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WHAT DETERMINES COAL CONSUMPTION FOR HEATING RESIDENTIAL SPACE IN CENTRAL ASIA?

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Abstract

Despite complete electrification in Kazakhstan and the Kyrgyz Republic, the reliance on coal for heating residential spaces is high. Using microdata from the national household surveys from Kazakhstan in 2017 and the Kyrgyz Republic in 2016, this study examines the factors affecting residential fuel choice and patterns of consumption for different fuel types—with an emphasis on coal—for heating in the two countries. We employ three models: logit, multinomial logit, and double-hurdle models. The results indicate that access to cleaner and more modern energy infrastructure such as natural gas pipelines and central heating are important for reducing solid fuel consumption, especially in rural areas. Regions with higher coal prices prefer cleaner heating, while regions with higher electricity prices prefer solid fuels. Education is important for the reduction of household solid fuel consumption. The results do not provide evidence that newer houses are more energy efficient.

Keywords: residential heating, coal, Kazakhstan, the Kyrgyz Republic, multinomial logit, double-hurdle model

JEL Classification: Q41, Q31, Q48

Contents

1. INTRODUCTION

The combustion of solid fuels in inefficient stoves results in the release of the products of incomplete combustion such as suspended particulate matter, carbon monoxide, polycyclic aromatic hydrocarbons, polycyclic organic matter, and formaldehyde, which have adverse effects on health (Kankaria, Nongkynrih, and Gupta 2014). Many areas in Kazakhstan and the Kyrgyz Republic suffer from poor air quality, and the wide household use of solid fuel is one of the contributing sources of outdoor and indoor air pollution (Kankaria, Nongkynrih, and Gupta 2014; UNDP 2012; Kenessary et al. 2019) In the highly populated cities of Kazakhstan and the Kyrgyz Republic, air pollution is higher during the winter, and the use of solid fuel for heating could be a contributing factor (Aiymgul Kerimray et al. 2020).

Developing countries are working hard to attain universal electrification, with commendable results in recent years. However, effective public policy to increase mass access to clean fuel needs to be coupled with an effective transition towards its use. This has been a concern in many developing countries, including Kazakhstan and the Kyrgyz Republic in Central Asia, where the use of solid fuels for space heating, especially in rural areas, is still widespread (Gassmann and Tsukada 2014; A. Kerimray et al. 2018). In Central Asia, solid fuels are used for heating to combat severe winter conditions mainly due to a lack of cleaner fuel options and the relatively inexpensive availability of solid fuels. In Kazakhstan and the Kyrgyz Republic, 75% and 72% of households, respectively, use solid fuel for heating. Public policy to guide the transition to cleaner fuels requires a clear understanding of consumer preferences and their relation to various economic and non-economic attributes.

Due to increased household income and the quantity and surface area of residential buildings, residential energy consumption can be expected to grow. Policymakers face challenges in achieving a balance between satisfying growing energy needs, reducing air pollution, and keeping energy prices affordable, especially for low income and vulnerable groups within the population. Efficient and adequately targeted policies and measures are needed to achieve energy transition from coal to cleaner fuels. To design these policies, quantitative assessments are needed to provide an adequate understanding of the determinants of household fuel choice.

Energy consumption structures are unique to each country and are determined by various specific features such as resource endowment, socio-cultural norms, behavior, and present market conditions and policies (Lenzen et al. 2006). There can even be differences within one country and across states and climatic zones. There is no one-fits-all recipe for energy transition policies (Lenzen et al. 2006). Determinants of household energy consumption may be substantially different in the selected two countries from other countries because of unique climatic conditions, population density, or availability of resources, as well as unique historical, social, cultural, and behavioral features. Policies for energy transition in developing countries must be carefully designed to account for these complex features, which can affect the success of policy intervention. This study aims to fill this knowledge gap by analyzing the determinants of household energy consumption for heating using multinomial logit and double hurdle models.

The objective of this study was to identify the determinants of residential heating fuel choice and provide evidence-based policy recommendations for promoting cleaner and more modern fuels in Kazakhstan and the Kyrgyz Republic. We used logit, multinomial logit, and double hurdle models for the empirical analysis. Using microdata from the national household surveys from Kazakhstan in 2017, which includes 21,000

households, and the Kyrgyz Republic in 2016, which includes 2,521 households, we analyzed the built environment and other socioeconomic factors affecting household energy choice for heating. The countries selected for this study share common challenges, such as extremely cold weather conditions, with high dependence on solid fuels, high poverty levels among households, and a lack of access to energy infrastructure.

2. LITERATURE REVIEW

The existing literature has considered the determinants of household fuel choice for cooking (Amoah 2019; Gould and Urpelainen 2018), heating (Jaime, Chávez, and Gómez 2020), and lighting (Martey 2019). This paper focused on the choice of fuel for heating, because households that use individual stoves rely heavily on coal (above 70%) and less on natural gas and electricity, while for cooking, households tend to use more electricity and natural gas and less solid fuel.

Most empirical studies include the following socioeconomic factors as determinants of heating fuel choice: household income and size, age of the household head, education, gender, household location (rural or urban), and fuel availability. Fuel *price* is also an important determinant of fuel demand, but few studies include fuel prices in their empirical analysis due to data scarcity (Alem et al. 2016). Household (and household head) characteristics include household income and size, as well as household head age, education, and gender. Income is one of the main determinants of fuel choice, and the impact of income on fuel choice can be explained by the energy ladder hypothesis (Leach 1992), which states that as, income increases, households use more reliable, modern, cleaner, and more efficient fuel. Household income is usually measured as total consumption expenditure per capita.

Household *size* is a key determinant of fuel choice (Alem et al. 2016). As household size increases, the demand for energy increases, and households switch to cheaper energy sources to satisfy the increased energy demand (Ngui et al. 2011). Larger households with more children and females have a lower opportunity cost for collecting biomass (Alem et al. 2016; Heltberg 2004; Narasimha Rao and Reddy 2007). Household heads with better *education* are more aware of the impact of indoor pollution caused by traditional fuels on health (Alem et al. 2016) and tend to opt out of using solid fuel.

