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Measurement of Energy Poverty and Influencing Factors of Rural Households in China

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ABSTRACT: Despite being the world's largest developing country, China faces significant disparities between urban and rural areas, which exacerbates energy poverty in rural regions. This issue of energy poverty is a global concern, as millions of people lack access to modern energy necessary for a decent quality of life. This research aims to analyze the levels and structures of energy consumption in rural Chinese households, using data from the Chinese General Social Survey (CGSS) conducted in 2015 and 2018. The research employs the poverty line threshold and Theil index methods to comprehensively assess energy poverty in diverse regions. It also examines the economic, social, and familial factors influencing rural energy poverty. The findings reveal a transition in rural energy consumption towards cleaner sources, but energy poverty remains a significant issue. Factors such as energy prices and household size have a positive impact on energy poverty, while per capita income, education level, and social factors exert a negative influence.

Keywords: Rural households; Energy poverty; Measurement; Poverty line threshold method

1. Introduction

Energy poverty is a pervasive issue globally, and while it affects all countries to varying degrees, it is particularly pronounced in developing nations. According to the International Energy Agency (IEA), approximately 733 million people globally lack regular access to electricity, and a staggering 2.4 billion individuals still heavily rely on traditional biomass energy for their daily needs (Source: Tracking Sustainable Development Goal 7: Energy Progress Report 2022, jointly published by the International Energy Agency, the International Renewable Energy Agency, the United Nations Department of Economic and Social Affairs, the World Bank and the World Health Organization). The majority of these individuals reside in Asia and Africa, regions marked by generally low levels of economic development. The importance of the energy sector as a major sector of a country cannot be overstated, and for developing and third world countries such as Africa, energy not only affects a country's environment, but also has a significant impact on the country's economy and politics (Borowski PF, 2021) [1]. As the largest developing country worldwide, the complexity and diversity of energy poverty in China surpass those in other nations. As energy poverty persists over time, its negative impacts are gradually amplified, significantly affecting people's health, the country's socio-economic development, and the progression towards an ecological civilization in China.

With its vast land area and large rural population, rural areas in China have long grappled with issues such as inefficient energy use and difficulties in energy supply. These challenges have severely hindered rural economic development and the enhancement of rural living standards. Due to the variations in economic development models and resource endowments across regions in China, and the inability to align region-specific policies with actual conditions, some energy poverty alleviation policies have failed to yield expected results. The resolution of rural energy poverty is intimately connected with the solutions to issues concerning agriculture, rural areas, and rural residents. While rural poverty manifests in numerous ways, one key aspect is rural energy poverty. Despite numerous theoretical findings on rural poverty, studies on rural energy poverty remain scarce.

This research initially analyzes the level and structure of energy consumption in rural households in China, using data from the Chinese General Social Survey (CGSS) conducted in 2015 and 2018. Subsequently, the research employs poverty line threshold methods to comprehensively measure energy poverty in rural areas nationwide as well as in the eastern, northeastern, central, and western regions. The Theil index method is then applied to analyze regional disparities in energy poverty among rural households in China. The research also examines the main factors influencing rural household energy poverty from three dimensions: economic,

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social, and household characteristics. Finally, based on the conclusions derived from these analyses, relevant policy recommendations are proposed to alleviate rural household energy poverty in China.

The measurement of rural energy poverty in this research offers a novel perspective for energy poverty studies and encourages scholars to conduct more in-depth research in this field. This will facilitate the implementation of future energy development strategies in China. Simultaneously, the research provides a more holistic and profound understanding of energy poverty in China and worldwide, thereby highlighting the significance of energy poverty.

2. Literature Review

2.1. Methods for Measuring Rural Energy Poverty

Since 2002, the International Energy Agency (IEA) has included a section on energy poverty in its annual World Energy Outlook publication. The IEA defines energy poverty as the lack of access to, and use of, clean energy such as electricity and clean cooking stoves for cooking with biomass, which includes straw, firewood, or other solid fuels. Subsequently, a plethora of studies have been undertaken by national and international researchers to assess and measure energy poverty.

In a summary of the different methods available for measuring energy poverty, Pachauri S et al. (2004) proposed a two-dimensional approach. This approach measures energy poverty in terms of both access and the quality of consumption, distinguishing between different types of energy sources [2]. Hills et al. (2011) conducted research into energy poverty and its measurement methods, defining energy poverty as a state of "low income, high expenditure". In this state, people must spend more than average on energy consumption to maintain a minimum quality of life, even though their income level is below the official income poverty line [3].

Several Chinese scholars have conducted comprehensive studies on energy poverty in rural areas from the perspective of farmers in China. After referring to studies and conclusions on energy poverty in other developing countries and the criteria of the energy poverty line, Sun Wei et al. (2013) constructed a measurement method for the dimensions of energy poverty and proposed relevant and targeted opinions. This approach has facilitated the measurement of the specific energy poverty situation in China [4]. After thoroughly analyzing and studying the definitions of energy poverty and assessment methods both domestically and internationally, Li & Wang et al. (2014) constructed a four-dimensional energy poverty assessment index system. This system accurately assesses the current situation of energy poverty in China and predicts its changing trends [5]. Li Lanlan et al. (2020) elucidated the principles and characteristics of some commonly used energy poverty measurement methods. However, they pointed out that some existing energy poverty measurement methods have shortcomings, necessitating the construction of more reasonable and operational multidimensional energy poverty measurement indicators and methods [6]. Liu Zimin et al. (2023) employed the energy poverty index and the likelihood of irrelevance regression method to analyze the spatial and temporal evolution of energy poverty in China and its influencing factors. They found that although the energy poverty situation in China has improved compared to the past, the overall situation remains severe [7].

2.2. Rural Energy Poverty in China

Presently, the state of rural energy poverty in China is primarily characterized by regional differences. Li Kang et al. (2011) demonstrated that regionality is a notable aspect of energy poverty in China, with energy poverty being particularly acute among rural residents in the northeastern and western provinces and municipalities. To address energy poverty, it is more effective to increase the income of rural residents than to improve the energy structure [8].

By analyzing regional disparities in energy poverty in China, scholars have identified factors such as regional economic level, regional resource endowment, rural residents' income level, and local energy prices as contributing to these regional differences. Hao Yu et al. (2014) and Li Shixiang et al. (2020) argued that regions should alleviate inter-regional differences in energy poverty by enhancing their respective economic development levels and improving their infrastructure [9,10].

Some researchers have examined the impact of energy poverty on people's welfare from both theoretical and empirical perspectives, using micro-survey data with the mediation effect. The research results show that energy poverty has varying degrees of impact in different regions, between urban and rural areas, and at different income levels (Liu Zimin et al., 2020) [11]. Cai Haiya et al. (2021) found that energy poverty differs widely among provinces and has significant spatial correlation characteristics, with the future trend of spatial development patterns first increasing and then decreasing [12]. Xu Yingzhi et al. (2021) argued that inclusive green development is significantly affected by energy poverty and that this impact is negative. They also found that the impact of energy poverty on inclusive green development varies with different environmental regulation intensities [13].

