Gender, Energy Poverty, and Energy Consumption

Abstract

This study explores gender differences in energy poverty, clean energy access, and energy expenditure in rural Chinese households. We employ the multidimensional energy poverty index (MEPI) to capture household energy poverty comprehensively. An exogenous switching treatment regression model is applied to analyze survey data of 1,485 rural households from eastern, central, and western China (Jiangsu, Hubei, and Yunnan provinces). The results show that rural households with female heads have a higher level of MEPI than those with male heads. Relative to rural households with female heads, those with male heads are more likely to access clean energy for cooking and heating and spend more on energy for heating than those with female heads. We also find that if rural households with female heads switch to male heads, the MEPI would be lowered while the probability of accessing clean energy for heating and cooking would be increased. The disaggregated analyses reveal that large-sized households, regardless of male or female household heads, tend to have a lower MEPI and higher probability of accessing clean energy for cooking and heating than medium- and small-sized households. Our findings highlight that gender is not neutral when determining rural energy poverty and use patterns. There is a great need to empower rural women and enable them to make household decisions in energy use activities, which would eventually help improve gender equality and rural energy transition.

Keywords: Gender; Multidimensional energy poverty; Clean energy access; Energy expenditure; Exogenous switching treatment; China

JEL Codes: D12; D13; J16

1. Introduction

Energy poverty and clean energy inaccessibility remain pressing issues worldwide. Energy poverty not only limits the ability of households to access basic energy services but also negatively affects many other aspects of people's lives, such as standard of living (Njiru and Letema, 2018; Qin et al., 2022), education equality and infant mortality (Acheampong et al., 2024; Sule et al., 2022), and physical and mental health (Lee and Yuan, 2024; Qin et al., 2024; Zhang et al., 2021). Besides, lack of access to clean energy leads to increased air pollution and human health problems (Zhu et al., 2023), exacerbating the cycle of poverty. Prior literature has argued that access to clean energy constitutes a pivotal determinant in improving livelihoods, alleviating gender inequality, and accelerating socioeconomic development (Pérez Gelves et al., 2023; Zhu et al., 2023).

Gender-based household labor division determines households' resource access and consumption because males and females are inherently heterogeneous in social capital accumulation, labor supply, and economic performance (Giovanis and Ozdamar, 2023). Accordingly, rural residents' gender is supposed to be deeply related to rural households' energy consumption patterns (Adusah-Poku et al., 2023; Zhong et al., 2024). Thus, rural residents' gender could be a precondition of household energy poverty and use patterns. In light of the widespread nature of gender inequality and energy poverty (Acheampong et al., 2024), investigating the relationship between rural residents' gender and energy poverty and use patterns is of great necessity for designing policy instruments targeting mitigating rural gender inequality and energy poverty and accelerating energy use transition in developing nations.

In the present study, we focus on the gender of household heads and explore their role in determining energy poverty, clean energy access, and energy expenditure. We pay more attention to household heads than others because the former dominates household decision-making. A considerable corpus of research has documented that household heads' decision-making plays a significant role in households' resource access, economic performance enhancement, and welfare improvement (Cholo et al., 2019; Nguyen Chau and Scrimgeour, 2023; Zheng and Ma, 2021). Accordingly, unlocking the association between household heads' gender and energy poverty and consumption can help seize the very pivotal factors in alleviating rural energy poverty and advancing energy transition.

Many studies have shown that females are more likely to be exposed to energy poverty than their male counterparts (Acheampong et al., 2024; Gayoso Heredia et al., 2022; Ngarava et al., 2022; Sen et al., 2023). For example, Moniruzzaman and Day (2020) observed that in Bangladesh, women are more burdened with energy use decisions as they are often responsible for household tasks such as fuel collection and cooking, and they take on more unpaid household and caregiving responsibilities. This consequently increases the amount of time they spend at home, thereby heightening their exposure to energy poverty. Heredia et al. (2022) pointed out that women's exclusion from the labor market makes it more challenging to earn a stable income, especially for single mothers who struggle to pay their energy bills and invest in energy-saving facilities. Sen et al. (2023) investigated the role of gender in eradicating energy poverty through financial inclusion. They found that male-headed households have a higher likelihood of experiencing severe energy poverty than female-headed households, and both male and female-educated households reduce severe energy poverty equally through financial inclusion. Nevertheless, the existing studies discussed above focus on gender in general.

A few studies analyzed how the gender of the household head affects household energy choices (Adusah-Poku et al., 2023; Nwaka et al., 2020). However, these studies focused on access to clean energy such as LPG and electricity, or non-clean energy such as coal, wood, and agricultural residues in African countries such as Ghana and Nigeria, without exploring how the gender of household heads influences energy poverty and expenditure. Besides, although cooking and heating are two essential energy-use activities in people's daily lives

(Duan et al., 2014; Ma et al., 2021; Perumpully et al., 2024), none of the previous studies have considered the gendered differences in households' access to clean energy for and expenditure on cooking and heating. We aim to fill in these research gaps in the present study.

The contributions of the present study are twofold. First, we provide a pioneering attempt to investigate the association between the gender of rural household heads and energy poverty and use patterns. Unlike previous studies using a single indicator (e.g., multidimensional energy poverty index (MEPI) or general clean energy use) to measure energy poverty or use (e.g., Abbas et al., 2021; Pérez Gelves et al., 2023; Wang et al., 2023), we use multiple indicators to enrich our understanding of the gender-energy nexus. Specifically, our analysis considers six energy-rated outcome variables. They include MEPI, clean energy access for cooking, clean energy access for heating, total energy expenditure, energy expenditure on cooking, and energy expenditure on heating. Second, we utilize an exogenous switching treatment regression (ESTR) model as the primary empirical method. The model is developed for the case of exogenous treatment variables, such as gender. Naturally, the model can help assess the accurate treatment effects of rural household heads' gender on energy poverty, clean energy access, and energy expenditure.

We use survey data from 1,485 farming households from eastern, central, and western China (Jiangsu, Hubei, and Yunnan provinces) to assess the gender-energy nexus. From a sustainable development perspective, identifying the role of gender in determining energy poverty and use patterns can help develop policy instruments that improve households' quality of life, promote economic development, and enhance the equity and sustainability of energy access. Ultimately, this contributes to achieving the United Nations Sustainable Development Goal (SDG), such as Goal 7, "Affordable and Clean Energy", which ensures affordable, reliable, and sustainable modern energy. It also contributes to Goal 5, "Gender Equality" of SDG, which targets achieving gender equality and empowering all women and girls (UN, 2018).

Rural China is an interesting example to analyze the link between gender and energy poverty and use. Gender inequality in rural China directly affects women's economic opportunities and energy access, which, in turn, affects the energy poverty status of the entire household (Chen et al., 2024). Statistically, the employment rate of women in rural areas is significantly lower than that of men. In 2023, the employment rate of rural women was 37.3%, compared to 62.7% for men (NBS, 2024a). This employment gap reflects deep-rooted social and economic structural issues that limit women's access to income and energy resources. Besides, rural households in China continue to rely more heavily on unclean energy sources for daily life. Official data suggest that more than 50% of rural households still use coal, firewood, and crop residues as their primary energy source for cooking and heating (NBS, 2024a). The dependence on non-clean energy is detrimental to rural people's health, especially women and children, and reinforces the cycle of energy poverty (Yun et al., 2020).

The rest of the paper is organized as follows. Section 2 presents a background. Section 3 describes the econometric models. Section 4 presents the data source, the measurement of key dependent variables, and descriptive statistics. Section 5 presents and discusses the empirical results. The final section summarizes the paper and highlights policy implications.

2. Background

Energy poverty, especially in rural areas of the developing world, remains a widespread issue unsolved (Apergis et al., 2022; Zhang et al., 2022). Despite global progress, the challenge of accessing clean and reliable energy remains. Rural energy poverty manifests in various forms, from lack of electricity to dependence on traditional biomass energy sources. The World Bank reported that more than 800 million people still do not have access to electricity services, and nearly 3 billion people rely on traditional biomass, such as wood, coal, and animal dung, as their primary source of energy for cooking and heating (World Bank, 2024).