Household location in *rural* or *urban* areas determines fuel access: biomass is more accessible in rural than in urban areas, for example, and fuel *availability* and accessibility are very important for the choice of fuel (Alem et al. 2016; Gupta and Köhlin 2006). Modern fuels, such as natural gas and electricity, are not widely available and accessible for households in developing countries due to lack of infrastructure. The availability of cleaner cookstoves that use liquefied petroleum gas (LPG), electric, or gas is another important determinant (Brooks et al. 2016). A systematic literature review of the determinants of fuel choice has already been provided in the literature (Lewis and Pattanayak 2012; Muller and Yan 2018; Timilsina 2014).

Most literature studying the choice of heating fuel use multinomial logit method, which creates a model that allows us to accommodate the use of more than one fuel type—that is, “fuel stacking” behavior (Muller and Yan 2018). This is important because many households use a combination of several heating fuels. Various studies have employed multinomial logistic regression model to explore the determinants of household fuel choice and energy transition, including, in the case of Afghanistan, using Demographic and Household Survey 2015 (Paudel, Khatri, and Pant 2018); to

determine the role of income and assets on the fuel transition from solid fuels to clean fuels in the People's Republic of China using 2012 National Survey of China Family Panel Studies (Hou, Liao, and Huang 2018); to model the choice concerning the energy used for heating in France (Couture, Garcia, and Reynaud 2012); and to analyze the factors determining urban household energy choices in Ouagadougou, Burkina Faso (Ouedraogo 2006). Studies in other countries have revealed that household income and socio-economic characteristics play a significant role in household fuel choice (Couture, Garcia, and Reynaud 2012; Ouedraogo 2006). Urban/rural differences were also found to be significant, with urban households consuming a larger share of clean and commercial fuels (Pachauri and Jiang 2008).

Our study's contribution is that it employs multinomial logit and double hurdle models to investigate the determinants of fuel choice and expenditure. This study contributes to the literature studying the determinants of heating fuel choice and expenditure. For Central Asia countries, only a few studies exist that profile household energy consumption. For the Kyrgyz Republic, a study by Sabyrbekov and Ukueva (2019) determined factors that affect household decisions to transition from solid energy to clean modern fuels using panel data from the Kyrgyz Integrated Household Survey (covering 5,000 households). Using the econometric method (multinomial probit model) and qualitative approach (interviews), they determined that income growth alone does not lead to full transition, but higher-income households tend to use multiple fuels. A study by Gassmann and Tsukada (2014) investigated the determinants of household choice of heating source using a multinomial outcome model of the data from the 2011 Kyrgyz Integrated Household Survey (covering 5,000 households). Their results suggest that households in the Kyrgyz Republic will switch to alternative sources if the electricity price increases.

To the best of our knowledge, there are no studies that have explored the determinants of household energy demand in Kazakhstan. A previous study by (A. Kerimray et al. 2018) only presented an energy consumption profile of households in Kazakhstan using a household living conditions survey conducted in 2013 (covering 12,000 households).

3. NATIONAL ENERGY CONSUMPTION TRENDS IN KAZAKHSTAN AND THE KYRGYZ REPUBLIC

Kazakhstan and the Kyrgyz Republic share similar features in terms of energy and economic structures due to their common history and close location, although progress in reducing poverty and energy transition in the last two decades has varied. Both countries experienced significant economic growth over a 17-year period (2000–2017), with GDP per capita growing from $10,275 to $24,862 (PPP, constant 2017) in Kazakhstan and from $3,078 to $5,046 (PPP, constant 2017) in the Kyrgyz Republic (World Bank 2020b) (Figure 1). The poverty gap[1] has declined substantially in both countries over the period 2000–2017, from 10% to 0.1% in Kazakhstan and 32.2% to 3.5% in the Kyrgyz Republic (World Bank 2020b).

In 2019, the Kyrgyz Republic was classified as a lower-middle-income economy and Kazakhstan and as an upper-middle-income economy (World Bank 2020a).

[1] Measured as $3.20 per day, 2011 PPP.

Figure 1: (left) GDP per Capita in Kazakhstan and the Kyrgyz Republic; (right) Poverty Gap in Kazakhstan and the Kyrgyz Republic (World Bank 2020b)

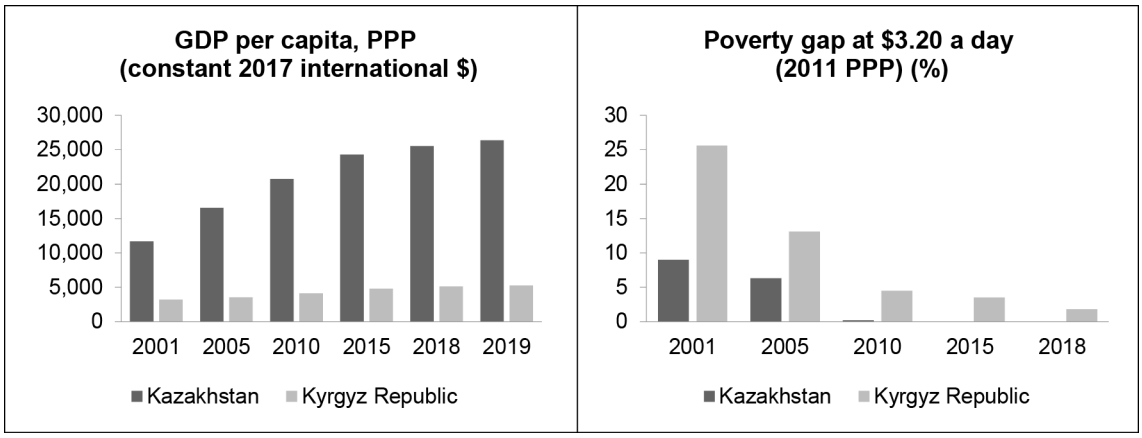
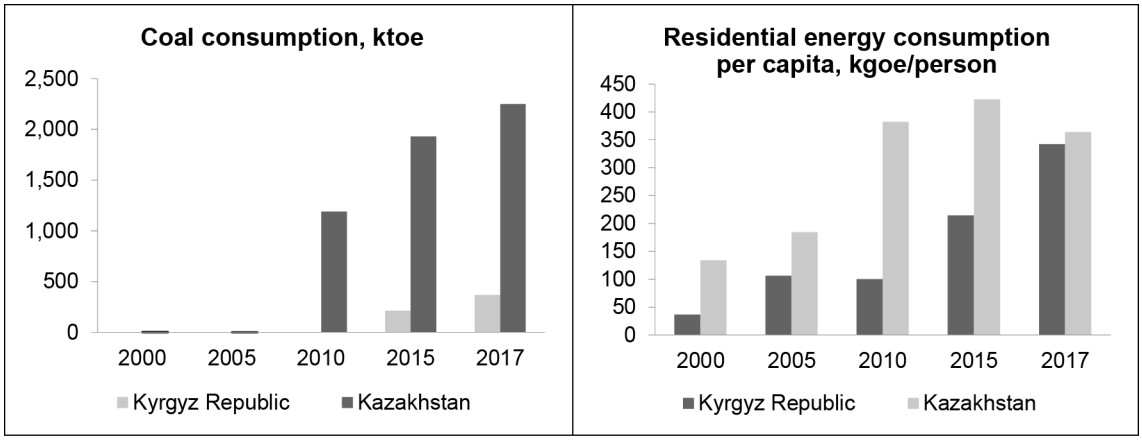


