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Role of Peer Effects in China's Energy Transition: Evidence from Rural Beijing

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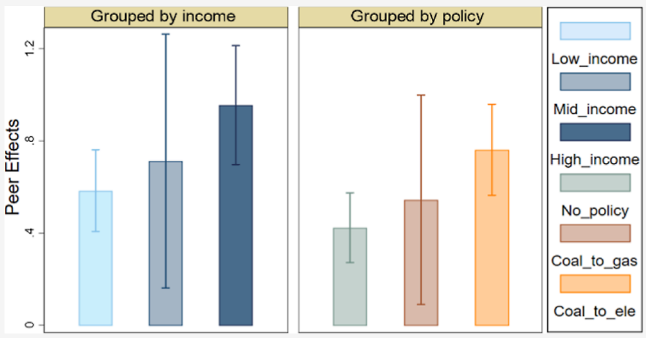
ABSTRACT: China's efforts to encourage energy transition from coal to cleaner methods of space heating have gained great achievement. However, not all progress met expectations; that is, some households still rely on solid fuel. Sociocultural factors provide one plausible explanation. While existing studies have examined and quantified the socioeconomic factors, little attention has been paid to the peer effects that are often critical in the Chinese cultural context. This study first presents household energy consumption patterns using household-level data on the coal-switching program in rural Beijing. It shows that the coal-switching program did not completely eliminate the use of solid fuel for space heating as expected. To explore the underlying determinants, we apply an econometric model of the forces driving energy transition, focusing on peer effects. The results confirm that the coal-switching program significantly reduces the use of solid fuel. Moreover, it reveals that the peer effect, measured by the average village-level solid fuel use rate, matters for households' fuel choices. We also find that the peer effect varies with different income levels and policies. These findings provide new evidence and insights for future policy design.



KEYWORDS: *energy transition, determinants, peer effects, rural China*

1. INTRODUCTION

Access to clean, abundant, and affordable energy is a key contributor to human welfare and is one of the Sustainable Development Goals. However, about 41% of global households (2.8 billion people), mostly in developing and transitional countries,[1] rely on traditional solid energy sources. This heavy reliance on traditional fuels has raised global concern over the adverse health consequences of household-sourced air pollution.[2,3] Meanwhile, the emissions from traditional solid fuel combustion contribute significantly to severe haze events, forest degradation, soil erosion, and climate change.[4−7]

The transition from traditional fuel to clean modern energy has encountered great practical challenges. The present study takes China as an example because it has the second-largest rural population in the world. During the last 4 decades, China's market-oriented reforms have overcome energy supply shortages in rural areas.[8] However, more than half of China's population, and 80% of rural households, still rely on coal to meet winter heating demands.[9] By 2017, coal still accounts for 35.5% of the total energy consumption in the residential sector (see Supporting Information Figure S1). Moreover, about 90% of the coal used in rural China is of poor quality, making rural household energy combustion a source of airborne particulates and haze shrouding in China.[6] An energy transition will be urgently needed if air pollution is to be curbed.

To accelerate the energy transition process and reduce the number and severity of extreme haze events, the Chinese government has implemented intensive energy transition programs focusing on rural residents in northern China. Beijing, for example, began promoting clean energy in core urban areas to achieve "coal-free" in 1998. In 2013, Beijing turned its focus to rural areas, attempting to eliminate poor-quality coal in rural areas. Beijing municipal government officially began its coal-to-electricity and coal-to-gas policies on a large scale in 2016, by issuing two official policy documents in succession, "Beijing 2016 Implementation Plan for "Coal to Clean Energy and Coal Reduction and Replacement" in Rural Areas" and "Beijing 2016−2020 Work Plan for Accelerating the Promotion of Clean Energy Replacement of Civilian Coal", which marked the beginning of the coal-to-electricity and coal-to-gas policies in rural Beijing.[10−12] Burning coal for heating in these rural households was officially forbidden,[13] and they were expected to achieve ″coal-free″ status before October 31, 2017—a goal explicitly stated in the Beijing Municipal

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Table 1. Socioeconomic Characteristics of the Sampled Rural Households[a]

variables	CRECS 2017-Beijing mean	std. dev.	95% confidence interval	official statistics
household size (persons)	3.6	1.69	[2,6]	3.1
householder gender (0 = female; 1 = male)	0.8	0.37	[0,1]	
householder age (years)	57.6	12.42	[35,78]	
householder education (years)	8.9	2.78	[6,14]	
the average number of workers per household (persons)	2.2	1.44	[0,4]	2.4
the average population supported by each worker per household (persons)	1.6	0.69	[1,3]	1.7
household annual income per capita (CNY)	23,643	32,639	[4000, 60,000]	24,240
dwelling age (years)	20.5	13.58	[2,40]	
separate kitchen (0−1)	0.9	0.28	[0,1]	
self-use toilet (0−1)	0.9	0.26	[0,1]	
dwelling ownership (number of ownership)	1.2	0.64	[1,2]	
dwelling size per capita (m^2)	49.4	41.76	[13.33,125]	44.9
dwelling retrofit (number of heating retrofits conducted)	0.8	1.08	[0,3]	
heating equipment (number of the heating device)	1.5	1.02	[1,3]	

[a]Source: official records are collected from the Beijing Statistical Year Book 2018.