Other scholars have explored energy poverty from different perspectives. For instance, several studies evaluated the level of energy poverty in Qinghai Province and found that a shortage of modern energy is the main manifestation of the energy poverty problem there, with more than 50% of the population experiencing energy poverty due to insufficient local energy supply (Jiang Lu, 2019) [14]. Using data from the 2015 China Comprehensive Social Survey, Zhang Ziyu et al. (2020) measured multidimensional energy poverty at the household level and examined its relationship with population health from both physical and psychological perspectives, finding that household-level multidimensional energy poverty negatively affects both the physical and mental health of residents [15]. Chang Huayi et al. (2020), after understanding the definition of a "poverty trap", referred to the energy poverty

"trap" as the predicament of energy use subject to asset poverty. They explored the reasons why low-income households are more likely to fall into energy poverty from the psychological perspective of farm households [16].

2.3. Factors Influencing Rural Energy Poverty

Some scholars have demonstrated that in the UK, households experiencing energy poverty increase as energy prices rise (Walker et al., 2007) [17]. In developing countries like India, traditional biomass remains the primary fuel for most households, largely due to the unaffordability of modern and clean energy sources caused by high prices (Jain G, 2010) [18]. Wang Jun (2010) suggested that residents' energy consumption patterns are influenced by unreasonable energy prices [19]. Ding Shijun et al. (2001) explored the connection between residential energy use and energy poverty in rural areas in the context of local development, focusing on the relationship between residential energy use, agricultural activities, modern energy use, and women's labor [20].

Regarding household income, numerous scholars have utilized multivariate economic modeling and determined that income has a positive effect on energy consumption (Masih AM et al., 1997) [21]. Wei Yiming et al. (2014) proposed the energy ladder hypothesis, suggesting that a household's economic standing influences its energy consumption. As a household's economic level increases, more modern, efficient, and clean energy sources become accessible for residents' use. The hypothesis further outlines that the availability of these sources is linked to an increase in energy consumption [22]. Xie E (2021) developed a multidimensional energy poverty index comprising of five dimensions and analyzed its determinants [23]. Liu Zimin et al. (2022) examined the correlation between individual carbon trading mechanisms and energy poverty using energy consumption survey data from Chinese residents and developed key parameters for China's individual carbon trading mechanisms [24].

Xiao Yunlai et al. (2010) discovered that the income and education levels of residents, along with the energy endowment, impact the extent of energy poverty within households [25]. Some scholars posit that both household and community factors affect household energy demand (Barnes DF et al., 2011) [26]. In regions afflicted by energy poverty, where the ecological environment is more fragile and resources are limited, it is essential to enhance the local energy supply and focus on local ecological environment management.

2.4. Review of Literature

Energy poverty, a critical issue globally, has been explored from various angles by scholars. International research predates and surpasses domestic studies in scope and depth, employing extensive micro-data, econometric models, and assessment frameworks. Predominantly, these studies utilize quantitative analyses and case studies. In contrast, research on energy poverty in China is less extensive, primarily focusing on qualitative assessments. This includes analyses of energy poverty's status quo, influencing factors, and potential mitigation strategies. Notably, case studies and econometric modeling in this realm are sparse, especially regarding rural households.

A significant gap in existing literature is the lack of a standardized, universally accepted methodology for measuring energy poverty. Each existing indicator and method exhibits unique advantages and limitations. Particularly, research on rural household energy poverty remains underexplored.

This paper seeks to address these gaps by applying the poverty line threshold method, using data from the China Integrated Social Survey (CISS) 2018. It specifically measures energy poverty among rural households in China, delving into the influential factors. This approach, utilizing recent, micro-level data on rural households, distinguishes our study from prior works (e.g., Li & Wang et al., 2014), which relied on provincial panel data [5]. The findings offer timely insights, enrich the academic discourse, and provide a valuable reference for subsequent studies in this field.

3. Measuring and analysis of rural household energy poverty in China

3.1. A Methodology for Measuring Energy Poverty among Rural Households in China

3.1.1. Model Setting for Measuring the Rural Energy Poverty Line in China

Based on the existing literature on energy poverty measurement and considering data availability, this research draws from the research conducted by Liu Zimin et al. (2020) [11]. It proposes the use of the Extended Linear Expenditure System (ELES) model to measure the energy poverty line of rural households in China. This methodology, which is based on per capita household income and per capita household energy consumption expenditure, allows this research to be independent of the influence of various energy price indices, thereby facilitating the measurement of the energy poverty line of rural households in China.

Luich (1973) expanded upon Stone's linear expenditure system model (ELES) by incorporating consumption-savings decisions, resulting in the creation of the Extended Linear Expenditure System (ELES) model. This model encompasses both basic demand and excess demand components. The basic form of the model is as follows:

$$p_i q_i = p_i y_i + \beta_i (I - \sum_{j=1}^{n} p_i y_i) \quad (1)$$

In Equation (1), p_i refers to the price of the 'ith' commodity, p_j refers to the price of the 'jth' commodity, q_i refers to the actual demand for the 'ith' commodity, y_i refers to the basic demand for the 'ith' commodity, y_j refers to the basic demand for the 'jth' commodity, β_i refers to the marginal propensity to consume the 'ith' commodity, and 'I' refers to the disposable income of the rural household. $p_i y_j$ denotes the basic demand for commodity i and $\beta_i (I - \sum_{j=1}^{n} p_i y_i)$ denotes the excess demand for commodity i.

Equation (1) simplifies to:

$$p_i q_i = (p_i y_i - \beta_i \sum_{j=1}^{n} p_i y_i) + \beta_i I \quad (2)$$

Let: $c_i = p_i q_i$, $\alpha_i = (p_i y_i - \beta_i \sum_{j=1}^{n} p_j y_j)$, then we have:

$$c_i = \alpha_i + \beta_i I + v_i \quad (3)$$

In Equation (3), the random interference term is represented by v_i.

The values for parameters α_i and β_i in Equation (3) can be approximated via a least squares regression (OLS) on Equation (3). Here, α_i represents the minimum per capita energy expenditure that fulfils the basic needs of a rural household, thereby also defining the energy poverty line, denoted as z ($z > 0$) in this research. If the per capita energy consumption expenditure of a rural household is below the energy poverty line z, then the household is considered to be energy impoverished, and vice versa.

3.1.2. Modelling the Extent and Differential Measurement of Rural Energy Poverty in China

After calculating the energy poverty line for rural households in China, this research analyzes data from the 2018 China Comprehensive Social Survey to determine the magnitude, diversity, disparity, and Sen index of energy poverty faced by rural households on a national scale. The objective of this research is to examine the level of energy poverty experienced by rural households and investigate regional variations in the eastern, northeastern, central, and western regions. Specifically, the research aims to assess the degree of energy poverty in rural households in China and compare the variations among the four regions, namely the eastern, northeastern, central, and western regions.