Figure 2: (left) Coal Consumption in the Residential Sector in India, Kazakhstan and the Kyrgyz Republic, thousand tons of Oil Equivalent (ktoe; IEA 2019) and (right) Residential Energy Consumption per Capita in Kazakhstan and the Kyrgyz Republic, kilograms of Oil Equivalent (kgoe/1000 persons; IEA 2019b)



Following economic growth, energy consumption in the residential sector (per capita) increased substantially in both countries, three-fold in Kazakhstan and nine-fold in the Kyrgyz Republic in 2017 compared to 2000 (IEA 2019a). In 2017, per capita residential energy consumption was 364 kgoe/person in Kazakhstan and 342 kgoe/person in the Kyrgyz Republic (Figure 2), which is higher than the world average (275 kgoe/person) and substantially lower than that of the US (754 kgoe/person; (IEA 2019b). Residential energy consumption per capita might be higher than the world average in these two Central Asian countries due to the high demand for heating (cold and long winters), low population density, and inefficiencies in energy consumption. Despite income growth in recent years, the consumption of solid fuels (coal) by households in Kazakhstan and the Kyrgyz Republic increased dramatically. In 2017, the share of coal in residential energy consumption reached 34% in Kazakhstan and 17% in the Kyrgyz Republic (IEA 2019b). This growth in residential energy consumption, particularly of solid fuels, indicates that the current policies for energy transition may be insufficient. Future policies must be carefully designed

based on a clear understanding of the factors and drivers of this growth in energy consumption.

Heating is a basic survival need in Kazakhstan and the Kyrgyz Republic, because the heating season lasts for at least one third and sometimes more than half of the year, depending on the region. In the Kyrgyz Republic, the length of the heating season is 135–197 days, with the average temperature during heating season varying from +1.4°C to −6.9°C (Balabanyan et al. 2015). In Kazakhstan, the length of the heating season is 136–226 days (depending on the region), with the average temperature varying from +2.5°C to −7.5°C (Committee for Construction and Housing and Communal Services of the Ministry of Investment and Development of the Republic of Kazakhstan 2017) Central heating is a common source of heat for most urban households living in multi-apartment buildings in Kazakhstan, while detached houses and mansions have had to rely on individual heating systems (gas, coal, electricity). In the Kyrgyz Republic, central heating covers only 19% and 1% of the urban and rural population, respectively (Balabanyan et al. 2015), with the remaining households rely on individual heating systems (gas, coal, electricity).

Solid fuels are commonly considered to be cheaper than cleaner alternatives. However, in Kazakhstan and the Kyrgyz Republic, coal expenditure in households relying on coal was actually higher than the expenditures of households using clean alternatives (piped gas, central heating) (Balabanyan et al. 2015; A. Kerimray et al. 2018). This could be because coal has additional transaction and transportation costs and coal prices are less regulated, while prices of gas and central heating remain regulated.

Although there is a nearly 100% electrification rate in Kazakhstan and the Kyrgyz Republic, households in Kazakhstan (A. Kerimray et al. 2018) and the Kyrgyz Republic (Sabyrbekov and Ukueva 2019)tend to use multiple fuels instead of solely relying on electricity as a clean alternative. Sabyrbekov and Ukueva (2019) interviewed households to determine the reason for not using electricity among respondents in the Kyrgyz Republic: 70% of respondents answered that the tariffs were too high, 15% answered that voltage was low for heating purposes, and 14% stated that they could not afford the associated expenses such as the installation of a steam boiler, pipes, or other expenses.

The Kyrgyz Republic has faced challenges in providing a secure supply of clean fuels (gas and electricity). There have been recurrent interruptions of gas supplies due to political and pricing issues (Balabanyan et al. 2015). These interruptions in the gas supply also forced households not connected to central heating to rely on electricity for heating (Balabanyan et al. 2015).Households with central heating in the Kyrgyz Republic also tend to use electricity as an additional source of heating. This has led to an increase in the demand for electricity at peak hours, resulting in power outages during the winter months (Balabanyan et al. 2015). A wider use of electricity for household heating is not a preferable option, as least until there is sufficient capacity to supply the needed electricity in the winter.

In Kazakhstan, there were a few cases of shortage of solid fuel and queues at points of sale for coal in 2018. As a result, officials called upon residents to stock up on coal prior to the heating season. It therefore seems that coal is even officially promoted for the use and security in the supply of heating fuel is a priority, although it is solid fuel.

Current efforts by the governments of Kazakhstan and the Kyrgyz Republic have mostly focused on the development of the supply-side energy infrastructure and ensuring security in the supply for central heating, gas, and electricity. To the best of our knowledge, there are no specific programs targeted to facilitate energy transition at

the household level, particularly addressing rural households. Development programs in the two countries envisage the expansion of energy-generating capacity via the construction of new power plants, government facilitation of the use of renewable energy sources, increased energy efficiency, and the use of energy-saving technologies. Policies in the heating sector mostly focus on the development of central heating systems in urban areas, while heating in rural areas remains overlooked in current policies.

The governments of the two countries have also focused on the expansion of the gas pipeline network. From 2013 to 2019, the gas network in Kazakhstan was expanded as the share of the population with access to piped gas network increased from 30% in 2013 to 52% in 2019 (Kaztransgas 2019). In 2019, construction of the Saryarka gas pipeline was completed, which aimed to provide natural gas access to the some of the gas-deficient regions of Kazakhstan (Karimova 2019).

