RESEARCH ARTICLE

Characteristics and influencing factors of energy consumption in Chinese rural households

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Abstract

In the 14th Five-Year Plan, China clearly proposed to achieve carbon peak by 2030 and carbon neutralization by 2060, which will be incorporated into the Ecological Civilization Construction. Therefore, it is particularly important to control the consumption of fossil energy in rural areas. Under this background, the paper is based on the filed survey data of rural households and uses the method of CLAD (the censored least absolute deviations) estimation of Tobit model to study the influencing factors and structural characteristics of rural households' energy consumption. The results show that the consumption of traditional energy with low-quality takes a main proportion of total energy consumption in rural households, which is unreasonable and needs transforming urgently. Also, there is heterogeneity among regions. Family characteristics, family wealth, and energy conservation initiative have an impact on total energy consumption and different types of energy. Especially, households with high frequency of energy conservation behavior and strong policy perception will reduce the consumption of high-polluting firewood and increase the use of coal and electricity.

Abbreviations

CLAD The censored least absolute deviations
LPG Liquefied petroleum gas

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Introduction

Responsible consumption and production as well as affordable and clean energy are two components of the 17 United Nations Sustainable Development Goals (SDGs 7 and 12). The population in rural areas of China accounts for 40% of the total population, which play an important role in renewable energy generation and climate change mitigation (Argent, 2017; Woods 2012). Therefore, it is of great significance to explore the characteristics and influencing factors of energy consumption structure of rural residents in the process of low carbon. With the entry of socialism with Chinese characteristics into a new era, the level of economic development continues to grow, increasing the domestic demand for energy consumption. However, the optimization of economic structure makes us pay more attention to the transformation of energy structure while focusing on the increase of total energy consumption. In 2012, China' total energy consumption was 4.02 billion tons of standard coal, reaching 4.86 billion tons in 2019. On the other hand, as a large agricultural country, China's rural population accounts for about 40% of the total population. In recent years, with the government issuing a series of policies to benefit the rural people and strengthening the construction of infrastructure facilities, the level of rural economy has

developed rapidly (Wu et al. 2016). At the same time, the total amount of energy consumption in rural areas shows a trend of rapid growth, and the energy structure has undergone significant changes. In 2005, the per capita domestic energy consumption of urban residents was 288 kg of standard coal, and that of rural residents was 155 kg of standard coal. In 2017, the per capita domestic energy consumption of urban and rural residents reached 415 kg and 417 kg of standard coal respectively (National Bureau of statistics of the People's Republic of China 2020). The growth rate of rural residents' living energy is much higher than that of urban residents. The gap between urban and rural energy consumption is gradually narrowing and the rural areas have been anti urban per capita energy consumption. Considering that non-commercial energy such as straw and firewood are widely used in rural areas, especially in northern China, the energy consumption of rural residents is much higher than that of urban residents, and the carbon monoxide, sulfur oxides, and nitrogen oxides produced by the combustion of these energy will have adverse effects on the ecological environment and personal health (Ekholm et al. 2010; Wei et al. 2013). In recent years, with the acceleration of urbanization, the consumption of commodity energy by rural residents has increased significantly, the energy consumption structure has transformed to the coexistence mode of traditional and modern energy, the popularization rate of clean energy has increased steadily, and most families can use modern energy such as electricity, liquefied petroleum gas, and natural gas (Liao, 2019). Figure 1 shows the current situation and changes of different types of energy consumption in rural China. The inner circle represents 2015, the outer circle is 2019, and the middle circle is 2017. There is a lack of statistical data on traditional biomass energy, such as firewood, and the data in Fig. 1 is from the National Bureau
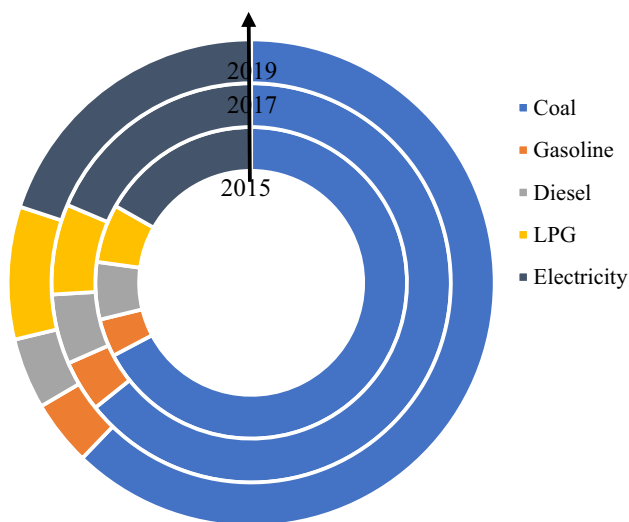
of statistics of the People's Republic of China. The Coal has always been the main energy used in rural areas, and its consumption is decreasing year by year, but the annual consumption accounts for more than half of the total consumption of five kinds of energy. The consumption of electricity is gradually increasing, which is preferred by rural residents, accounting for about 20% of the total. Moreover, the consumption of gasoline, natural gas, and diesel is small, but there is an upward trend.

With the background mentioned above, the transformation of energy consumption structure of rural residents in China has a significant impact on the optimization of energy consumption structure in China. Therefore, the scientific problems of the research are as follows: (1) What are the current situation and influencing factors of rural household energy consumption? (2) What are the different influencing factors of different types of energy consumption? Significantly, energy consumption is affected by macro-economy. In the endogenous growth model, it is reasonable to assume that energy demand lacks elasticity, and the redistribution of resources from energy production to manufacturing triggers the acceleration of total factor productivity (TFP) growth, thus increasing energy consumption (Peretto, 2008). Besides, "Value-belief-norm" (VBN) theory holds that environmental values, beliefs, and subjective norms will have an impact on energy conservation behavior (Stern et al. 1999). So, this appears as a more straightforward problem compared to the research on energy structure turns out to be even more challenging because the influencing factors not only lie in the economic and social aspects, but also psychological factors play an important role. This poses some difficulties when carrying out the energy consumption data collection of rural residents. Therefore, there has been less previous evidence for comprehensive influencing factors of energy consumption in rural areas in China. It would be of special interest to use first-hand data for analyzing the characteristics of regional differences in energy consumption. Moreover, for this study, it is of importance to investigate influencing factors of different types of energy consumption. To examine the impact of different variables, we use the data of face-to-face interviews with farmers to analyze the characteristics of rural household energy consumption and explore the differences between different regions. In addition, based on the CLAD estimation method of Tobit model, this paper analyzes the influencing factors of different types of energy consumption of rural households, which is of great significance to optimize the structure of rural energy consumption.

The contribution of this research to the existing literature can be summarized as follows: firstly, the data of this study is the first-hand data obtained from the field research of the research group, which is closer to the actual situation of rural families, especially the consumption data of firewood

Fig. 1 Energy consumption in rural areas from 2015 to 2019

commonly used in rural areas; secondly, we explore the characteristics of different types of energy structure and the relationship between regional development gap and energy consumption. Moreover, the psychological factors of rural residents are the focus of our research. This paper considers the effect of psychological factors from the aspects of energy conservation behavior, energy conservation consciousness, and policy perception. Finally, the content is not only limited to the comprehensive factors and characteristics of the total energy consumption, but also further analyzes the influencing factors and characteristics of different types of energy consumption, so as to provide empirical suggestions for optimizing rural energy structure.

Literature review

In terms of energy options, Chambwera and Folmer (2007) ascribed the transforming of family's energy choice to the increase of income, that is, from traditional energy such as firewood to coal and finally choose modern energy such as natural gas and electricity. Masera (2000) proposed that modern energy is a possible substitute for traditional energy, and would not be completely replaced by traditional energy. And the empirical results show that the energy consumption of rural households indeed shows diversification (Han et al. 2018; Ravindra et al. 2019).

