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Fuel choices for cooking and heating and gender empowerment: Implications for promoting gender equality and sustainable rural development

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ABSTRACT

This study evaluates the impact of fuel choices for cooking and heating on gender empowerment using rural household survey data from China. We investigate rural households' fuel-stacking behaviors by classifying fuels into non-clean, clean, and mixed categories and distinguish an incomplete energy transition (i.e. switching from non-clean fuels to mixed fuels) from a complete energy transition (i.e. switching from non-clean to clean fuels). The decision-making power of men and women measures gender empowerment. We use the multinomial endogenous switching regression model to address the endogeneity issue associated with rural households' fuel choices. The results show that incomplete and complete energy transitions for heating significantly increase men's decision-making power, while the same transitions for cooking have no significant impact. Incomplete and complete energy transitions for cooking significantly empower rural women, while a complete energy transition for heating also significantly empowers women. These findings suggest that promoting a complete energy transition supports broader rural development by empowering women to participate more actively in household decision-making. We also find that a complete energy transition for cooking and heating reduces the decision-making power gap between men and women more than an incomplete one, highlighting that a complete energy transition contributes more to gender equality. Therefore, fostering complete energy transitions is essential for closing gender disparities and establishing a foundation for sustainable rural development through enhanced female empowerment.

1. Introduction

Non-clean fuels, such as crop residues and wood, have traditionally supported human development for cooking and heating. In 2021, approximately 2.3 billion people still rely on non-clean fuels and technologies for cooking, primarily in rural areas of developing and underdeveloped countries. This widespread reliance on non-clean fuels underscores a significant global energy transition challenge. Around 95 % of rural residents in sub-Saharan African countries rely on non-clean fuels and technologies for cooking, compared to 51 % in Central and Southern Asian countries (IEA et al., 2023), highlighting the region's significant energy access gap and the urgent need for clean energy transitions. Using non-clean fuels causes indoor air pollution, negatively impacting mental and physical health (Adhvaryu et al., 2023; Imelda, 2020; Liu et al., 2020; Pillarisetti et al., 2022). Imelda (2020) evaluated the health impacts of Indonesia's nationwide clean fuel switching program. They found that the program significantly reduces infant mortality and the prevalence of low birth weight. Adhvaryu et al. (2023) reported that dirty (fossil fuel-driven) energy production increased cardiovascular-related mortality and respiratory-related morbidity in Colombia. This evidence calls for switching from non-clean fuels to clean fuels like natural gas and electricity, as this transition would positively impact people's lives and economic development.

Due to the gendered nature of intra-household tasks, rural women are primarily responsible for fuel collection and cooking (Odo et al., 2021; Picchioni et al., 2020; Totouom, 2024), making them disproportionately vulnerable to the negative impacts of non-clean fuel use. This situation exacerbates both health risks and gender inequality, as the

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reliance on non-clean fuels limits women's time for educational, economic, and decision-making opportunities. Picchioni et al. (2020) highlighted that women in India and Nepal spend most of their time and energy on household chores such as cooking. The burden of using non-clean fuels often falls disproportionately on women and children, especially girls (IEA et al., 2023). The time and effort required to collect non-clean fuels and cook with inefficient technologies limits rural women's time to participate in other household decision-making processes. Additionally, rural women's physical health is more affected by indoor air pollution caused by the use of non-clean fuels (James et al., 2020; Nie et al., 2016; Okyere et al., 2024), directly impairing their ability to engage in household decision-making. Thus, addressing the use of non-clean fuels is an energy transition issue and a critical gender equality challenge.

Existing studies have highlighted the impact of rural households' fuel choices on women's contributions to household decision-making (e.g., Adom and Nsabimana, 2022; Atahau et al., 2021; Bera et al., 2024; Hermawati et al., 2023). For example, Nguyen and Su (2021) found that reduced energy poverty positively influences gender equality in education and socioeconomic rights. Hermawati et al. (2023) reported that the development of micro-hydropower in Indonesia increased the knowledge and skills of rural women, enabling them to occupy more significant roles in their families. A study by Bera et al. (2024) in India shows that micro solar domes enhanced women's participation in decision-making and improved their mobility, financial autonomy, and social activities.

Although the existing literature emphasizes the positive impact of switching from non-clean fuels to clean fuels on enhancing women's decision-making power within households, three potential research gaps still exist. First, current estimates predominantly consider complete clean energy transitions (i.e. switching from non-clean or mixed fuels to clean fuels). In reality, some rural households exhibit fuel-stacking behaviors, using clean and non-clean fuels simultaneously (i.e. users of mixed fuels) (Hou et al., 2022; Ma et al., 2022a). However, how incomplete energy transition (i.e. switching from non-clean to mixed fuels) affects gender empowerment has been neglected. Second, current studies focus solely on the impact of fuels used for cooking (Li et al., 2024; Mishra et al., 2024). The negative effects of non-clean fuel use in households would likely be even greater if the fuels for heating were also considered (Barrington-Leigh et al., 2019; Jaime et al., 2020). Third, non-clean fuel use may affect the decision-making powers of men and women differently, while this has not been explored in the literature. Previous studies assume that women are primarily responsible for fuel collection and cooking (Adom and Nsabimana, 2022); however, men also undertake these responsibilities in some rural areas. This indicates that non-clean fuel use also affects men's decision-making power.[1] These gaps highlight the need for a more nuanced understanding of fuel choices for cooking and heating and their implications for gender empowerment.

Accordingly, we extend the previous studies by evaluating the impact of fuel choices for cooking and heating on gender empowerment using rural household survey data from China. We focus on rural energy transition because rural residents face more challenges accessing clean fuels than urban residents in developing countries. Globally, in 2021, approximately 51 % of the rural population and 86 % of the urban population had access to clean cooking fuels and technologies, underscoring the critical need to prioritize rural energy transitions (IEA et al., 2023; Ma et al., 2022b). We utilize the multinomial endogenous switching regression (MESR) model to address the endogeneity issue related to rural households' fuel choices. Previous research has identified the endogeneity of rural households' fuel choices (Adom and Nsabimana, 2022; Liao et al., 2019), which must be addressed when estimating the impact of fuel choices for cooking and heating on gender empowerment.

This study makes four contributions. First, it examines rural households' fuel-stacking behaviors by classifying fuels into non-clean, clean, and mixed categories, considering incomplete (switching from non-clean to mixed fuels) and complete energy transitions (switching from non-clean to clean fuels). Maji et al. (2021) found that incomplete energy transitions adversely affect women's respiratory health, reinforcing gender inequality in India. Thus, it is crucial to consider both incomplete and complete energy transitions. Second, it simultaneously considers rural households' fuel choices for cooking and heating, which differs from existing studies that only focus on cooking fuel choices (Gupta and Pelli, 2021; Hou et al., 2022). Third, this study examines the effects of fuel choices for cooking and heating on men's and women's empowerment, precisely measured by men's and women's decision-making power scores. Fourth, we also consider the decision-making power gap between men and women as an outcome variable, enriching our understanding.

The rest of the paper is organized as follows: Section 2 presents the analytical framework. Section 3 outlines the empirical strategy. Section 4 introduces the data source and variable definitions and presents descriptive statistics. Section 5 discusses the empirical results. The final section provides the conclusion and policy implications.

2. Analytical framework

Collecting non-clean fuel for cooking and heating is a time-consuming activity. It is reported that rural Indian households spent 1–2 h per day collecting firewood (including travel time) and approximately three hours on cooking. Furthermore, indoor air pollution caused by non-clean fuel use adversely affects rural residents' mental and physical health (Imelda, 2020). A slow and incomplete transition to clean fuels means households continue to use non-clean fuels alongside clean fuels. Thus, an incomplete energy transition only partially reduces the negative impacts of non-clean fuels, resulting in limited benefits. A complete transition to clean fuels provides more benefits (Ma et al., 2022a; Maji et al., 2021).