Apart from its diffuse attribute, the reason energy poverty attracts ample attention is that it has multiple toxic effects on the development of societies, manifesting in a vector of problems like health deterioration (Churchill and Smyth, 2021), life quality decrease (Qin et al., 2022), poor educational performance (Amin et al., 2020; Banerjee et al., 2021), and environment degradation (Reyes et al., 2019). Meanwhile, energy poverty has been found to hinder economic development by limiting productivity, increasing production costs, and reducing overall economic growth in South Asian countries (Amin et al., 2020). Undoubtedly, it is necessary to explore effective strategies for alleviating energy poverty.

Improving rural households' clean energy access is important for achieving energy transition and mitigating energy poverty. In practice, official support promotes the usage of renewable energy sources in rural areas (Acheampong, 2023; Hong et al., 2022). For example, the Chinese government has promoted the adoption of renewable energy sources such as solar, wind, and biomass through subsidies and policy support. These policy instruments have not only helped to reduce the use of traditional energy sources but have also played an essential role in reducing energy poverty occurence in rural areas (Ma et al., 2022). However, we should note that some regions have not fully utilized these renewable energy technologies due to insufficient technical support, financial investment, and policy implementation (Xie et al., 2022). More importantly, the effectiveness of implementation and breadth of coverage of these efforts still varies significantly across regions (Acheampong, 2023).

Household energy expenditure is also an important dimension of energy poverty, especially in rural areas, where they tend to occupy a large proportion of total household expenditures. An increase in the proportion of household energy expenditure to its total expenditures would reduce household investment in education, health, and nutrition and deepen the vicious circle of poverty (Li and Ma, 2023). Therefore, improving energy use efficiency is essential for pursuing higher life quality for rural residents (Ma et al., 2022). This reinforces the significance of identifying effective strategies. Xie et al. (2022) suggested that introducing more efficient cooking technologies and subsidies for renewable energy installations have effectively reduced household energy costs, freeing up budgets for other critical needs. Furthermore, interventions targeting the disproportionate impact of high energy costs on poor households are also in order. In particular, these interventions should aim to reduce energy costs and enhance overall energy security, which is essential for breaking the cycle of poverty and promoting sustainable development (Castaño-Rosa et al., 2020).

Gender is seen as a critical factor influencing energy poverty, energy access and energy expenditure because there are significant differences between men and women regarding income levels and educational opportunities (Apergis et al., 2022; Moniruzzaman and Day, 2020; Ozughalu and Ogwumike, 2019). For example, females typically receive lower incomes and have less access to financial resources than males. Besides, there are significant differences in socioeconomic status between males and females (Pueyo and Maestre, 2019). Compared to men, women are usually disadvantaged in accumulating social capital and accessing employment opportunities (Adedeji et al., 2023). These gender differences lead to substantial asymmetries between men and women in labor market performance, career development, and economic conditions. As a result, male and female household heads determine the ability of households to access and use energy for daily activities differently. Therefore, it is significant to understand how and to what extant gender determines household energy poverty, clean energy access and energy expenditure among rural households.

3. Econometric models

In the case of binary treatment variables and cross-sectional datasets, empirical methods such as the propensity score matching (PSM) and endogenous switching regression (ESR) models have been widely used in previous studies to analyze the impact of program participation or policy intervention on outcome variables of interest (Amankwah and Gwatidzo, 2024; Suresh et al., 2021; Wordofa et al., 2021). In empirical analyses, the PSM and ESR models are apt for estimating the unbiased treatment effects of endogenous treatment variables on the dependent variables. Regarding exogenous treatment variables, the PSM and ESR models are not appropriate. In this study, our treatment variable is gender, which is strictly exogenous to humans (Fan and Zhang, 2021; Liu et al., 2021). Therefore, following previous studies (Adusah-Poku et al., 2023; Aryal et al., 2019; Nwaka et al., 2020), we employ the exogenous switching treatment regression (ESTR) model to estimate the treatment effects of gender on energy poverty, clean energy access, and energy expenditure.

The ESTR model estimates three steps. The first step estimates two equations to separately determine the factors influencing the outcome variables (e.g., clean energy access) of male household heads (M-HHs) and female household heads (F-HHs).

$$\begin{cases} y_m = X_m\beta_m + \mu_m & \text{if } g = 1 \\ y_f = X_f\beta_f + \mu_f & \text{if } g = 0 \end{cases} \tag{1}$$

where the subscript m denotes M-HHs, while f denotes F-HHs. Correspondingly, y_m and y_f refer to the outcomes (i.e. MEPI, access to clean energy, and energy expenditure) of M-HHs and F-HHs, respectively. g refers to the gender classification. Specifically, when the household head is male, g=1, and when the household head is female, g=0. X_m and X_f are vectors of explanatory variables that determine the outcomes. β_m and β_f are parameters to be estimated. μ_m and μ_f are the error terms.

The second step of the ESTR model predicts the outcome variables for M-HHs and F-HHs in observed and counterfactual scenarios. Following Nwaka et al. (2020) and Adusah-Poku et al. (2023), the equations for calculating the observed and counterfactual expectations of the outcomes can be expressed in the following forms:

$$\text{Observed outcome for M-HHs:} \quad E(y_m|g = 1) = x_m\beta_m \tag{2a}$$

$$\text{Observed outcome for F-HHs:} \quad E(y_f|g = 0) = x_f\beta_f \tag{2b}$$

$$\text{Counterfactual outcome for F-HHs:} \quad E(y_f|g = 1) = x_m\beta_f \tag{2c}$$

Counterfactual outcome for M-HHs: $E(y_m|g = 0) = x_f \beta_m$ (2d)

where E denotes the calculated expectation. g, y_m, and y_f are defined above. Equations (2a) and (2b) represent the observed expectations of the outcome variables (e.g., MEPI) for M-HHs and F-HHs, respectively. Equations (2c) and (2d) represent counterfactual expectations of outcomes if M-HHs and F-HHs get the same coefficients as their counterparts.

The third step of the ESTR model is to calculate the treatment effects of gender on outcome variables. In this study, we calculate the average treatment effects on the treated (ATT) and average treatment effects on the untreated (ATU). Then, using the observed and counterfactual expectations predicted by Equations (2a) – (2d), the ATT and ATU can be calculated as follows:

$$ATT_{M-HHs} = E(y_m|g = 1) - E(y_f|g = 1) \quad (3a)$$

$$ATU_{F-HHs} = E\left(y_f|g = 0\right) - E(y_m|g = 1) \quad (3b)$$

It is worth notifying that even if the observed attributes (e.g., age, education, and household size) are similar between M-HHs and F-HHs, there may be differences in unobserved factors (e.g., innate ability, managerial skills, and motivations) that influence household energy use decisions. These factors would lead to heterogeneity in outcome variables between M-HHs and F-HHs with the same observed attributes. Therefore, we also calculate the heterogeneous effects of gender on outcome variables as follows:

$$HE_m = E(y_m|g = 1) - E(y_m|g = 0) \quad (4a)$$

$$HE_f = E\left(y_f|g = 1\right) - E(y_f|g = 0) \quad (4b)$$

where HE_m and HE_f measure the heterogeneity effects of gender on outcome variables regarding M-HHs and F-HHs, respectively.

4. Data, variables, and descriptive statistics

4.1 Data

The data analyzed in this study was derived from a rural household survey conducted in eastern, central, and western China. In practice, the data were generated by applying a multi-stage sampling procedure. In the first step, we randomly selected Jiangsu, Hubei, and Yunnan provinces from eastern, central, and western China. Second, we purposively selected each province's top three municipalities and counties engaged in agricultural production. Third, we used the information from the local agricultural bureaus and agricultural science academies to randomly select three villages from each county. Finally, 15-25 rural households within each village were randomly selected and interviewed, resulting in a sample of 1,561 rural households. After cleaning the data by removing samples with missing data on the selected variables, we obtained a sample of 1,485, of which 1,002 were male-headed rural households, and 483 were female-headed.

The survey was conducted between November and December 2023. The gathered information was referred to the year of 2023. A team of researchers and students from local universities who can speak Mandarin and understand local dialects sponsored and conducted the survey. The survey collected information covering farmers' characteristics (e.g., age, education, and health status), household-level characteristics (e.g., household size, older dependency ratio, child dependency ratio, and ownership of assets), farm-level characteristics (e.g., farm size), and energy access and expenditure. We also collected information (e.g., indoor pollution, entertainment activities, and communication tools) that helps us measure MEPI.