Regarding to the factors affecting rural residents' energy consumption, many studies focus on socioeconomic factors (Ding et al. 2017; Jin et al. 2019; Jones et al. 2010). In China, wages of rural population have a significant positive impact on rural electricity consumption and new energy consumption, and a negative impact on traditional biomass consumption (Qiu et al. 2018; Zou and Mishra, 2020). At the same time, the role of energy price could not be ignored. Farsi et al. (2007) and Ondraczek et al. (2013) found that the price of kerosene was negatively correlated with the expectation of households choosing kerosene in India and Kenya respectively. In terms of population factors, the improvement of education level and income level may increase a family's utilization of electricity and reduce the consumption of wood (Gebreegziabher et al. 2012). There is a negative relationship between family size and energy consumption, and there are regional differences (Zhai and Jun, 2016; Yang et al. 2018). And the cooking habits of rural families have an important impact on energy transformation. The longer cooking time, the less likely a family is to choose natural gas and electricity (Baiyegunhi and Hassan, 2014). Moreover, terrain has a significant impact on fuel conversion in energy structure conversion, and the availability of different energy sources is different, resulting in large differences in use (Peng et al. 2010).

In addition, some scholars believe that the energy consumption structure of rural households may be related to the production characteristics of households. Some research results show that the household assets such as land and livestock play an important role in energy use and substitution, and the number of large livestock had a positive relationship with family firewood collection (Jean-Marie et al. 2018; Guta, 2014). The research on the rural household energy use patterns of Tujia and Miao Nationalities in Chongqing shows that the household energy use patterns are significantly affected by electrical appliances and pig production (Mao et al. 2020). Also, women, as the main labor force that can collect firewood, affect the transformation of energy structure from traditional to modern (Link et al. 2012). Some scholars also emphasized the importance of infrastructure for modern fuel acquisition (Leach, 1992). However, a study of South Africa shows that infrastructure is of little importance (Davis, 1998).

Some studies have found the influence of psychological factors on energy consumption. Steg et al. (2005) confirmed the VBN theory that people's general values affect behaviors, beliefs, and norms about the environment, and reducing energy consumption is significantly related to the sense of moral obligation. The research of domestic scholars shows that the willingness of low-carbon behavior is the most direct driving force of low-carbon energy consumption behavior, and the subjective norms of residents are the most indirect driving force (Lingyun et al. 2016). At the same time, people's perception of the benefits of energy conservation (Iwata et al. 2015) and the cognition of labels of energy conservation appliances (Mills and Schleich, 2010), this information processing will have a significant impact on energy conservation behavior. In addition, providing sufficient information and cognition to rural residents is conducive to the popularization of alternative energy (Nduka, 2020).

In conclusion, a large number of scholars at home and abroad have analyzed the factors influencing the choice of energy consumption, but a small number of researches focus on developing countries, and the scope and data of this studies focus on the overall situation of macro scope. From the perspective of the research, many scholars focus on the factors affecting the energy consumption of the rural households in the economic and social aspects (Baiyegunhi and Hassan, 2014; Farsi et al. 2007; Ondraczek et al. 2013; Yang et al. 2018; Zhai and Jun, 2016). Some scholars pay attention to the influence of psychological factors on energy consumption (Iwata et al. 2015; Lingyun et al. 2016; Mills and Schleich, 2010), but most of them are limited to urban residents, and few scholars study the structure of energy consumption for the psychological factors of rural residents.

In order to explore the scientific problems of the research, based on the energy consumption data of six rural villages in central and eastern China, this paper uses the methods of questionnaire survey to investigate the household situation of villagers in each village, consumption of various types of energy, and energy conservation initiative of villagers. Then, this paper uses the method of CLAD in Tobin model to regress the total energy consumption and different types of energy consumption respectively. The characteristics of energy consumption show that the energy structure of rural households is not reasonable, the popularization rate of clean energy is high, but the consumption is low. Regression results show that the increase of household wealth, education level and household appliances will accelerate the transformation of clean energy. The stronger the energy conservation initiative, the more rural residents will reduce the use of traditional energy. Different aspects of energy conservation initiative have different effects on the energy consumption structure. Among them, energy conservation behavior and policy perception are conducive to the transformation of rural energy structure from firewood to coal, while energy conservation awareness is conducive to reducing the use of coal, which is conducive to cleaning transforming of energy structure.

Data and methodology

Data

Due to the lack of public data on the characteristics of rural household energy consumption, this paper uses the 2017 rural energy consumption questionnaire of the research group to collect data. The choice and consumption of energy in different regions are mainly affected by the economic development and natural environment. The survey was conducted mainly on the topic of the current status of the energy consumption of rural residents in China. Considering the different geographical climate and economic development level of rural areas in different regions, this paper only selects the central and eastern regions of China as the research area. The field survey was conducted in the survey area from January to February 2017 by random sampling and on-site interview. In this sampling survey, six villages in three provinces were selected, a total of 483 questionnaires were issued, and 474 valid questionnaires were recovered from on-site interviews. The effective recovery rate reached 98.1%. The geographical distribution of the investigated villages is shown in Fig. 2. The number of villages in Fig. 2 is the same as that in Table 1. Among them, we selected

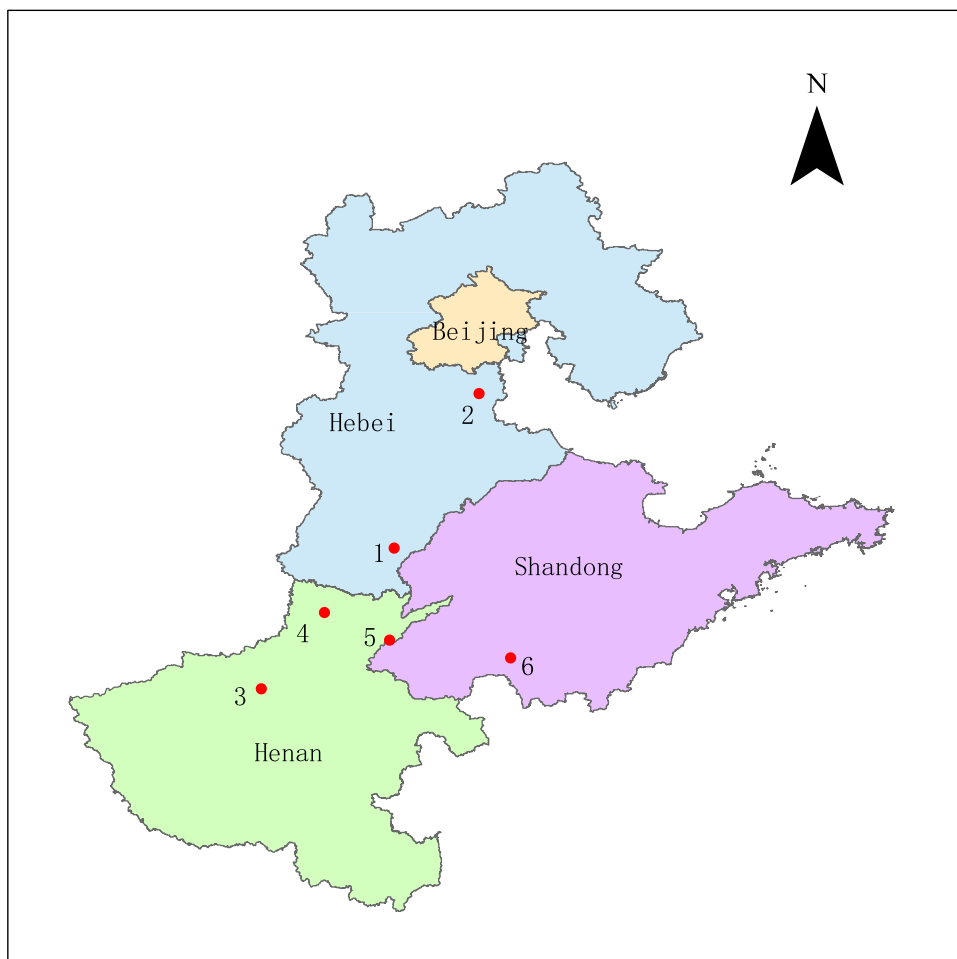**Fig. 2** The village distribution map of questionnaire survey