(1) Energy Poverty Breadth

The energy poverty breadth, also known as the extent of energy poverty, refers to the proportion of rural Chinese households experiencing energy poverty in relation to the sample size of the research study. To calculate this, let m represent the total number of households in rural China living in energy poverty, and n be the sample size of the research. The formula for determining the incidence of energy poverty can be expressed as follows:

$$p = \frac{m}{n} \quad (4)$$

(2) Energy poverty depth

The level of energy poverty in rural Chinese households is assessed by measuring the difference between the per capita consumption expenditure on energy and the energy poverty line. This discrepancy quantifies the depth of energy poverty, where a larger gap indicates a higher level of poverty. In this research, the depth of energy poverty is calculated using the FGT index developed by Foster (1984), as outlined below:

$$I_p = \frac{1}{n} \sum_{i=1}^{m} \left(\frac{z - c_i}{z}\right)^a \quad (5)$$

(3) Energy Poverty Disparity

Energy poverty disparities are analyzed using a methodology similar to the Gini coefficient, which measures income disparities within a population. The Gini coefficient is commonly used to assess income inequality among residents in a country or region, and its value ranges from 0 to 1. A value closer to 0 indicates a more equitable income distribution. Equation (6) demonstrates the calculation of the energy poverty gap in this research:

$$G_p = \left|1 - \sum_{K=1}^{N\_1} (X_{K+1} - X_K)(Y_{K+1} + Y_k)\right| \quad (6)$$

In Equation (6), G_p indicates the level of disparity in energy poverty, while X_k represents the total proportion of energy consumption and spending by rural households in China, and Y_k represents the cumulative percentage of households sampled in this research.

(4) Sen Index

Foreign scholars Sen (1976) combined the breadth, depth, and degree of difference in energy poverty to propose an indicator for measuring energy poverty, known as the Sen index. The Sen index is expressed as:

$$\text{sen} = P[I_p + (1 - I_p)G_p] \quad (7)$$

The Sen index ranges between 0 and 1, with higher values denoting greater energy deprivation.

3.1.3. Selection of Variables for Measuring Energy Poverty in Chinese Rural Households

In the specific research context of this research, the measurements of energy poverty in rural households are based on the variables of per capita income and per capita energy expenditure in China. The per capita income of rural households is calculated by dividing the total yearly income of rural households by the number of individuals within those households. Similarly, the per capita energy consumption expenditure of rural households is determined by dividing the total yearly expenditure on energy sources, including electricity and various types of gas (such as LPG, town gas, and natural gas), by the number of people in rural households.

3.2. Results of Energy Poverty Measurement for Rural Households in China

3.2.1. Rural Energy Poverty Line in China

To determine the energy poverty line for rural households in China, this research selected a total of seven key variables. Table 1 provides detailed information on the sample size, mean, standard deviation, minimum, and maximum values of these variables.

The specific results of this research for measuring the energy poverty line of rural households in China are shown in Table 2.

Table 1. Summary statistics of key variables.

Variable	Obs.	Mean	Std.Dev.	Min	Max
Per capita income of rural households	1938	18733.0	38456.7	25.0	700000.0
Per capita consumption expenditure on electricity	1938	69.9	172.1	0.0	3000.0
Per capita coal consumption expenditure	1938	67.6	230.7	0.0	4000.0
Per capita gas consumption expenditure	1938	142.1	367.7	0.0	6500.0
Per capita oil consumption expenditure	1938	114.0	1153.6	0.0	36000.0
Per capita consumption expenditure on traditional biomass	1938	5.1	50.7	0.0	960.0
Per capita energy consumption expenditure	1938	398.8	1311.7	0.7	38500.0

Source: CGSS 2018, Per capita consumption of coal by households includes consumption of cellular coal and briquettes, per capita consumption of gas includes consumption of liquefied petroleum gas, natural gas and town gas and per capita consumption of oil includes consumption of petrol and diesel.

Table 2. Energy poverty line for rural households in China, 2018.

	Per Capita Consumption Expenditure on Electricity	Per Capita Coal Consumption Expenditure	Per Capita Gas Consumption Expenditure	Per Capita Oil Consumption Expenditure	Per Capita Consumption Expenditure on Traditional Biomass	Per capita Consumption Expenditure on Traditional Biomass
α_i	1.357 ***	4.228 ***	3.495 ***	3.921 ***	4.711 ***	2.141 ***
	(7.304)	(7.622)	(13.929)	(2.861)	(4.519)	(8.784)
β_i	0.207 ***	0.227 ***	0.193 ***	0.249 **	0.134	0.237 ***
	(14.722)	(5.504)	(10.698)	(2.512)	(1.411)	(12.836)

Note: Sample size N = 1938, error terms in brackets, *, ** and *** indicate 10%, 5% and 1% significance levels respectively.

Table 2 presents the specific findings of this research regarding the measurement of the energy poverty line for rural households in China. In this context, "ln" represents the natural logarithm of the minimum per capita energy consumption expenditure of rural households in China under specific conditions. Additionally, "β" denotes the marginal propensity to consume of rural households in China, which can be interpreted as the change in per capita energy consumption expenditure for every one RMB increase in per capita income of rural households.

The results of this research reveal that, at a significance level of 1%, the minimum per capita consumption expenditure on energy by rural households in China is found to be 99.34 yuan per year. This finding indicates that the energy poverty line for rural households in China is established at 99.34 yuan per year. Consequently, a rural household is considered to be experiencing energy poverty if its minimum per capita consumption expenditure on energy falls below 99.34 yuan per year.

3.2.2. Results of Measuring the Breadth of Rural Energy Poverty in China

At the national level, a screening of the 1938 sample households examined in this research, based on the energy poverty line of 99.34 yuan per year calculated in the previous section, reveals that there are 756 rural households in China that are afflicted by energy poverty. Calculations based on Equation (4) yield an energy poverty incidence rate of 39.01% for rural households in China, which differs somewhat from the findings of previous related studies. The calculation results are shown in Figure 1.

Equation (4) demonstrate that rural households in different regions of China experience varying levels of energy poverty. In the eastern region, the incidence rate is 19.08%, while it stands at 35.09% in the northeastern region, 43.42% in the central region, and 50.51% in the western region. Overall, the incidence of energy poverty among rural households is lower than the national level solely in the eastern and northeastern regions. Conversely, for rural households in the central and western regions, the incidence of energy poverty exceeds the national level. These findings align with the conclusions drawn from the research conducted by Wei Yiming (2014) and Li Shixiang (2020) [10,22].

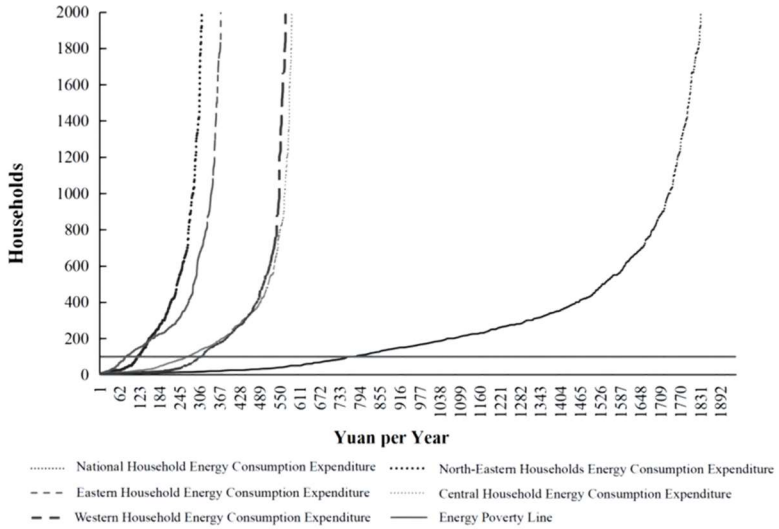

Figure 1. Breadth of energy poverty among rural households in China, 2018. Source: CGSS (2018).