With the purchase of the majority of shares in Kyrgyzgas SUE for 25 years by the Russian gas company Gazprom JSC in 2013, gas infrastructure development may see improvements (Balabanyan et al. 2015). Gazprom JSC plans to invest in the rehabilitation of the existing gas infrastructure and the development of the Kyrgyz Republic's indigenous natural gas reserves (Balabanyan et al. 2015), which could lead to better access to and reliability for natural gas. Additionally, a gasification plan was adopted targeting to ensure access to natural gas to 60% of the population by 2030 (Gazprom 2015). However, these plans for expanded access to piped gas do not cover all areas, leaving many distant and remote rural households without access to clean fuels.

In Kazakhstan, even if piped gas is available in a neighborhood, some households do not switch to gas and continue using coal, possibly because of the relatively high cost of connection or the high cost of a gas boiler and the price of gas. Due to the higher cost of cleaner options, the wide use of efficient heating technologies at scale would require dedicated targeted financing mechanisms and a targeted incentive program from the government alongside awareness-raising campaigns (Balabanyan et al. 2015). Balabanyan et al. (2015)has recommended, for example, that the Kyrgyz Republic launch a scalable program for more efficient small heating technologies (more efficient individual stoves, boilers, and heat pumps) targeted to households using inefficient individual heating solutions as a primary heat source.

4. DATA AND DESCRIPTIVE STATISTICS

4.1 Data

For Kazakhstan, we used microdata from the household fuel and energy consumption survey, 2017, which was collected by the Statistics Committee of the Republic of Kazakhstan. This was the first survey implemented for Kazakhstan. This cross-sectional dataset has a sample of 21,000 collected proportionately to the population from all five regions of the country. The survey includes information on household fuel choice in the type of settlement, year of housing construction, housing area, number of residents, type of housing, heating system, consumption of fuel types and energy, and other information related to the user equipment for space heating. The limitation of this dataset is that it does not include information related to the socio-economic and demographic characteristics of households.

In Kazakhstan there are four major types of residential heating systems installed within household premises: central heating, autonomous heating based on natural gas and

electricity, autonomous heating based on firewood and coal, and individual stoves. Households that use central heating or autonomous heating systems do not have control over the fuel choices: they pay a fixed price set by the heating providers. In turn, households that use an individual stove for heating incur expenditures related to energy use and have greater control over the choice of fuel based on the type of stove.

For the Kyrgyz Republic, data from the 2016 Life in the Kyrgyz Republic survey were used. This survey was conducted by a consortium of institutions comprised of the Leibniz Institute of Vegetable and Ornamental Crops (IGZ), Food and Agriculture Organization of the United Nations (FAO), International Food Policy Research Institute (IFPRI), and UCA. Data include widespread information on the household level and is representative at the national level. Generally, the proportionate survey includes about 3,000 households. After controlling for the available information, the final sample was reduced to 2,521 households, but due to missing data for some answers, the sample size varied depending on the outcome variable.

Along with the characteristics of the household and household head, information on the household expenditure on the main energy types was used. In particular, the survey recorded household expenditures on electricity, coal, petrol, and gas, although it did not identify the quantity of consumed energy. Price information for each region for each type of energy source was used to convert expenditures into the physical quantity for each energy type. There is, however, no available information with detailed data on energy prices at the regional level. Because of this, energy prices at the regional level were obtained using the consumer price index for the item “energy, gas, and other types of fuels” for each region and the average price at the national level. However, in our estimations petrol was excluded because it is mainly used for transportation and not for residential heating.

4.2 Descriptive Statistics

Examining heating types across Kazakhstan, 51% of households use central heating, 32% use individual stoves, and 17% use autonomous systems. Across settlements, urban households tend to use more central heating, while rural households tend to use individual stoves. Households that use individual stoves primarily use coal (above 70%) and less natural gas and electricity. Demand for fuel used for cooking has more balanced representation, as households use more electricity and natural gas, and less solid fuel. Out of all households, 34% live in rural areas and 66% in urban areas. Of all respondents 58% live in apartments and 41% in detached houses, while the remaining live in dormitories and large mansions. We used monthly per capita expenditure decile classes to control for income. Summary statistics are presented in Tables 1–5.

Table 1: Number of Households by Heating System, Kazakhstan

	Kazakhstan		Rural		Urban	
Heating Types	**Frequency**	**%**	**Frequency**	**%**	**Frequency**	**%**
Central heating	10,728	51.09	1,448	20.07	9,280	67.32
Autonomous (gas, electricity)	2,907	13.84	1,193	16.53	1,714	12.43
Autonomous (wood, coal)	660	3.14	458	6.35	202	1.47
Individual stove (natural gas, electricity)	973	4.63	556	7.71	417	3.03
Individual stove (mixed: coal and others)	735	3.5	410	5.68	325	2.36
Individual stove (coal)	4,997	23.8	3,150	43.66	1,847	13.4
Total	21,000	100	7,215	100	13,785	100

Table 2: Demand for Heating Fuel Types Used in Individual Stoves by Household, Kazakhstan

Fuel Types Used in Individual Stove	Kazakhstan		Rural		Urban	
	Frequency	%	Frequency	%	Frequency	%
Solid	4,997	74.53	3,150	76.53	1,847	71.34
Mixed solid	735	10.96	410	9.96	325	12.55
Natural gas and electricity	973	14.51	556	13.51	417	16.11
Total	6,705	100	4,116	100	2,589	100

Table 3: Distribution of Households by Primary Heating Source, the Kyrgyz Republic

Main Source of Heating	Rural		Urban		Total	
	Frequency	%	Frequency	%	Frequency	%
Central heating	35	2.24	332	34.73	367	14.58
Electric heating	140	8.97	172	17.99	312	12.4
Stove (coal and wood)	1,386	88.79	430	44.98	1,816	72.15
Gas heating	—	—	22	2.3	22	0.87
Total	1,561	100	956	100	2,517	100

Source: Life in the Kyrgyz Republic 2016, authors' calculations.