Table 1 Data sources of questionnaire survey

Number	Region	Number of valid questionnaires	Ratio
1	Xinxianzhuang village, Qiu county, Hebei Province	93	19.62%
2	Shicheng village, Bazhou City, Hebei Province	87	18.35%
3	Gaomiao village, Gongyi City, Henan Province	71	14.98%
4	Shangyu village, Hebi City, Henan Province	68	14.35%
5	Lanzhan village, Puyang City, Henan Province	75	15.82%
6	RenQian village, Tengzhou City, Shandong province	80	16.88%

two villages in Hebei Province, three villages in Henan Province, and one village in Shandong Province. In terms of economic development, in 2016, the per capita disposable income of rural residents in Shandong Province ranked eighth in the country, while Hebei Province and Henan Province ranked 14th and 18th, respectively. The economic levels of the three regions were similar, and they were in the middle level of the country. Hebei, Henan, and Shandong provinces are located in the North China Plain, with similar geographical conditions and temperate monsoon climate. The following are the reasons for choosing the specific investigation sites. The villages surveyed are located in the middle and lower reaches of the Yellow River, and there are differences in natural resources and environmental policies. From the perspective the development of industry, Xinxianzhuang village, Qiu county, Hebei Province pays more attention to the development of tourism and environmental and ecological protection. As the policy direction may affect the psychology and behavior of residents, Shicheng village in Bazhou, Hebei Province, is closer to Beijing, so it is more vulnerable to environmental policies. Considering the differences in economic development, the people's living standard in Gaomiao village in Gongyi City of Henan Province is relatively high, while Puyang County in Puyang City of Henan Province belongs to the key county of poverty alleviation and development. The resource endowment and the availability of energy may make the energy consumption characteristics of this region different from other regions. Shangyu village of Hebi City in Henan Province and RenQian village of Tengzhou City in Shandong Province are rich in coal resources, and the fossil fuel resources of Xinxianzhuang village in Qiu county and Lanzhan village in Puyang City villages are insufficient. Based on the above considerations, we selected the residents of 6 villages as the research objects, making the sampling survey random and representative under limited conditions. Generally speaking, the six villages are different in economic development and physical geography, but they are representative, representing several models of the current situation of rural development in China.

The questionnaire is mainly divided into three parts. The first part is the basic situation of the family, including the basic characteristics of family members, family characteristics, housing situation, household appliances, and transportation.

The second part is about the energy consumption of residents, including the types of energy consumption, consumption and expenditure, as well as the energy consumption of cooking, bathroom, heating, refrigeration, biogas, and solar energy. The third part investigates the residents' energy conservation initiative, which is divided into energy conservation behavior, energy conservation awareness, and policy perception. The higher the score is, the higher the frequency of energy conservation behaviors, the stronger the awareness of energy conservation, and the greater the sensitivity to energy conservation policies. Specifically, energy conservation behavior mainly refers to the energy conservation behaviors in terms of energy use for electrical appliances or transportation as well as persuading others to save energy. Energy conservation awareness mainly refers to energy conservation responsibility, willingness to purchase energy-saving products, and environmental protection knowledge. Policy perception mainly measures rural households' understanding of and participation in energy conservation subsidy policies. With the help of random sampling survey, the effective recovery rate reached 98.1%. The KMO value of the questionnaire is 0.840, and the significance of Bartlett spherical test is. 000, which indicates that it is suitable for factor analysis. Moreover, the reliability test of three indicators of energy conservation initiative has passed; these variables meet the quite good reliability. As shown in Table 1, there is little difference in the number and proportion of valid questionnaires collected in the six regions and the distribution is basically uniform.

Method

According to the results of the questionnaire, the energy consumption types of rural households mainly include electricity, coal, liquefied gas, gasoline, diesel, and firewood (including straw, etc.). The dependent variable of this paper is the annual energy consumption of rural households. In order to unify the standard, the consumption is converted into standard coal by using the standard coal conversion coefficient of energy.

$$E_{ci} = \sum_{i=1}^{n} E_i \bullet f_i \tag{1}$$

E_{ci} is the total amount of energy consumption converted into standard coal, n is the type of energy, and E_i is the actual consumption of the energy i. f_i indicates the standard coal conversion coefficient of the energy i. That is, E_{ci} is the dependent variable Y in the following. The specific values of standard coal converted from various energy sources are shown in the Table 2.

According to the survey data, rural households have a variety of energy consumption choices. Except for electricity consumption, other kinds of energy consumption are composed of zero and positive numbers. So, the paper uses OLS regression model to analyze the relationship between electricity consumption and its influencing factors. Besides, there are a large number of 0 elements in the other dependent variable (coal, LPG, gasoline, diesel, and firewood), which become the restricted dependent variable. Tobit model is different from discrete choice model and general continuous variable choice model. Its characteristic is that the dependent variable is a limited variable. The model is actually composed of two kinds of equations. In this case, Tobit model of type I proposed by Tobin (1985) should be used for regression. Tobit model is assumed as follows:

$$Y^* = \alpha + \sum_{j=1}^{n} \beta_j x_j + \varepsilon$$

$$\varepsilon \sim N(0, \sigma^2)$$

$$Y = \begin{cases} Y^*, Y^* > 0 \\ 0, Y^* \leq 0 \end{cases} \tag{2}$$

In this model, α is a constant term and β_j is the parameter to be estimated and ε is the error term. When the latent variable Y^* is less than or equal to 0, the explained variable Y is equal to 0; when Y^* is greater than 0, the explained variable Y is equal to Y^* itself.

The standard type I Tobit model requires that the error term obey the standard normal distribution, but the error term in this study does not obey the standard normal distribution, so the censored least absolute deviations (CLAD)

in Tobin model is used in this paper. CLAD is a semi parametric estimation method of Tobit model, which allows the error term to be more widely distributed, including asymmetric distribution. When the error term of Tobit model does not conform to normal distribution, Monte Carlo simulation shows that CLAD estimation performs well and is robust to heteroscedasticity.

Considering the research at home and abroad, rural households have many choices in daily energy use, and many factors affect their choices, including socio-economic and cultural factors (Guta, 2014; Jones et al. 2010; Ravindra et al. 2019), family characteristics (Baiyegunhi and Hassan, 2014; Jin et al. 2019; Zhai and Jun, 2016), and so on. Therefore, according to the previous literature and field research, this paper selects 12 kinds of variables related to family basic situation, family income and consumption, and energy conservation initiative as explanatory variables. Based on CLAD estimation of Tobit model, this paper constructs the model that includes influencing factors of rural household energy consumption as Eq. 3. The definition and assignment of variables in the model are shown in Table 3.

$$Y = \alpha_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_{41} x_{41} + \beta_{42} x_{42} + \beta_{51} x_{51} + \beta_{52} x_{52} + \beta_{53} x_{53}$$
$$+ \beta_6 x_6 + \beta_7 x_7 + \beta_8 x_8 + \beta_9 x_9 + \beta_{10} x_{10} + \beta_{11} x_{11} + \beta_{12} x_{12} + \varepsilon \tag{3}$$

Results and discussion

Descriptive statistics and correlation analysis of variables

The main dependent variables of this study are the consumption of various kinds of energy, including electricity, coal, gasoline, diesel, LPG, firewood, and total energy consumption. The descriptive statistics of the dependent variables and the independent variables are shown in Table 4: among the 474 samples, electricity and coal are the two energy sources with the largest average consumption of the surveyed households, among which the electricity penetration rate is the highest and all households use it. The consumption of LPG, firewood, and gasoline firewood took the second place, while the average consumption of diesel was the least. In terms of family characteristics, 68.8% of the households surveyed are headed by men, which is consistent with the fact that most of the households in China are headed by men; 94.9% of the heads of households are married, with an average age of 48.46 years old. Most of the respondents are married, and the number of unmarried, divorced, or widowed families is small. Moreover, the number of rural families with two or three generations living together is higher, which is in line with the actual situation of older heads of households. Further, 16.5% of the families with education above high school

Table 2 Reference conversion coefficient of standard coal for energy sources

Energy	Conversion coefficient of standard coal
Electricity	0.12299 Kgce/kWh
Coal	0.7143 Kgce/kg
LPG	1.7143 Kgce/kg
Gasoline	1.4714 Kgce/kg
Diesel	1.4571 Kgce/kg
Firewood	0.5710 Kgce/kg