Government Work Program.[14] Further, in 2017, China's Ministry of Ecology and Environment issued the "Planning of Winter Clean Heating in North China", implying a wider implementation of coal-to-electricity and coal-to-gas policy in the Beijing−Tianjin−Hebei region.[12,14−16] The implementation of the coal-switching program is detailed in Supporting Information S1.

The academic society also attracted much attention to explaining and guiding the energy transition.[17−27] Most empirical literature agrees that income is the dominant energy transition factor.[17−20] In addition, cultural and social characteristics are crucial in shaping human consumption behavior.[22,24] One of the key factors regarding cultural and social characteristics is "peer effects", which refers to the influences to which an individual is subjected by others in the same group and which may influence that individual's decision concerning a specific action.[28] Notably, peer effects are potentially essential mechanisms for promoting the energy transition in rural China, where face consciousness is a prominent issue,[29,30] and the culture is based on acquaintances and society.[31−33] To the best of our knowledge, relevant studies are rare. Srinivasan and Carattini (2020) suggest that social spillover effects have played a role in Indian households' long-term decisions regarding the use of LPG.[34] Wen et al. (2021) find that peer effects exist in the diffusion of clean cooking fuels among rural households in China.[31] Balta-Ozkan et al. (2021) use data on the number of charities as a proxy to capture peer effects on domestic photovoltaic adoption in the UK.[35] These three studies have made great contributions by examining the existence of peer spillover and its temporal−spatial variation. However, little attention has been devoted to how peer effects work and the impact of such peer effects on rural energy transition has been inadequately assessed.[36]

Our study overcomes a major obstacle to measuring peer effects. Under conditions of underdeveloped living, rural residents have fewer consumption options, so visible consumption, which is crucial for measuring peer effects,[37,38] is not as popular in rural China as it is in urban areas. In our study, the residential coal-switching program in rural China created an opportunity to investigate peer effects by creating a consumer environment that made energy-related consumption visible and prices perceptible. Therefore, this study aims to quantify the magnitude and mechanisms of peer effects in China's rural energy transition by investigating the interaction effects of exogenous economic and cultural variables and peer effects. Based on a representative household survey, this paper presents different energy consumption patterns and examines their determinants, focusing on the role of peer effects. We find the coal-switching policies have helped rural residents switch from traditional to commercial energy, with a lower share of solid fuels about 7.5−13.2%. In addition, higher-income, newly constructed, multi-family buildings are positively associated with clean energy penetration. The results also suggest that peer effects exist in rural China and could be harnessed to assist the country's energy transition further. Finally, the results show that lower-income families are less likely to be affected by peer effects, thus hindering the energy transition process. The findings also show that peer effects are stronger in the context of the coal-switching policies, which affect both social norms and information transmission.

2. MATERIALS AND METHODS

2.1. Data. The data for our study are drawn from the Chinese Residential Energy Consumption Survey (CRECS). The CRECS is China's most comprehensive, representative, and open-access household data set on energy demand. It has been managed by Renmin University of China since 2012. The survey is run annually to trace the development of Chinese household energy consumption.[39,40] The fifth wave survey, namely, CRECS 2017, has two different modules implemented in Beijing and Hebei Province, respectively.[41,42] The Beijing module (CRECS 2017-Beijing) was implemented from June 2017 to October 2017, 1 year after the coal-switching program started. It covered 3949 rural households and 183 villages in Beijing. A three-level "Probability Proportionate to Size" procedure was applied to ensure that sampling was representative (see Supporting Information S2).

Table 1 compares the major variables of our sampled rural households against those in the official statistics. For each household, the average rural household size is 3.6 persons, close to the official statistics of 3.1. Regarding the head of the household, 80% are men with an average of 8.9 years of schooling and an average of 57.6 years old. The average number of workers is 2.2, close to the official statistics (2.4). About 1.6 people are supported by each working person in a household, while the official statistic is 1.7. The annual income

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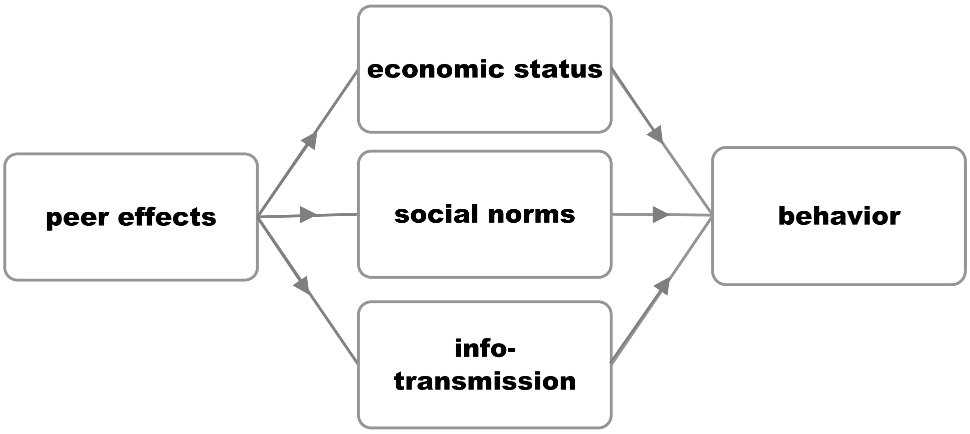