4.2 Exogenous treatment variable

Household heads' gender is considered the exogenous treatment variable in the present study. In the survey questionnaire, we prepared a question to help identify whether males or females head a household. Aligning with the dichotomous nature of human gender, we define the treatment variable using a dummy. In particular, the gender variable takes the value of 1 if the head of a rural household is male and 0 otherwise. Accordingly, in our ESTR model estimations, the rural households headed by males are regarded as the treatment group, while those headed by females are assigned to the control group. This definition is consistent with existing studies using gender as an exogenous treatment variable (Adusah-Poku et al., 2023; Paudel et al., 2020).

4.3 Measurements of energy variables

This study comprehensively considers six outcome variables to capture rural households' energy poverty and use patterns: MEPI, access to clean energy for cooking, access to clean energy for heating, total energy expenditure, energy expenditure on cooking, and energy expenditure on heating. Next, we introduce their measurements.

4.3.1 Multidimensional energy poverty

Multiple indices have been developed to measure rural energy poverty. Generally, they include the income benchmark method (Dong et al., 2021), the insufficient energy services method (Luo and Zhang, 2012), the subjective assessment method (Llorca et al., 2020), and the MEPI (Nussbaumer et al., 2012; Sadath and Acharya, 2017; Y. Wang et al., 2023). Among them, the income benchmark method assesses energy poverty by comparing a household's energy expenditures as a proportion of its total income. Still, it may ignore variations in energy quality and accessibility. Although the insufficient energy services method emphasizes service availability, it has difficulty accurately quantifying a household's energy consumption. The subjective assessment method relies on individual perceptions to assess energy poverty, which is susceptible to personal expectations and memory bias and lacks objectivity. In comparison, MEPI, suggested by Nussbaumer et al. (2012), is a better indicator because it considers multiple dimensions of household energy consumption to measure household energy poverty. Previous studies have confirmed that the MEPI efficiently provided a comprehensive and accurate picture of energy poverty (e.g., Li and Ma, 2023; Pérez Gelves et al., 2023). Therefore, this study uses the MEPI to measure rural households' energy poverty comprehensively.

The MEPI is a weighted sum of multiple dimensions of households' energy consumption

(Nussbaumer et al., 2012). Thus, the primary task for MEPI calculation is identifying the dimensions reflecting households' energy consumption. Usually, six dimensions of households' energy consumption, including cooking, lighting, heating/cooling, household appliances, and entertainment/education, are considered for MEPI calculation (Alem and Demeke, 2020; Lin and Zhao, 2021; Wu et al., 2021). In practice, a dummy variable is used to measure each dimension. In particular, the dummy takes the value of 1 if the household lacks the corresponding facility (e.g. computer non-ownership for the entertainment dimension) and 0 otherwise. For the case of our study, since China achieved full electricity coverage in rural areas in 2013, the dimension of lighting is excluded from our consideration. For this reason, we only include the rest five indicators to measure MEPI (see details in Table A1 in the Appendix). Another task for calculating MEPI is assigning a weight to a specific dimension of households' energy consumption. At present, there is no consensus weight matrix for MEPI calculation. Thus, we take the weight matrix suggested by Nussbaumer et al. (2012).

Depending on the identification of the dimensions of energy consumption and the corresponding weight matrix (see Table A1 in the Appendix), the MEPI can be calculated as follows:

$$MEPI_i = \sum_{i=1}^{n} w_j I_{ij} \tag{5}$$

where $MEPI_i$ refers to household i's MEPI; I_{ij} refers to the *j*-indicator used to calculate the MEPI, covering the dimensions of cooking, ownership of assets entertainment, and communication. w_j refers to the specific weight assigned to I_{ij}. $MEPI_i$ takes a value between 0 and 1. A higher level of $MEPI_i$ indicates a higher level of multidimensional energy poverty in a household i.

4.3.2 Access to clean energy for cooking and heating

Clean energy access is a critical prerequisite of rural households' energy consumption; thus, we consider it a component of our outcome variables. Regarding the content of rural households' daily energy consumption, we detail clean energy access from cooking and heating dimensions. In this study, we use two dummies to measure these outcome variables: access to clean energy for cooking and access to clean energy for heating. In particular, the dummy equals 1 if a household has accessed clean energy (e.g., LPG, natural gas, electricity, methane, and solar energy) for cooking/heating and 0 otherwise. These measurements are consistent with previous studies (e.g., Liu et al., 2022).

4.3.3 Energy expenditure on cooking and heating

The spending on energy is the most direct manifestation of household consumption. We use three variables to comprehensively capture rural households' energy spending patterns, including rural households' total energy expenditure, energy expenditure on cooking, and energy expenditure on heating. Specifically, the total energy expenditure variable refers to annual household spending on all energy consumption items, such as cooking, heating, and agricultural production. Energy expenditure on cooking and energy expenditure on heating is the money that rural households allocate on energy for cooking and heating, respectively. The three energy expenditure variables are measured at 100 yuan/capita.

4.4 Control variables

This study also includes a vector of exogenous variables determining rural households' energy poverty and use patterns as control variables. Following previous studies (e.g., Jiang et al., 2024; Pérez Gelves et al., 2023; Pueyo and Maestre, 2019; Zhu et al., 2023), we use age, education, health status, and life satisfaction to capture individual-level-characteristics of household heads. We include household size and old and child dependency ratios to capture household-level demographic characteristics. Variables representing household income, farm size, washing machine ownership, motorbike ownership, and agricultural tricycle ownership are used to reflect rural households' economic conditions. This study also uses the road condition variable to capture the transportation accessibility of the village. Additionally, three location dummies (i.e. Jiangsu, Hubei, and Yunnan provinces) are introduced into our empirical model to capture spatial disparities.

4.5 Descriptive statistics

The definitions of the selected variables and descriptive statistics are presented in Table 1. The mean value of MEPI is 0.414. Around 80% of rural households have accessed clean energy for cooking, and 60% have accessed clean energy for heating. The average total energy expenditure is 352 yuan/capita. Rural households spend 141 yuan/capita and 92 yuan/capita on cooking and heating activities, respectively. Male household heads account for approximately 67.7%, and the rest, 32.3%, are female household heads. Regarding control variables, Table 1 shows that the average age of sampled household heads is 58 years. The mean values of self-reported health status and life satisfaction are 3.59 and 3.89 out of 5, respectively. The average household size is about 5 persons. The mean values of variables for old and child dependency ratios are 28.7% and 21.6%, respectively. Approximately 48% of households in our sample have farm tricycles.

[Insert Table 1 here]

Table 2 presents the mean differences in the selected variables between male and female-headed households. It shows that only the mean difference in the MEPI between rural households with M-HHs and F-HHs is significant among the six energy outcome variables. In particular, MEPI in rural households with M-HHs (0.41) is significantly lower than that with F-HHs (0.43), suggesting that rural households headed by females are more vulnerable to MEPI than those headed by males. Significant mean differences can also be observed in household heads' age and education variables. M-HHs tend to be older and better educated than F-HHs. Relative to households with F-HHs, those with M-HHs tend to have a higher elder dependency ratio. Furthermore, households with M-HHs are more likely to have motorcycles and agricultural tricycles than their counterparts with F-HHs.

[Insert Table 2 here]

The results illustrated in Table 2 suggest that M-HHs and F-HHs are systematically different in MEPI and some control variables. Although the mean differences in clean energy access and expenditure are not statistically significant between households with M-HHs and F-HHs, we cannot conclude that gender does not determine rural household energy access and expenditure. Simple mean comparisons do not account for the confounding factors affecting gender roles in choosing energy for household cooking and heating activities. Therefore, one should conduct a rigorous analysis relying on a suitable econometric model, such as the ESTR model, to unlock the association between gender and energy poverty and expenditure.