Table 3 Definition and assignment of variables

Variables	Definition	Symbol	Assignment
Energy consumption	Consumption of standard coal converted of energy sources	Y	Ln (Kilogram of standard coal equivalent to energy sources))
Household income	RMB Yuan	x_1	Ln (Annual household income)
Gender of household head	/	x_2	Male = 1, Female = 0
Age of household head	year	x_3	According to the questionnaire data
Marital status of household head	Unmarried	x_{41}	Yes = 1, No = 0
	Married	x_{42}	Yes = 1, No = 0
Occupation of family members	Farming	x_{51}	Yes = 1, No = 0
	Migrant workers	x_{52}	Yes = 1, No = 0
	Private enterprise staff /cadre	x_{53}	Yes = 1, No = 0
Idleness	Is there anyone at home all day	x_6	Yes = 1, No = 0
Education	High school or technical secondary school or above	x_7	Yes = 1, No = 0
Energy conservation behavior	The full score is 10	x_8	According to the questionnaire data
Energy conservation awareness	The full score is 10	x_9	According to the questionnaire data
Policy perception	The full score is 10	x_{10}	According to the questionnaire data
Electrical appliances	Number (Including household appliances, digital products, electric blankets, etc.)	x_{11}	According to the questionnaire data
Vehicles	Number (except bicycles)	x_{12}	According to the questionnaire data

or technical secondary school are close to 14% of the latest census data in 2010. Restricted by the level of education, about 75% of the families are mainly engaged in farming and migrant workers. The proportion of private enterprise staff and off-duty cadres is about 17.9%, and the proportion of other occupations (such as short-term hired labor) is 6.6%. In terms of energy conservation initiative, the three indicators are between 5 and 6, which indicates that the overall energy conservation initiative of rural families is not high, which is in the middle level. Among them, the scores of energy conservation behavior and awareness are higher than policy perception, which is about 1 point higher on average. In addition, each household has an average of 14 electrical appliances and 2.8 vehicles.

The correlation analysis of independent variables in the model is shown in Table 5. There is a significant positive correlation between education level and energy conservation behavior, energy conservation awareness, and policy perception, indicating that the higher the education level, the stronger the energy conservation initiative. At the same time, there is a significant negative correlation between energy conservation behavior and idleness. If someone is at home all day, they will not pay attention to some energy conservation behaviors, such as turning off the lights and setting the air-conditioning temperature reasonably. The higher the income, the stronger the awareness of energy conservation, and the more vulnerable to the impact of policies. The income of male headed households is higher, and the income is positively related to the number of electrical appliances and vehicles, which is consistent with the consumption habits of the public. The increase of income will increase the use of electrical appliances and the number of vehicles. There is a negative relationship between the age of the head of household and education level, policy perception, the use

Table 4 Descriptive statistics

Name	Number	Mean	Std	Min	Max
Electricity	474	5.060	0.709	1.902	7.232
Coal	474	5.307	2.688	0	8.768
Gasoline	474	2.475	2.851	0	8.926
Diesel	474	1.224	2.151	0	10.37
LPG	474	3.325	2.015	0	7.341
Firewood	473	2.611	3.394	0	10.04
Total energy	474	7.337	0.998	3.675	10.42
Income	474	10.91	0.783	6.802	13.03
Gender	474	0.688	0.464	0	1
Age	474	48.46	12.50	18	83
Unmarried	474	0.0211	0.144	0	1
Married	474	0.949	0.219	0	1
Farming	474	0.502	0.501	0	1
Migrant workers	474	0.253	0.435	0	1
Private enterprise staff / cadre	474	0.179	0.384	0	1
Idleness	474	0.835	0.371	0	1
Education	474	0.165	0.371	0	1
Energy conservation behavior	474	5.968	0.929	2.910	8.730
Energy conservation awareness	474	5.974	0.820	3.600	9.200
Policy perception	474	5.026	1.847	2	9.110
Electrical appliances	474	14.01	5.104	1	60
Vehicles	474	2.808	1.512	0	10

Table 5 The correlation analysis

	Income	Gender	Age	Married	Other occupations	Idleness	Education	Energy conservation behavior	Energy conservation awareness	Policy perception	Electrical appliances	Vehicles
Income	1											
Gender	0.161***	1										
Age	−0.237***	0.138***	1									
Married	0.0300	0.0170	−0.165***	1								
Other occupations	−0.162***	−0.0490	0.0380	0.00400	1							
Idleness	0.091**	0.217***	0.080*	−0.0440	−0.094**	1						
Education	0.157***	0.0290	−0.162***	−0.0230	0.00200	−0.0490	1					
Energy conservation behavior	0.0700	−0.0180	0.0240	−0.0180	0.00100	−0.121***	0.082*	1				
Energy conservation awareness	0.195***	0.0720	0.0110	0.0250	−0.0570	0.0670	0.148***	0.435***	1			
Policy perception	0.310***	0.141***	−0.095**	0.0530	−0.0370	−0.0280	0.175***	0.337***	0.413***	1		
Electrical appliances	0.429***	0.0420	−0.164***	0.0370	−0.203***	0.0600	0.104**	0.0090	0.151***	0.224***	1	
Vehicles	0.274***	0.0140	−0.144***	0.0440	0.0510	−0.324***	0.0110	0.0540	0.00200	0.251***	0.391***	1

Fig. 3 The choice of rural household energy consumption
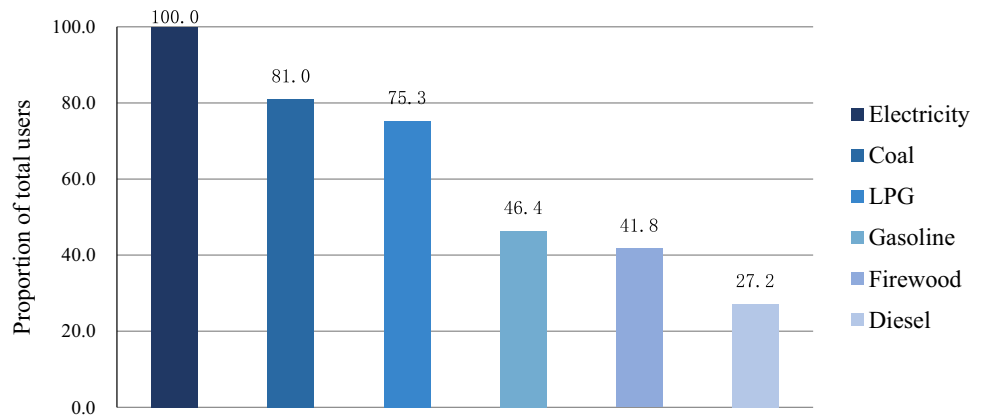
of vehicles, and electrical appliances. It may be because the older the head of household is, the more difficult it is to skill-fully use modern equipment, and the lower the acceptance of external policy propaganda. In addition, it can be seen from the table that the correlation coefficient between the variables is not high, which can eliminate the collinearity problem between the variables.

Characteristics of rural household energy consumption structure

In the choice of living energy, rural households have a high penetration rate of electricity, coal, and liquefied gas. All households choose diversified energy structure rather than single energy. In addition, some families still use firewood. As shown in Fig. 3, all surveyed households used electricity, and coal (81.0%) and liquefied petroleum gas (75.3%) were also the choice of most households as

common cooking and heating energy. Further, 46.4% of households use gasoline, which is generally used as energy for travel, and 27.2% of the households use diesel as the fuel for agricultural vehicles or trucks. In addition, 41.8% of households still use traditional biomass energy such as straw and firewood.

There are great differences in energy consumption and energy use choice of rural households. As shown in Fig. 4, the consumption of firewood and coal accounted for 42.0% and 31.0% of the total energy consumption respectively. Firewood, the traditional biomass energy, only accounts for 41.8% of the total energy consumption of households, but it accounts for 42% of the total energy consumption. It may be because the utilization efficiency of firewood is low and it can't be used up immediately, which makes the households that choose firewood use a lot. Coal has become the preferred commercial energy for rural households, accounting for 31.0% of the total