Figure 1. Peer effect mechanisms in the literature.

per capita in sampled households is 23,643 Yuan (CNY), consistent with the official data of 24,240 Yuan (CNY). Concerning the dwelling characteristics, the average age of the houses is 20 years, and 90% of the households have a separate kitchen and a toilet for their own use. The number of dwelling properties owned per household is 1.2. The housing space per capita in CRECS is 49.4 m^2, compared to approximately 44.9 m^2 in the official records. Regarding dwelling warming, most of the homes have not been retrofitted for warming, and each home has 1.5 heating devices. These figures suggest that the data are representative.

2.2. Energy Data Accounting. We use a "device-based bottom-up accounting method" to estimate the energy data.[43] Of the 3949 valid samples, 2999 were not covered by the district heating system (DHS)[a]. These 2999 households used a wide range of fuels for heating, including electricity, natural gas, coal gas, LPG, diesel, other fuel oil, wood, charcoal, coal, geothermal, and so on. The questionnaire includes 15 energy/fuel types for various kinds of heating equipment. This study groups these energy types into five categories: coal, coal products, biomass, oil, gas, and electricity. The survey also collected data on electric heating equipment, including air conditioners[b], electric radiant heating (electric heaters), and electric floor heating. Using this, we estimate the ith household's space-heating energy consumption (Energy_i) in standard kg coal equivalent (kgce) as follows.

$$\text{Energy}_i = \sum_{n=1}^{N} \text{power}_{i,n} \times \text{freq}_{i,n} \times \text{dur}_{i,n} \times \text{para}_{i,n} \times \text{livingdays}_i \times \text{coef}_n \quad (1)$$

where n is the fuel type, $\text{power}_{i,n}$ is the parameter of the device's output power (when the device is a stove, this refers to consumption rate), $\text{freq}_{i,n}$ refers to usage frequency, $\text{dur}_{i,n}$ is the usage duration of each use, $\text{para}_{i,n}$ is the energy efficiency level, livingdays_i refers to the residents' duration in the surveyed dwelling in 2017, and coef_n refers to the energy conversion coefficient (see Supporting Information Table S1).

Regarding nonelectric heating equipment, the survey data include Kang[c], heating stoves (burning wood, coal, etc.), and oil heaters. The energy consumption for space-heating purposes is given as follows

$$\text{Energy}_i = \text{heatcoef}_n \times \text{area}_i \times \text{livingdays}_i \times \text{coef}_n \quad (2)$$

where heatcoef_n is the unit area heat load coefficient of each fuel (see Supporting Information Table S2) and area_i is the actual heating area.

We estimate the effective energy of rural energy consumption to investigate the actual delivered energy service. Effective energy is the energy available to be used and is an important measure of energy quality.[44] It can be specified as below

$$\text{EH}_i = \sum_{n=1}^{N} \text{energy}_{i,n} \times \textit{thermal}\text{Eff}_n \quad (3)$$

where EH_i is the effective energy level and thermalEff_n refers to thermal efficiency for various energy types.[45]

2.3. Hypothesis and Regression Model. *2.3.1. Do Peer Effects Matter?* Previous studies have approached the complexities of the energy transition by using a multiplicity of explanatory variables to analyze the drivers (see Supporting Information S3). Here, we introduce peer effects as an explanatory variable and argue that they help capture the influence of neighborhood culture on household fuel choices in rural China. "Peer effects" describes the influences to which an individual is subjected by others in the same group and which may influence that individual's decision with respect to a specific action.[28] Individuals within a group tend to behave similarly because they tend to have consonant characteristics or face similar conditions. Each individual's behavior influences the group and is simultaneously influenced by it. Our motivation to use the peer effects is discussed in Supporting Information S4.

Given rural China's strong face consciousness and its acquaintance-based social traditions, ignoring peer effects may lead to an incomplete picture and misunderstanding of the rural energy transition. However, few studies have been conducted in rural China. The reason is that consumption visibility is vital in measuring peer effects,[37,38] but visible consumption is not as much a feature of rural China (where there are fewer consumption choices) as it is of urban areas. The coal-switching program created an opportunity to examine peer effects. Whether or not households purchase clean energy heating appliances, the prices of these appliances are publicly posted in the village, thus creating a consumption environment that makes consumption visible and prices perceptible.

Our first hypothesis is as follows.