Fig. 1 illustrates three potential pathways through which fuel choices for cooking and heating impact gender empowerment and the decision-making power gap. First, clean fuels are generally more efficient and easier to use than non-clean fuels (Totouom, 2024; Wijayarathne et al., 2023). Thus, transitioning from non-clean to clean fuels (complete energy transition) would significantly reduce the time burden, allowing rural residents more flexibility in time management and greater participation in household decision-making. Ding et al. (2014) found that biogas can save rural women up to 50 % of their daily cooking time in China. As a result, 91 % of these women used the savings to purchase clothes and cosmetics, and 3.1 % even enjoyed traveling. Second, using clean fuels improves rural residents' physical and mental health (Adhvaryu et al., 2023; Ma et al., 2022a; Zhang et al., 2017; Zhu et al., 2023). Clean fuels such as biogas produce fewer harmful emissions than non-clean fuels, improving respiratory and overall health (Imelda, 2020; Pillarisetti et al., 2022). With better health, rural residents can engage more effectively in income-generating activities, such as agricultural production or business operation, enhancing their economic contributions and decision-making power within the household. Third, transitioning from non-clean to clean fuels reduces the time and effort spent on fuel collection, cooking, and heating, allowing rural residents to dedicate more time to educational, economic, and social activities, thereby enhancing their capacity to participate in household decision-making. Nguyen and Su (2021) found that reducing energy poverty consistently contributes to reducing gender inequality in education by improving the ratio of women-to-men in school enrollment. These three pathways illustrate how transitioning to clean energy can empower

[1] For example, our data show that in 19.2 % of households, men and women have equal decision-making power. In 46.5 % of households, men hold more decision-making power, while in 34.3 % of households, women hold more decision-making power.

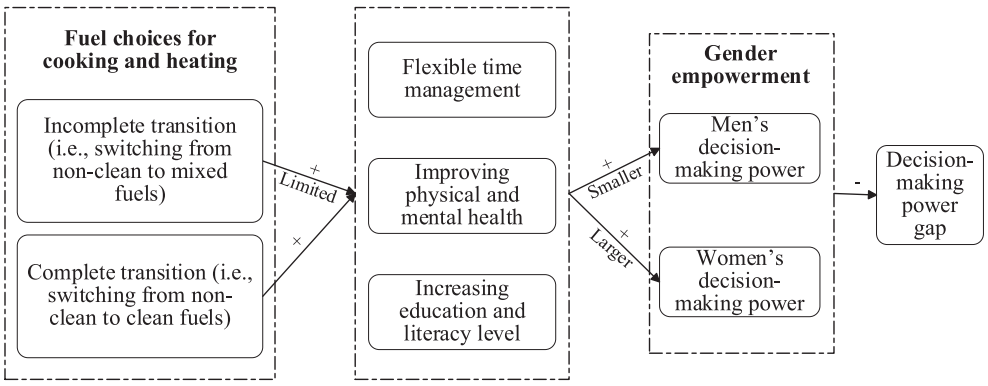

Fig. 1. Pathways of the impact of fuel choices for cooking and heating on gender empowerment.

rural residents.

Fuel choices for cooking and heating have differing empowerment effects on men and women. In many rural settings, women are primarily responsible for household tasks such as cooking and fuel collection (Picchioni et al., 2020), and they are expected to benefit more from energy transitions. Nguyen and Su (2021) found that reducing energy poverty increases female wage and salaried workers compared to their male counterparts. Women's empowerment in rural households is typically lower than men's (Abdurazzakova et al., 2024; Augsburg et al., 2023). Consequently, energy transitions have a greater impact on women's decision-making power than men's, ultimately narrowing the decision-making power gap between genders.

By considering incomplete and complete energy transitions for cooking and heating and their differential effects on men's and women's decision-making power, this study offers empirical insights into how rural energy transitions should be promoted to achieve gender equality and sustainable development in rural areas.

3. Empirical strategies

3.1. Endogeneity issue of fuel choices for cooking and heating

Observable characteristics (e.g., the age and gender of rural residents and family size) and unobservable characteristics (e.g., rural residents' energy preferences and motivations) tend to simultaneously determine rural households' fuel choice decisions (Adom and Nsabimana, 2022; Liao et al., 2019; Zhu et al., 2023). This indicates that rural households' fuel choices for cooking and heating are not randomly assigned, and the endogeneity issue of fuel choice variables should not be ignored when estimating the impact of fuel choices on gender empowerment. Besides, the endogeneity issue also potentially arises from reverse causality, as households with more gender empowerment might prefer clean fuel use (Abdurazzakova et al., 2024; Totouom, 2024).

Existing studies have employed various empirical strategies when treatment involves more than two options. For example, Ma et al. (2024) utilized a multivalued treatment effects (MVTE) model to estimate the impact of three types of farming strategies on the non-farm employment of rural women in China. Khonje et al. (2018) used the multinomial endogenous treatment effects (METE) model to analyze the impacts of multiple agricultural technologies on poverty in Zambia. Setsoafia et al. (2022) employed the multinomial endogenous switching regression (MESR) model to evaluate the effects of a set of sustainable agricultural practices on farm income and food security in Ghana. Theoretically, the MVTE, METE, and MESR models address the issue of selection bias. Among them, the MVTE method only accounts for bias arising from observed factors, whereas the METE and MESR approaches address both observed and unobserved heterogeneities by including instrumental variables in the estimations (Khonje et al., 2018; Tesfaye et al., 2021; Zhou and Ma, 2022). Additionally, the MESR model estimates the average treatment effects of different fuel types, generating comparative treatment effects of incomplete and complete energy transitions on gender empowerment. Thus, this study employs the MESR model.

3.2. MESR model

The MESR model estimation comprises two stages. The first stage employs a multinomial logit (MNL) model to estimate rural households' fuel choices for cooking and heating. The second stage specifies outcome equations for households using non-clean, mixed, and clean fuels, focusing on gender empowerment as the outcome variable. These outcome equations are estimated using the Ordinary Least Squares (OLS) method. The selectivity correction terms predicted from the first stage of the MNL model are included as regressors in the second stage. Following these two-stage estimations, the average treatment effects can be calculated.

3.2.1. First stage: Modeling rural households' decisions on fuel choices

The first stage posits that a rural household i selects one of three fuel types (non-clean, mixed, and clean fuels) within a random utility framework (Amankwah and Gwatidzo, 2024). Rural household i ($i = 1, 2, \ldots, N$) is assumed to be rational and risk-neutral and opts for fuel type j for cooking or heating if and only if the expected utility (U_{ij}) derived from fuel type j exceeds that (U_{ik}) obtained from alternative type k ($j \neq k$). In other words, rural household i's decision to use fuel type j is determined by the utility difference ($U_{ij}^{*} = U_{ij} - U_{ik} > 0$). The utility difference U_{ij}^{*} can be represented by a latent variable model:

$$U_{ij}^{*} = \beta_j X_i + \varepsilon_{ij}, where\ j = 1, 2, 3 \tag{1}$$

where the subscript j indicates the three fuel types. In this study, $j = 1$ for non-clean fuels, $j = 2$ for mixed fuels, and $j = 3$ for clean fuels, X_i refers to a vector of observed variables, β_j represents corresponding parameters, ε_{ij} is an error term that captures unobserved heterogeneities and is assumed to be identical and independently Gumbel distributed. Although the utility difference U_{ij}^{*} in Eq. (1) cannot be directly observed, the decision to use the j-th fuel type can be modeled as follows:

$$U_i = \begin{cases} 1, & if U_{i1}^{*} > max_{j \neq 1}\left(U_{ij}^{*}\right) \\ 2, & if U_{i2}^{*} > max_{j \neq 2}\left(U_{ij}^{*}\right) \\ 3, & if U_{i3}^{*} > max_{j \neq 3}\left(U_{ij}^{*}\right) \end{cases} \tag{2}$$

where U_i represents an index reflecting household i's fuel choices for cooking or heating. In this study, $U_i = 1$ for non-clean fuels, $U_i = 2$ for mixed fuels, and $U_i = 3$ for clean fuels. The MNL model can be employed to evaluate the probability that household i would use the j-th fuel type for cooking or heating:

$$P_{ij} = Pr(\tau_{ij} < 0|X_i) = \frac{exp(X_i\beta_j)}{\sum_{j=1}^{3} exp(X_i\beta_j)}, j = 1,2,3 \quad (3)$$

where $\tau_{ij} = max_{k\neq j}\left(U_{ik}^{*} - U_{ij}^{*}\right)$. P_{ij} represents the probability of choosing non-clean fuels ($j = 1$), mixed fuels ($j = 2$), and clean fuels ($j = 3$). Eq. (3) is estimated using the maximum likelihood approach.