3.2.3. Results of Measuring the Depth of Rural Energy Poverty in China

Based on the measurement of the energy poverty line for rural households in China, the depth of energy poverty is calculated for each household using Equation (5). The specific results of these calculations are presented in Table 3.

Table 3. Depth of energy poverty among rural households in China, 2018.

	Depth of Energy Poverty among Rural Households Ip
Nationwide	0.271
Northeastern Region of China	0.242
Eastern Region of China	0.115
Central Region of China	0.281
Western Region of China	0.386

Source: CGSS2018 Survey Data.

Table 3 reveals that the depth of energy poverty among rural households in the Eastern and Northeastern regions is lower than the national level, while the depth of energy poverty in the Central and Western regions exceeds the national level. These findings indicate that the extent of energy poverty varies across regions, likely due to differences in economic development and resource endowments.

To assess the deviation of rural households' energy consumption expenditure from the energy poverty line determined in the previous section, this research establishes a per capita consumption expenditure grouping interval of 50 yuan per year. This allows for the analysis of the distribution of rural households' energy consumption expenditure. Based on the rural household energy poverty line of 99.34 yuan per year, the research calculates the specific results, which are visualized in Figure 2.

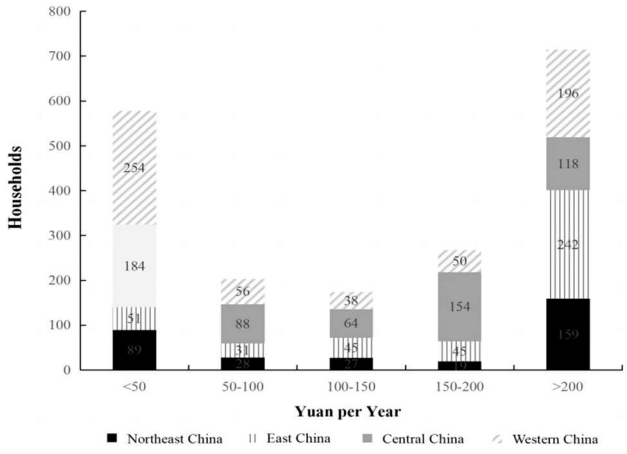

Figure 2. Deep Energy Poverty Gap for Rural Households in China, 2018. Source: CGSS (2018).

3.2.4. Rural Energy Poverty Disparity and Sen Index in China

By utilizing Equation (6) and considering the energy poverty line of 99.34 yuan per year, the energy poverty variance of rural households in China is calculated as follows: at the national level, the disparity in energy poverty among rural households is 0.23, indicating a relatively average level of disparity. In the eastern region of China, the disparity in energy poverty among rural

households is 0.17, which is categorized as an absolute average level. Meanwhile, the disparities in energy poverty among rural households in the northeastern, central, and western regions of China are 0.25, 0.26, and 0.28, respectively, all falling within the relative average level. These results indicate that the differences in energy poverty among rural households are generally minimal nationwide, with the eastern region exhibiting the smallest disparity compared to the other three regions.

Furthermore, when calculating the energy poverty Sen index of rural households in China using Equation (7), the results are depicted in Figure 3.

Based on Figure 3, the energy poverty Sen index for rural households at the national level is 0.33. In the eastern region, the energy poverty Sen index is 0.16, indicating a lower level of energy poverty compared to the national average. Similarly, in the northeastern region, the energy poverty Sen index for rural households is 0.26, also lower than the national level. However, in the central region, the energy poverty Sen index exceeds the national average at 0.36. In the western region, the energy poverty Sen index is 0.46, suggesting a higher level of energy poverty compared to the national average. These findings underscore the relatively serious energy poverty situation among rural households in China, particularly in the central and western regions, where a larger number of rural households are affected.

This disparity can primarily be attributed to the low level of economic development in these regions and the resulting low income levels of rural residents. These factors create financial challenges for farmers, making it difficult for them to afford modern and clean energy sources, thus exacerbating the energy poverty situation. Moreover, the lack of adequate energy infrastructure further contributes to the energy poverty issue in these regions.

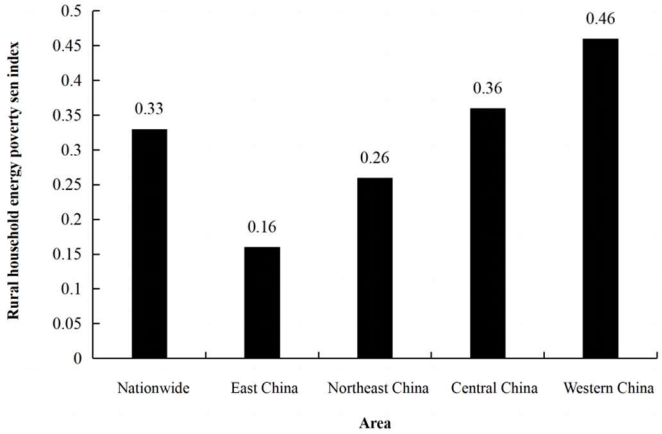

Figure 3. Rural Household Energy Poverty Sen Index, in China, 2018. Source: CGSS (2018).

3.3. Regional Differences in Energy Poverty among Rural Households in China

Considering the specific research context of this research, the Theil index method was selected to analyze the disparities in energy poverty among rural households in China across different regions and their distribution characteristics.

The Theil index, also known as Theil's entropy criterion (Theil, 1967), is commonly employed to examine inequality between individuals or regions. In this research, the magnitude of the Theil index reflects the extent of regional disparities in energy poverty among rural households in China. A higher value of the Theil index indicates greater regional disparities in energy poverty among rural households in the country. The fundamental formula for calculating the Theil index is as follows:

$$T = \sum_{i=1}^{n} \frac{y_i}{\overline{y}} \ln\left(\frac{y_i}{\overline{y}}\right) \tag{8}$$

In Equation (8), T denotes the Theil index, which is used to measure the magnitude of regional differences in energy poverty among rural households in China; i denotes the grouping by province, and since this study includes data from 28 provinces, i = 1, 2, 3, ..., 28; y_i denotes the Sen index of rural households in the ith province; and $\overline{y}$ denotes the average value of the Sen index of rural households in each province.

The research categorizes the regional disparities in energy poverty among rural households in China using the Theil index. These disparities are examined within the eastern, northeastern, central, and western regions, as well as between the four regions. The specific formula for calculating the Theil index is as follows:

$$T = T_{bT} + T_{wT} \tag{9}$$

$$T_{br} = T_e \ln\left(T_e \frac{n}{n_e}\right) + T_m \ln\left(T_m \frac{n}{n_m}\right) + T_w \ln\left(T_w \frac{n}{n_w}\right) + T_{\mathrm{ne}} \ln\left(T_{ne} \frac{n}{n_{ne}}\right) \tag{10}$$

$$T_{wr} = \sum_{i=1}^{n_e} T_i \ln\left(n_e \frac{T_i}{T_e}\right) + \sum_{i=1}^{n_m} T_i \ln\left(n_m \frac{T_i}{T_m}\right) + \sum_{i=1}^{n_w} T_w \ln\left(n_w \frac{T_i}{T_w}\right) + \sum_{i=1}^{n_{ne}} T_i \ln\left(n_{\mathrm{ne}} \frac{T_i}{T_{ne}}\right) \tag{11}$$

In Equation (9), T_{wr} represents the difference in rural household energy poverty within each region, and T_{br} represents the difference in rural household energy poverty between the four regions. In Equations (10) and (11), n denotes 28 provinces, and n_e, n_{ne}, n_m, and n_w denote the number of provinces in the eastern, northeastern, central, and western regions, respectively; T_e, T_{ne}, T_m and T_w denote the Thiel's Index in the eastern, northeastern, central and western regions respectively.