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2.3.1.1. H1. Peer Effects Matter in Households' Choices of Heating Fuel and Energy Transition. We test H1 by using the following econometric model

$$S_i = \beta_0 + \beta_1 S_j + \beta_2 X_i + \gamma_1 P_j^{ele} + \gamma_2 P_j^{gas} + \mu j \quad (4)$$

where the dependent variable S_i denotes the share of solid fuels in total energy consumption for the ith household. A decline in the share of solid fuels is a good indicator of a successful energy transition.[46] The main independent variable of interest, $S_{j,}$ indicates peer effects. Following previous studies of behavioral peer effects,[34,47] we represent the peer effect as the average share of solid fuels among households within the jth village where the ith household is located (Supporting Information S5). X_i is a vector of household-specific controls, such as household income (in log form), building type, year of construction, and location. Income is a significant driver of clean energy consumption.[20] Two variables related to building characteristics, namely, the building type and construction year, are included. Whether village j where household i is located has implemented the coal-to-electricity or coal-to-gas policy is denoted by P_k^{ele} and P_k^{gas}, respectively. μ_j denotes a stochastic error term. Standard errors are clustered at the village level in order to control for the possibility that errors are correlated across geographical units. β_1 is our coefficient of concern, which indicates the strength of peer effects. If it is significantly positive, households are positively influenced by their neighbors' behavior, which indicates that peer effects do exist, confirming H1.

2.3.2. How Do Peer Effects Work? The different channels through which peer effects work are also important. The existing literature suggested that peer effects are mediated by social norms,[48] social networks, and membership in social organizations,[31,34,49] information transmission,[50] and economic conditions.[48,51,52]

Figure 1 illustrates three main mechanisms in our case (Supporting Information S6). The first channel is the linkage between peer effects and economic position. It is argued that the peer effects faced by wealthy and poor households are inconsistent. For example, Frank (1985) finds that low-income groups are more susceptible to peer effects,[53] while Hopkins and Kornienko (2004) argue that high-income groups face greater peer effects when income inequality increases.[51] Zhao and Qu (2021) use household-level data and suggest that peer effects are crucial in pension decision-making among low-income people.[48] The second mechanism is that peer effects may reflect a desire for conformity, implying that social participants want to conform as much as possible to the social norms of their reference groups.[48] A third potential mechanism is information transmission. This is especially relevant for people in rural areas of developing countries who have relatively low levels of education and who have few other sources of information about government policy. The increase in information transmission from peers increases peer effects among individuals.[50]

The existing literature treats income as a controlling factor without differentiating households with different income levels. This tacitly presumes that the peer effects are homogeneous across households. However, households with different income levels may vary in their sensitivity to peer pressure. Therefore, by using household income as a representative indicator, we are testing whether economic status is an essential mechanism. The second hypothesis is described as follows.

2.3.2.1. H2. Households with Higher Incomes Are More Susceptible to Peer Effects. The econometric specification is given as follows

$$S_i = \beta_0 + \beta_1 S_j + \beta_2 X_i + \beta_3(\ln\mathrm{Inc}_i \times S_j) + \gamma_1 P_j^{ele} + \gamma_2 P_j^{gas} + \mu j \quad (5)$$

where $\ln\mathrm{Inc}_i$ denotes household income in log form. The interaction term $(\ln\mathrm{Inc}_i \times S_j)$ is introduced to capture the intermediary effect, testing how much of the influence of other households on the ith household is related to the ith household's own income level. β_3 is the coefficient of our concern. If it is significantly positive, households with higher incomes are subject to greater peer effects, indicating that H2 is verified.

We next argue that the coal-switching program may affect social norms[54−56] and information transmission.[12] There are two reasons for this. On the one hand, the Beijing Municipal Government, through the issuance of documents, has explicitly called on rural residents to participate in energy transition projects, directly influencing the formation of social norms.[54−56] These social norms may induce households to follow suit more rapidly than they would otherwise have done, reflecting the expectation of social acceptance and recognition, the desire for conformity,[48] and the pressure of social sanctions. The second reason is that residents in rural areas of China are relatively less educated and have not been fully exposed to information about environmental protection in the past. Their primary information comes from government propaganda, TV, newspapers, and social media like Weibo, which are accessible approaches the government can use to disseminate policy information (Supporting Information S7). Implementing the coal-switching program has accelerated the dissemination of information about environmental protection and the benefits of using clean fuels.[12]

We are also interested in testing whether peer effects on energy transition are mediated by different policies that affect social norms and information transmission; therefore, the third hypothesis is described as follows.

2.3.2.2. H3. Peer Effects Are Stronger in Communities under Coal-Switching Policies. This is specified as follows

$$S_i = \beta_0 + \beta_1 S_j + \beta_2 X_i + \beta_3(\ln\mathrm{Inc}_i \times S_j) + \beta_4(P_j \times S_j) + \gamma_1 P_j^{ele} + \gamma_2 P_j^{gas} + \mu j \quad (6)$$

where P_j is a dummy variable, denoting whether village j has implemented the coal-to-electricity or coal-to-gas policy. The interaction term $(P_j \times S_j)$ is introduced to capture the intermediary effect (Supporting Information S8). β_4 is the coefficient of concern. Supporting Information Table S3 lists the descriptive statistics for all variables.