3.2.2. Second stage: Modeling the impact of fuel choices on gender empowerment

The second stage estimates the impact of rural households' fuel choices for cooking and heating on gender empowerment indicators (i.e. men's decision-making power, women's decision-making power, and decision-making power gap). The outcome equations are specified separately for rural households using non-clean, mixed, and clean fuels. The outcome equations for each potential regime j are:

$$\begin{cases} Regime\ 1\ (non-clean\ fuel): E_{i1} = \theta_1 Z_i + \nu_{i1}\ if U_i = 1 \\ Regime\ 2\ (mixed\ fuel): E_{i2} = \theta_2 Z_i + \nu_{i2}\ if U_i = 2 \\ Regime\ 3\ (clean\ fuel): E_{i3} = \theta_3 Z_i + \nu_{i3}\ if U_i = 3 \end{cases} \quad (4)$$

where E_{ij} $(j = 1,2,3)$ is the household i's gender empowerment indicators in regime j, $\theta_j (j = 1,2,3)$ refers to the unknown parameters, Z_i represents control variables, $\nu_{ij} (j = 1,2,3)$ refers to error terms. Eq. (4) only addresses the bias from observed heterogeneities (i.e., Z_i). However, rural households' fuel choices for cooking and heating depend on observable and unobservable factors (Adom and Nsabimana, 2022). To account for the bias from unobservable factors, the second stage of the MESR model includes the selectivity correction terms $\widehat{\lambda}_j$ $(j = 1,2,3)$ as additional regressors:

$$\begin{cases} Regime\ 1\ (non-clean\ fuel): E_{i1} = \theta_1 Z_i + \gamma_1\widehat{\lambda}_{1i} + \nu_{i1}\ if U_i = 1 \\ Regime\ 2\ (mixed\ fuel): E_{i2} = \theta_2 Z_i + \gamma_2\widehat{\lambda}_{2i} + \nu_{i2}\ if U_i = 2 \\ Regime\ 3\ (clean\ fuel): E_{i3} = \theta_3 Z_i + \gamma_3\widehat{\lambda}_{3i} + \nu_{i3}\ if U_i = 3 \end{cases} \quad (5)$$

where $\widehat{\lambda}_{ji} = \sum_{m\neq j}^{j} \rho_j \left[\frac{\widehat{p}_{mi} ln(\widehat{p}_{mi})}{1-\widehat{p}_{mi}} + ln\left(\widehat{p}_{ij}\right)\right]$ $(j = 1,2,3)$ is a vector of selectivity correction terms and ρ_j refers to the correlation coefficient between error terms ε_{ij} and $\mu_{ij} (j = 1,2,3)$, γ_j $(j = 1,2,3)$ represents unknown parameters. For each regime, $\widehat{\lambda}_{ji}$ includes only two selectivity correction terms, excluding the one for the alternative fuel type. Eq. (5) is estimated using the Ordinary Least Squares (OLS) method, and the standard errors are bootstrapped 100 times to address the heteroscedasticity from the generated regressors because of the two-stage estimation procedures.

3.2.3. Estimation of the treatment effects

The average treatment effects on the treated (ATT) can be estimated after the two-stage estimations. The expected values of outcome variables can be calculated in actual and counterfactual scenarios. For example, the expected outcomes for households using mixed and clean fuels in an observed scenario (actual) are:

$$E\left(E_{ij}|U = j, X, \widehat{\lambda}_{Ji}\right) = \theta_j Z_i + \gamma_j\widehat{\lambda}_{ji}, j = 2,3 \quad (6a)$$

The expected outcomes for households using mixed and clean fuels under the counterfactual scenario where they did not adopt these fuels are as follows:

$$E(E_{i1}|U = j, X, \widehat{\lambda}_{Ji}) = \theta_1 Z_i + \gamma_1\widehat{\lambda}_{ji}, j = 2,3 \quad (6b)$$

Eq. (6b) means that the coefficients on their characteristics (Z_i) had been the same as the coefficients on the characteristics of the scenario if they had not been using this fuel type. The ATT can be calculated by taking the difference between Eqs. (6a) and (6b):

$$ATT = E\left(E_{ij}|U = j, X, \widehat{\lambda}_{Ji}\right) - E(E_{i1}|U = j, X, \widehat{\lambda}_{Ji})$$

$$= (\theta_j - \theta_1)Z_i + \left(\gamma_j - \gamma_1\right)\widehat{\lambda}_{ji}, j = 2,3 \quad (7)$$

3.2.4. Identification of the instrumental variable

To identify Eq. (5) and calculate the ATTs, at least one instrumental variable (IV) is to be included in X_i in Eq. (1) but not in Z_i in Eq. (5). The selected IVs are expected to influence rural households' fuel choices but are not correlated with outcome variables directly. We use two variables as the IVs: IV1 refers to the household head's perception of the extent to which using non-clean fuels for heating would pollute the environment. They were presented with five options: 1 = pollution is very little, 2 = pollution is little, 3 = fair, 4 = pollution is significant, and 5 = pollution is very significant. Farmers' perceptions of potential environmental pollution directly influence their fuel choices for cooking and heating (Chattopadhyay et al., 2021; Li et al., 2021). For example, Chattopadhyay et al. (2021) found that subjective probabilistic expectations of becoming sick from dirty fuel usage significantly reduce the fraction of days of dirty fuel usage in households in India. However, it does not directly affect gender empowerment.

The IV2 is the distance from the living village to the nearest enterprise where employment opportunities are available. The establishment and operation of enterprises rely on local infrastructure, including pipelines for clean energy such as gas. Therefore, proximity to enterprises indicates higher accessibility to clean energy for rural households (Liao and Liu, 2024; Okyere et al., 2024). For example, Okyere et al. (2024) emphasized that infrastructure (i.e., roads and internet) is vital in switching from firewood to gas/electricity in Ghana. However, directly linking enterprise development in a region to the gender empowerment of individual rural households is challenging.

4. Data, variables, and descriptive statistics

4.1. Data source

The data for this study come from a rural household survey conducted in China between January and February 2022. We used a stratified random sampling method, beginning with the purposive selection of five provinces: Jiangsu, Henan, Hubei, Hunan, and Sichuan. We randomly selected 8–10 counties from each selected province to ensure geographical diversity. Next, we randomly chose 1–2 villages from each selected county to represent rural populations within each county. Finally, we selected approximately ten households from each village to participate in the survey. For the survey, we selected either the woman or her husband, identified as the household's primary decision-maker, to ensure that our data accurately captured the dynamics of decision-making related to fuel use and its impact on gender empowerment. Focusing on the primary decision-maker allows us to understand better how fuel choices influence household power structures and gender roles. In cases where multiple generations lived together, we identified the couple responsible for household decisions, thus eliminating generational influence. This approach ensured that we focused on households with a clear decision-making structure, excluding unmarried, divorced, or widowed respondents. Additionally, we removed respondents with missing or extreme values in critical variables to ensure data quality. The final data consists of 997 households.

We focus on rural households' fuel choices and their impact on gender empowerment. To this end, the questionnaire includes modules on household fuel consumption and gender empowerment. We asked respondents about the main fuel types used for cooking and heating. These questions were structured as multiple-choice and included standard non-clean fuels such as crop straw, firewood, and coal and clean fuels such as liquid gas, natural gas, electricity, methane, and solar energy in rural China. Gender empowerment within households was

measured using nine indicators across five domains, adapted from Alkire et al. (2013), with necessary adjustments. Zheng et al. (2023) discussed the adjustments. Additionally, the questionnaire collected data on respondents' characteristics and household-level and socioeconomic characteristics to provide a comprehensive understanding.

4.2. Variable definitions

4.2.1. Gendered decision-making power

The outcome variable in this study is gender empowerment, measured by men's decision-making power and women's decision-making power. Men's and women's decision-making power (E_{ig}) are quantified as weighted scores based on nine indicators across five domains (i.e., production, resources, income, leadership, and time). This can be expressed as:

$$E_{ig} = \sum_{q=1}^{9} Indicator_{iqg} * Weight_{iqg} \quad (8)$$

where the subscript g denotes gender, indicating male when $g = 1$ and female when g=0; $Indicator_{iqg}$ and $Weight_{iqg}$ represent the variables included in the decision-making power calculation and their weights. Details of the variables, domains, and weights are provided in Table A1 of the Appendix. Each domain is assigned a weight of 2/10, with individual scores ranging from 0 to 0.20. Summing the scores of all domains yields men's and women's decision-making power scores that range from 0 to 1, where a higher score signifies greater gender empowerment.

4.2.2. Decision-making power gap

In addition, we define a new variable, the decision-making power gap, to capture the difference between men's and women's decision-making power (Zheng et al., 2023). This variable is calculated as the absolute difference between the decision-making power scores of men and women within the household.

$$Gap_i = \left| E_{ig=1} - E_{ig=0} \right| \quad (9)$$

where Gap_i refers to the decision-making power gap between men and women.

4.2.3. Treatment variable

The treatment variable refers to rural households' fuel choices for cooking and heating. We examine these households' fuel-stacking behaviors by categorizing the fuels into three types: non-clean (crop straw, firewood, and coal), clean (including liquid gas, natural gas, electricity, methane, and solar energy), and mixed (combines one or more clean fuels with one or more non-clean fuels) fuels. This classification allows us to investigate incomplete energy transitions (from non-clean to mixed fuels) and complete energy transitions (from non-clean to clean fuels).