We also graphically show the differences in outcome variables between rural households with M-HHs and F-HHs. Figure 1 reveals that rural households with M-HHs have a lower MEPI than those with F-HHs. The means of MEPI are 0.406 and 0.432 for rural households with M-HHs and F-HHs, respectively. Figure 2 shows that the means of clean energy access for cooking and heating are higher for rural households with M-HHs than for rural households with F-HHs. For example, the means of clean energy for cooking for rural households with M-HHs and F-HHs are 0.804 and 0.615, respectively. Figure 3 demonstrates the energy expenditures between rural households with M-HHs and F-HHs. It shows that total energy expenditure and energy expenditure on cooking for rural households with M-HHs are higher than those with F-HHs. In comparison, the energy expenditure on heating shows a reverse pattern between male and female-headed households.

[Insert Figure 1 here]

[Insert Figure 2 here]

[Insert Figure 3 here]

5. Empirical results and discussion

5.1 Determinants of MEPI

Table 3 presents the results showing the impacts of control variables on MEPI for rural households with M-HHs and F-HHs. Table A2 in the Appendix presents the results for the impact of control variables on access to clean energy for cooking and heating. Tables A3 and A4 in the Appendix demonstrate the results for the impact of control variables on total energy expenditure and energy expenditures on cooking and heating. Because discussing the factors that influence the energy-related outcome variables is not our main interest, we only present and discuss the results of Table 3 on MEPI for simplicity.

Table 3 shows that the age variable positively and significantly impacts MEPI, suggesting that rural households with older M-HHs and F-HHs tend to have a higher level of MEPI. Due to unfavorable health conditions, older people receive fewer job opportunities and less income, limiting their energy consumption. Besides, older people often cling to traditional ways of living (Wang et al., 2023), which hinders them from using energy-saving appliances and clean energy. Therefore, households headed by older people, regardless of males or females, tend to be exposed to a high level of MEPI.

[Insert Table 3 here]

Education has a negative and statistically significant impact on MEPI. The finding suggests that rural households with better-educated M-HHs/F-HHs have a lower level of MEPI. Better education enables rural residents to obtain well-paid jobs; this can uplift rural households' energy affordability and accessibility. Moreover, better education improves rural people's awareness and understanding of the benefits of using clean energy and enables them to find better ways to improve energy use efficiency (Niu et al., 2023). Thus, better-educated household heads can help their households escape from energy poverty. This finding is supported by the work of Abbas et al. (2020) on South Asia.

The significant and positive coefficient of the old dependency ratio variable in the M-HHs specification suggests that rural households with a higher level of old dependency ratio tend to have a higher level of MEPI. Rural households with a large proportion of elderly tend to confront heavy budgets on healthcare and medicine bills (Qiu et al., 2021), which crowd out their expenditure on energy and lead them to energy poverty. Therefore, an increasing old dependency ratio can lift rural households' MEPI. The variables representing household assets, including washing machines, motorcycles, and farm tricycles, have significant and negative coefficients. To some extent, rural household assets are proxies of wealth. Therefore, wealthier households have a lower level of MEPI. Our findings are primarily aligned with Abbas et al. (2020), showing that the wealth index is negatively associated with MEPI.

The geographical locations also matter with MEPI. Our results reveal that relative to rural households residing in Hubei province (the reference location), those in Jiangsu province have a lower level of MEPI, and those headed by males in Yunnan have a higher level of MEPI. The differences in income distributions across those three provinces can largely explain the findings. In 2023, rural households' per capita disposable incomes in Jiangsu, Hubei, and Yunnan were 30,488 yuan，21,293 yuan, and 16,361 yuan, respectively (NBS, 2024b). Therefore, a region with a high economic condition has a lower level of MEPI.

5.2 Treatment effects of gender

Table 4 shows the treatment effects of household heads' gender on the MEPI, clean energy access, and energy expenditure. The ATT estimate for the impact of gender on MEPI is negative and statistically significant, suggesting that rural households with M-HHs have a 4.5% lower level of MEPI than their counterparts with F-HHs. The negative and significant ATU in the MEPI specification suggests that if rural households with F-HHs switch to M-HHs, the MEPI would be lowered by 3.9%. Rural males are usually endowed with stronger social capital and better linked to markets than their female counterparts, allowing them to earn extra income and invest in household energy-efficient appliances. Consequently, rural households with M-

HHs are less likely to experience MEPI compared with those with F-HHs. More importantly, this finding is highly policy-relevant as it highlights that females can achieve the same as males in terms of energy poverty mitigation if the former is granted the same endowment as the latter (Nguyen and Su, 2021).

[Insert Table 4 here]

The ATT and ATU estimates for the impact of gender on access to clean energy for cooking and access to clean energy for heating are positive and statistically significant. The ATT estimates suggest that rural households with M-HHs tend to have a 3.4% and 8.9% higher probability of accessing clean energy for cooking and heating, respectively. The ATU estimates reveal that for households with F-HHs, switching to M-HHs would increase the probability of accessing clean energy for cooking and heating by 6.6% and 5.9%, respectively. From a pragmatic perspective, accessing and using clean energy is cost-intensive (Li and Ma, 2023). For example, rural households must install gap pipelines if they want to use LPG, which is costly. Rural households with M-HHs usually have better economic conditions and financial resources than their F-HHs counterparts (Adusah-Poku et al., 2023; Vo and Ho, 2023). Thus, the former is more likely to afford the costs associated with clean energy access than the latter. As it stands, equalizing the endowments owned by M-HHs with F-HHs can largely popularize the use of clean energy in rural areas.

Gender does not have a statistically significant impact on total and energy expenditure on cooking. However, gender matters in energy expenditure on heating. Specifically, the significant and positive ATT in Table 4 suggests that rural households with M-HHs tend to spend 13.3% more on energy for heating. Besides, the results of the ATU estimate show that if rural households with F-HHs switch to M-HHs, their energy expenditure on heating would increase by 17.5%. In reality, energy for cooking is recognized as a basic need in people's daily lives. This makes the energy expenditure on cooking numb to external shocks. Thus, gender exerts no impact on energy expenditure on cooking. F-HHs tend to be more conservative than M-HHS in using clean energy (e.g., electricity) and heating equipment (e.g., heater and air-conditioner), which costs more. As a result, rural households with F-HHs tend to be more likely to rely on non-clean energy (e.g., coal and wood) for heating and spend less on energy for heating than those with M-HHs.

In Table 4, the estimated heterogeneity effects are also significant in most estimations. The findings confirm that M-HHs and F-HHs with the same observed attributes (e.g., age, education, self-reported health status, household size, and farm size) but different unobserved attributes (e.g., innate abilities and motivations) appear to make different decisions when choosing energy for daily activities such as cooking and heating.

5.3 Disaggregated analyses

To solidify our understanding of the association between gender and energy poverty, clean energy access, and energy expenditure, we also disaggregated the treatment effects of gender by household sizes, categorizing into small-sized households (1-4 persons), medium-sized households (5-6 persons), and large-sized households (7 persons and above).[1] The empirical results are presented in Table 5. The results of ATT and ATU estimates confirm that gender determines MEPI, access to clean energy, and energy expenditure differently across small, medium, and large-sized households. For example, based on ATT estimates, gender significantly and negatively impacts the MEPI of small- and large-sized households. However, it does not affect the MEPI of medium-sized households. In terms of total energy expenditure and energy expenditure on cooking, the ATU estimates show that gender only affects small-sized rural households significantly.

[1] Because there is no offial definition about small, medium and large-sized households, we use "xtile, nq(3)"commands in Stata to clarify our samples into those three groups.

[Insert Table 5 here]

To improve our understanding of the estimated treatment effects, we calculate the percentage changes in ATT and ATU and present the results in Table 6. The upper part of Table 6 presents the percentage changes in ATT, calculated as the ratio of ATT to the predicted outcomes of the control group (i.e., households with F-HHs). It shows that gender affects MEPI and the probability of accessing clean energy for cooking among large households. Specifically, Table 6 shows that for large-sized households, the MEPI is 6.9% lower with M-HHs than those with F-HHs, while the probability of accessing clean energy for cooking is 6.0% higher with M-HHs than those with F-HHs. For small- and medium-sized households, the MEPI of households with M-HHs is 2.7- 4.9% lower than those with F-HHs. Besides, relative to small- and medium-sized households with F-HHs, those with M-HHs are 2% more likely to access clean energy for cooking. The total energy expenditure for rural households with M-HHs tends to be 7.5% higher than those with F-HHs among small-sized households. In comparison, the total energy expenditures are 0.3% and 4.9% higher for male-headed households than those in female-headed households among medium- and larger-sized households.