Table 4: Summary Statistics for Kazakhstan

Variable	Obs	Mean	Std. Dev.	Min	Max
MPCE_class (logs)	8,466	5.48	2.88	1.00	10.00
Log of coal price	21,000	9.42	0.22	8.97	9.74
Log of liquefied gas price	21,000	7.88	0.29	7.08	8.19
Log of electricity price	21,000	7.37	0.25	6.57	7.70
Heating type					
Stove: clean and mixed dirty	21,000	0.32	0.47	0.00	1.00
Household size	21,000	3.28	1.88	1.00	15.00
Heated area, m^2	21,000	55.12	33.91	2.00	864.00
Apartment, dormitory	21,000	0.59	0.49	0.00	1.00
Year of housing construction	21,000	1,980.61	46.99	100.00	2,018.00
Cooking fuel: natural gas	21,000	0.29	0.45	0.00	1.00
Cooking fuel: electricity	21,000	0.40	0.49	0.00	1.00
Cooking fuel: liquefied petroleum gas	21,000	0.27	0.44	0.00	1.00
Rural	21,000	0.34	0.47	0.00	1.00
Regions					
East	21,000	0.10	0.30	0.00	1.00
South	21,000	0.40	0.49	0.00	1.00
North	21,000	0.16	0.36	0.00	1.00
Central	21,000	0.21	0.40	0.00	1.00

Source: Authors' calculations.

Table 5: Summary Statistics for the Kyrgyz Republic

Variable	Obs	Mean	Std. Dev.	Min	Max
Coal consumption, quantity	2,529	9.97601	9.053324	0	62.49
MPCE classes	2,521	5.496628	2.872849	1	10
Coal price, log	2,529	8.425956	0.020627	8.3615	8.45
Cooking fuel: natural gas	2,509	0.156238	0.363153	0	1
Cooking fuel: liquefied petroleum gas	2,509	0.104823	0.306386	0	1
Cooking fuel: electricity	2,509	0.262654	0.440164	0	1
Heating: electric	2,517	0.123957	0.329598	0	1
Heating: stove	2,517	0.721494	0.448353	0	1
Heating: natural gas	2,517	0.008741	0.0931	0	1
Household head age	2,529	53.97707	13.45119	21	90
Household head education: secondary	2,175	0.52092	0.499677	0	1
Household head education: technical	2,175	0.168276	0.374197	0	1
Household head education: tertiary	2,175	0.168276	0.374197	0	1
Household Size	2,529	5.253855	2.537303	1	17
Number of rooms in dwelling	2,325	3.606022	1.357569	1	12
Ownership: rented	2,176	0.028033	0.165105	0	1
Sector: rural	2,529	0.621194	0.485186	0	1
Access to gas	2,529	0.283511	0.450792	0	1
Regional dummy	2,529	4.716093	2.580673	1	9

Source: Life in the Kyrgyz Republic 2016, authors' calculations.

5. EMPIRICAL METHODS

Using national representative data from Kazakhstan and the Kyrgyz Republic, the study used different country-level regression models to analyze the household energy consumption patterns. The main objective of the paper was to model:

1. participation in clean energy for space heating,
2. dominant fuel choices for space heating, and
3. consumption of coal

Due to the differences in the survey orientation in the two countries, the model specification varies slightly across the two countries. However, efforts have been made to keep the variables/indicators as close possible to yield comparable results across the specific country regression model.

For modeling household participation in clean energy for space heating, we considered participation in the central heating as the outcome of interest, with choice of the dominant fuel and the quantity of various fuels consumed by the households. First, we used a logit model to analyze the participation in central heating as a function of the built environment and household regional and socioeconomic factors (Equation 1). We estimated the following models:

$$Pr(central\ heating = 1) = \alpha + \sum \beta X_{idr} + \sum \gamma B_{idr} + \sum \delta I_{idr} + \sum \eta U_{idr} + \sum \theta U_d + \varepsilon \quad (1)$$

and

$$Pr\ (fuel\ type = k) = \alpha + \sum \beta X_{idr} + \sum \gamma B_{idr} + \sum \delta I_{idr} + \sum \eta U_{idr} + \sum \theta U_d + \varepsilon, \quad (2)$$

where X_{idr} is a vector of household variables for household *i* from sub-region *d* and region *r*; B_{idr} is the vector of built-in quality, dwelling status, and appliances; and U_d and K_r are sub-regional and region controls. In the model we also controlled for the income/assets of the household as I_{idr}. We included average national price minus the price for that particular region as an instrument of fuel prices in the model. We further used a multinomial logit model to estimate the dominant fuel choices for heating in case the households use an individual stove (Equation 2).

Adapting from Adusah-Poku and Takeuchi (2019)we finally estimated the determinants of total expenditure on coal by household using a double hurdle model. This model provides an efficient method to model household expenditure/consumption patterns for a certain commodity. The model assumes that there are two hurdles the households need to pass before they are observed with a positive level of consumption. The first hurdle is the participation decision. The second hurdle (quantity purchased decision) is the decision related to how much to spend/consume conditional on having a positive participation decision. It can be specified as follows:

$y_{i1}^{*} = w_i \gamma + u_i$(participation decision) (3)

$y_{i2}^{*} = x_i \delta + v_i$ (quantity purchased decision) (4)

$y_i = x_i \delta + u_i$ if $y_{i1}^{*} > 0 \; and \; y_{i2}^{*} > 0$ (5)

y_i=0 otherwise, (6)

where y_i is the observed level of expenditure, w_i and x_i are the various household and built environment factors related to each sample household, and u_i and v_i are independent normally distributed error terms. The final double hurdle model was estimated as the log-likelihood of the Tobit equation.

The results obtained from the maximum likelihood estimation were used to compute three types of marginal effects: the overall effect E[y_i| x]; the conditional expectation; and the probability of the positive value of y_i for all values of the regression. The first unconditional expectation can be decomposed into the latter two.

6. RESULTS AND DISCUSSIONS

6.1 Participation in Central Heating

Central heating is considered a reliable, modern, and clean source of heating. Although it does not reduce greenhouse gas emissions, it does reduce indoor pollution. The main drawback of choosing central heating for households is that the expenditure is outside of the household's control—because it is calculated based on the dwelling size—and it requires access to infrastructure. Alternatives to central heating are individual heating systems using coal, gas, or electricity.

Central heating disincentivizes energy efficiency improvements in buildings. Central Asia also lacks policies incentivizing energy efficiency improvements in buildings more generally, such as mandatory codes and standards, including building energy codes. A standardized, uniform, and credible certification of energy performance and rating system for buildings could make energy efficiency improvements in buildings more visible and thus more attractive.

The results of the estimation of the determinants of participation in central heating in Kazakhstan and the Kyrgyz Republic are presented in Table 6. The determinants are categorized as follows: household and household head characteristics, dwelling characteristics, fuel access and price. The variables included in the estimations for the two countries are not identical due to the data limitations.