4.3. Descriptive statistics

Table 1 presents the descriptive statistics for the outcome and treatment variables. The mean values of men's and women's decision-making power scores are 0.60 and 0.55, respectively, indicating that, on average, men have greater decision-making power than women in the sampled households. However, this trend does not hold for all households. The average absolute difference between men's and women's decision-making power scores is 0.28.

Rural households' fuel choices for cooking and heating exhibit heterogeneity. For cooking fuel choices of the sampled households, 14 % use non-clean fuels only, 52 % use clean fuels only, and 34 % use mixed fuels. In comparison, for heating, 26 % of households use non-clean fuels only, 48 % use clean fuels only, and the remaining 26 % use mixed fuels. The proportion of households using clean fuels for cooking is higher than heating, potentially because cooking is a daily necessity, whereas heating is primarily required during winter. The data indicates that the average annual expenditure on cooking fuel for the sampled households is 1117.55 yuan (approximately 154.36 USD), whereas the expenditure on heating fuel is only 607.98 yuan (approximately 83.98 USD).

Table 1
Definitions and descriptive statistics of the dependent and treatment variables.

Variable	Definitions	Mean	S.D.
Dependent variables			
Men's decision-making power	Men's decision-making power is calculated based on Eq. (8)	0.60	0.22
Women's decision-making power	Women's decision-making power is calculated based on Eq. (8)	0.55	0.23
Decision-making power gap	The absolute difference between men's and women's decision-making power score	0.28	0.23
Treatment variable			
Fuels for cooking			
Non-clean fuels for cooking	1 = Household uses one or more non-clean fuels (e.g., crop straw, firewood, and coal) for cooking; 0 = otherwise	0.14	0.35
Clean fuels for cooking	1 = Household uses one or more clean fuels from available options (e.g., liquid gas, natural gas, electricity, methane, and solar energy) for cooking; 0 = otherwise	0.52	0.50
Mixed fuels for cooking	1 = Household combines one or more clean fuels with one or more non-clean fuels for cooking; 0 = otherwise	0.34	0.47
Cooking fuel choices	1 = Non-clean fuels for cooking; 2 = Mixed fuels for cooking; 3 = Clean fuels for cooking	2.38	0.72
Fuels for heating			
Non-clean fuels for heating	1 = Household uses one or more non-clean fuels from available options for heating; 0 = otherwise	0.26	0.44
Clean fuels for heating	1 = Household uses one or more clean fuels from available options for heating; 0 = otherwise	0.48	0.50
Mixed fuels for heating	1 = Household combines one or more clean fuels with one or more non-clean fuels for heating; 0 = otherwise	0.26	0.44
Heating fuel choices	1 = Non-clean fuels for heating; 2 = Mixed fuels for heating; 3 = Clean fuels for heating	2.22	0.83
Observations		997	

Note: S.D. refers to standard deviations.

The definitions and descriptive statistics of the control variables are reported in Table 2. The average age of household heads is 52 years, with 63 % male. On average, household heads have received 7.7 years of education and are generally considered healthy. Regarding household-level characteristics, the average household size is four members, with an average of 5.88 mu of cultivated land. Additionally, 46 % of households own a car.

Table 3 reports the mean differences in the outcome and control variables by fuel type. The *F*-statistics and their corresponding significance levels test whether the means of the variables differ across the fuel types. Men's decision-making power and decision-making power gap do not show significant statistical differences among households using the three fuel types for cooking or heating. In comparison, women's decision-making power displays significant statistical differences across the three fuel choices for cooking and heating. As rural households transition their cooking fuel choices from non-clean to mixed to clean fuels, women's decision-making power scores increase from 0.49 to 0.53 to 0.58, respectively. Similarly, as rural households transition their heating fuel choices from non-clean to mixed to clean fuels, women's decision-making power scores rise from 0.51 to 0.54 to 0.58, respectively. Therefore, the rural energy transition towards clean fuels appears to be positively correlated with women's, but not men's, decision-making power.

Table 3 also reveals systematic differences among the characteristics

Table 2
Definitions and descriptive statistics of control and instrumental variables.

Variable	Definitions	Mean	S.D.
Control variables			
Age	Age of household head (years)	52.33	11.80
Gender	1 = Male; 0 = female	0.63	0.48
Education	Educational level of household head (years)	7.68	3.74
Health status	Self-reported health status of household head: 1 = very unhealthy, 2 = unhealthy, 3 = average, 4 = healthy, 5 = very healthy	4.03	1.02
Household size	Number of household members (persons)	4.41	1.46
Land size	Total land size for agricultural production (mu)[a]	5.88	18.74
Car ownership	1 = Owned car(s); 0 = otherwise	0.46	0.50
Road condition	1 = Household reported that the road condition from the living village to the nearest transportation station is good; 0 = otherwise	0.76	0.43
Jiangsu	1 = Located in Jiangsu province; 0 = otherwise	0.12	0.33
Henan	1 = Located in Henan province; 0 = otherwise	0.17	0.38
Hubei	1 = Located in Hubei province; 0 = otherwise	0.23	0.42
Hunan	1 = Located in Hunan province; 0 = otherwise	0.26	0.44
Sichuan	1 = Located in Sichuan province; 0 = otherwise	0.22	0.41
Instrumental variables			
IV1	Household head's perception of the extent to which using non-clean fuels for heating would pollute the environment: 1 = pollution is very little, 2 = pollution is little, 3 = fair, 4 = pollution is significant, and 5 = pollution is very significant	3.09	1.27
IV2	Distance from the living village to the nearest enterprise where employment opportunities are available (Kilometers)	9.22	13.39
Observations		997	

Note: S.D. refers to standard deviations.
[a] 1 mu = 1/15 ha.

of the sampled households, evident in nearly all selected control variables. For example, as rural households transition their cooking fuel choices from non-clean to mixed to clean fuels, the household head's education level increases monotonically from 6.56 to 7.04 to 8.40 years. Similarly, as rural households transition their heating fuel choices from non-clean to mixed to clean fuels, the household head's education level rises from 6.11 to 8.18 to 8.26 years. The systematic differences highlight the necessity of employing econometric approaches such as the MESR model to estimate the relationship between rural households' fuel choices for cooking and heating and gender empowerment.

5. Empirical results and discussions

5.1. Determinants of fuel choices for cooking and heating

This section presents the determinants of rural households' fuel choices for cooking and heating and their implications for gender empowerment. Only the marginal effects from the MNL model are shown in Table 4 to facilitate interpretation (Khonje et al., 2018). The full estimations of the corresponding coefficients can be found in Table A2 in the Appendix.

The marginal effects of the age variable indicate that each additional year of household heads' age increases the likelihood of using non-clean fuels for cooking by 0.2 % and decreases the possibility of using mixed fuels for cooking by 0.3 %. This finding suggests that older household heads are less inclined to transition energy. Similarly, the study by Wijayarathne et al. (2023) found that the age of the household head is negatively associated with the probability of selecting clean fuels in Sri Lanka. These findings highlight the need for targeted policies to encourage older households to adopt clean energy solutions, such as tailored subsidies or awareness campaigns that address generational preferences and barriers to clean energy adoption. Male-headed households are 4 % less likely to use non-clean fuels for cooking, 8.5 % more likely to use mixed fuels for cooking, and 4.7 % less likely to use mixed fuels for heating than female-headed households. These findings suggest a potential area for gender-focused energy policies to ensure equitable access to clean energy solutions. The significance of the education variable indicates that every additional year of education for the household heads decreases the use of mixed fuels for cooking by 2.2 %, increases the use of clean fuels for cooking by 2.2 %, and reduces the use of non-clean fuels for heating by 2 % while increasing the use of mixed fuels for heating by 1.2 %. These results suggest that households with better-educated heads are more inclined towards a complete energy transition for cooking and an incomplete transition for heating, underscoring the importance of investing in educational initiatives as a long-term strategy to promote clean energy adoption and support energy transition policies. Our finding aligns with Okyere et al. (2024), showing that better-educated households are more likely to use cooking gas/electricity over firewood in Ghana.

The significant and negative marginal effects of the household size variable suggest that an increase in household size by one person reduces the use of clean fuels for cooking and heating by 1.8 % and 1.9 %,

Table 3
Mean differences in the selected variables by the fuel choices.

