating system with electricity and an estimated 0.4% decrease in that of distributed firewood stove. Among the decision-maker characteristics, the educational level of the respondent is a statistically significant explanatory variable for both choices of decentralized coal heating and centralized electricity heating system. It can be seen from its marginal effects that increasing the educational level of the respondent simultaneously leads to a significant decrease in the choice probability of distributed heating stove

[11] Actually, 280 households were not using any heating fuels at the time of the survey. But most of them thought that the local weather conditions are cold and wet in winter.

with firewood and an obvious increase in that of distributed coal stove.

In respect to other household characteristics, the statistically significant coefficients of the ASCL model demonstrate that demographic structure and household location are important factors influencing household stated heating fuel choices. In detail, fractions of adults, children and elderly people in household have negative effects on the potential preferences for district electricity heating. According to the marginal effects, households with higher fractions of children and elderly people have a higher likelihood of collecting firewood for space heating. The possible reasons for this could be that children and elderly people usually have more spare time than the other adult family members and that they face a relatively lower opportunity cost of time. Moreover, households with higher fractions of children and adults are less likely to choose district heating with electricity. This is partly due to the fact that in the study region, an increasing number of adult members work off-farm, leaving their aged parents to take care of their children. As a result, they might spend less time staying in their homes in rural areas and have lower probabilities of installing the district heating devices. As for household location, the longer the distance between the nearest forest and home, the higher is the probability for a household to use district heating with electricity. The estimated coefficients of the household location dummies illustrate that households from different geographic areas potentially have different heating fuel choice behaviors. Compared with those living in hilly areas, households located in mountainous areas and plain areas are more likely to choose distributed heating stove with coal over that with firewood. Households from mountainous areas are more inclined than those from hilly areas to choose firewood stove over centralized electricity heating device. By contrary, households from plain areas are more likely to select district heating with electricity over firewood stove, in comparison to those located in hilly areas. The calculated marginal effect values of the location dummies illustrate that households in mountainous areas are about 14.0% more likely to choose distributed heating system with coal and about 12.6% less likely to choose district heating system with electricity than those living in hilly areas. The plausible reasons for this could be that the electricity price is relatively high and the power supply is still unstable in remote areas. Besides, because of the higher development level of the local economy, households located in plain areas are on average about 17.7% and 4.0% more likely than those from hilly areas to select heating systems with superior energy sources of coal and electricity, and about 21.8% less likely to use heating system with firewood.

5. Discussions

Methodologically, as the MNL model analyzing household actual choice behaviors has limitation to capture the effects of alternative-specific (energy-specific) characteristics (such as device and fuel using costs, smoky level and safety level), the ASCL model provides evidence that households prefer to use the cheaper stoves (or devices) with lower-cost and safer fuels that emit lower level of smoke. Among case-specific variables, household demographic structure characteristics (such as fractions of children and female adults) and household location (measured by the distance between home and the nearest forest) significantly affect heating fuel choices, but have opposite signs in the two logit models. Since the results from the ASCL model are consistent with the economic theoretical speculations, the findings of this paper indicate that household heating energy choice behaviors are constrained by the real situation. That is to say that in the study region, a large number of rural female adults got their jobs in nearby townships and cities. Meanwhile, their children attended schools there. Therefore, they usually spent less time on firewood collection than they were supposed to be. Besides, households living in mountainous areas are usually located farther from the forest, but they still have higher likelihood to use firewood because the winter there is longer and colder than that in any other geographic areas.

On the contrary, as has been already mentioned in the analysis of the empirical results of this paper, the coefficient estimates of the selection equation (See Table 4) provide insight into how households make their decision on whether to heat their homes. Furthermore, the estimated coefficients of the MNL model can be used to interpret the effects of different factors on household heating energy using status, while those of the ASCL model can reflect households' priorities and perspectives in different heating systems. Beyond that, the ASCL model provides more effective information to detect household potential preference for some possible future programs (e.g. the construction of district heating in rural areas of South China), its estimates are more proper to be applied to identify and assess what matters most to rural households when they make decision on adopting district heating. Thus, by comparing the estimation results of these models, it can be found that income and the educational level of the decision-maker can determine household heating fuel using behaviors in both of the actual and hypothesized choice situations. Under the current situation, households with higher income level tend to use clean and modern energy (such as electricity) instead of firewood. And potentially, raising income level could further increase the probability of adopting distribute heating with electricity and decrease that of selecting distributed firewood stove at the same time. These results are consistent with the findings of researches from some developed countries (Vaage, 2000; Braun, 2010; Couture et al., 2012; Michelsen and Madlener, 2013; Decker and Menrad, 2015) that income is an important influencing factor of household energy transition in space heating from traditional solid biomass to modern clean fuels. It should also be noted that the higher the educational level of the decision-maker, the lower is the probability of adopting heating system under current situation. The underlying reason for this could be that households where the heads have lower educational level usually live in remote mountainous areas. They have to heat their houses due to the harsh local weather conditions. However, an increase in educational level of the decision-maker simultaneously leads to a significant decrease in the choice probability of firewood stove and an apparent increase in the adoption probability of electricity heating. Equally important are the estimated parameters on location dummies in the ASCL model. They reveal that households from plain areas are much more likely to use district heating system with electricity than those from hilly and mountainous areas.