Fig. 4 Proportion of rural household energy consumption
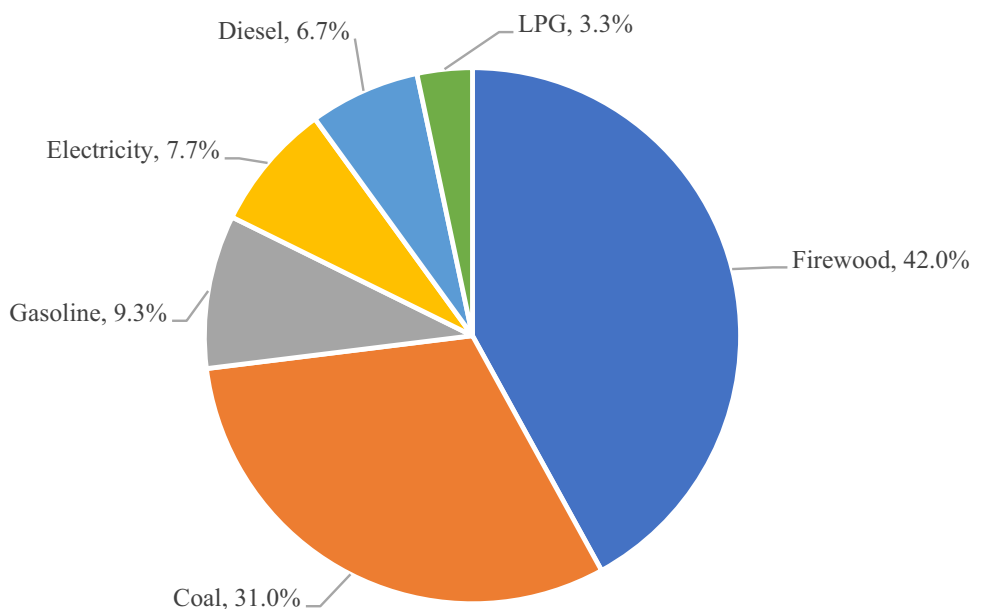
energy consumption. All households choose electricity, which accounts for 7.7% of the total energy consumption. In addition, gasoline and diesel are mainly used for transportation, accounting for 9.3% and 6.7% of the total energy consumption, respectively. From Fig. 4, we can see that the energy structure of rural households is not reasonable, and the proportion of coal and traditional biomass energy consumption is too large, which has a great negative impact on the environment and residents' health. The popularization rate of clean energy is high, but the use of clean energy accounts for a relatively small proportion. There is a large space for upgrading and optimizing the rural energy structure.

From the regional point of view, different regions have different characteristics in energy structure. As shown in Fig. 5, except for Puyang in Henan Province, the average coal consumption of other villages is the highest, probably because Puyang County in Henan Province is a poor county, people generally not in high standard of living. It is easy to obtain firewood and its cost is low, and most farmers still choose traditional biomass energy for cooking and heating activities. The consumption of electricity, LPG, and gasoline tends to be the same in different regions. The consumption of diesel in Shicheng village, Bazhou City, Hebei Province and Gaomiao village, Gongyi City, Henan Province is relatively low, which may reduce the use of agricultural diesel vehicles due to the high level of economic development of the two places.

A large number of scholars have proved that income is one of the main factors affecting the energy consumption of residents (Qiu et al. 2018; Zhai and Jun, 2016; Zou and Mishra, 2020). Therefore, this paper divides the sample energy consumption by the average of the annual income of all the respondents. As shown in Fig. 6, the samples of each area are divided into families with annual income greater than average and those with annual income less than average, showing the average consumption of electricity, coal, gasoline, diesel, liquefied gas, and firewood respectively. From Fig. 6, we can see that the households with high income consume more electricity, gasoline, and diesel than those with low income, and the increase in income decreases the consumption of firewood. This may be because it takes a lot of time and energy to collect firewood, and the increase of income will naturally reduce the labor with low added value. The income has little influence on the consumption of electricity, which may be because electricity is a daily and necessary living energy, and the income gap in the same region cannot greatly affect the consumption of this energy power. Puyang, Henan Province, belongs to a poor county in China. The overall living standard of rural residents is low. Although the income gap has little impact on electricity consumption, it has obvious impact on commercial energy such as coal, gasoline, and diesel, especially gasoline. This may be due to the fact that most families use gasoline for automobile transportation, while the car ownership of low-income families is generally low. In contrast, Gongyi City, an economically developed region in Henan Province, consumes more commercial energy such as electricity, coal, gasoline, and liquefied gas. As the secondary and tertiary industries are relatively developed in this area, agriculture accounts for a small
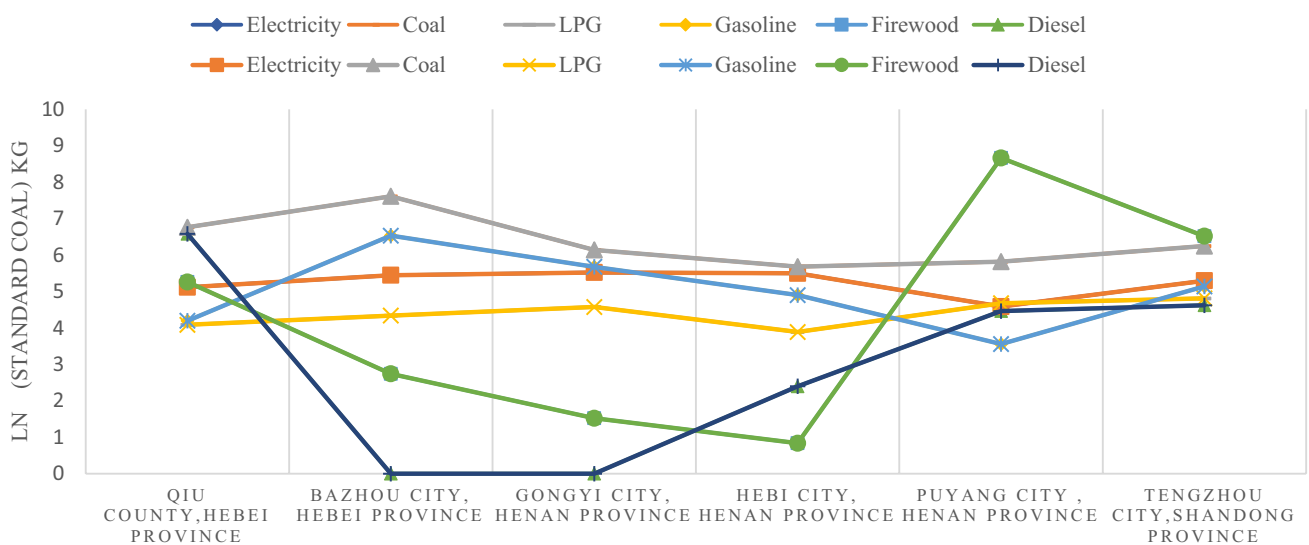

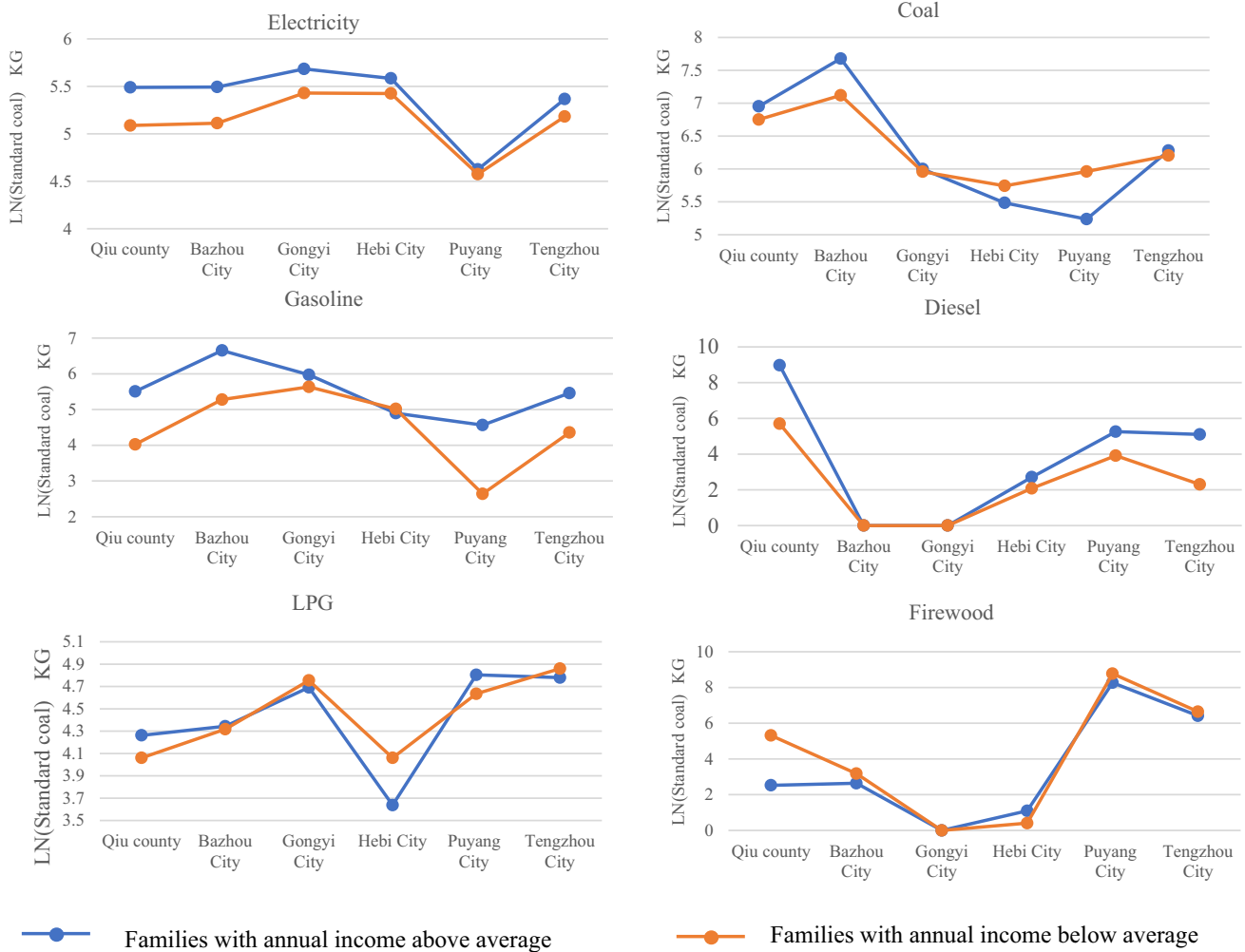**Fig. 5** Average rural energy consumption by Region