	Cooking fuel choices				*Heating fuel choices*			
Variables	Non-clean fuels	Mixed fuels	Clean fuels	*F*-statistics	Non-clean fuels	Mixed fuels	Clean fuels	*F*-statistics
Men's decision-making power	0.59 (0.20)	0.62 (0.20)	0.59 (0.23)	1.28	0.58 (0.21)	0.62 (0.20)	0.60 (0.24)	1.93
Women's decision-making power	0.49 (0.26)	0.53 (0.21)	0.58 (0.23)	10.96***	0.51 (0.24)	0.54 (0.23)	0.58 (0.22)	9.85***
Decision-making power gap	0.29 (0.25)	0.26 (0.21)	0.28 (0.24)	0.94	0.29 (0.25)	0.27 (0.22)	0.27 (0.23)	0.41
Age	55.40 (11.81)	52.42 (11.88)	51.44 (11.62)	6.28***	55.13 (12.35)	51.34 (10.15)	51.34 (12.10)	10.06***
Gender	0.55 (0.50)	0.67 (0.47)	0.63 (0.48)	3.14**	0.64 (0.48)	0.61 (0.49)	0.64 (0.48)	0.54
Education	6.56 (4.00)	7.04 (3.54)	8.40 (3.65)	21.71***	6.11 (3.96)	8.18 (3.06)	8.26 (3.72)	32.90***
Health status	3.83 (1.18)	3.98 (1.05)	4.11 (0.95)	4.40**	3.86 (1.19)	3.99 (0.98)	4.13 (0.93)	6.26***
Household size	4.21 (1.54)	4.48 (1.53)	4.43 (1.37)	1.73	4.27 (1.60)	4.49 (1.41)	4.45 (1.39)	1.68
Land size	3.62 (3.41)	5.05 (5.95)	7.03 (25.44)	2.33*	5.32 (7.07)	4.15 (5.89)	7.13 (26.18)	2.30
Car ownership	0.24 (0.43)	0.41 (0.49)	0.55 (0.50)	24.09***	0.28 (0.45)	0.45 (0.50)	0.56 (0.50)	27.06***
Road condition	0.63 (0.48)	0.73 (0.44)	0.82 (0.39)	12.05***	0.67 (0.47)	0.72 (0.45)	0.84 (0.37)	15.48***
Jiangsu	0.03 (0.17)	0.11 (0.31)	0.16 (0.37)	9.36***	0.04 (0.19)	0.03 (0.17)	0.22 (0.41)	42.19***
Henan	0.12 (0.33)	0.20 (0.40)	0.17 (0.38)	1.96	0.12 (0.33)	0.13 (0.34)	0.22 (0.42)	8.04***
Hubei	0.42 (0.50)	0.20 (0.40)	0.19 (0.40)	18.15***	0.44 (0.50)	0.24 (0.43)	0.11 (0.31)	58.20***
Hunan	0.12 (0.32)	0.32 (0.47)	0.26 (0.44)	11.31***	0.17 (0.38)	0.43 (0.50)	0.22 (0.41)	27.86***
Sichuan	0.31 (0.46)	0.17 (0.38)	0.22 (0.41)	5.45***	0.22 (0.42)	0.17 (0.38)	0.23 (0.42)	1.91
IV1	2.55 (1.24)	2.86 (1.18)	3.39 (1.25)	35.55***	2.56 (1.24)	2.88 (1.16)	3.49 (1.21)	55.84***
IV2	13.19 (17.55)	9.40 (13.41)	8.04 (11.81)	8.25***	13.06 (17.65)	9.27 (12.46)	7.12 (10.44)	17.07***
Observations	139	340	518		259	261	477	

Note: Standard deviations are presented in parentheses; * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$; *F*-statistics show the tests for mean differences across fuel choices.

Table 4
Determinants of fuel choices: Marginal effects of the MNL estimates.

	Cooking fuel choices			*Heating fuel choices*		
Variables	Non-clean fuels	Mixed fuels	Clean fuels	Non-clean fuels	Mixed fuels	Clean fuels
Age	0.002 (0.001)**	−0.003 (0.002)*	0.001 (0.002)	0.001 (0.001)	0.001 (0.001)	−0.002 (0.001)
Gender	−0.040 (0.020)*	0.085 (0.031)***	−0.045 (0.031)	0.039 (0.025)	−0.047 (0.028)*	0.008 (0.028)
Education	−0.000 (0.003)	−0.022 (0.005)***	0.022 (0.005)***	−0.020 (0.004)***	0.012 (0.004)***	0.008 (0.005)
Health status	−0.010 (0.010)	0.010 (0.015)	0.000 (0.015)	0.001 (0.012)	0.002 (0.014)	−0.003 (0.014)
Household size	0.005 (0.007)	0.013 (0.011)	−0.018 (0.010)*	0.010 (0.009)	0.009 (0.010)	−0.019 (0.010)**
Land size	−0.004 (0.001)***	0.000 (0.001)	0.004 (0.001)***	−0.001 (0.001)	−0.002 (0.001)	0.003 (0.001)**
Car ownership	−0.097 (0.024)***	−0.045 (0.031)	0.142 (0.031)***	−0.124 (0.026)***	−0.022 (0.028)	0.146 (0.029)***
Road condition	−0.091 (0.021)***	−0.041 (0.035)	0.132 (0.035)***	−0.123 (0.027)***	−0.047 (0.031)	0.170 (0.031)***
Jiangsu	−0.145 (0.055)***	0.143 (0.058)**	0.002 (0.060)	−0.038 (0.066)	−0.155 (0.076)**	0.193 (0.058)***
Henan	−0.063 (0.031)**	0.128 (0.047)***	−0.065 (0.047)	−0.040 (0.039)	0.004 (0.046)	0.035 (0.044)
Hubei	0.050 (0.024)**	0.045 (0.045)	−0.096 (0.045)**	0.198 (0.033)***	0.102 (0.040)**	−0.300 (0.041)***
Hunan	−0.142 (0.032)***	0.170 (0.043)***	−0.028 (0.044)	−0.061 (0.036)*	0.175 (0.036)***	−0.114 (0.038)***
IV1	−0.034 (0.008)***	−0.049 (0.011)***	0.082 (0.011)***	−0.060 (0.009)***	−0.022 (0.010)**	0.082 (0.010)***
IV2	0.002 (0.001)***	−0.000 (0.001)	−0.002 (0.001)	0.004 (0.001)***	−0.001 (0.001)	−0.003 (0.001)***
Observations		997			997	

Note: Robust standard errors are presented in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$; The reference province is Sichuan.

respectively. Zhu et al. (2023) reported similar findings in their study on the relationship between household size and clean energy use for cooking in China. Larger households typically consume more fuel, making clean fuels often more expensive and less affordable. Each additional unit of cultivated land reduces the use of non-clean fuels for cooking by 0.4 % and increases the use of clean fuels for cooking and heating by 0.4 % and 0.3 %, respectively. Similarly, Gupta and Pelli (2021) found that total land owned is positively associated with liquefied petroleum gas use and negatively associated with fuelwood use in rural India. Larger farms generally produce more agricultural output, which can translate into higher household income. This increased financial capacity makes it more feasible to use clean fuels for cooking and heating. Households with a car are 9.7 % and 12.4 % less likely to use non-clean fuels for cooking and heating, respectively, and 14.2 % and 14.6 % more likely to use clean fuels for cooking and heating compared to those without a car. Car ownership is often an indicator of higher household income. This finding highlights the role of household wealth in enabling clean energy transitions, suggesting that financial support mechanisms such as subsidies or microloans could help lower-income households adopt clean fuel technologies. Martey et al. (2022) found similar results in Ghana, where household assets were positively associated with liquefied petroleum gas use and negatively associated with fuelwood use.

The marginal effects of instrumental variables align with expectations. Greater perceived pollution from non-clean fuels reduces their use for cooking and heating by 3.4 % and 6 %, respectively, decreases mixed fuels usage by 4.9 % and 2.2 %, and increases clean fuels usage by 8.2 %. Households that perceive higher pollution levels from non-clean fuels are more likely to be aware of the associated health risks, such as respiratory problems. This awareness drives the adoption of cleaner fuels. This indicates that the perception of pollution plays a crucial role in promoting a complete energy transition (Ma et al., 2022b). Each additional kilometer to the nearest enterprise increases the use of non-clean fuels for cooking and heating by 2 % and 4 %, respectively, and reduces the use of clean fuels for heating by 3 %. This observation underscores the importance of improving infrastructure and lowering barriers to clean fuel accessibility in remote areas (Okyere et al., 2024).

5.2. Treatment effects of fuel choices on gender empowerment

This section presents the treatment effects of fuel choices for cooking and heating on gender empowerment, identifying how these choices influence decision-making power within households. Before introducing the MESR-estimated treatment effects, it is essential to clarify that our main objective in estimating the MESR model is to calculate the treatment effects of fuel choices for cooking and heating on gender empowerment rather than implicitly interpreting the results to investigate the factors influencing gender empowerment. Therefore, we report the results of the second-stage estimations of the MESR model (see Eq. (5)) in Tables A3–A6 in the Appendix to maintain simplicity. It should be noted that the results in Tables A3–A6 show that the parameters (λ_1, λ_2,λ_3) are statistically significant. This indicates that common unobservable factors influence rural households' fuel choice decisions and gender empowerment, confirming the effectiveness of using the MESR model to control unobserved heterogeneity (Khonje et al., 2018).