Household and household head characteristics were important determinants in household choice of centralized heating. Household head education and household location had a significant impact on the choice of central heating. Households in which the household head has a technical or tertiary education were more likely to have access to central heating by 4% and 8%, respectively, compared to those with only a school education in the Kyrgyz Republic. More educated household heads were more aware of the impact of indoor pollution caused by heating the dwelling using traditional stoves with solid fuels on health (Alem et al. 2016). Living in rural areas reduced the probability of choosing the central heating by 2.4% in Kazakhstan and by 10.2% in the Kyrgyz Republic relative to urban areas, which is quite intuitive given that rural areas rely on individual stove more than urban areas do. This leads to the result that urban households appear to prefer cleaner heating, which is consistent with (Pachauri and Jiang 2008). Also, household head education and household location could be a proxy for household income. More educated household heads and urban households are likely to have higher incomes. Households with higher incomes choose central heating as a more reliable, modern, and cleaner heating source. This result is consistent with the energy ladder hypothesis by (Leach 1992). Other household head and household characteristics, such as household size, as well as household head age and gender, have no significant effect of the household choice of central heating.

Dwelling characteristics have a significant effect on the probability of choosing central heating. Households living in apartments or dormitories have a higher probability of participating in central heating compared to households living in detached houses or mansions in Kazakhstan. Dwelling size has a significant impact on the choice of central heating, but the results for Kazakhstan and the Kyrgyz Republic are controversial. Dwelling size has a positive impact on the choice of central heating in Kazakhstan and a negative impact in the Kyrgyz Republic. An increase in the dwelling size, measured by the heated area, of 10 m^2 increases the probability of choosing central heating by 0.22% in Kazakhstan, while an increase in the dwelling size, measured by number of rooms, of one room reduces the probability of choosing central heating by 4.37% in the Kyrgyz Republic. Other dwelling characteristics, such as year of construction and ownership (private or rented), have no significant effect on participation in central heating.

Fuel access has a significant impact on the choice of central heating. Access to fuel is measured by the fuel used for cooking. Households with access to gas are more likely to use central heating in Kazakhstan and the Kyrgyz Republic. Households without access to gas, which use electricity for cooking, are less likely to use central heating in Kazakhstan. However, in the Kyrgyz Republic, this has no significant impact.

Fuel prices have a significant impact on the choice of central heating in Kazakhstan. Higher prices for coal and natural gas price increase the probability of using central heating, so it appears that central heating is a substitute for coal and gas. However, the electricity price reduces the probability of using central heating. Because we use regional energy prices instead of household prices due to data availability, these results suggest that households living in regions with higher prices for coal and natural gas tend, on average, to have a higher share of central heating. The results are as expected, because higher prices for fuel will lead to a transition to the use of other heating systems, such as central heating. In turn, households from regions that

experience higher electricity prices are likely to have a lower probability of using central heating versus other types of heating. Regions with lower electricity prices are mainly Western regions that also have better access to pipeline gas, so they have a lower likelihood of choosing central heating compared to other regions. Households with central heating have lower per capita expenditure on energy (MPCE) in Kazakhstan.

Table 6: Determinants of Participation in Central Heating in Kazakhstan and the Kyrgyz Republic, Marginal Effects (Logit)

Dependent variable: central heating (central heating=1; autonomous heating=0; and individual stove=0)	Kazakhstan	The Kyrgyz Republic
Household head age		0.000339
		(0.000444)
Household head gender (male=1)		–0.00479
		(0.0111)
Household head education (base category: school)		
Secondary		0.0160
		(0.0188)
Technical		0.0409**
		(0.0203)
Tertiary		0.0839***
Household size	–0.000629	–0.00273
	(0.00111)	(0.00313)
Heated area, m^2	0.000220***	
	(6.94e-05)	
Apartment, dormitory	0.0868***	
(detached house=0)	(0.00403)	
Year of housing construction	3.39e-05	
	(0.000117)	
No. of dwelling rooms		–0.0437***
		(0.00509)
Ownership: rented		–0.00842
		(0.0261)
Cooking fuel: natural gas	0.0151	0.181***
	(0.0153)	(0.0375)
Cooking fuel: electricity	–0.00778**	0.00592
	(0.00373)	(0.0241)
Cooking fuel: liquefied petroleum gas	0.0238***	–0.0250
	(0.00380)	(0.0189)
Rural (urban=0)	–0.0238***	–0.102***
	(0.00349)	(0.0185)
Access to gas		0.00444
		(0.0144)
Coal price, log	0.150***	
	(0.0437)	
Liquefied gas price, log	0.0790***	
	(0.0239)	
Electricity price, log	–0.112***	
	(0.0251)	
Control for region	Yes	Yes
Control for income class	Yes	Yes
Observations	8,466	1,940

Note: Standard errors in parentheses.

6.2 Dominant Heating Systems

The choice of heating fuel is determined by the heating system installed in the premises. We analyzed the determinants of heating systems by estimating a multinomial logit regression (Eq. 2). The dependent variable was a categorical variable—an indicator of the type of heating used by the individual households. All explanatory variables from the previous model (Eq. 1) were included. Table 7 includes five dependent variables, because five types of heating system are used in Kazakhstan. Table 8 includes four dependent variables, because four types of heating system are used in the Kyrgyz Republic. For both the countries, we calculated the margins, using participation in the central heating as a base category.

Table 7: Determinants of Participation in Different Heating Systems in Kazakhstan, Marginal Effects (Multinomial Logit)

Variables	Central Heating	Autonomous Heating	Individual Stove: Gas and Electricity	Individual Stove: Coal and Firewood
Coal price, log	0.186***	0.170***	–0.220***	–0.427***
	(0.0447)	(0.0389)	(0.0610)	(0.0675)
Liquefied gas price, log	0.100***	0.125***	0.0175	–0.242***
	(0.0233)	(0.0245)	(0.0203)	(0.0357)
Electricity price, log	–0.0563**	0.101***	0.0215	0.561***
	(0.0255)	(0.0297)	(0.0392)	(0.0664)
Household size	–0.000316	–9.59e-05	5.44e-05	–0.00759***
	(0.00106)	(0.00162)	(0.000558)	(0.00216)
Heated area, m^2	0.000154**	0.000412***	–0.000127***	–0.000508***
	(6.47e-05)	(9.81e-05)	(4.46e-05)	(0.000149)
Apartment, dormitory	0.0771***	0.00975	0.00283	–0.105***
(detached house=0)	(0.00386)	(0.00603)	(0.00203)	(0.00934)
Year of housing construction	0.000163	–0.000170***	0.000404***	–0.000386**
	(0.000112)	(5.26e-05)	(6.06e-05)	(0.000155)
Cooking fuel: natural gas	0.0108	0.0975***	0.00346	0.0679
	(0.0146)	(0.0237)	(0.00446)	(0.0637)
Cooking fuel: electricity	–0.0104***	0.0106*	–0.0126***	–0.0274***
	(0.00359)	(0.00615)	(0.00221)	(0.00863)
Cooking fuel: liquefied petroleum gas	0.0168***	–0.00243	–0.0313***	0.0747***
	(0.00349)	(0.00689)	(0.00208)	(0.00913)
Rural (urban=0)	–0.0237***	0.0221***	0.00468**	0.0290***
	(0.00341)	(0.00638)	(0.00218)	(0.00877)
Regional controls	Yes	Yes	Yes	Yes
Income class controls	Yes	Yes	Yes	Yes
Observations	8,466	8,466	8,466	8,466