Based on the previous research, the Theil index was calculated at the national level and then decomposed into regional differences in energy poverty among rural households in China according to the provinces included in the four regions, and the following results were obtained: the value of the overall Theil index was 0.139, and compared with the inter-regional and intra-regional Tel indices, the Sen Theil index of the provinces in China was larger, indicating that there are large regional differences in energy poverty among rural households in China. This suggests that there are large regional differences in energy poverty among rural households in China. In terms of the inter-regional Theil index, the value of the inter-regional Theil index (T_{br}) is 0.058, with a contribution rate of 41.92%. In terms of the intra-regional tyre index, the value of the intra-regional tyre index (T_{wr}) is 0.081, with a contribution rate of 58.08%. The comparison shows that the value of the T_{wr} within a region is greater than the value of the T_{br} between regions, suggesting that the differences in rural household energy poverty within each region are greater than the differences in rural household energy poverty between the four regions.

4. Analysis of Factors Affecting Energy Poverty among Rural Households in China

4.1. Variable Selection and Descriptive Statistics

In this research, the variable "whether rural households are in energy poverty" is utilized as an explanatory variable. A rural household is considered to be in energy poverty if its per capita consumption expenditure on energy is below 99.34 yuan per year, and it is assigned a value of 1. Conversely, if the per capita consumption expenditure on energy of a rural household exceeds 99.34 yuan per year, it is deemed not to be in energy poverty and assigned a value of 0.

The research identifies three primary factors that influence energy poverty among rural households in China: economic factors (including rural household per capita income and energy prices), social factors (such as rural residents' choice of social employment and their purchase of social insurance), and household characteristics (including rural household size, the education level of the rural household head, the age of the rural household head, and gender). Table 4 provides detailed explanations for each of these main variables.

This research presents descriptive statistics for the factors that potentially influence energy poverty among rural households in China across five categories: sample size, mean, standard deviation, maximum, and minimum values. These statistics are provided in Table 5.

Table 4. Main variables explanatory table.

Variable		Assignment of Values
Implicit variable		
Energy poverty		Yes = 1; No = 0
Independent variable		
Economic factor	lncome	Per capita income of rural households in the past year
	Price	Fuel price index
Social factor	Work	Whether to choose non-farm employment: Yes = 1; No = 0
	Insurance	Whether to purchase medical or pension insurance: Yes = 1; No = 0
Household Characteristics Factors	Familysize	Number of persons in the household
	Education	Years of education of head of household: Illiteracy/semiliterate = 0; Graduate from primary school = 6; Graduate from junior high school = 9; Graduate from high school/junior college/vocational high school = 12; Graduate from a junior college = 15; Undergraduate graduate = 16; Postgraduate student = 19; PhD graduation = 23
	Age	2018 - Year of birth
	Gender	Female = 1; Male = 0

Table 5. Summary statistics of key variables.

Variable	Obs.	Mean	Std.Dev.	Min	Max
Whether in energy poverty	1938	0.390	0.488	0.000	1.000
Per capita household income (log)	1938	9.636	2.186	3.219	16.118
Energy price	1938	108.215	1.807	105.100	113.000
Social employment options	1938	0.299	0.458	0.000	1.000
Purchase of social insurance	1938	0.943	0.231	0.000	1.000
Family size	1938	3.579	1.912	1.000	16.000
Educational level	1938	6.406	1.428	6.000	15.000
Age	1938	50.975	15.990	18.000	118.000
Gender	1938	0.555	0.497	0.000	1.000

Source: CGSS2018 Survey Data.

4.2. Method Selection and Model Construction

In this research, a binary logit regression model is chosen to correlate the factors that may affect energy poverty among rural households in China. The specific form of the binary Logit regression model selected for this research is:

$$p = \frac{\exp(u_0+\sum_{i=0}^{k} u_i x_i)}{1+\exp(u_0+\sum_{i=0}^{k} u_i x_i)} \quad (12)$$

A linear transformation of Equation (12) yields:

$$\ln(\frac{p}{1-p}) = u_0 + \sum_{i=0}^{k} u_i x_i + \mu \quad (13)$$

In Equation (12), p denotes the likelihood of rural households in China falling into energy poverty, that is, the incidence of energy poverty in Chinese rural households, x_i denotes the explanatory variables for each sample studied in this research, u_i denotes the correlation coefficient, and μ denotes the random error term.

4.2. An Empirical Analysis of the Factors Influencing Rural Household Energy Poverty in China

4.2.1. Model Checking

The variables were assessed for multicollinearity, and the results are presented in Table 6. The Variance Inflation Factor (VIF) values of the selected variables are all below 10, indicating the absence of multicollinearity among them. This confirms the suitability for conducting logistic regression analysis.

Table 6. Results of the multicollinearity test.

Variable	VIF
Per capita household income	1.11
Energy price	1.04
Social employment options	1.21
Purchase of social insurance	1.02
Family size	1.05
Educational attainment	1.23
Age	1.34
Gender	1.02

4.2.2. Benchmark Regression Analysis

Regression results on factors affecting energy poverty in rural households nationwide are shown in Table 7. The regression results of model (1) show the economic factors affecting energy poverty among rural households in China; the regression results of model (2) show the economic and social factors affecting energy poverty among rural households in China; and the regression results of model (3) show the economic and social factors and household characteristics affecting energy poverty among rural households in China.

Table 7. Regression results on factors affecting energy poverty in rural households nationwide.

Explanatory Variable	Whether Rural Households Are in Energy Poverty					
	Model(1)		Model(2)		Model(3)	
	Ratio	Marginal Effect	Ratio	Marginal Effect	Ratio	Marginal Effect
Per capita household income	−0.187*** (−7.664)	−0.043	−0.159*** (−6.582)	−0.036	−0.139*** (−5.653)	−0.031
Energy price	0.037*** (1.428)	0.009	0.044** (1.690)	0.010	0.054** (2.014)	0.012
Social employment options			−0.602*** (−5.404)	−0.136	−0.505*** (−4.124)	−0.111
Purchase of social insurance			−0.309	−0.070	−0.456** (−2.185)	−0.100
Family size			(− 1.499)		0.136*** (5.230)	0.030
Educational attainment					−0.063*** (1.599)	−0.014
Age					−0.013 (3.703)	−0.003
Gender					0.297 (3.003)	0.066
Constant term (math.)	−2.673 (−0.949)		−3.263 (−1.145)		−5.764** (−1.967)	
Observed value	1938		1938		1938	
LR Statistic	68.25		99.86		150.07	

Note: values in parentheses are t-values, *, **, *** indicate 10%, 5% and 1% significance levels, respectively.