Fig. 6 Average energy consumption of different regions under different income levels

proportion, and the consumption of diesel and firewood for general agriculture is less.

This paper mainly explores the impact of psychological factors of residents from the energy conservation initiative of rural households, which can be divided into energy conservation behavior, energy conservation awareness and policy perception. As shown in Fig. 7, in terms of energy conservation behaviors, there are interesting parallels in different regions, which are medium level. Also, the average level of energy conservation awareness is similar in each region, all of which are about 5.6 points, and at the middle level. And the scores of energy conservation behaviors in regions with strong energy conservation awareness are also higher, which conforms to the conclusion that the values in the study can affect human behavior (Stern et al. 1999). On policy perception, it may be affected by energy conservation and environmental protection publicity due to the proximity of Bazhou and Beijing in Hebei Province. The policy

perception reaches 7.73 points, while other regions are about 3.4 points, which is weak in policy perception and at the lower and middle level, which may be related to the relatively closed information of rural areas, and the frequency of environmental protection publicity and policy transmission is relatively low. Interestingly, although the policy stimulation in some areas has little impact, the energy conservation behavior score is relatively good. It may be because of the low living standard in rural areas, residents need to save household expenditure by reducing energy consumption.

As shown in the previous correlation analysis, there is a significant positive relationship between education level and energy conservation initiative. As shown in Fig. 8, according to education level (whether education level is high school or technical secondary school or above), the three indicators of energy conservation initiative of rural residents (energy conservation behavior, energy conservation awareness and policy perception) are significantly

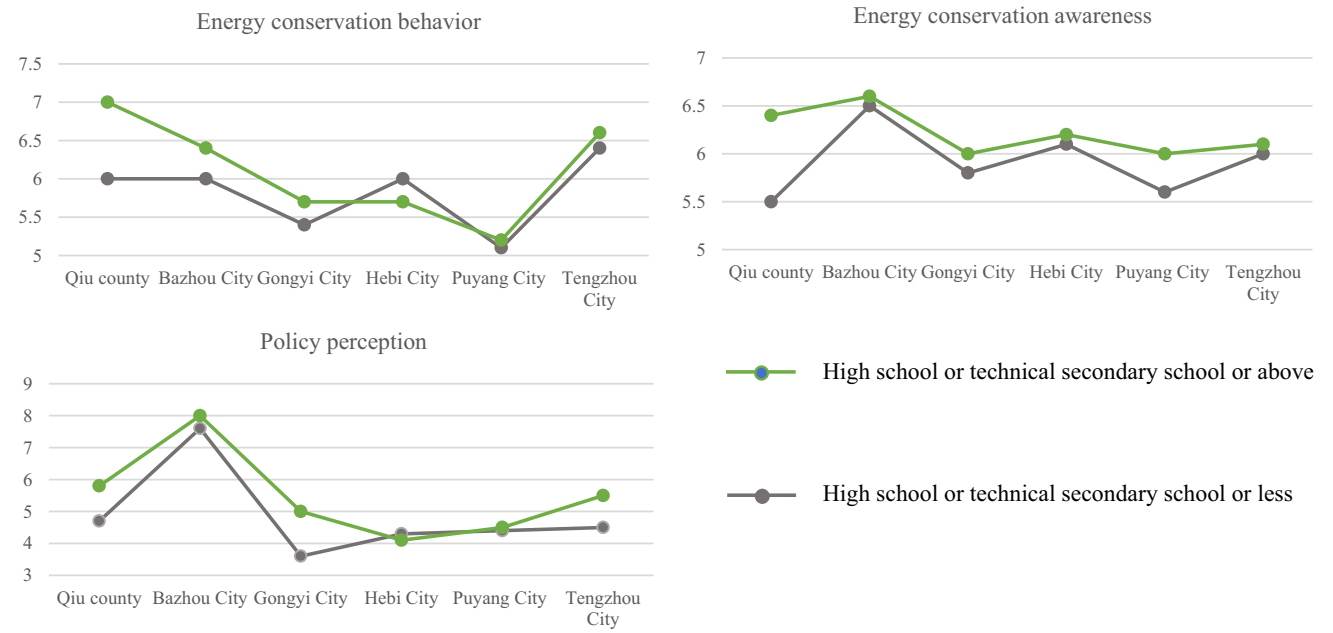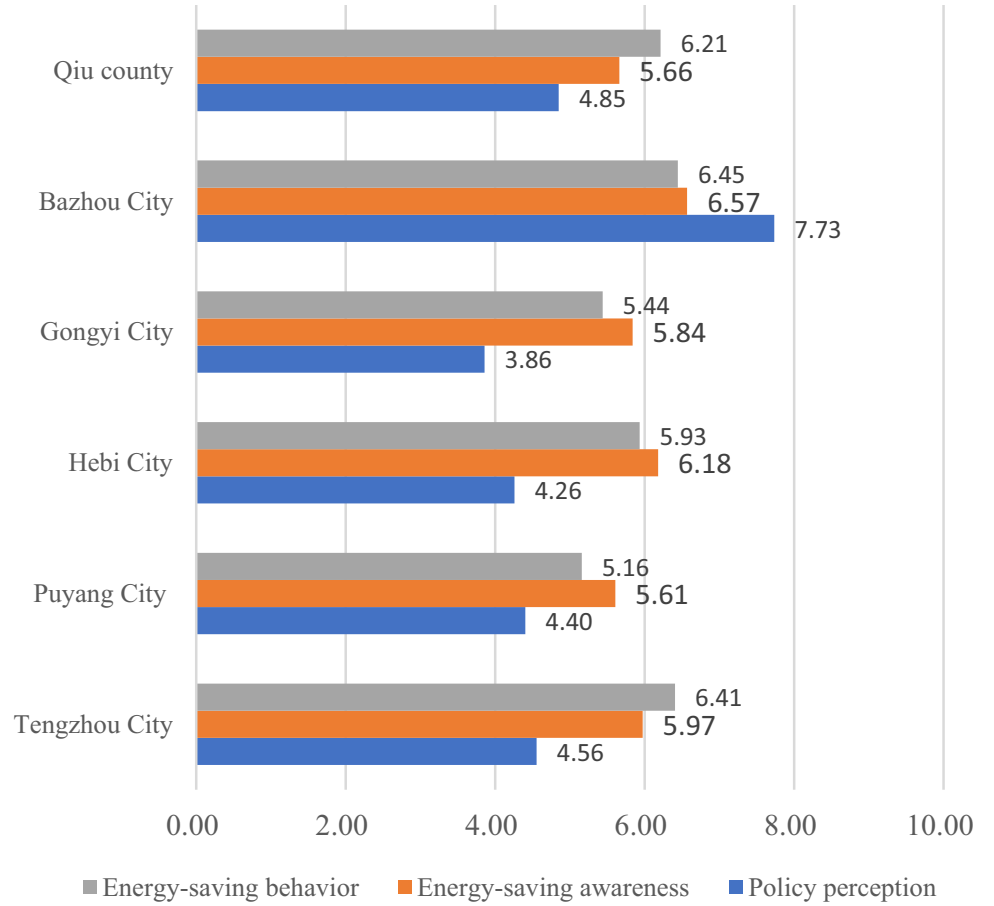**Fig. 7** Energy conservation initiative of rural households

Fig. 8 Mean value of energy conservation initiative in different regions under different education levels

affected by degree of education. In all areas, the residents with high school or technical secondary school education are more aware of energy conservation than those with lower education. In Qiu county, Hebei Province, the degree of education gap affecting energy conservation behavior and energy conservation consciousness is much greater than that in other regions. It may be that Qiu county attaches importance to the development of tourism, and people with higher education pay more attention to energy conservation and environmental protection and the protection of natural resources. However, in Hebi of Henan Province and Tengzhou of Shandong Province, where coal resources are abundant, due to the better natural endowment of energy, education level does not significantly affect the indicators of residents' energy conservation initiative.