3. RESULTS AND DISCUSSION

3.1. Energy Flowchart. According to our survey data, among these 2999 non-DHS households, 2119 were not participating in any coal-switching programs, while 751 chose the coal-to-electricity program and 128 chose the coal-to-gas program. Thus, the non-DHS sample households are further divided into three groups. Group 1 is the 2119 households not participating in the coal-switching program, group 2 includes the 751 households in the coal-to-electricity program, and group 3 covers the 128 households in the coal-to-gas program.

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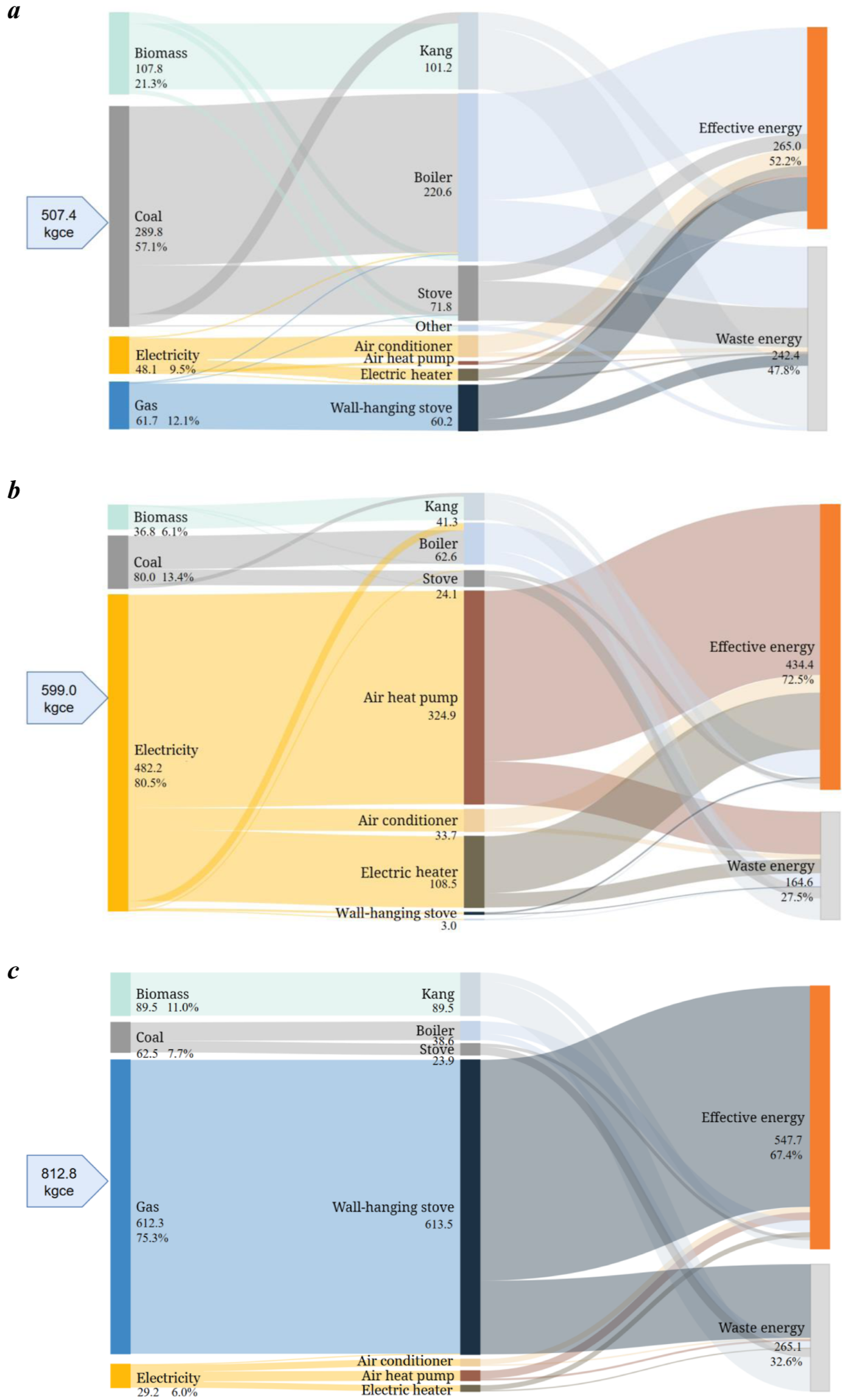

Figure 2. Energy flows for three types of rural households in Beijing. (a) Group 1 without any coal-switching program; (b) group 2 adopted the coal-to-electricity program; (c) group 3 chose the coal-to-gas program.