Firstly, the impact of economic factors is analyzed. Among these factors, both per capita rural household income and energy prices demonstrate a significant influence on the level of energy poverty among rural households in China. Specifically, (1) the effect of rural household per capita income on energy poverty of rural households in China is significant at the 1% level. The marginal effect is negative, indicating that the incidence of energy poverty in rural households in China decreases with the increase in rural household per capita income. The probability of a Chinese rural household falling into energy poverty decreases by 3. 1% for every 1% increase in rural household per capita income. This result is consistent with the results of other scholars' related studies (Liang Yutian, 2012; Li Shixiang, 2020) [10,28]. The reason is that as the per capita income of rural residents increases, they can afford to use modern and clean energy, which makes households less likely to fall into energy poverty. (2) The impact of energy prices on energy poverty among rural households in China is significant at the 5% level, with a positive marginal effect that is smaller than that of rural per capita income, suggesting that the incidence of energy poverty among rural households in China increases with energy prices, with each unit increase in the energy price index increasing the likelihood of a rural household falling into energy poverty by 1.2%. The reason for this may be that rural households consume energy out of necessity, mainly to meet their basic needs, and when energy prices rise, rural households' consumption expenditure on energy increases accordingly, making it easier for them to fall into energy poverty if their income remains unchanged. At the same time, when making energy consumption choices, rural households with lower incomes are more likely to choose cheaper alternatives to modern clean energy, which may also increase the incidence of energy poverty among rural households.

Secondly, the impact of social factors is analyzed. Among the social factors, both rural residents' choice of social employment and their purchase of social insurance have a significant impact on the level of energy poverty among rural households in China. Specifically, (1) The impact of rural residents' social employment choices on the energy poverty of rural households in China is significant at the 1% level, with a negative marginal effect, suggesting that rural residents' non-agricultural employment choices have the potential to reduce the likelihood of households falling into energy poverty. This may be because rural dwellers can earn more by choosing non-agricultural employment rather than agricultural work, increasing their affordability of modern clean energy. In addition, the fact that most non-farm households work outside the home and have access to a wealth of information creates a desire for a better quality of life, which in turn leads to increased consumption expenditure on modern and cleaner energy. (2) The impact of rural residents' social insurance purchases on energy poverty among rural households in China is significant at the 5% level, with a negative marginal effect, which is smaller than that of rural residents' social employment choices, suggesting that the purchase of social insurance by rural households reduces the likelihood of falling into energy poverty, a result that is basically in line with the findings of other scholars' related studies (Huang F et al., 2020) [29]. The reason may be that rural household members who choose to buy social health insurance tend to pay more attention to physical health, and they will use safer and more hygienic, modern clean energy. Moreover, rural household members who choose to buy social pension insurance have stronger consumption intentions, and they may be more inclined to choose higher-priced modern clean energy for use.

Thirdly, the impact of household characteristics is analyzed. Among the household characteristics, the size of the rural household and the education level of the rural household head significantly affect the level of energy poverty of rural households in China. In contrast, the age and gender of the rural household head do not significantly affect the level of energy poverty in rural households in China. Specifically, (1) The effect of rural household size on energy poverty among rural households in China is significant at the 1% level, with a positive marginal effect, suggesting that the incidence of energy poverty among rural households in China increases with the size of the rural household, with the probability of falling into energy poverty increasing by 3.0% for each additional person in the rural household. This may be because energy consumption expenditure increases with the size of the rural household, and rural households choose cheaper energy sources to meet their basic needs, making them more likely to fall into energy poverty. Rural households with larger populations are also more likely to be under financial pressure to support the elderly and children. They are therefore less likely to voluntarily choose to use modern, cleaner energy at higher prices, increasing the likelihood of rural households falling into energy poverty. (2) The effect of the education level of rural household heads on the energy poverty of rural households in China is significant at the 1% level, with a negative marginal effect, suggesting that the incidence of energy poverty among rural households in China decreases as the education level of rural household heads increases and that for every one year increase in the number of years of schooling of a rural household head, the probability of his or her household falling into energy poverty decreases by 1.4%. This may be because better-educated rural dwellers have better overall skills and can find well-paid jobs, improving the income level and quality of life of the whole household, and are more likely to choose modern, cleaner energy sources for their use. (3) The effects of age and gender of the rural household head on energy poverty among rural households in China are not significant. The marginal effect of the age of the rural household head suggests that the incidence of energy poverty among rural households in China decreases as the age of the rural household head increases. The reason for this may be that as the age of the rural household head increases, the income from work increases, which in turn increases the wealth accumulation of the household, and the rural household will actively choose to use modern and clean energy sources, thus reducing the likelihood of falling into energy poverty. The marginal effect of the gender of the rural household head suggests that being a female head of a rural household increases the likelihood of the household falling into energy poverty. This may be because rural women generally have lower income levels and are more frugal than men. Female rural household heads may choose to use something other than modern, cleaner energy sources, which are more expensive in terms of energy consumption.

4.2.3. Heterogeneity Analysis

In this paper, we delve into the determinants of energy poverty among rural households across various regions. Our methodological approach draws upon the heterogeneity analysis by Li Baoxin et al. (2022) and Yong Ming et al. (2023), among others. By conducting region-specific correlation analyses, we aim to capture the unique factors influencing energy poverty in each locale [30,31]. The empirical findings from our regression analyses are systematically documented in Table 8.

Table 8. Regression results of factors influencing rural household energy poverty in Northeastern, Eastern, Central and Western of China.

Whether Rural Households Are in Energy Poverty								
Explanatory Variable	**Northeastern Part of China**		**Eastern Part of China**		**Central Part of China**		**Western Part of China**	
	Ratio	**Marginal Effect**	**Ratio**	**Marginal Effect**	**Ratio**	**Marginal Effect**	**Ratio**	**Marginal Effect**
Per capita household income	−0.151 (1.439)	−0.033	−0.072 (1.024)	−0.011	−0.135*** (3.384)	−0.029	−0.128** (3.036)	−0.029
Energy price	0.165** (2.455)	0.036	0.167 (1.144)	0.025	0.030** (0.669)	0.006	0.357*** (5.859)	0.080
Social employment options	−0.203 (0.613)	−0.044	0.082 (0.276)	0.012	−0.529** (2.323)	−0.098	−0.442* (1.908)	−0.113
Purchase of social insurance	−0.541 (1.342)	−0.118	−0.683** (1.525)	−0.102	−0.001 (0.002)	−0.000	−0.791 (1.800)	−0.176
Family size	0.006 (0.073)	0.001	0.004** (0.048)	0.001	0.251*** (5.145)	0.054	0.084* (1.821)	0.019
Educational attainment	−0.020 (0.186)	−0.004	−0.054 (0.716)	−0.008	−0.010** (0.101)	−0.002	−0.173** (2.481)	−0.039
Age	0.001 (0.091)	0.000	0.010 (1.008)	0.001	−0.023 (3.582)	−0.005	−0.018 (2.887)	−0.004
Gender	0.143 (0.587)	0.031	0.661 (2.494)	0.098	0.279 (1.519)	0.060	0.210 (1.191)	0.047
Constant term (math.)	19.259*** (2.636)		17.316 (1.107)		−4.065 (−0.811)		−38.558* (−5.782)	
Observed value	322		414		608		594	
LR Statistic	14.03		14.72		83.26		66.76	

Note: values in parentheses are t-values, *, **, *** indicate 10%, 5% and 1% significance levels, respectively.