Table 5 presents the MESR-based average treatment effects of fuel choices for cooking and heating on gender empowerment. The upper part of Table 5 presents the results estimating the treatment effects of fuel choices on men's decision-making power. It shows that incomplete (switching from non-clean to mixed fuels) and complete energy transitions (switching from non-clean to clean fuels) for cooking do not significantly affect men's decision-making power. However, incomplete and complete energy transitions for heating significantly enhance men's decision-making power, increasing the decision-making power scores by 12.9 % and 4.9 %, respectively. The lower part of Table 5 presents the results estimating the treatment effects of fuel choices on women's decision-making power. The results reveal that incomplete and complete energy transitions for cooking significantly enhance women's decision-making power scores by 5.8 % and 20.5 %, respectively. Furthermore, a complete energy transition for heating substantially enhances women's decision-making power score by 25.2 %, while an incomplete energy transition for heating has no significant impact.

Table 5 reveals that incomplete and complete transitions for cooking and heating affect men's and women's decision-making power differently. First, energy transitions influence women's decision-making power more than men's. Both types of energy transitions for cooking and heating significantly affect women's decision-making power, whereas men's decision-making power is only affected by energy transitions for heating. Second, complete energy transitions for cooking and heating have a greater impact on women's decision-making power than incomplete energy transitions. This provides new empirical evidence from the perspective of complete energy transitions. While existing research has confirmed the impact of clean fuel use on women's empowerment (Adom and Nsabimana, 2022; Atahau et al., 2021; Ding et al., 2014), our study emphasizes that complete, rather than incomplete, transitions towards clean energy have a more substantial effect on women's empowerment.

5.3. Treatment effects of fuel choices on decision-making gap

This section highlights whether promoting energy transitions can effectively reduce gender disparities in household decision-making

Table 5
Treatment effects of fuel choices on decision-making power: MESR estimates.

Outcome variable	Fuel choice	Mean outcomes			Change (%)
		Actual	Counterfactual	ATT	
Men's decision-making power	***Cooking fuel choices***				
	Mixed fuels vs. non-clean fuels [a]	0.616 (0.040)	0.618 (0.111)	−0.003 (0.108)	−0.5
	Clean fuels vs. non-clean fuels [b]	0.594 (0.079)	0.602 (0.201)	−0.008 (0.224)	−1.3
	Heating fuel choices				
	Mixed fuels vs. non-clean fuels	0.621 (0.071)	0.550 (0.082)	0.071 (0.112)***	12.9
	Clean fuels vs. non-clean fuels	0.599 (0.075)	0.571 (0.107)	0.028 (0.095)***	4.9
Women's decision-making power	***Cooking fuel choices***				
	Mixed fuels vs. non-clean fuels	0.527 (0.064)	0.498 (0.148)	0.029 (0.111)***	5.8
	Clean fuels vs. non-clean fuels	0.581 (0.068)	0.482 (0.393)	0.099 (0.360)***	20.5
	Heating fuel choices				
	Mixed fuels vs. non-clean fuels	0.535 (0.084)	0.526 (0.105)	0.010 (0.111)	1.9
	Clean fuels vs. non-clean fuels	0.582 (0.060)	0.464 (0.195)	0.117 (0.172)***	25.2

Note: Standard deviations are presented in parentheses; *** $p < 0.01$; ATT refers to average treatment effects on the treated.

[a] Switching from non-clean to mixed fuels indicates an incomplete energy transition;

[b] Switching from non-clean fuels to clean fuels indicates a complete energy transition.

power, thus supporting broader gender empowerment goals. From a gender equality perspective, exploring how incomplete and complete energy transitions influence the decision-making gap between men and women is interesting. Therefore, we estimated the treatment effects of fuel choices on the decision-making gap between men and women and presented the results in Table 6.[2]

The results in Table 6 reveal that an incomplete transition for cooking and heating reduces the decision-making power gap by 6.4 % and 17.2 %, respectively. A complete energy transition for cooking and heating reduces the decision-making power gap by 11.4 % and 21.9 %, respectively. The finding that a complete energy transition for heating reduces the decision-making power gap by 21.9 % emphasizes that clean energy initiatives extend beyond environmental benefits; they also play

[2] The corresponding second-stage estimations of the MESR model are detailed in Tables A7 and A8 in the Appendix.

Table 6
Treatment effects of fuel choices on decision-making power gap: MESR estimates.

Outcome variable	Fuel choice	Mean outcomes			Change (%)
		Actual	Counterfactual	ATT	
Decision-making power gap	***Cooking fuel choices***				
	Mixed fuels vs. non-clean fuels [a]	0.264 (0.066)	0.282 (0.130)	−0.018 (0.129)**	−6.4
	Clean fuels vs. non-clean fuels [b]	0.279 (0.056)	0.316 (0.287)	−0.036 (0.278)***	−11.4
	Heating fuel choices				
	Mixed fuels vs. non-clean fuels	0.269 (0.060)	0.325 (0.082)	−0.056 (0.094)***	−17.2
	Clean fuels vs. non-clean fuels	0.274 (0.064)	0.351 (0.083)	−0.077 (0.086)***	−21.9

Note: Standard deviations are presented in parentheses; ** $p < 0.05$ and *** $p < 0.01$; ATT refers to average treatment effects on the treated.

[a] Switching from non-clean to mixed fuels indicates an incomplete energy transition;

[b] Switching from non-clean fuels to clean fuels indicates a complete energy transition.

a crucial role in promoting gender equality by empowering women in household decision-making. We further illustrate the kernel density distribution of predicted decision-making power gap by fuel choices in Figs. 2 and 3. It shows that the kernel density of mixed and clean fuels for cooking and heating lies to the left compared to non-clean fuel. This aligns with expectations, as non-clean fuels require more time and effort to gather and manage, and women typically undertake these tasks. The additional burden reduces the time and energy devoted to other empowering activities. In contrast, clean fuels are easier and quicker to use, freeing time and reducing the physical strain on women, contributing more significantly to narrowing the gender empowerment gap.

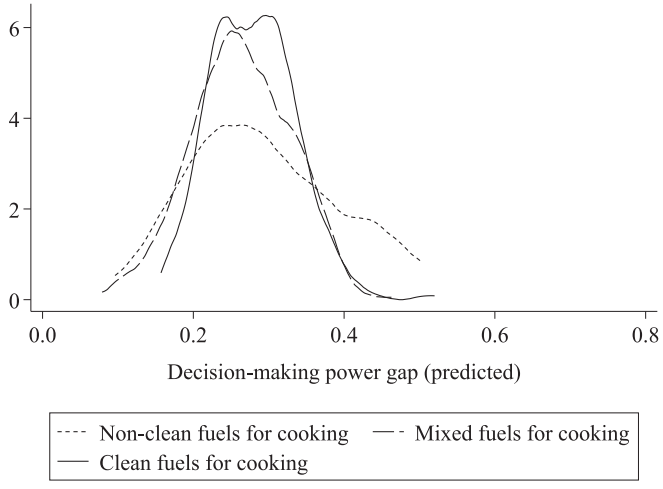

Fig. 2. Kernel density distribution of decision-making power gap by cooking fuel choices.

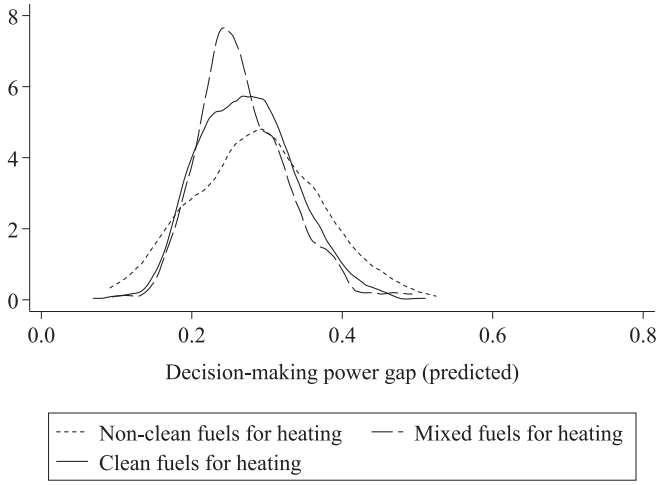

Fig. 3. Kernel density distribution of decision-making power gap by heating fuel choices.