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Table 2. Results of Baseline Estimations[a]

	H1		H2	H3
	(1)	(2)	(3)	(4)
Peer_effc	0.991***	0.878***	0.792***	0.731***
	(0.0166)	(0.0241)	(0.0422)	(0.0491)
Peer_effc × lnInc			0.043**	0.042**
			(0.0174)	(0.0174)
Peer_effc × coal-to-ele				0.119**
				(0.0494)
Peer_effc × coal-to-gas				0.074
				(0.0909)
lnInc	−0.015*	−0.013	−0.042***	−0.041***
	(0.00813)	(0.00803)	(0.0141)	(0.0141)
single	−0.004	0.068**	0.061**	0.095***
	(0.0259)	(0.0278)	(0.0279)	(0.0311)
detached	−0.021	0.045	0.038	0.070
	(0.0320)	(0.0331)	(0.0332)	(0.0357)
year	−0.072***	−0.065***	−0.066***	−0.067***
	(0.0168)	(0.0166)	(0.0166)	(0.0166)
coal-to-ele		−0.132***	−0.135***	−0.207***
		(0.0197)	(0.0197)	(0.0356)
coal-to-gas		−0.075**	−0.079***	−0.132***
		(0.0302)	(0.0302)	(0.0420)
average marginal effects of peer effect			0.883*** (0.0241)	0.851*** (0.0275)
observations	1,771	1,771	1,771	1,771
R^2	0.72	0.73	0.73	0.73

[a]Note: *t* statistics in parentheses. *, **, and *** refer to significance at 5, 1, and 0.1%, respectively.

Figure 2 illustrates the energy flow diagrams for the three types of Beijing rural households in 2017. It represents all the primary energy flows into various end uses. The arrows' widths are proportional to the energy consumption, utilization, and losses. There are five types of primary energy (biomass, coal, gas, oil, and electricity) and eight types of equipment (Kang, boiler, stove, air conditioner, air heat pump, electric heater, wall-hanging stove, and others). The energy sources are treated as the energy inputs on the left side of the diagram, the equipment is in the middle, and the effective heat and loss are on the right side. Regarding the rural household energy consumption pattern, four findings are summarized as follows.

First, group 1 exhibits a hybrid pattern. As Figure 2a shows, a representative rural household in Beijing that is not involved in any coal transition consumed 507.4 kgce energy for space heating on average in 2017. However, only 265.0 kgce, or around 52.2% of their primary energy consumption, contributed to their heating demand as effective energy. Coal was the dominant energy source and accounted for 57.1% of total energy consumption, followed by biomass (21.3%), gas (12.1%), and electricity (9.5%). Boilers and Kang were the main items of heating equipment.

Second, households involved in one of the coal-switching programs (groups 2 and 3) are associated with far greater use of modern energy. Taking Figure 2b as an example, electricity has become the primary energy source; its share of total energy consumption reaches 80.5%, much greater than that in Figure 2a. Air heat pumps and electric heaters are the dominant heating appliances.

Third, the coal-to-gas households (group 3) consumed more gas for space heating than group 1. The share of gas in total energy consumption is significantly greater than that in Figure 2a, reaching 75.3%. For these households, gas has become the primary energy source and a wall-hanging stove fueled by gas has become the dominant heating appliance. Compared with group 1, the households that chose to participate in one of the coal-switching programs consumed more energy but also had improved thermal efficiency and more effective energy service. On average, a representative coal-to-electricity household in group 2 consumed 599 kgce in the 2017 heating season, of which 434.4 kgce energy input was converted into effective space-heating energy service, with the highest thermal efficiency (72.5%) among the three groups. We also noted that group 3 had the most extensive primary energy consumption among the three groups. A representative coal-to-gas household consumed 812.8 kgce in 2017. Although group 3's effective energy (547.7 kgce) also ranks highest relative to the other two groups, its thermal efficiency (67.4%) is lower than coal-to-electricity. If we treat group 1 as the benchmark, then group 2 and group 3, associated with higher effective energy and thermal efficiency, have improved living comfort and well-being.[57,58]

Fourth, the comparison also shows that electricity and gas have not entirely replaced coal. The ultimate purpose of the coal-switching policies is to keep villagers from using solid fuels such as coal. However, our first observation is that non-coal-switching households (group 1) account for 71% of non-DHS samples, implying there is still a large number of households that have not transformed their energy structure for space heating, even with the incentive of high subsidies. The second observation is that coal and biomass are still used, even by households that chose to transition to electricity or gas. The solid fuel share (78.4%) for group 1 is high because they do not participate in any coal-switching program. However, Figure 2b shows that a representative coal-to-electricity household in group 2 still used 116.8 kgce solid fuel (80 kgce coal, 36.8 kgce biomass), accounting for 19.5% of total energy consumption. As for the coal-to-gas households, solid fuel consumption was

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152 kgce (62.5 kgce coal, 89.5 kgce biomass) or 18.7% of total space-heating-related energy.

3.2. Basic Regression Results. The space-heating energy consumption pattern in rural Beijing is complex. As expected, households involved in the coal-switching program make greater use of modern energy, and their demand for traditional fuels such as coal and wood has substantially fallen. However, not all households have completely forgone coal and other solid fuels. What determines adherence to coal and biomass and hinders energy transition? Answering the above question will help in the design of more effective policies.