Table 8: Determinants of Participation in Different Heating Systems in the Kyrgyz Republic, Marginal Effects (Multinomial Logit)

Variables	Central Heating	Electric Heating	Stove (Coal and Firewood)	Gas
Household head age	0.000245	–0.00123**	0.00117*	–0.000182
	(0.000427)	(0.000544)	(0.000616)	(0.000181)
Household head gender (male=1)	–0.00731	–0.0176	0.0269	–0.00195
	(0.0107)	(0.0149)	(0.0165)	(0.00414)
Household head education (base: school)				
Secondary	0.00905	0.00260	–0.0272	0.0155
	(0.0180)	(0.0205)	(0.0240)	(0.0103)
Technical	0.0365*	–0.00198	–0.0341	–0.000377
	(0.0192)	(0.0239)	(0.0276)	(0.00867)
Tertiary	0.0782***	–0.0123	–0.0626**	–0.00338
	(0.0207)	(0.0246)	(0.0288)	(0.00824)
Household size	–0.00233	–0.00813**	0.00817*	0.00230**
	(0.00298)	(0.00392)	(0.00429)	(0.00103)
No. of dwelling rooms	–0.0422***	0.00102	0.0366***	0.00464***
	(0.00488)	(0.00538)	(0.00625)	(0.00175)
Ownership: rented	0.0729	0.0704	–0.00895	–0.134
	(24.87)	(1.560)	(15.36)	(41.79)
Cooking fuel: natural gas	0.204***	0.162***	–0.382***	0.0157***
	(0.0410)	(0.0505)	(0.0554)	(0.00535)
Cooking fuel: electricity	0.0139	0.284***	–0.296***	–0.00216
	(0.0224)	(0.0409)	(0.0447)	(0.00265)
Cooking fuel: liquefied petroleum gas	–0.0157	0.141***	–0.128***	0.00219
	(0.0177)	(0.0202)	(0.0267)	(0.00517)
Rural (urban=0)	–0.0315	–0.0836	0.223	–0.108
	(4.347)	(0.273)	(2.684)	(7.304)
Access to Gas	0.00393	0.0251	–0.0292	0.000197
	(0.0139)	(0.0172)	(0.0193)	(0.00516)
Control for region	Yes	Yes	Yes	Yes
Control for income class	Yes	Yes	Yes	Yes
Observations	2,023	2,023	2,023	2,023

Energy prices are important determinants for heating system choice in Kazakhstan. Regions with higher coal prices are more likely to use central or autonomous heating and less likely to use coal and firewood. Regions with higher electricity prices are more likely to have an autonomous system and solid fuel. The results indicate that the prices of coal and electricity are important determinants for choosing solid fuels. In Kazakhstan, newer buildings are less likely to have autonomous heating and individual stoves based on solid fuels and more likely to have individual stoves based on clean fuels, such as natural gas and electricity. This result is expected, as newer houses are more modern and therefore use cleaner and more modern fuels.

Access to infrastructure provides more modern and cleaner heating options and thus discourages the use of solid fuels. Cooking fuels are used as proxies for access to heating fuels. Households with access to piped natural gas are more likely to use gas for heating and less likely to use solid fuels in the Kyrgyz Republic by 1.58% and 38.2%, respectively. Households with access to electricity are more likely to use electric heating and less likely to use solid fuels in the Kyrgyz Republic by 28.4%

and 29.6%, respectively. Unfortunately access to infrastructure in Kazakhstan is of insignificant or very minor importance, and rural households are less likely to use central heating and more likely to use solid fuels by 2.37% and 2.90%, respectively. This may be due to a lack of clean energy supply infrastructure (e.g., natural gas pipeline and central heating) in rural areas.

Table 9: Estimated Elasticities for Coal Consumption in Kazakhstan using Double Hurdle Model

Dependent Variable: Coal Consumption (quantity)	**Prob. P[y_i>0|x]**	**Cond. Mean E[y_i|x, y_i>0]**	**Uncond. Mean E[y_i|x]**
(1)	**(2)**	**(3)**	**(4)**
Coal price, log	–0.511	1.030**	–0.181***
	(0.344)	(0.436)	(0.048)
Liquefied gas price, log	–1.379***	0.219	–0.227***
	(0.188)	(0.229)	(0.029)
Electricity price, log	–0.738**	–1.559***	0.049
	(0.301)	(0.342)	(0.033)
Heating			
Stove clean and mixed solid	0.669***	–0.119	0.122***
	(0.081)	(0.080)	(0.011)
Household size	0.024*	0.023	0.001
	(0.013)	(0.014)	(0.002)
Heated area, m^2	0.014***	0.019***	0.0002**
	(0.001)	(0.001)	(0.0001)
Apartment, dormitory	–0.601***	–0.101	–0.079***
(detached house=0)	(0.060)	(0.063)	(0.006)
Year of housing construction	–0.001*	0.004***	–0.001***
	(0.001)	(0.001)	(0.0002)
Cooking fuel: natural gas	–0.815***	–0.786**	–0.041
	(0.281)	(0.329)	(0.027)
Cooking fuel: electricity	0.089*	–0.191***	0.033***
	(0.051)	(0.057)	(0.006)
Cooking fuel: liquefied petroleum gas	–0.307***	–0.550***	0.010*
	(0.055)	(0.062)	(0.006)
Rural (urban=0)	–0.137***	–0.173***	–0.003
	(0.051)	(0.057)	(0.006)
Control for regions	Yes	Yes	Yes
Control for income class	Yes	Yes	Yes
Observations	8,466	8,466	8,466

Note: Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

Tables 9 and 10 report the results for the double hurdle model of the use of coal as a heating fuel in Kazakhstan and the Kyrgyz Republic, respectively: all reported values are marginal effects. Columns (2) and (3) of Tables 9–10 show the factors influencing the probability that households participate in the coal market, as well as coal consumption conditional on the coal market participation. The results indicate that the factors influencing the decision to participate in the coal market are different from those influencing the quantity of household coal consumption.