6. Conclusion and implications

This study investigates the impacts of rural households' fuel choices for cooking and heating on gender empowerment. The fuel choices are categorized into three types: non-clean fuels only, clean fuels only, and mixed fuels. Accordingly, rural energy transitions are classified as incomplete (transitioning from non-clean to mixed fuels) or complete (transitioning from non-clean to clean fuels). Gender empowerment is measured by men's and women's decision-making power. The MESR model addresses the endogeneity issues associated with fuel-stacking behaviors and estimates data collected from rural households in China. Additionally, the study examines the link between rural energy transitions and the gender empowerment gap.

Our analysis reveals a positive correlation between energy transitions for cooking and heating and gender empowerment in rural households, with varying effects on men's and women's decision-making power depending on whether the transition is incomplete or complete. The findings provide valuable policy implications for achieving sustainable development and gender equality.

First, we found that incomplete and complete energy transitions for cooking do not significantly affect men's decision-making power, while heating transitions increase it by 12.9 % and 4.9 %, respectively. For women, incomplete and complete cooking fuel transitions raise decision-making power by 5.8 % and 20.5 %, respectively, and a complete heating transition boosts it by 25.2 %. In contrast, an incomplete heating fuel transition has no significant effect. These findings imply that energy transitions in cooking have a greater impact on empowering women, enhancing their role in household decision-making. Given these implications, policymakers should prioritize complete energy transitions by increasing subsidies for clean energy technologies, reducing tariffs on clean energy appliances, and investing in infrastructure to ensure availability and reliability. This approach can help create an environment where women and men benefit from energy transitions, focusing on empowering women in household dynamics. Moreover, an integrated approach addressing both cooking and heating needs is essential. Comprehensive policies should promote clean fuels by distributing combined cooking and heating appliances and initiating community-based clean energy projects to facilitate accessibility for rural households.

Additionally, we found that incomplete energy transitions for cooking and heating reduce the decision-making power gap by 6.4 % and 17.2 %, respectively. In contrast, complete energy transitions for cooking and heating have a more substantial effect, reducing the decision-making power gap by 11.4 % and 21.9 %, respectively. These results suggest that comprehensive energy transitions are critical for advancing gender equity in household decision-making, especially in rural areas. To support this, governments should implement gender-sensitive programs to promote clean energy adoption, including targeted financial incentives and micro-loans for women. Such measures will ensure that women benefit from energy transitions, helping bridge the gender gap in household decision-making power.

Ethics statement

Not applicable.

CRediT authorship contribution statement

Hongyun Zheng: Writing – original draft, Software, Investigation, Formal analysis, Conceptualization. **Wanglin Ma:** Writing – review & editing, Supervision, Methodology. **Dil Bahadur Rahut:** Writing – review & editing.

Declaration of competing interest

There is no conflict of interest.

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Appendix A. Appendix

Table A1
Definitions and weights of indicators that measure decision-making power.

Domain	Indicator	Definition	Weight
Production	Agricultural input decisions	1 if individual had sole or joint input into making decisions about agricultural inputs, 0 otherwise	1/10
	Agricultural sale decisions	1 if individual had sole or joint input into making decisions about marketing sales, 0 otherwise	1/10
Resources	Asset decisions	1 if individual had sole or joint input into making decisions about purchase, sale, or transfer of assets (e.g., land or agricultural machinery), 0 otherwise	1/10
	Credit decisions	1 if individual had sole or joint input into making decisions about credit and access, 0 otherwise	1/10
Income	Control over use of income	1 if individual had sole or joint input into making decisions about use of income, 0 otherwise	2/10
Leadership	CCP member	1 if individual was a member of China Communist Party, 0 otherwise	1/10
	Village cadre	1 if individual was a village cadre, 0 otherwise	1/10

(*continued on next page*)

Table A1 (*continued*)

Domain	Indicator	Definition	Weight
Time	Workload	1 if individual worked less than six months on farm work last year, 0 otherwise	1/10
	Leisure time	1 if individual had enough time for leisure activities (e.g., visiting friends or relatives, watching TV, or doing sports), 0 otherwise	1/10

Note: Table reproduced from Alkire et al. (2013) with necessary adjustments.

Table A2
Determinants of fuel choices: Coefficients of the MNL estimates.

Variables	***Cooking fuel choices***		***Heating fuel choices***	
	Mixed fuels	Clean fuels	Mixed fuels	Clean fuels
Age	−0.028 (0.011)**	−0.018 (0.011)	−0.003 (0.010)	−0.014 (0.010)
Gender	0.588 (0.229)**	0.233 (0.220)	−0.382 (0.203)*	−0.181 (0.198)
Education	−0.062 (0.039)	0.055 (0.036)	0.151 (0.034)***	0.132 (0.035)***
Health status	0.118 (0.108)	0.090 (0.102)	−0.000 (0.098)	−0.019 (0.098)
Household size	−0.011 (0.081)	−0.092 (0.076)	−0.017 (0.069)	−0.117 (0.068)*
Land size	0.040 (0.013)***	0.049 (0.013)***	−0.002 (0.008)	0.013 (0.008)*
Car ownership	0.721 (0.259)***	1.206 (0.253)***	0.574 (0.216)***	1.144 (0.215)***
Road condition	0.676 (0.238)***	1.128 (0.236)***	0.473 (0.224)**	1.217 (0.218)***
Jiangsu	1.673 (0.587)***	1.269 (0.581)**	−0.372 (0.581)	0.849 (0.446)*
Henan	0.917 (0.348)***	0.388 (0.338)	0.227 (0.322)	0.329 (0.291)
Hubei	−0.312 (0.277)	−0.682 (0.263)***	−0.668 (0.283)**	−2.052 (0.293)***
Hunan	1.724 (0.366)***	1.168 (0.355)***	0.970 (0.288)***	−0.061 (0.282)
IV1	0.153 (0.085)*	0.501 (0.086)***	0.236 (0.079)***	0.592 (0.078)***
IV2	−0.016 (0.007)**	−0.020 (0.006)***	−0.022 (0.007)***	−0.030 (0.007)***
Constant	0.421 (1.039)	−1.180 (1.028)	−1.576 (0.910)*	−1.411 (0.903)
Weak identification test: Cragg-Donald Wald statistic				
F statistic	27.885***		45.400***	

Note: Robust standard errors are presented in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$; The reference province is Sichuan.

Table A3
Determinants of men's decision-making power: Second stage of MESR estimates.

	Outcome = men's decision-making power		
Variables	Non-clean fuels	Mixed fuels	Clean fuels
Treat* = *Cooking fuel choices			
Age	−0.002 (0.004)	0.000 (0.001)	0.000 (0.001)
Gender	0.194 (0.096)**	0.051 (0.026)*	0.093 (0.027)***
Education	−0.012 (0.017)	0.000 (0.005)	0.011 (0.005)**
Health status	−0.001 (0.025)	0.007 (0.013)	0.001 (0.010)
Household size	−0.003 (0.019)	0.008 (0.010)	−0.008 (0.008)
Land size	−0.001 (0.006)	−0.002 (0.002)	0.001 (0.000)***
Car ownership	0.137 (0.059)**	0.002 (0.031)	0.029 (0.027)
Road condition	0.049 (0.070)	−0.024 (0.027)	−0.038 (0.028)
Jiangsu	0.377 (0.295)	0.017 (0.054)	0.040 (0.040)
Henan	0.158 (0.170)	0.042 (0.053)	−0.052 (0.045)
Hubei	−0.008 (0.064)	−0.036 (0.044)	0.045 (0.038)
Hunan	0.404 (0.225)*	0.004 (0.061)	−0.038 (0.050)
Constant	0.839 (0.400)**	0.493 (0.132)***	0.483 (0.107)***
Ancillary			
σ^2	0.390 (0.915)	0.041 (0.014)***	0.049 (0.037)
λ_1		−0.073 (0.473)	0.000 (0.438)
λ_2	1.066 (0.620)*		−0.084 (0.464)
λ_3	−0.747 (0.513)	−0.199 (0.404)	
Observations	139	340	518

Note: Bootstrapped standard errors are presented in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$; The reference province is Sichuan.

Table A4
Determinants of men's decision-making power: Second stage of MESR estimates.