[Insert Table 6 here]

The lower part of Table 6 presents the results of the percentage changes in ATU, which are calculated as the ratio of ATU to the predicted outcomes of the control group (i.e., households with F-HHs). The results show that if large-sized rural households with F-HHs switch to M-HHs, their MEPI would reduce by 6.6%. In comparison, if small-sized rural households with F-HHs switch to M-HHs, their MEPI would reduce by 4.7%. Gender also has the largest effect on clean energy access among large-sized households. The results indicate that if large-sized rural households with F-HHs switch to M-HHs, their probabilities of accessing clean energy for cooking and heating would increase by 7.5% and 14.3%. In comparison, if small-sized rural households with F-HHs switch to M-HHs, their probabilities of accessing clean energy for cooking and heating would increase by 6.6% and 10.6%, respectively. If rural households with F-HHs switch to M-HHs, the energy expenditure on heating for small-, medium-, and large-sized households would increase by 19.1%, 12.1%, and 53.7%, respectively.

6. Conclusions, policy implications, and limitations

This study utilized rural household data from Jiangsu, Hubei, and Yunnan provinces of China to examine the impacts of household heads' gender on MEPI, clean energy access, and energy expenditure. Given the exogenous nature of gender as a treated variable, we estimated an ESTR model. The results showed that rural households with M-HHs and those with F-HHs differ in MEPI, clean energy access, and energy expenditure. In particular, our ATT estimates revealed that rural households with F-HHs are more prone to a higher level of MEPI than those with M-HHs. Relative to rural households with F-HHs, those with M-HHs were more likely to access clean energy for heating and cooking. Besides, the energy expenditure on heating for rural households with M-HHs was higher than that with F-HHs. Our ATU estimates confirmed that if rural households with F-HHs switch to M-HHs, their households' MEPI would be lowered, and the likelihood of accessing clean energy for cooking, heating, and energy expenditure on heating would increase. The disaggregated analyses reveal that the effects of gender on MEPI, clean energy access, and energy expenditure differ across small-, medium-, and large-sized households. Large-sized households, regardless of male or female household heads, tend to have a lower MEPI and higher probability of accessing clean energy for cooking and heating than medium- and small-sized households.

Our results also identified important factors influencing MEPI. In particular, the MEPI of rural households with F-HHs was negatively and significantly affected by education level, life satisfaction, child dependency ratio, and ownership of household assets (i.e. washing machines, motorcycles, and farm tricycles). For rural households with M-HHs, MEPI is significantly and negatively affected by education, health status, life satisfaction, and ownership of household assets. Age positively and significantly affected the MEPI of rural households, whether their heads are male or female.

Our study contains significant policy implications for China and other nations confronting similar rural gender inequality and energy poverty conditions. The study reveals that rural households' energy poverty and use patterns are not gender-neutral. In particular, compared with rural households with M-HHs, those with F-HHs are more vulnerable to MEP and less likely to use clean energy for cooking and heating. Thus, policy instruments should be focused on rural women's empowerment to strengthen their decision-making power on household energy consumption. In particular, the local government should provide rural women with training and financial support to incite them to participate in the labor market and help improve their economic status. Meanwhile, penetrating women's mutual aid organizations among rural residents to elevate women's status within their households should be prioritized. Besides, intensifying the advocacy for gender equality in rural areas is expected to effectively enhance women's role in mitigating energy poverty. It was found that both M-HHs and F-HHs obtained significant MEPI mitigation when their education level increased. As a long-term strategy to reduce energy poverty, policy efforts should improve rural residents' education, especially in rural and undeveloped areas.

The estimations of this study rely on cross-sectional data collected from three provinces in China due to a lack of panel data. This limits our ability to capture the spatial and temporal variances in the impacts of household heads' gender on energy poverty and use patterns. This calls for future studies to explore the dynamic relationship between gender and energy when panel data is available. Although the findings are interesting, they hardly fit all situations well because this study only takes China as an analytical example. The spatial heterogeneities across countries call for more research on other developing regions (e.g., Southeast Asia, Africa, and Latin America) to help generalize our understanding of the gender-energy nexus.