Table 10: Estimated Elasticities for the Double Hurdle Model for the Kyrgyz Republic: Coal Quantities

	Prob. $P[y_i>0\|x]$	Cond. Mean $E[y_i\|x, y_i>0]$	Uncond. Mean $E[y_i\|x]$
Household head age	0.007	0.0093936	–0.000
	(0.012)	(0.012)	(0.000)
Household head education (base: school)			
Secondary	–0.754	–0.735*	–0.014
	(0.473)	(0.450)	(0.015)
Technical	–1.762***	–1.675***	–0.038**
	(0.578)	(0.547)	(0.017)
Tertiary	–1.182**	–1.005*	–0.0376306
	(0.615)	(0.616)	(0.017)
Household size	1.152***	1.116***	0.023***
	(0.077)	(0.080)	(0.002)
No. of dwelling rooms	0.502***	0.416***	0.017***
	(0.1294)	(0.143)	(0.003)
Ownership: rented	–1.097	–0.9075848	–0.0374401
	(1.303)	(1.284)	(0.029)
Cooking system: gas pipeline	–3.594***	–2.880***	–0.135***
	(0.890)	(0.833)	(0.035)
Cooking system: electric stove	–0.780*	–0.223	–0.056**
	(0.472)	(0.488)	(0.022)
Cooking system: liquefied petroleum gas	–0.3334307	0.138	–0.040
	(0.748)	(0.722)	(0.025)
Heating system: electric	0.274	–3.508*	0.206***
	(1.705)	(2.144)	(0.065)
Heating system: stove	6.513***	0.7310272	0.477***
	(1.698)	(2.064)	(0.064)
Heating system: natural gas	–4.180**	–7.295***	–0.124
	(1.882)	(0.315)	(0.120)
Rural (urban=0)	–2.356***	–2.712***	–0.0047128
	(0.430)	(0.679)	(0.014)
Access to gas	0.5169502	–0.4148596	–0.018*
	(0.456)	(0.452)	(0.011)
Control for region	Yes	Yes	Yes
Control for income class	Yes	Yes	Yes
Observations	2,023	2,023	2,023

Note: Standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1.

Base categories.

Cooking System: Stove.

Heating System: central heating.

More educated household heads consume less coal in the Kyrgyz Republic. Households with individual stoves are 66.9% more likely to participate in the coal market; however this has no effect on coal consumption conditional on participation in the coal market. Larger houses and households are more likely to use coal and have greater coal consumption in both countries. Households living in apartments or dormitories are 60% less likely to consume coal, while the effect on coal consumption is not significant in Kazakhstan. Newer houses are less likely to have coal heating by only 0.1% and consume more coal by 0.4% in Kazakhstan. This suggests that newer houses are not more energy efficient.

Households with access to natural gas, electricity, and LPG are less likely to consume coal and have lower coal consumption in Kazakhstan. However, in the Kyrgyz Republic, households using natural gas for cooking are three times less likely to participate in the coal market and also to consume less coal if they do use it. Similarly, in the Kyrgyz Republic, households using natural gas as a dominant heating fuel are four times less likely to consume coal. This indicates a clear policy implication for the establishment of pipeline supply infrastructure with wider geographical coverage for both cooking and heating needs.

Rural households are less likely to use coal in both country samples. Estimations conditional on coal market participation show the same result. This could be due to access to other traditional solid fuels, such as firewood, in rural areas.

7. CONCLUSIONS AND POLICY RECOMMENDATIONS

Three models—logit, multinomial logit and double hurdle—were used to identify the determinants of solid heating fuel use in Kazakhstan and the Kyrgyz Republic. The following determinants have policy implications. Energy prices are important determinants of the choice of heating system. Regions with higher coal prices prefer central heating, while regions with higher electricity prices prefer to use solid fuels. Increases in the price of electricity are usually recommended in the literature to promote renewable energy and energy efficiency, but in Central Asia a higher electricity price could lead to greater solid fuel consumption, which would lead to greater indoor pollution.

Education is important to reduce household solid fuel consumption. Thus, policymakers could help reduce household solid fuel consumption and thus indoor pollution by educating households about the indoor pollution and its harmful effects on health.

Access to modern and clean energy infrastructure, such as central heating and natural gas pipelines, could also reduce household solid fuel consumption. It is important to ensure access to cleaner and more modern fuels, especially in rural areas, to reduce dependence on solid fuels.

Unfortunately, the heating of newer dwellings does not lead to lower coal consumption. This could be due to the lack of energy efficiency improvements in newer residential buildings, perhaps because centralized heating and subsidized/controlled energy prices in Central Asia disincentivize energy efficiency improvements. Central Asia also lacks policies that incentivize improvements in building energy efficiency, such as mandatory codes and standards, including building energy codes. A standardized, uniform, and credible certification of energy performance and a rating system for buildings could make improved energy efficiency more visible and thus more attractive.

Dwelling size increases coal consumption. This raises a concern given that energy prices in Central Asia are heavily subsidized or controlled by the government and do not include the full social cost—including negative externalities. Energy prices in Central Asia are usually flat and do not depend on the amount of energy consumed, so households with larger dwellings receive greater benefits from subsidized or controlled energy prices. Dwelling size can reach 864 m^2 in Kazakhstan and 12 rooms in the Kyrgyz Republic. Higher energy prices could incentivize smaller dwellings and thus lower energy consumption for heating.

Energy pricing reforms in Central Asia should be undertaken with care to avoid any tendency to switch to solid fuels, which would lead to greater indoor pollution. Policies promoting cleaner fuels to reduce indoor pollution could include (1) providing access to cleaner fuels (e.g., natural gas pipeline and central heating); (2) education about indoor pollution; (3) usage-based progressive heating tariffs; and (4) a standardized, uniform, and credible certification for energy performance and a rating system for energy efficiency in buildings.

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