Analysis of influencing factors of rural household energy consumption

The CLAD estimation results of Tobit model for influencing factors of rural household energy consumption are shown in Table 6. The results show that the variables selected by the model have different degrees of influence on energy consumption. Therefore, this paper will analyze from three aspects: family characteristics, family wealth (including income, number of electrical appliances, and vehicles), and energy conservation initiative.

Household characteristics

There is a significant relationship between the gender of the head of household and energy consumption. The male head of household prefers gasoline and firewood. There is a significant positive correlation between the age of the head of household and the total energy consumption. The average age of the head of household increases by 1 year, the total energy consumption increases by 0.4%, and the gasoline consumption increases by 5.6%. Because of the increasing age, it may difficult to collect firewood, and the firewood consumption decreases by 3.0% every year. The marital status also has significant influence on energy consumption. Compared with other families (divorced or widowed) under the same conditions, the use of firewood in married families has increased by 67.0%, which may be due to the fact that married families have more labors, so they can have time to collect firewood; and the unmarried families are more likely to use electricity, an increase of 39% compared with other families. The coal consumption may increase by 40.8% compared with other families due to the increase of family population, and the consumption of natural gas and diesel decreased significantly.

Compared with divorced or widowed families, the total energy consumption of unmarried and married families increased.

There is also a significant relationship between major occupations of member of families and energy consumption. Farmers, migrant workers, private enterprise employees, and full-time cadres' families consume more energy than families engaged in other occupations (such as part-time jobs). Farmers' families consume more gasoline. Farmers need to use agricultural equipment, and the growth rate of gasoline is as high as 116.9%. Due to migrant workers' families may not be at home for a long time, compared with families engaged in other occupations, electricity and coal consumption decreased by 31.7% and 57.4% respectively. LPG, the energy that is more convenient for cooking and heating, become a preferred choice of migrant workers' families. Private enterprise employees and cadre families reduce the use of coal, which is conducive to promoting the transformation of clean energy. Families with people idle at home consumed more energy, and the consumption of firewood increased significantly (123.4%). Because there is no firewood market in the research area, in order to obtain firewood, farmers need to spend extra time collecting firewood in addition to agricultural and non-agricultural activities, while some people are more likely to spend time collecting firewood at home all day.

Education level is a significant influencing factor of energy consumption. The higher the level of education, the less energy consumption. The household energy consumption of high school or technical secondary school or above decreased by 10.9% than other households. With the improvement of education level, the consumption of coal and firewood (46.9%) for poor quality cooking and heating energy can be greatly reduced, and the consumption of liquefied gas (37.2%) can be increased.

In conclusion, the employment and education level of family members can significantly improve the rural energy consumption structure. Having a formal job and reducing family members' idleness can increase the use of gasoline, and reduce the consumption of highly polluting firewood; improving education can also promote the transformation to the clean energy mode.

Household wealth

As many scholars have found, there is a positive relationship between rural household energy consumption and income (Zou and Mishra 2020; Jin et al. 2019; Qiu et al. 2018). When the income doubled, the total energy consumption increased by 25.8%. With the rise of income, the consumption of electricity, coal and gasoline increased by 17%, 30.0% and 197.7% respectively, while the consumption of

Table 6 Regression results of Tobit model of rural household energy consumption

Variables	Total	Electricity	Coal	Gasoline	LPG	Diesel	Firewood
Income	0.258*** (29.69)	0.170*** (4.48)	0.300*** (4.71)	1.977*** (8.68)	−0.007 (−0.17)	−0.062 (−1.58)	−0.200*** (−3.37)
Gender	−0.055*** (−3.88)	−0.032 (−0.54)	0.007 (0.07)	0.995*** (3.15)	0.097 (1.57)	−0.024 (−0.36)	0.620*** (7.76)
Age	0.004*** (7.17)	−0.003 (−1.26)	−0.001 (−0.28)	0.056*** (5.13)	0.002 (0.97)	−0.021*** (−7.13)	−0.030*** (−9.93)
Unmarried	0.105* (1.94)	0.390* (1.69)					
Married	0.108*** (3.06)	0.226 (1.53)	0.408* (1.93)	−0.380 (−0.75)	−0.337** (−2.13)	−2.112*** (−15.11)	0.670*** (3.41)
Farming	0.294*** (11.37)	−0.086 (−0.79)	−0.026 (−0.14)	1.169** (2.31)	−0.017 (−0.14)		
Migrant workers	0.164*** (6.02)	−0.317*** (−2.82)	−0.574*** (−3.05)	−0.610 (−1.18)	0.234* (1.90)		
Private enterprise staff /cadre	0.119*** (4.40)	−0.088 (−0.75)	−0.285 (−1.48)	0.027 (0.05)	−0.361*** (−2.78)		
Idleness	0.446*** (23.21)	−0.000 (0.01)	−0.232* (−1.66)	1.955*** (3.62)	0.011 (0.14)		1.234*** (11.42)
Education	−0.109*** (−6.39)	−0.019 (−0.26)	−0.192 (−1.50)	1.153*** (3.63)	0.372*** (4.42)	−0.855*** (−11.57)	−0.469*** (−4.40)
Energy conservation behavior	−0.002 (−0.34)	0.072** (2.34)	0.072 (1.34)	−0.397*** (−2.59)	0.026 (0.79)	−0.089*** (−2.73)	−0.657*** (−14.08)
Energy conservation awareness	0.054*** (5.68)	−0.013 (−0.80)	−0.176** (−2.51)	1.151*** (6.08)	0.007 (0.17)	0.330*** (7.96)	0.032 (0.60)
Policy perception	0.069*** (17.98)	0.086** (2.36)	0.328*** (11.65)	−0.062 (−0.75)	0.049*** (2.76)	−0.058** (−2.30)	−0.321*** (−10.17)
Electrical appliances	−0.008*** (−4.98)	0.036*** (6.12)	−0.029*** (−2.94)	0.208*** (7.27)	0.078*** (10.81)	0.021*** (2.77)	−0.034*** (−3.30)
Vehicles	0.138*** (27.66)	−0.004 (−0.22)	0.131*** (4.03)	0.452*** (4.32)	0.080*** (3.95)	0.294*** (13.16)	
Constants	2.730*** (24.27)	1.926*** (3.87)	2.145** (2.55)	−33.675*** (−11.30)	2.352*** (4.44)	5.642*** (10.96)	13.805*** (19.08)

$*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

firewood decreased by 20.0%. It shows that the increase of income will reduce the farmers' use of traditional energy and turn to cleaner commercial energy.

The number of electrical appliances owned by rural households has a negative relationship with the total energy consumption. Each additional electrical appliance will reduce energy consumption by 0.8%. Families with more electrical appliances will have a better energy structure. With the addition of an electrical appliance, households will switch to more modern energy sources, increase the consumption of electricity (3.6%), gasoline (20.8%), diesel (7.8%), and liquefied petroleum gas (2.1%), and reduce the consumption of coal (2.9%) and firewood (3.4%). Furthermore, the number of vehicles has a positive impact on the total energy consumption. For each additional vehicle, the total energy consumption will increase by 13.8%. At the same time, each additional vehicle will increase the consumption of gasoline (45.2%) and diesel (8%).