In the northeast region, the impact of energy prices on rural household energy poverty is significant at the 5% level, with a positive marginal effect, suggesting that energy prices have a more significant impact on rural household energy poverty in northeast China and that the incidence of energy poverty among rural households in the northeast region increases with energy prices, with the probability of rural households falling into energy poverty increasing by 3.6% for every 1 unit increase in the energy price index. This may be because the cold climate of the Northeast region results in higher energy consumption expenditure for heating by rural residents, which has a more significant impact on the total energy consumption expenditure of rural households when energy prices change.

In the Eastern Region, social insurance coverage has a significant effect on energy poverty among rural households. Specifically, the effect of rural household size on energy poverty among rural households in the Eastern Region is significant at the 5% level, with a positive marginal effect, suggesting that the incidence of energy poverty among rural households in the Eastern Region increases with the size of the rural household and that for every additional person in a rural household, the probability of falling into energy poverty increases by 0.1%. The effect of social insurance coverage for rural residents on energy poverty among rural households in the Eastern Region is significant at the 5% level, with a negative marginal effect, indicating that the probability of falling into energy poverty decreases by 10.2% when rural households in the Eastern Region are covered by social insurance.

In the Central Region, the effect of rural household income per capita on rural household energy poverty is significant at the 1% level, with a negative marginal effect, suggesting that the incidence of energy poverty among rural households in the Central Region decreases as rural household income per capita increases and that for every 1% increase in rural household income per capita, the probability of a rural household in the Central Region falling into energy poverty decreases by 2.9%. The effect of energy prices on energy poverty among rural households in the Central Region is significant at the 5% level, with a positive marginal effect, indicating that the incidence of energy poverty among rural households in the Central Region increases as energy prices rise and that for every unit increase in the energy price index, the probability of a rural household falling into energy poverty increases by 0.6%. The effect of the rural resident's choice of social employment on energy poverty among rural households in the Central Region is significant at the 5% level, with a negative marginal effect, suggesting that the likelihood of a rural household falling into energy poverty decreases by 9.8% when the rural resident chooses non-agricultural employment. The effect of rural household size on energy poverty among rural households in the Central Region is significant at the 1% level, with a positive marginal effect, indicating that the incidence of energy poverty among rural households in the Central Region increases with the size of the rural household and that for each additional person in the rural household, the probability of the household falling into energy poverty increases by 5.4%. The effect of the level of education of the rural household head on energy poverty in rural households in the Central Region is significant at the 5% level, with a negative marginal effect, suggesting that the incidence of energy poverty in

rural households in the Central Region decreases as the level of education of the rural household head increases and that for each additional year of education, the likelihood of a household falling into energy poverty decreases by 0.2%.

In the Western Region, the impact of rural household income per capita on rural household energy poverty is significant at the 5% level, with a negative marginal effect, indicating that the incidence of energy poverty among rural households in the Western Region decreases as rural household income per capita increases and that for every 1% increase in rural household income per capita, the probability of a rural household in the Western Region falling into energy poverty decreases by 2.9%. The impact of energy prices on energy poverty among rural households in the Western Region is significant at the 1% level, with a positive marginal effect, indicating that the incidence of energy poverty among rural households in the Western Region increases with the increase in energy prices and that for every 1 unit increase in the energy price index, the likelihood of a rural household falling into energy poverty increases by 8.0%. The impact of the rural resident's choice of social employment on the energy poverty of rural households in the Western Region is significant at the 10% level, with a negative marginal effect, indicating that the likelihood of a rural household falling into energy poverty decreases by 11.3% when the rural resident chooses non-agricultural employment. The effect of rural household size on energy poverty among rural households in the Western Region is significant at the 10% level, with a positive marginal effect, indicating that the incidence of energy poverty among rural households in the Western Region increases as the size of the rural household increases and that for each increase in the size of the rural household, the probability of falling into energy poverty increases by 1.9%. The effect of the education level of the rural household head on the energy poverty of rural households in the Western Region is significant at the 5% level, with a negative marginal effect, indicating that the incidence of energy poverty in rural households in the Western Region decreases as the education level of the rural household head increases and that for every one year increase in the number of years of education of the rural household head, the probability of the household falling into energy poverty decreases by 3.9%.

4.3. Robustness Test

Drawing upon the foundational frameworks of the Multidimensional Energy Poverty Index (MEPI) as delineated by Koomson et al. (2021) and Paudel et al. (2021) [32,33], alongside the subjective indicators of energy poverty as proposed by Churchill SA et al. (2020) and Thomson et al. (2017) [34,35], this study has adapted its analytical approach to accommodate data availability and to fortify the robustness of its findings. Consequently, the primary explanatory variable has been refined to focus on the 'depth of energy poverty among rural households.' This modification not only aligns with the conceptual underpinnings of the aforementioned studies but also ensures that our analysis is grounded in a contextually relevant and empirically sound framework, thereby enhancing the validity and applicability of our research outcomes. The Tobit regression model is employed to test the reliability of the previous study's results. Table 9 presents the specific test results, which are found to be consistent with the earlier findings. Specifically, the average per capita income of rural households, energy prices, social employment choices of rural residents, their purchase of social insurance, household size, and the education level of the rural household head all significantly influence the degree of energy poverty among rural households in China.

Table 9. Model robustness test results.

	Depth of Energy Poverty in Rural Households				
Explanatory Variable	**Nationwide**	**Northeastern Part of China**	**Eastern Part of China**	**Central Part of China**	**Western Part of China**
	Ratio	**Ratio**	**Ratio**	**Ratio**	**Ratio**
Per capita household income	−0.025*** (6.247)	−0.020 (1.402)	−0.004 (0.654)	−0.020*** (3.768)	−0.022*** (3.129)
Energy price	0.010** (2.166)	−0.024** (2.514)	−0.014 (1.115)	0.006** (1.023)	0.059*** (6.012)
Social employment options	−0.108*** (5.110)	−0.031 (0.645)	−0.009 (0.363)	−0.073** (2.345)	−0.080** (2.040)
Purchase of social insurance	−0.050** (1.412)	−0.070 (1.188)	−0.052 (1.290)	0.018 (0.288)	−0.108** (1.556)
Family size	0.022*** (5.109)	0.002 (0.123)	0.000 (0.046)	0.027*** (4.756)	0.008* (1.092)
Educational attainment	−0.014** (2.204)	−0.001 (0.052)	−0.006 (0.867)	−0.003** (0.273)	−0.034*** (2.955)
Age	−0.002 (3.146)	−0.000 (0.106)	−0.001 (0.901)	−0.003 (3.655)	−0.003 (2.738)
Gender	0.044 (2.620)	−0.029 (0.811)	−0.061 (2.598)	0.037 (1.499)	0.020 (0.698)
Constant term (math.)	−1.039** (−2.066)	2.819*** (2.691)	1.448 (1.053)	−0.742 (− 1.104)	−6.309*** (−5.858)
Observed value	1938	322	414	608	594
LR Statistic	161.42	13.47	13.99	78.86	64.16

Note: values in parentheses are t-values, *, **, *** indicate 10%, 5% and 1% significance levels, respectively.