	Outcome = men's decision-making power		
Variables	Non-clean fuels	Mixed fuels	Clean fuels
Treat* = *Heating fuel choices			
Age	0.001 (0.001)	0.001 (0.002)	−0.001 (0.002)

(*continued on next page*)

Table A4 (*continued*)

	Outcome = men's decision-making power		
Variables	Non-clean fuels	Mixed fuels	Clean fuels
Gender	0.103 (0.039)***	0.097 (0.033)***	0.081 (0.030)***
Education	0.000 (0.009)	0.003 (0.008)	0.002 (0.006)
Health status	0.005 (0.013)	−0.005 (0.015)	0.009 (0.014)
Household size	0.002 (0.011)	0.007 (0.008)	−0.007 (0.010)
Land size	0.003 (0.003)	0.000 (0.002)	0.001 (0.000)*
Car ownership	−0.003 (0.046)	0.026 (0.038)	0.027 (0.030)
Road condition	−0.071 (0.034)**	0.044 (0.038)	−0.051 (0.038)
Jiangsu	−0.074 (0.111)	−0.039 (0.097)	0.095 (0.051)*
Henan	0.011 (0.047)	−0.074 (0.060)	−0.007 (0.037)
Hubei	−0.023 (0.054)	0.022 (0.060)	0.033 (0.067)
Hunan	−0.140 (0.115)	0.058 (0.056)	−0.117 (0.081)
Constant	0.451 (0.146)***	0.397 (0.210)*	0.556 (0.126)***
Ancillary			
σ^2	0.042 (0.190)	0.035 (0.012)***	0.132 (0.137)
λ_1		0.054 (0.466)	0.786 (0.444)*
λ_2	−0.370 (0.817)		−0.904 (0.579)
λ_3	0.253 (0.658)	−0.068 (0.405)	
Observations	259	261	477

Note: Bootstrapped standard errors are presented in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$; The reference province is Sichuan.

Table A5
Determinants of women's decision-making power: Second stage of MESR estimates.

	Outcome = women's decision-making power		
Variables	Non-clean fuels	Mixed fuels	Clean fuels
Treat* = *Cooking fuel choices			
Age	−0.005 (0.006)	0.001 (0.002)	−0.005 (0.002)***
Gender	−0.163 (0.123)	−0.078 (0.036)**	−0.048 (0.032)
Education	0.009 (0.024)	0.012 (0.006)**	−0.013 (0.006)**
Health status	0.014 (0.035)	0.003 (0.015)	0.012 (0.013)
Household size	0.012 (0.022)	−0.003 (0.011)	0.007 (0.008)
Land size	−0.014 (0.011)	−0.007 (0.002)***	−0.001 (0.001)
Car ownership	0.085 (0.109)	0.034 (0.035)	−0.009 (0.028)
Road condition	0.019 (0.089)	−0.014 (0.035)	0.007 (0.036)
Jiangsu	0.072 (0.427)	−0.002 (0.072)	0.068 (0.047)
Henan	−0.079 (0.233)	−0.006 (0.057)	0.036 (0.045)
Hubei	−0.063 (0.081)	0.088 (0.042)**	−0.021 (0.039)
Hunan	−0.018 (0.355)	−0.039 (0.064)	0.057 (0.055)
Constant	0.731 (0.586)	0.676 (0.138)***	0.980 (0.162)***
Ancillary			
σ^2	0.137 (1.919)	0.051 (0.024)**	0.104 (0.067)
λ_1		0.737 (0.530)	−0.626 (0.389)
λ_2	−0.762 (0.755)		0.889 (0.406)**
λ_3	0.747 (0.548)	0.104 (0.395)	
Observations	139	340	518

Note: Bootstrapped standard errors are presented in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$; The reference province is Sichuan.

Table A6
Determinants of women's decision-making power: Second stage of MESR estimates.

	Outcome = women's decision-making power		
Variables	Non-clean fuels	Mixed fuels	Clean fuels
Treat* = *Heating fuel choices			
Age	−0.005 (0.002)***	−0.001 (0.002)	−0.003 (0.001)***
Gender	−0.079 (0.051)	−0.049 (0.039)	−0.069 (0.028)**
Education	0.000 (0.009)	−0.002 (0.009)	−0.001 (0.005)
Health status	0.004 (0.015)	0.001 (0.021)	0.012 (0.013)
Household size	0.006 (0.012)	0.009 (0.012)	0.002 (0.009)
Land size	−0.006 (0.002)**	−0.005 (0.003)*	−0.001 (0.001)
Car ownership	0.120 (0.047)**	−0.004 (0.039)	−0.014 (0.024)
Road condition	0.064 (0.041)	0.015 (0.043)	−0.051 (0.036)
Jiangsu	0.089 (0.129)	0.249 (0.12)**	−0.026 (0.055)
Henan	−0.059 (0.063)	0.106 (0.064)*	−0.040 (0.033)

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Table A6 (*continued*)

	Outcome = women's decision-making power		
Variables	Non-clean fuels	Mixed fuels	Clean fuels
Hubei	0.023 (0.055)	0.031 (0.068)	−0.038 (0.056)
Hunan	0.122 (0.115)	−0.12 (0.094)	0.046 (0.076)
Constant	0.801 (0.165)***	0.918 (0.304)***	0.847 (0.114)***
Ancillary			
σ^2	0.052 (0.170)	0.064 (0.026)**	0.067 (0.110)
λ_1		0.805 (0.435)*	−0.501 (0.548)
λ_2	0.327 (0.760)		0.714 (0.676)
λ_3	0.077 (0.613)	0.056 (0.385)	
Observations	259	261	477

Note: Bootstrapped standard errors are presented in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$. The reference province is Sichuan.

Table A7
Determinants of decision-making power gap: Second stage of MESR estimates.

	Outcome = decision-making power gap		
Variables	Non-clean fuels	Mixed fuels	Clean fuels
Treat* = *Cooking fuel choices			
Age	0.005 (0.006)	−0.001 (0.002)	0.004 (0.001)**
Gender	−0.075 (0.124)	0.064 (0.031)**	−0.017 (0.032)
Education	0.013 (0.019)	−0.016 (0.006)***	0.007 (0.007)
Health status	0.007 (0.035)	0.020 (0.015)	0.002 (0.013)
Household size	−0.018 (0.021)	0.005 (0.011)	−0.004 (0.009)
Land size	0.009 (0.011)	0.004 (0.002)*	0.001 (0.001)
Car ownership	−0.089 (0.086)	−0.052 (0.04)	0.029 (0.028)
Road condition	−0.054 (0.075)	0.044 (0.039)	0.005 (0.037)
Jiangsu	−0.124 (0.376)	0.041 (0.074)	−0.051 (0.053)
Henan	0.166 (0.183)	0.074 (0.056)	−0.052 (0.05)
Hubei	0.055 (0.08)	−0.058 (0.05)	−0.079 (0.039)**
Hunan	−0.072 (0.278)	0.15 (0.069)**	0.033 (0.058)
Constant	−0.077 (0.481)	−0.062 (0.163)	0.03 (0.151)
Ancillary			
σ^2	0.052 (1.072)	0.058 (0.029)**	0.059 (0.051)
λ_1		−0.834 (0.512)	−0.429 (0.474)
λ_2	−0.065 (0.866)		0.198 (0.562)
λ_3	−0.169 (0.657)	−0.212 (0.408)	
Observations	139	340	518

Note: Bootstrapped standard errors are presented in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$. The reference province is Sichuan.

Table A8
Determinants of decision-making power gap: Second stage of MESR estimates.

	Outcome = decision-making power gap		
Variables	Non-clean fuels	Mixed fuels	Clean fuels
Treat* = *Heating fuel choices			
Age	0.004 (0.002)**	0.000 (0.002)	0.004 (0.001)***
Gender	−0.113 (0.068)*	−0.044 (0.038)	−0.032 (0.031)
Education	0.019 (0.014)	0.005 (0.009)	0.016 (0.006)**
Health status	0.008 (0.021)	0.019 (0.020)	−0.006 (0.013)
Household size	0.006 (0.013)	−0.015 (0.013)	0.000 (0.009)
Land size	0.000 (0.003)	0.000 (0.002)	0.001 (0.001)
Car ownership	−0.083 (0.052)	0.003 (0.047)	0.004 (0.032)
Road condition	−0.005 (0.057)	−0.025 (0.052)	0.024 (0.039)
Jiangsu	−0.087 (0.150)	−0.142 (0.150)	−0.086 (0.053)
Henan	0.064 (0.069)	−0.069 (0.068)	0.010 (0.033)
Hubei	0.019 (0.080)	−0.002 (0.079)	−0.044 (0.061)
Hunan	0.168 (0.187)	0.13 (0.077)*	0.134 (0.076)*
Constant	−0.006 (0.168)	−0.111 (0.267)	−0.038 (0.110)
Ancillary			
σ^2	0.295 (0.586)	0.057 (0.026)**	0.175 (0.140)
λ_1		−0.499 (0.424)	−0.905 (0.400)**
λ_2	0.959 (0.841)		0.926 (0.559)*
λ_3	−0.855 (0.640)	−0.480 (0.413)	
Observations	259	261	477

Note: Bootstrapped standard errors are presented in parentheses; *** $p < 0.01$, ** $p < 0.05$, and * $p < 0.10$. The reference province is Sichuan.

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2024.108104.

Data availability

The data supporting this study's findings are available from Hongyun Zheng upon request.

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