To address the issue of many regressors in a model with possibly non-Gaussian and heteroscedastic disturbances, we apply the post-double selection (PDS) procedure for OLS estimation. This can overcome the imperfect selection of the controls and provides confidence intervals that are valid uniformly across a large class of models.[59] The regression results for the baseline model are shown in Table 2. Columns 1 and 2 examine H1; the first column includes fundamental variables, while the second column introduces the policy dummy variable. Column 3 tests H2 by including the interaction term of income and peer effects. Finally, column 4 introduces the interaction terms of policy and peer effects to test H3.

Reading from Table 2, we find that the coefficient of household income across most columns is significantly negative. A 1% increase in household income is associated with a 1.5−4.2% decrease in solid fuel rate. This means an increase in income facilitates energy transition, which is consistent with the literature.[60]

As for the effects of policy, we find that households participating in coal-switching policies are associated with a lower share of solid fuel. For example, in villages where the coal-to-electricity policy was implemented, the rate of solid fuels in household energy consumption decreased by an average of 13.2%, compared to rural households in areas without the policy. In addition, the rate of solid fuels in household energy consumption decreased by an average of 7.5% in villages where the coal-to-gas policy was implemented.

Regarding the demographic characteristics, the house type is significantly positive, except in the first column. This indicates that, compared with households living in multi-family buildings, households living in a single-family bungalow use 6.1−9.5% more solid fuel; the result is statistically significant. However, living in a detached building is not significant in all estimates. The building vintage, measured by construction year, is significant in all estimates. Columns 1−4 show a negative and significant coefficient, indicating that a household living in a newly constructed building is 6.5−7.2% less likely to use solid fuel. These results parallel an existing study, which found that households in newer houses are more likely to use clean energy for heating.[61]

3.3. Impact of Peer Effects. We begin by testing our first hypothesis. The first and second columns in Table 2 show a positive and significant coefficient for the average solid fuel rate, confirming the existence of peer effects on energy transition. A 1% decrease in the village-level solid fuel rate is associated with a 0.878−0.991% decrease in a household's rate of solid fuel use. This finding is consistent and comparable with the existing empirical evidence. For example, Wen et al. (2021) found that a 1% increase in a village's adoption of clean cooking fuels increased a local household's probability of adopting clean cooking fuels by about 0.632%.[31]

Next, we test H2, that is, the mechanisms of peer spillover. The moderating variable is household income. The third column in Table 2 shows that the estimated coefficient for the interaction term (Peer_effc × lnInc) is positive and statistically significant. This suggests that income plays a positive role in moderating the relationship between household adoption of fuels and peer effects. Recall that in eq 5, the marginal effect of S_i on S_j is $\mathrm{d}S_i/\mathrm{d}S_j = \beta_1 + \beta_3 * \ln\mathrm{Inc}_i$. Given the positive coefficients of β_1 and β_3, a household with an income lower than 2.72 thousand Yuan (accounting for 22% of the sample) will yield a negative $\ln\mathrm{Inc}_i$, implying that the peer effect is less than β_1. As shown in Table S3, lnInc ranges from −2.30 to 6.39. Accordingly, the peer effect ranges from the lowest score of 0.693 to the highest of 1.067. The last row shows that, on average, the marginal effect of peer pressure on a household's solid fuel rate is 0.883 and is significant at the 1% level. Our result indicates that, if a family is wealthier, its choice of heating fuel is more likely to be affected by peer pressure in the same village—that is, rising incomes make households more susceptible to peer effects.

Previous studies have argued that an increase in household income facilitates clean energy consumption, while low income is a crucial constraint to the energy transition process.[62] Our work indicates that lower-income families are less likely to be affected by the peer effect on energy transition. This finding is consistent with the finding of Hopkins and Kornienko (2004) that there are more substantial peer effects in high-income groups.[51] From the perspective of the unequal energy transition between urban and rural areas, if peer effects exist in the choice of fuels in rural areas, it is not implausible to expect that they will catch up to urban areas. However, since lower-income households are less susceptible to peer effects, the energy transition is even more difficult for poor rural residents. This can lead to an unequal consequence where the poor continue to use solid fuels and the rich adopt clean energy. This may explain the behavioral disparities in energy consumption observed in households and the heterogeneous impacts among peer groups within the same village. It also helps explain the polarization of the urban and rural energy transition.

Finally, we test our third hypothesis regarding the heterogeneity of peer effects under different policy shocks. The fourth column in Table 2 shows the moderating effects of different policies. Both coefficients on the interaction variables (Peer_effc × coal-to-ele and Peer_effc × coal-to-gas) are positive. The coefficient on the interaction variable of the coal-to-electricity policy and peer effects is significant at the 5% level. This indicates that coal-to-electricity policy positively moderates the relationship between household adoption of fuels and peer effects. Moreover, we also find a positive sizable impact through the coefficient on the interaction variable of the coal-to-gas policy but not significant. Recall from eq 6 that the marginal effect of S_i on S_j is $\mathrm{d}S_i/\mathrm{d}S_j = \beta_1 + \beta_3 * \ln\mathrm{Inc}_i + \beta_4 * P_j$. For households with equal income, the implementation of a coal-to-electricity policy would increase the effects of peer pressures on households by an average of 11.9%. A household with an average income faces a peer effect of 0.938 if located in a village where the coal-to-electricity policy exists, while the same household faces a peer effect of 0.819 if located in a village without the policy.