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Figures

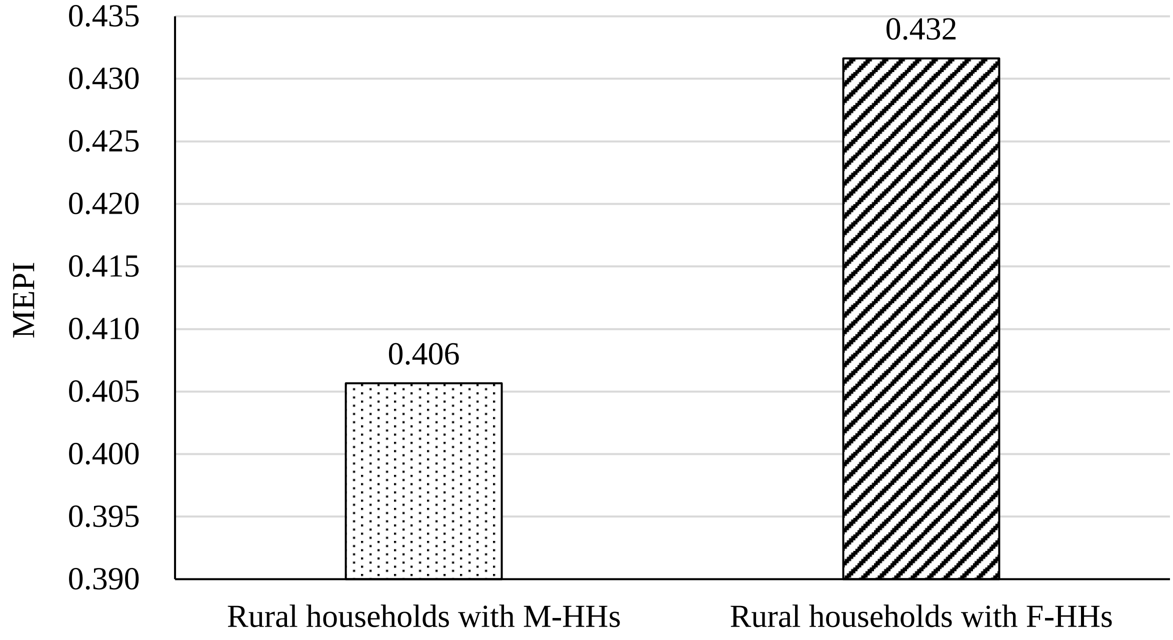

Figure 1 Means of MEPI between M-HHs and F-HHs

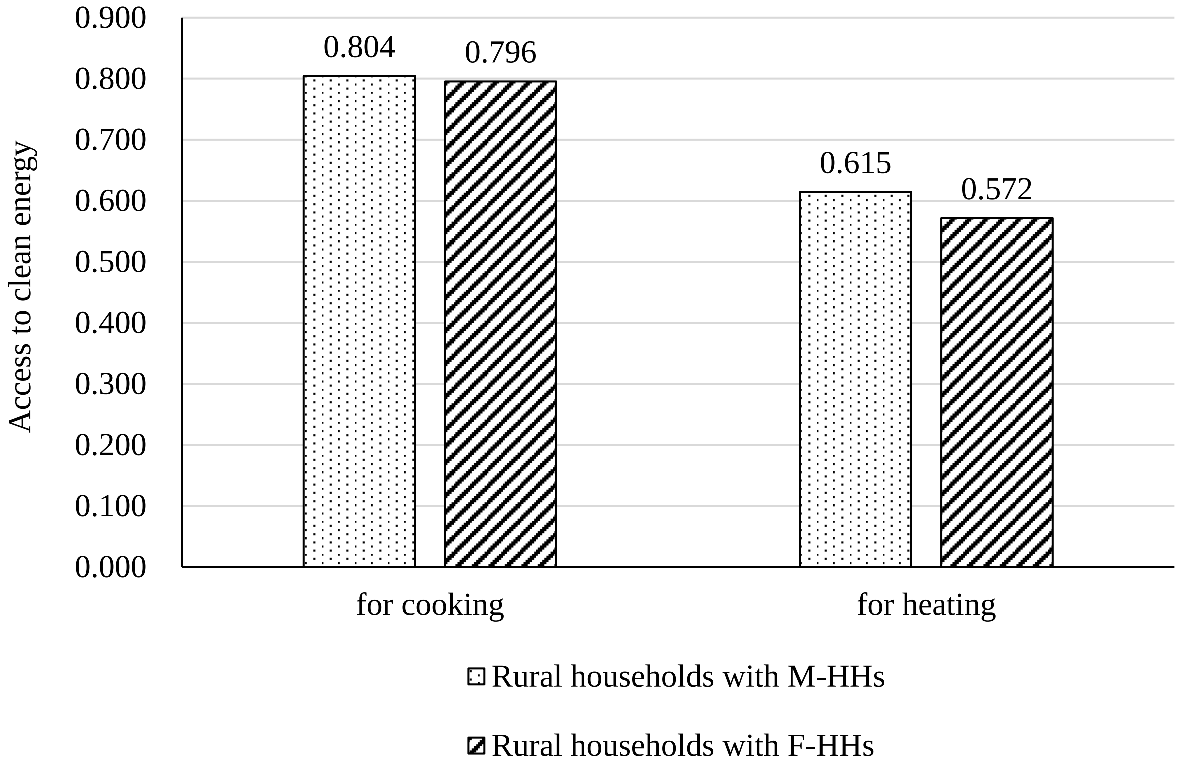

Figure 2 Means of clean energy access for cooking and heating

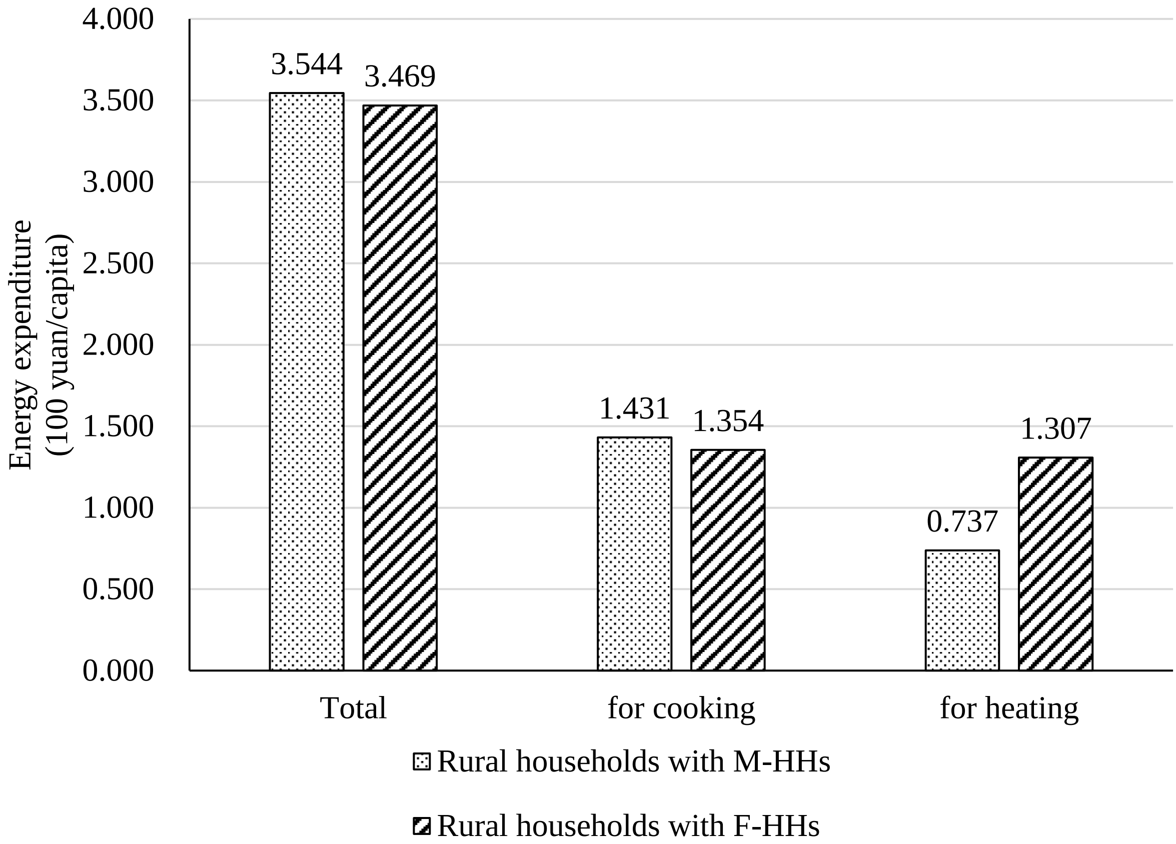

Figure 3 Total energy expendigure and energy expenditure on cooking and heating

Tables

Table 1 Definitions and summary statistics of selected variables

Variables	Definitions	Mean	S.D.
Dependent variables			
MEPI	Multidimensional energy poverty index, calculated by Equation (5)	0.414	0.204
Access to clean energy for cooking	1 If a household has access to clean energy (e.g. LPG, natural gas, electricity, methane, or solar energy) for cooking activities, 0 otherwise	0.802	0.399
Access to clean energy for heating	1 If a household has access to clean energy for heating, 0 otherwise	0.601	0.490
Total energy expenditure	(100 yuan/capita) [a]	3.520	3.939
Energy expenditure on cooking	(100 yuan/capita)	1.406	1.384
Energy expenditure on heating	(100 yuan/capita)	0.915	8.079
Exogenous treatment variable			
Gender	1 if a household head is male, 0 otherwise	0.677	0.468
Control variables			
Age	Age of household head (HH) in years	58.775	12.130
Education	Education of HH in years	7.367	4.084
Health status	HH self-reported health status (from 1=very unhealthy to 5=very healthy)	3.594	1.058
Life satisfaction	HH self-reported life satisfaction (from 1=very unsatisfied to 5=very satisfied)	3.885	0.862
Household size	Number of household members in persons	5.034	2.093
Old dependency ratio	The ratio of people older than 64 to the number of people aged between 15 and 64	0.287	0.451
Child dependency ratio	The ratio of people younger than 15 to the number of people aged between 15 and 64	0.216	0.354
Household income	(10,000 yuan/capita)	2.252	9.214
Farm size	The total land area owned by a household (mu) [b]	26.43	212.1
Washing machine	1 If a household owns a washing machine, 0 otherwise	0.905	0.293
Motorcycle	1 If a household owns a motorcycle, 0 otherwise	0.455	0.498
Farm tricycles	1 If a household owns a farm tricycles, 0 otherwise	0.479	0.500
Road condition	1 If HH reports that village road condition is good, 0 otherwise	0.911	0.284

Jiangsu	1 If a household is located in Jiangsu province, 0 otherwise	0.328	0.470
Hubei	1 If a household is located in Hubei province, 0 otherwise	0.323	0.468
Yunnan	1 if a household is located in Yunnan province, 0 otherwise	0.349	0.477
Observations		1,485	

Note: S.D. refers to standard deviation. [a] Yuan is a Chinese currency unit ($1=7.23 yuan). [b] 1 mu=1/15 hectare.