In particular, comparing with the estimation results of the previous research that has been done in the same region (Chen et al., 2016), this paper finds that household energy choice making in the context of heating is very similar to that of cooking. The results of both studies suggest that income and the educational level of the decision-maker are key factors in promoting energy transition process in rural residential sector in Sichuan Province. Demographic structure such as fractions of children and female adults has statistically significant influences on household stated preference towards modern and clean fuels. However, the energy use for space heating shows seasonality and has more obvious regional characteristics than that for cooking in the study areas.

6. Conclusions and policy implications

Nowadays, in Chinese rural residential sector, distributed heating stoves or devices with corresponding energy sources are commonly adopted by individual households. However, as promoting the centralized district heating system is considered to be not only an effective measure to achieve the national goal of energy conservation and emission reduction (Liu, 2015), but also a crucial way of enhancing rural livelihoods, whether and how to establish and develop the centralized district heating system in South China have become major topics of debate for the public and the government recently. Hence, this paper examined the heating energy choice behaviors of the rural households using the survey data from Sichuan Province.

In the DCE, the number of households that choose 'opt-out' is tiny (only 4), compared with that under real situation (280). This indicates that households in the study areas have great potential demand for heating in winter. The analysis results of household actual heating energy choices show that at present, households with higher income and well-educated heads are more likely to choose electric heater over firewood stove. Whereas, the results of the discrete choice experiment reveal that although coal is potentially the most preferred fuel (59.1%) over other types of energy sources, an increase in household income will result in a shift in heating fuel choices from firewood to district electricity heating. Raising the educational level of household members might also increase the choice probability of district heating. With respect to other influencing factors of household heating energy choice behaviors, energy-specific attributes such as smoky level and safety risk have statistically significant effects. According to this paper, households prefer to use heaters with higher safety and less indoor air pollution. The household demographic characteristics, for instance, fractions of children and female adults, are also found to be important factors affecting the adoption of district heating system. Furthermore, as regional differences exist in household heating choice behaviors, household geographic location and the distance of it from the nearest forest are also crucial determinants of household heating energy transition.

Combining these findings of this paper with the Chinese real situation, three suggestions are provided on future energy policy design for rural development in South China. Firstly, rural residential heating should be attached more importance. Specifically, the energy policies concerning the construction of centralized heating system should pay more attention to the combined effect on both cost and quality of heating systems. This means that the government should give priority to energy development projects aiming at the promotion of the low-cost heating systems with fuels of high quality and efficiency. Meanwhile, more subsidies should be offered to support R&D and extension of advanced energy technologies and to facilitate rural households to adopt better heating systems. Secondly, despite the fact the centralized district heating system is cleaner and more efficient, the current distributed system still has many advantages such as low construction cost, simple operation and maintenance, and profitable performance for rural households (Zhang and Yang, 2010; Chen and Liu, 2017). Therefore, it is imperative to coordinate the development of both heating systems to enhance the contrasting strengths of them while reducing their weaknesses. Especially for households from different geographic regions, which system is preferred depends heavily on local conditions. The district heating should be first constructed in relatively affluent rural areas. Last but not the least, indirect policy measures with the purpose of increasing rural income per capita as well as improving educational level should be implemented to accelerate the heating energy transition towards modern energy sources. On one hand, more skill trainings related to the installation and use of modern and clean heating devices should be provided. On the other hand, more non-farm job and education opportunities should be offered to rural households.

CRediT authorship contribution statement

Qiu Chen: is the only author of this paper, Conceptualization, Methodology, Writing - original draft, Writing, Formal analysis, Data collection and analysis, Writing - review & editing, Reviewing and Editing, etc.

Declaration of competing interest

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled.

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Nomenclature list

Symbols

C^i	choice set faced by household *i*
$\widehat{IMR}_j$	inverse mills ratio for each household *j*
Pr	probability
U_j^i	attainable maximum utility for household *i* to choose available alternative *j*
X_j^i	attributes related to alternative *j* and to household *i*
X_i	characteristics of household *i*
Y_{im}^*	probability that household *i* chooses alternative m
Y_j^*	Probability that household *j* adopts space heating energy
Z_j	determinants of the probability of adopting space heating for each household *j*
λ, β, γ	unknown regression parameters to be estimated
ε, μ, η	random error terms

Common Abbreviations

ASCL	alternative-specific conditional logit
CNY	Chinese Yuan
DCE	discrete choice experiment
GHG	greenhouse gas
kgsce	kilogram(s) standard coal equivalent
km	kilometer(s)
LR	Likelihood ratio
MNL	multinomial logit

ML maximum likelihood
RUT random utility theory
R&D research and development
RRR relative risk ratios
tsce ton(s) standard coal equivalent

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