This study also supports the literature[48] showing that the different channels through which peer effects work have different policy implications. One possible mechanism is the effect of the coal-switching program on social norms and information transmission, both of which can influence peer effects. Peer effects may arise out of a desire for conformity—that is, each individual wants to conform as much as possible with the social norms of his/her reference group. The traditional reliance on coal and biomass to heat the house is deeply rooted in Chinese rural society. However, the coal-switching program has accelerated the spread of information on environmental awareness and the benefits of using cleaner fuels.[12] This, together with the government's strong promotion of the coal-switching program, may mean that conformity will point toward cleaner energy.

3.4. Robustness Analysis. We test for robustness by conducting a sensitivity analysis of the number of households per village. For this purpose, we re-estimated the models shown in Table 2, with different restrictions for the sample size per village.[31] The robustness check regression results regarding sample size thresholds and different regression strategies are listed in Supporting Information Tables S4 and S5.

As shown in Table S4, columns 1−4 include only sampled villages with more than 10 households. Columns 5−8 set a higher sample selection criterion (more than 20 households per village). Table S4 shows results consistent with the previous estimate, confirming our hypothesis with respect to peer effects and indicating its robustness across sample sizes. Additional robustness tests with different estimation strategies are run by conducting grouped regression. In Table S5 (columns 1−3), households are evenly divided by income ranking into three groups. The result shows that low-income households are associated with weaker peer effects, while high-income households have more substantial peer effects. This result is consistent with the baseline estimation. Tables S4 and S5 show that our findings are robust to these different estimation strategies.

3.5. Implications, Limitations, and Outlook. Understanding the determinants of the energy transition is key to ensuring its success. Previous studies have identified and examined various determinants related to the characteristics of households and buildings. However, little work has been done on the impacts of neighbors, which may be profound in the cultural context of China. We aim to fill this research gap. Using 2017 household-level data set drawn from rural households in Beijing, this paper provides detailed patterns of energy consumption when coal-switching policies are implemented. We further examine the factors driving the energy transition and provide empirical evidence on the existence and mechanisms of peer effects. The paper has two major implications.

First, we find that the implementation of coal-switching programs significantly contributes to the energy transition in rural Beijing, which is consistent with the previous study.[10−12,14−16] The Sankey diagrams show that households involved in one of the coal-switching programs are related to far greater use of modern energy. Besides, the regression results show that households participating in coal-to-electricity and coal-to-gas policies are associated with lower solid fuels by an average of 7.5−13.2%, taking households without participating in any policy as a benchmark.

Second, our study finds that peer effects facilitate the energy transition and thus offer interesting insights into the promotion of clean energy in the future. The existence of peer effects on the energy transition in rural China opens up some new solutions. For example, to supplement financial incentives, a cost-effective option is to make use of social norms—for example, use the peer spillover within a village to accelerate clean energy adoption. An example is the public recognition of the "pioneer family" in a village for adopting clean energy and the publication of households' rankings in terms of clean energy use. China will focus on the propagation of wind, PV power, and other clean energy in the next five years. Our findings are not limited to the choice of coal but can be extended to the choice of other clean energy alternatives such as wind and PV power. Introducing peer effects as a nonprice intervention can change consumer behavior substantially and cost-effectively. Governments can promote peer effects by strengthening social norms and messaging, which is more cost-effective than high government subsidies, as well as positively impacting energy transition.

The shortcomings of this study and future research directions are worth noting. First, there is a lack of comprehensive, widely covered, and detailed panel data sets on household energy consumption in China. The cross-sectional data used in the present study limit a causal effect assessment of policy and do not identify the families involved in the substitution of high-quality coal for low-quality coal policy, which was an important component of the energy transition program. Thus, a new round of surveys to trace these surveyed households in the future would hopefully enable us to quantify the causal effects of the various coal-switching programs and identify the families with multiple heterogeneous policies. In addition, we admit that testing peer effect sensitivities to income and policy is an indirect method to characterize the mechanisms of peer effects. However, a limited and selected set of variables and boundaries cannot reveal the real mechanism and sometimes even obtain misleading results. Therefore, we expect to identify a better measurement of mechanisms and adopt more precise variables in our future research.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge at https://pubs.acs.org/doi/10.1021/acs.est.2c06446.

> Brief introduction of coal-switching program, sampling procedure, and determinants of energy transition; potential impact of peer effects on energy transition; validity of the reference group; details of the mechanism analysis; residential energy consumption in rural China; coefficients in energy data accounting; descriptive statistics; and robustness check results (PDF)

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Notes

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■ ADDITIONAL NOTES

[a]In some parts of northern China, district heating, also known as central heating, provides heat from a central location. Households served by this system do not choose their source of heating fuel.
[b]"Air conditioners" also describe heating equipment in China.
[c]Kang is a bed made of bricks and billets in northern China, with a hole underneath and connected to a chimney, which can be heated by fire.

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