Table 2 Mean differences in the selected variables between rural households with M-HHs and those with F-HHs

Variables	M-HHs		F-HHs		Mean difference	S.E.
	Mean	S.E.	Mean	S.E.		
Dependent variables						
MEPI	0.41	0.01	0.43	0.01	-0.03**	0.03
Access to clean energy for cooking	0.81	0.01	0.80	0.02	0.01	0.02
Access to clean energy for heating	0.61	0.01	0.57	0.02	0.04	0.03
Total energy expenditure	3.54	0.12	3.47	0.17	0.08	0.21
Energy expenditure on cooking	1.43	0.04	1.35	0.06	0.08	0.08
Energy expenditure on heating	0.74	0.05	1.31	0.68	-0.57	0.46
Control variables						
Age	60.18	0.36	55.82	0.54	4.36***	0.64
Education	7.98	0.11	6.08	0.20	1.91***	0.22
Health status	3.62	0.03	3.54	0.05	0.07	0.06
Life satisfaction	3.91	0.03	3.83	0.04	0.07	0.05
Household size	5.08	0.07	4.94	0.09	0.13	0.11
Old dependency ratio	0.30	0.01	0.25	0.02	0.06**	0.03
Child dependency ratio	0.21	0.01	0.23	0.02	-0.02	0.02
Household income	2.50	0.33	1.73	0.18	0.78	0.50
Farm size	30.55	7.22	17.83	6.76	12.72	11.44
Washing machine	0.91	0.01	0.90	0.01	0.01	0.02
Motorcycle	0.47	0.02	0.42	0.02	0.05*	0.03
Farm tricycles	0.51	0.02	0.42	0.02	0.09***	0.03
Road condition	0.92	0.01	0.90	0.01	0.02	0.02
Jiangsu	0.34	0.01	0.30	0.02	0.05*	0.03
Hubei	0.33	0.01	0.31	0.02	0.02	0.03
Yunnan	0.33	0.01	0.40	0.02	-0.07***	0.03
Observations	1,002		483			

Note: S.E. refers to standard error. * p<0.1, ** p<0.05, and *** p<0.01

Table 3 Impacts of control variables on MEPI of rural households with M-HHs and those with F-HHs

Variables	Rural households with M-HHs	Rural households with F-HHs
Age	0.002 (0.001)***	0.002 (0.001)**
Education	-0.007 (0.002)***	-0.005 (0.002)**
Health status	-0.001 (0.006)	-0.018 (0.008)**
Life satisfaction	-0.023 (0.007)***	-0.019 (0.009)**
Household size	0.000 (0.003)	-0.003 (0.004)
Old dependency ratio	0.038 (0.013)***	0.022 (0.018)
Child dependency ratio	-0.051 (0.018)***	-0.035 (0.025)
Household income	-0.001 (0.001)	-0.005 (0.003)
Farm size	0.000 (0.000)	0.000 (0.000)
Washing machine	-0.084 (0.020)***	-0.091 (0.027)***
Motorcycles	-0.069 (0.012)***	-0.062 (0.019)***
Farm tricycles	-0.058 (0.012)***	-0.065 (0.017)***
Road condition	-0.009 (0.020)	-0.028 (0.027)
Jiangsu	-0.117 (0.015)***	-0.100 (0.024)***
Yunnan	0.029 (0.016)*	-0.011 (0.022)
Constant	0.589 (0.059)***	0.690 (0.088)***
Observations	1,002	483

Note: Standard errors are in parentheses. * $p<0.1$, ** $p<0.05$, and *** $p<0.01$; The reference location is Hubei province.

Table 4 Treatment effects estimates

	Rural households with M-HHs	Rural households with F-HHs	Treatment effects		Change (%)
	MEPI				
M-HHs	0.402	0.421	-0.019 (0.006)***	ATT	4.5
F-HHs	0.415	0.433	-0.017 (0.006)***	ATU	3.9
Heterogeneity effects	-0.013 (0.005)***	-0.012 (0.007)*			
	Access to clean energy for cooking				
M-HHs	0.816	0.789	0.027 (0.005)***	ATT	3.4
F-HHs	0.840	0.789	0.052 (0.006)***	ATU	6.6
Heterogeneity effects	-0.024 (0.004)***	0.000 (0.007)			
	Access to clean energy for heating				
M-HHs	0.621	0.570	0.051 (0.008)***	ATT	8.9
F-HHs	0.608	0.574	0.034 (0.007)***	ATU	5.9
Heterogeneity effects	0.034 (0.007)***	-0.004 (0.009)			
	Total energy expenditure				
M-HHs	3.427	3.346	0.081 (0.081)	ATT	2.4
F-HHs	3.361	3.249	0.112 (0.075)	ATU	4.2
Heterogeneity effects	0.067 (0.064)	0.097 (0.089)			
	Energy expenditure on cooking				
M-HHs	1.394	1.398	-0.004 (0.033)	ATT	0.3
F-HHs	1.327	1.280	0.047 (0.031)	ATU	3.7
Heterogeneity effects	0.067 (0.027)**	0.118 (0.032)***			
	Energy expenditure on heating				
M-HHs	0.681	0.601	0.080 (0.026)***	ATT	13.3
F-HHs	0.583	0.497	0.087 (0.020)***	ATU	17.5
Heterogeneity effects	0.097 (0.018)***	0.104 (0.028)***			

Note: Standard errors are in parentheses. Access to clean energy for cooking and Access to clean energy for heating are measured as dummy variables. Total energy expenditure, energy expenditure on cooking, and energy expenditure on heating are measured at 100 yuan/capita. * p<0.1, ** p<0.05, and *** p<0.01.

Table 5 Heterogeneous effects by household sizes

Outcomes	Small-sized households			Medium-sized households			Large-sized households		
	Rural households with M-HHs								
	M-HHs	F-HHs	ATT	M-HHs	F-HHs	ATT	M-HHs	F-HHs	ATT
MEPI	0.411	0.432	-0.021 (0.010)**	0.392	0.403	-0.011 (0.009)	0.405	0.435	-0.030 (0.013)**
Access to clean energy for cooking	0.818	0.801	0.016 (0.008)**	0.824	0.809	0.016 (0.007)**	0.796	0.751	0.045 (0.013)**
Access to clean energy for heating	0.595	0.533	0.062 (0.012)***	0.634	0.590	0.044 (0.011)***	0.644	0.577	0.067 (0.016)***
Total energy expenditure	4.294	3.993	0.301 (0.114)***	3.338	3.329	0.009 (0.094)	1.857	1.771	0.086 (0.160)
Energy expenditure on cooking	1.897	1.852	0.045 (0.032)	1.311	1.374	-0.064 (0.022)**	0.552	0.619	-0.067 (0.060)
Energy expenditure on heating	0.868	0.784	0.084 (0.036)*	0.675	0.661	0.015 (0.033)	0.256	0.174	0.082 (0.052)
	Rural households with F-HHs								
	Small-sized households			Medium-sized households			Large-sized households		
	M-HHs	F-HHs	ATU	M-HHs	F-HHs	ATU	M-HHs	F-HHs	ATU
MEPI	0.423	0.444	-0.021 (0.010)**	0.409	0.417	-0.008 (0.008)	0.412	0.441	-0.029 (0.012)**
Access to clean energy for cooking	0.821	0.771	0.051 (0.009)***	0.848	0.804	0.044 (0.008)***	0.860	0.801	0.060 (0.012)***
Access to clean energy for heating	0.635	0.574	0.061 (0.012)***	0.636	0.590	0.046 (0.011)***	0.615	0.537	0.077 (0.016)***
Total energy expenditure	4.249	3.983	0.266 (0.090)***	3.299	3.201	0.098 (0.077)	1.682	1.530	0.152 (0.158)
Energy expenditure on cooking	1.647	1.546	0.100 (0.053)**	1.263	1.258	0.005 (0.026)	0.725	0.666	0.059 (0.050)
Energy expenditure on heating	0.680	0.572	0.109 (0.032)***	0.567	0.506	0.061 (0.027)*	0.272	0.177	0.095 (0.046)*
Observations	385	207		429	193		188	83	

Note: standard error are in parentheses. Access to clean energy for cooking and Access to clean energy for heating are measured as dummy variables. Total energy expenditure, energy expenditure on cooking, and energy expenditure on heating are measured at 100 yuan/capita.* p<0.1, ** p<0.05, and *** p<0.01. Small-sized households: 1-4 persons; medium-sized households: 5-6 persons, large-sized households: 7 persons and above.