To sum up, we have measured the household wealth of rural regions from the perspectives of household income and household durable goods (electrical appliances and vehicles). The increase of household income and the number of vehicles in durable goods will lead to the increase of energy consumption. The increase of the number of electrical appliances in durable goods can reduce the total energy consumption. The increase of household income and the number of electrical appliances is conducive to the transformation of energy consumption structure to modern type and the use of more commercial energy.

Energy conservation initiative

At present, the energy conservation behavior of rural households is at the medium level. Enhancing energy conservation behavior will help to reduce energy consumption, promote electricity and coal to replace firewood in cooking and heating, and optimize rural energy structure. As shown in Table 6, with each increase in household energy conservation behavior, electricity consumption increases by 7.2% and firewood consumption decreases by 65.7%. It may be that households with high energy conservation behavior are more willing to buy energy conservation products. Under the joint effect of higher energy efficiency of electricity and energy conservation technology of energy conservation products, household energy waste is alleviated, and total energy consumption is reduced. Firewood, as the traditional energy for cooking and heating in rural families, plays an important role in residents' daily energy consumption. However, the thermal efficiency of firewood is low. The large use of firewood is not only harmful to the environment, but also has adverse effects on the health of residents. Therefore, on the premise of ensuring the daily energy consumption of residents, we should try to reduce the use of firewood. The improvement of energy conservation behavior is conducive to the substantial improvement of energy consumption structure.

The increase of energy conservation awareness can increase energy consumption and increase the use of total energy. Every increase of energy conservation awareness can reduce the use of coal by 17.6%, which is conducive to the transformation of energy consumption to clean and modernization. It may be that households with strong energy conservation awareness have a stronger sense of responsibility for energy conservation, consciously reduce coal with serious pollution and low energy efficiency when choosing energy, and use more electricity or liquefied petroleum gas as alternative energy, resulting in an increase in energy consumption.

The stronger the rural households' perception of the policy, the higher the total energy consumption, but it is conducive to promoting the conversion of energy from firewood to coal. Households with high policy perception scores reduce the use of firewood and diesel, and increase the consumption of electricity, coal, and liquefied gas. On the one hand, in the process of rural development, the government emphasizes promoting the improvement of rural living environment and ecological environment protection, which may increase the electricity consumption of rural households. On the other hand, some local governments implement policies such as "Closing Hillsides for afforestation" and "returning straw to field" to reduce the pollution caused by forest harvesting and straw burning. Households with high policy perception may reduce the use of traditional energy.

This study analyzes the impact of rural household energy conservation initiative on energy consumption from energy conservation behavior, energy conservation awareness, and policy perception. The results show that energy conservation behavior and policy perception are conducive to the transformation of rural energy structure from firewood to coal, while energy conservation awareness is helpful to reduce the use of coal and optimize the energy structure. Therefore, energy conservation initiative has an important and positive impact on the optimization of rural household energy consumption structure.

Conclusions and implications

Conclusions

Based on 474 rural household energy consumption questionnaires, this paper uses CLAD estimation of Tobit model to analyze the factors influencing rural household energy consumption and the characteristics of energy consumption structure. The main findings of this paper are as follows:

1. At present, the energy structure of rural households is unreasonable, the penetration rate of commercial energy is high, such as electricity and coal, more than 75% of the surveyed households use LPG, coal, and electricity. However, the corresponding energy consumption is low, and the sum of these three kinds of energy consumption does not exceed 50% of the total energy consumption. The consumption of firewood, which is low-quality and highly polluting, is chosen by only 41.8% of households, accounts for 42% of the total energy consumption. And is much higher than other kinds of energy. At the regional level, poor counties still use more traditional energy such as firewood, while areas with better economic development consume more commercial energy. Moreover, although the income gap has little impact on electricity consumption, it has a more obvious impact on commercial energy such as coal, gasoline and diesel.

2. The energy conservation initiative of rural households is a key topic of this paper. Maybe due to the low living standard and the lack of information in rural areas, the policy perception of rural households in central and eastern China is generally weak, and the frequency of energy conservation behavior and energy conservation awareness are low at the general level. There is a significant positive relationship between education level and energy conservation initiative, especially in areas paying attention to ecological protection. In addition, energy conservation initiative has a significant impact on energy consumption in rural households. Households with high frequency of energy conservation behavior and strong policy perception will reduce the consumption of high-polluting firewood and increase the use of coal and electricity, which is not only conducive to the transformation of traditional biomass energy into commercial energy, but also helpful to rural residents' health. And, households with a strong energy conservation awareness will reduce the consumption of seriously polluting coal and promote the transformation of high pollution energy into clean energy.

3. Household characteristics and wealth also become significant influencing factors of energy consumption. The age of the head of household is positively correlated with the total energy consumption. Compared with other families (divorced or widowed), married and unmarried families consume more total energy, and the firewood consumption of married families is significantly higher than that of other families, and idle family members also greatly increase the use of this low-quality energy. However, higher education level is conducive to reducing the consumption of coal and firewood, as are migrant workers' families. Finally, with the increase of household income, the energy consumption structure could change from firewood to cleaner electricity and firewood liquid gas. At the same time, the number of electrical appliances is negatively correlated with the consumption of firewood and coal, and more use of electrical appliances is conducive to clean energy transformation.

Policy implications

The energy use of rural residents is an important part of the development of China's energy structure. Promoting clean and efficient energy consumption in rural areas will bring many benefits to rural residents' health, rural economic development, and reducing environmental pollution. Based on the conclusions of this paper, in order to alleviate the energy pressure and optimize the rural energy structure, the following suggestions are put forward.

1. Shortening the income gap between regions and paying attention to the improvement of energy structure in poor areas. Regional economic level affects the choice of energy types. There are disparities in economic development and resource, poor areas are encouraged to pay attention to tourism development and reduce their dependence on traditional energy. It is therefore recommended that policy makers provide subsidies and industrial assistance.

2. A sound social energy conservation publicity will bring additional benefits, that is, to promote the initiative of rural residents in energy conservation. Energy conservation behavior and strong policy perception have significant positive significance to improve the energy structure. Due to the low understanding of energy conservation policies in rural areas, it is suggested that the authorities popularize the concept of energy conservation and environmental protection in various forms, such as television, radio, network, and billboards. At the same time, the local grass-roots government should emphasize the importance of environmental protection in the process of rural development and adopt financial subsidies to encourage residents to reduce the use of traditional firewood. Enhancing the energy conservation awareness of rural residents and promoting economic development will contribute to clean energy conversion.

3. Household appliances upgrading policies needs to be put on the agenda, such as "Home Appliances to the Countryside," so as to reduce the cost of new equipment and gradually eliminate backward cooking and heating equipment in rural areas. Families with more electrical appliances tend to reduce the consumption of coal and firewood and use more electricity. Therefore, the government should adopt comprehensive taxation and subsidies, and rise the ownership of household electrical appliances, so as to reduce energy waste and environmental protection.

4. Education should be given a priority in rural areas since the households with high education level reduce low-quality energy consumption such as coal and firewood, and promote the proportion of clean energy. At the same time, education is very crucial in any economic development. Strengthening

rural education is also conducive to increasing family income and reducing unemployment, so as to greatly decrease the consumption of traditional biomass energy and environmental pollution.

Limitations and prospects

The data of this paper is based on the household survey data of our research group in 2017, and the number of respondents is just 474, which is cross-sectional data. In the future research, we can re optimize the questionnaire question setting, and visit the survey households every five or ten years to obtain panel data, so as to more accurately analyze the energy consumption behavior and its changing trend of rural households. In addition, this study confirmed that energy conservation initiative has a significant impact on energy consumption of rural families, but the mechanism of this psychological factor is not clear. In the future, we can further explore the mechanism of psychological factors on energy consumption from the perspective of environmental psychology, so as to promote the transformation of energy cleaning and modernization.

Author contributions Conceptualization, M. X., L.D., C.D., W. M. and L. C.; methodology, M. X., L.D., C.D.; software, L.D., C.D.; formal analysis, C.D. and L.D.; investigation, L.D., C.D., and L. C.; writing—original Chinese draft preparation, L.D and C.D.; writing—English review and editing, L.D., M.X. and W.M.; supervision, M.X.; funding acquisition, M.X.

Data availability The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Conflict of interest The authors declare no conflicts of interest.

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