5. Conclusions and Policy Recommendations

5.1. Conclusions

Addressing the issue of energy poverty among rural households in China, this paper undertakes a comprehensive analysis. Utilizing micro-level household data, the research quantifies the extent of energy poverty and dissects its determinants through rigorous quantitative and comparative methods. The findings offer a nuanced understanding of shifts in energy consumption patterns and the intricacies of energy poverty, aligning closely with international scholarship. Simultaneously, the study delineates regional disparities within the context of Chinese energy poverty, resonating with national academic discourse. Consequently, this paper presents four principal conclusions:

Firstly, the type of energy consumption in rural households has gradually evolved to become predominantly clean energy consumption. The type of energy consumed by rural households in China is shifting from a predominantly non-clean energy source to a predominantly clean one. This is reflected in the increasing use of modern clean energy sources, with gas (including liquid fossil fuels, natural gas and coal gas) being the most widely used by rural households, accounting for 36.05% of the energy consumption structure of rural households in China, a significant increase compared with the previous level; the use of coal (including cellular coal and coal briquettes) and electricity by rural households has decreased compared with the previous level, but they still account for 17.76% and 16.99% of the energy consumption structure of China's rural households, respectively. The use of coal (including cellular coal and coal briquettes) and electricity by rural households has decreased compared to the past, but their shares in the energy consumption structure of rural households in China have reached 17.76% and 16.99%, respectively. Some rural residents still use traditional biomass energy, such as firewood, in their daily lives. There are still some rural residents who use traditional biomass energy, such as firewood, in their daily lives, accounting for 1.15% of the energy consumption structure of rural households in China.

Secondly, energy poverty among rural households in China is a pressing issue. Despite progress, a significant number of rural households still face energy poverty. In this research, the energy poverty line for rural households in China is determined to be 99.34 yuan per year, calculated using data from the China Integrated Social Survey (CISS) 2018 and the Extended Linear Expenditure System (ELES) model. This threshold indicates that if a rural household's per capita consumption expenditure on energy falls below 99.34 yuan per year, the household is considered to be experiencing energy poverty. Among the 1938 households surveyed, 756 rural households are identified as energy poor. The severity of energy poverty varies across regions, with higher levels observed among rural households in the central and western regions.

Thirdly, significant regional disparities exist in energy poverty among rural households. This research examines the inter-regional and intra-regional Thiel indices to assess the differences in energy poverty among rural households in China. By calculating the Thiel index at the national level and disaggregating the regional disparities based on the included provinces within the four regions, the study reveals important findings. The overall Thiel index is determined to be 0.139, indicating the presence of substantial regional disparities. The interregional Thiel index, denoted as (T_{br}), measures 0.058, with a contribution rate of 41.92%. Additionally, the intraregional Thiel index, denoted as (T_{wr}), stands at 0.081, with a contribution rate of 58.08%. These results highlight two key insights: first, significant regional discrepancies exist in energy poverty among rural households in China, and second, the variations in energy poverty among rural households within each region surpass the disparities observed between the four regions.

Finally, rural household energy poverty in China is influenced by economic factors, social factors, and household characteristics. Various factors play a role, including per capita rural household income, energy prices, rural residents' social employment choices, purchases of social insurance, rural household size, and the education level of the household head. Specifically, per capita income, social employment choices, social insurance purchases, and the education level of the rural household head have a negative impact on energy poverty among rural households in China. Conversely, energy prices and household size have a positive impact on energy poverty among rural households.

When considering different regions, rural household size and social insurance purchases affect energy poverty in the eastern region. Energy prices have an impact in the northeastern region. In the central and western regions, per capita rural household income, energy prices, social employment choices, household size, and the education level of the household head all contribute to energy poverty among rural households.

5.2. Policy Recommendations

Based on the measurement of energy poverty among rural households in China and the analysis of influencing factors, this research offers recommendations to alleviate energy poverty in this context.

Firstly, it is crucial to intensify the promotion of modernized clean energy in rural areas. The adoption of modern clean energy sources should be encouraged among rural residents to replace traditional biomass energy, such as firewood. This transition is essential to mitigate environmental pollution and protect the health of rural inhabitants. Based on the research findings, the relevant government departments should conduct extensive awareness campaigns on modern clean energy in rural areas. Various methods can be employed, such as organizing lectures and arranging visits by party members and officials to households to provide detailed explanations.

Secondly, it is recommended to regulate energy prices in rural areas. The research findings clearly indicate that rural household per capita income and energy prices significantly influence energy poverty. By implementing appropriate policies to support rural

economic development, the income level of rural residents can be improved, making modern and clean energy more affordable. Additionally, regulating energy prices can alleviate the burden on rural residents in terms of energy consumption, particularly for households with lower incomes. This measure will effectively reduce the risk of energy poverty among rural households.

Thirdly, it is crucial to promote region-specific approaches in managing rural energy poverty in China. Considering the distinctive characteristics of each region, it is recommended to introduce tailored policies and measures to address energy poverty among rural households. The research findings demonstrate that the factors influencing rural household energy poverty differ across the eastern, northeastern, central, and western regions of China. Specifically, in the eastern region, rural household size and the purchase of social insurance by rural residents significantly affect energy poverty. In the northeastern region, energy prices have a greater impact on energy poverty. In the central and western regions, rural household per capita income, energy prices, social employment choices of rural residents, household size, and the education level of the household head play significant roles in energy poverty.

Implementing the same government policies to alleviate energy poverty for the majority of rural households in China would greatly diminish their effectiveness. Therefore, the Chinese government should consider the unique advantages of each region and develop targeted policies to alleviate energy poverty among rural households in specific regions.

Finally, it is essential to enhance rural education infrastructure. The findings of this study highlight the significant impact of rural residents' education level on household energy poverty, particularly in the central and western regions where educational resources are limited, leading to lower overall education levels. Increasing the number of years of schooling would enhance the literacy level of rural residents and provide them with greater opportunities for well-paying jobs. This, in turn, would elevate their income levels and improve affordability for modern clean energy adoption. To address this issue, the Chinese government should intensify efforts to develop educational infrastructure in rural areas and enhance educational resources. By doing so, the educational level of rural residents can be significantly improved.

This paper provides a detailed analysis of the energy consumption structure of rural households in China, utilizing data from the China Integrated Social Survey (CISS) conducted in 2015 and 2018. After reviewing relevant research literature, the paper examines the factors that may influence energy poverty among Chinese rural households and presents policy recommendations to alleviate this issue. However, it is important to note that there are areas in this paper that require improvement due to limited research time and a lack of research experience.

One limitation of this study is the use of cross-sectional data instead of panel data, which restricts the application of certain methods and limits the comprehensiveness of the analysis. Moreover, due to the challenges in accessing energy-related data, this paper only considers a limited number of energy indicators when selecting relevant variables to measure energy poverty among rural households in China. This may have an impact on the research outcomes.

Based on the findings of this paper, there is still scope for further in-depth research. Future studies could explore the use of multidimensional energy poverty index methods to investigate the energy poverty of Chinese rural households, particularly when subsequent data becomes available.

Author Contributions

Conceptualization, Z.Z.; methodology, Z.Z. and R.Y.; writing—original draft preparation, Z.Z and W.W.; writing—review and editing, W.W.; supervision, R.Y.; writing—revision, W.W and R.Y.; All authors have read and agreed to the published version of the manuscript.

Declaration of Competing Interest

Ethical review and approval were waived for this study because it uses second-hand data collected from an open access database.

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