Table 6 Percentage changes in ATT and ATU

Outcomes	**Rural households with M-HHs:** Change in ATT (%)		
	Small-sized households	Medium-sized households	Large-sized households
MEPI	-4.9	-2.7	-6.9
Access to clean energy for cooking	2.0	2.0	6.0
Access to clean energy for heating	11.6	7.5	11.6
Total energy expenditure	7.5	0.3	4.9
Energy expenditure on cooking	2.4	-4.7	-10.8
Energy expenditure on heating	10.7	2.3	47.1
	Rural households with F-HHs: Change in ATU (%)		
	Small-sized households	Medium-sized households	Large-sized households
MEPI	-4.7	-1.9	-6.6
Access to clean energy for cooking	6.6	5.5	7.5
Access to clean energy for heating	10.6	7.8	14.3
Total energy expenditure	6.7	3.1	9.9
Energy expenditure on cooking	6.5	0.4	8.9
Energy expenditure on heating	19.1	12.1	53.7
Observations	592	622	271

Note: The changes in ATT and ATU are calculated based on the information presented in Table 5. Specifically, the perchance changes in ATT, are calculated as the ratio of ATT to the predicted outcomes of the control group (i.e. F-HHs). The percentage changes in ATU, which are calculated as the ratio of ATU to the predicted outcomes of the control group (i.e. F-HHs)

Appendix

Table A1 Dimensions of MEPI and indicators used to calculate it

Dimensions	Indicators	Nussbaumer et al. (2012)		This study	
		Definitions	**Weights**	**Definitions**	**Weights**
Cooking	Modern cooking fuel	Any fuel used besides electricity, LPG, kerosene, natural gas, or biogas	0.20	Any fuel other than liquefied petroleum gas, natural gas, electricity, methane, or solar energy.	0.20
	Indoor pollution	Food cooked on a stove or open fire (no hood/chimney), indoors, if using any polluting fuels (e.g. firewood and coal)	0.20	Poor kitchen ventilation	0.20
Electricity access	Lighting	Has no electricity access	0.20	NA.	NA.
Ownership of assets	Fridge ownership	Has no fridge	0.13	NA.	NA.
	Microwaves ownership	NA.	NA.	Has no microwaves	0.13
	AC ownership	NA.	NA.	Has no AC	0.13
Entertainment	Television ownership	Has no television	0.13	NA.	NA.
	Computer ownership			Has no computer	0.20
Communication	Mobile phone ownership	Has no landline or mobile phone	0.13	NA.	NA.
	Network broadband ownership	NA.	NA.	Has no network broadband	0.13
Total weight			1.00		1.00

Table A2 Impacts of control variables on access to clean energy for cooking and heating between rural households with M-HHs and those with F-HHs

	Access to clean energy for cooking		Access to clean energy for heating	
Variables	Rural households with M-HHs	Rural households with F-HHs	Rural households with M-HHs	Rural households with F-HHs
Age	0.001 (0.005)	0.003 (0.007)	-0.004 (0.005)	-0.002 (0.007)
Education	-0.002 (0.017)	0.066 (0.020)***	0.070 (0.015)***	0.075 (0.018)***
Health status	-0.059 (0.048)	0.053 (0.068)	-0.106 (0.043)**	-0.074 (0.062)
Life satisfaction	0.117 (0.057)**	0.046 (0.075)	-0.05 (0.052)	-0.068 (0.068)
Household size	-0.033 (0.024)	0.036 (0.035)	0.040 (0.022)*	0.012 (0.032)
Old dependency ratio	-0.257 (0.111)**	0.000 (0.152)	0.050 (0.103)	0.148 (0.138)
Child dependency ratio	0.101 (0.156)	0.215 (0.228)	-0.102 (0.137)	-0.067 (0.187)
Household income	0.010 (0.025)	0.140 (0.062)**	0.000 (0.010)	0.083 (0.048)*
Farm size	0.011 (0.004)**	-0.001 (0.001)	0.001 (0.001)	0.001 (0.001)
Washing machine	0.250 (0.154)	0.015 (0.216)	-0.043 (0.148)	0.022 (0.202)
Motorcycle	-0.031 (0.109)	-0.003 (0.156)	0.136 (0.095)	-0.175 (0.140)
Farm tricycles	0.260 (0.102)**	0.302 (0.145)**	0.204 (0.089)**	0.160 (0.129)
Road condition	0.008 (0.172)	0.075 (0.216)	0.167 (0.150)	-0.108 (0.197)
Jiangsu	0.185 (0.144)	0.017 (0.206)	0.945 (0.120)***	0.589 (0.180)***
Yunnan	-0.192 (0.138)	-0.041 (0.18)	0.525 (0.121)***	0.645 (0.162)***
Constant	0.432 (0.506)	-0.658 (0.726)	-0.400 (0.451)	-0.181 (0.657)
Observations	1,002	483	1,002	483

Note: Access to clean energy for cooking and Access to clean energy for heating are measured as dummy variables.
Standard errors are in parentheses. * p<0.1, ** p<0.05, and *** p<0.01.

Table A3 Impacts of control variables on total energy expenditure between rural households with M-HHs and those with F-HHs

Variables	Rural households with M-HHs	Rural households with F-HHs
Age	-0.028 (0.013)**	-0.020 (0.015)
Education	0.055 (0.042)	0.070 (0.040)*
Health status	0.085 (0.119)	-0.093 (0.146)
Life satisfaction	-0.188 (0.145)	0.089 (0.159)
Household size	-0.416 (0.060)***	-0.483 (0.074)***
Old dependency ratio	0.134 (0.284)	0.225 (0.318)
Child dependency ratio	0.031 (0.374)	0.008 (0.440)
Household income	-0.006 (0.027)	-0.042 (0.058)
Farm size	0.003 (0.001)**	0.002 (0.002)
Washing machine	0.138 (0.416)	0.656 (0.479)
Motorcycle	0.241 (0.264)	0.568 (0.328)*
Farm tricycles	0.298 (0.245)	-0.027 (0.298)
Road condition	-0.635 (0.424)	0.158 (0.466)
Jiangsu	1.021 (0.325)***	0.784 (0.418)*
Yunnan	-0.760 (0.335)**	-0.909 (0.379)**
Constant	7.246 (1.241)***	5.528 (1.535)**
Observations	1,002	483

Note: Standard errors are in parentheses. Total energy expenditure is measured at 100 yuan/capita. * $p<0.1$, ** $p<0.05$, and *** $p<0.01$.

Table A4 Impacts of control variables on energy expenditures on cooking and heating between rural households with M-HHs and those with F-HHs

Variables	Energy expenditure on cooking		Energy expenditure on heating	
	Rural households with M-HHs	Rural households with F-HHs	Rural households with M-HHs	Rural households with F-HHs
Age	-0.028 (0.013)**	-0.020 (0.015)	-0.006 (0.005)	-0.010 (0.005)*
Education	0.055 (0.042)	0.070 (0.040)*	0.026 (0.016)*	0.046 (0.013)***
Health status	0.085 (0.119)	-0.093 (0.146)	0.025 (0.046)	-0.099 (0.049)**
Life satisfaction	-0.188 (0.145)	0.089 (0.159)	0.049 (0.057)	0.073 (0.056)
Household size	-0.416 (0.060)***	-0.483 (0.074)***	-0.112 (0.022)***	-0.071 (0.024)***
Old dependency ratio	0.134 (0.284)	0.225 (0.318)	0.047 (0.106)	-0.009 (0.104)
Child dependency ratio	0.031 (0.374)	0.008 (0.440)	0.183 (0.152)	0.007 (0.150)
Household income	-0.006 (0.027)	-0.042 (0.058)	-0.009 (0.010)	-0.008 (0.018)
Farm size	0.003 (0.001)**	0.002 (0.002)	0.001 (0.000)	0.000 (0.000)
Washing machine	0.138 (0.416)	0.656 (0.479)	0.204 (0.163)	0.131 (0.160)
Motorcycle	0.241 (0.264)	0.568 (0.328)*	-0.086 (0.101)	0.205 (0.108)*
Farm tricycles	0.298 (0.245)	-0.027 (0.298)	-0.085 (0.092)	0.001 (0.096)
Road condition	-0.635 (0.424)	0.158 (0.466)	-0.208 (0.168)	0.018 (0.162)
Jiangsu	1.021 (0.325)***	0.784 (0.418)*	0.750 (0.119)***	0.457 (0.129)***
Yunnan	-0.760 (0.335)**	-0.909 (0.379)**	-0.062 (0.128)	-0.165 (0.125)
Constant	7.246 (1.241)***	5.528 (1.535)**	0.962 (0.480)**	0.884 (0.510)*
Observations	1,002	483	1,002	483

Note: Standard errors are in parentheses. Energy expenditure on cooking and energy expenditure on heating are measured at 100 yuan/capita. * p<0.1, ** p<0.05, and *** p<0.01.