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Research article

Why energy access is not enough for choosing clean cooking fuels? Evidence from the multinomial logit model

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A B S T R A C T

The transition to sustainable energy requires an assessment of drivers of the use of clean and dirty fuels for cooking. Literature highlights the importance of access to clean fuel for switching from dirty fuels to clean fuels. Though access to cleaner fuels, such as electricity promotes clean fuel use, it does not necessarily lead to a complete transition to the use of clean fuels. Households continue using traditional fuels in addition to the clean fuels. The main objective of this paper is to explain the choice of dirty cooking fuels even when access to electricity is provided. We use nationally representative household survey data to study the household energy use decisions in three middle-income countries, namely, India, Kazakhstan, and the Kyrgyz Republic. The study discusses the role of access to natural gas, free fuel, convenience or multi-use of fuels featured by the heating system installed, built-in environment, and other socio-economic factors in household fuel choice for cooking. The results show that access to natural gas increases the likelihood of opting for clean fuel, while the availability of free fuel in rural areas and the coal-based heating system promote the use of solid fuels.

1. Introduction

Ensuring access to affordable, reliable, sustainable, and modern energy for all by 2030 is the seventh of the 17 UN Sustainable Development Goals (Resolution of the General Assembly on 25 September, 2015). Fuel choices for cooking are not only important for SDG 7.1—"to ensure universal access to affordable, reliable, and modern energy services"—but are highly important to achieve other goals such as good health and wellbeing (SDG 3) and climate action (SDG 13). There is a strong evidence that the combustion of solid fuels in inefficient stoves leads to the release of suspended particulate matter, carbon monoxide, polyaromatic hydrocarbons, polyorganic matter, and formaldehyde that have adverse effects on health (Kankaria et al. 2014). Cooking with solid fuels presents high health risks, especially for women and children. Household choice of fuel also contributes to climate change due to greenhouse gas (GHG) emissions (Smith and Haigler 2008). Recognizing the above facts, SDG 7 includes SDG 7.1 which is to ensure universal access to affordable, reliable, and modern energy services by 2030.

Developing countries are striving hard toward their gasification and electrification targets, with commendable results in the past few years. However, effective public policy aiming to increase large-scale access to clean fuels needs to be coupled with an effective transition. This has been a concern of many middle-income countries, including India, Kazakhstan, and the Kyrgyz Republic, where 'dirty' solid fuels are still used, especially in rural areas (Gassmann and Tsukada 2014; Kerimray et al., 2018; Ravindra et al., 2019). In India, 78% of rural households rely on solid biomass for cooking due to poor quality of life, equity, and economy (Ravindra et al., 2019), while in Kazakhstan only 6% of surveyed households were using solid fuels for cooking. Widespread power cuts in the Kyrgyz Republic could be one of the factors limiting households from switching fully to cooking with electricity in the Kyrgyz Republic. Many areas in India, Kazakhstan, and the Kyrgyz Republic suffer from poor air quality, due to the use of solid fuels by households which contribute to outdoor and indoor air pollution (Kankaria et al.

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2014; Kenessary et al., 2019; UNDP 2012b). Rasoulinezhad et al. (2020) study for Kazakhstan, the Kyrgyz Republic and other CIS[1] countries found that CO_2 emissions and fossil fuel consumption are associated with increase in mortality from cardiovascular disease, diabetes, cancer, and chronic respiratory disease. Another study by Taghizadeh-Hesary and Taghizadeh-Hesary (2020) also found that CO_2 and $PM_{2.5}$ are major risk factors of lung cancer in the Southeast Asian region and therefore deployment of renewable energy can reduce air pollution, and consequently, reduce the lung cancer prevalence. International Energy Agency (2020) estimates that the switch from coal to gas in the residential sector of Kazakhstan by 2030 would result in the reduction of emissions of $PM_{2.5}$ by 88% from the 2018 level by 2030, as well as CO (−78%), NOx (−41%), SOx (−77%), CO_2 (−93%).

Transition to clean cooking is imperative due to its multiple co-benefits, primarily health and climate benefits (Goldemberg et al., 2018). To design efficient policies targeting the transition to clean energy use, quantitative assessments are needed for a better understanding of the determinants of households' fuel choice.

Previous studies on the determinants of household cooking fuel choice focus on socioeconomic characteristics (e.g., income, gender and age of household head, dwelling, and cookstove), behavioral and cultural factors (e.g., food taste and lifestyle), and external factors such as availability of fuels, physical environment, market conditions, and government policies (Alem et al., 2016; Brooks et al., 2016; Timilsina 2014). Countries have unique characteristics which result in different energy consumption and different determinants of fuel mix (Lenzen et al., 2006). Hence, there is no one-size-fits-all recipe for energy transition or energy ladder, a theory suggesting that a transition from traditional to clean fuels is mainly driven by economic factors, as these factors can differ across regions, countries, and climatic zones, thus highlighting the complexity of fuel switching (Karimu et al. 2016; Lenzen et al., 2006; Martey 2019). Moreover, higher incomes do not necessarily lead to a complete transition to the use of clean fuels. Households tend to continue using traditional fuels in addition to clean fuel, showing 'fuel stacking' behavior (Choumert-Nkolo et al. 2019; Lay et al. 2013; Masera et al. 2000; Quinn et al., 2018; Shankar et al., 2020).

The extant literature on the choice of cooking fuel mainly focused on the importance of energy access. Why households consume solid fuels even when access to cleaner fuels is provided, is still poorly understood. This paper contributes to the literature by explaining the choice of solid fuels when access to clean cooking fuel, i.e. natural gas, liquefied petroleum gas (LPG), and electricity is already provided.

The main objective of this paper is to assess the role of access to natural gas, free fuel, convenience or multi-use of fuels taking into consideration the heating system installed, built-in environment, and socioeconomic factors on the choice of cooking fuels or cookstove. To have a wider impact, we tried to accommodate diverse population densities, availability of resources, geographical and climatic characteristics, and socioeconomic aspects. However, we were constrained by the comparative micro-data availability at a country level. The scope of the study has been narrowed down to three countries, one from South Asia and two from Central Asia, namely India, Kazakhstan, and the Kyrgyz Republic. Kazakhstan and the Kyrgyz Republic are selected as examples of countries with almost total energy access—i.e., electrification. Although India has not achieved 100% energy access, our sample is limited only to households with access to electricity.

The remainder of the paper is structured as follows. Section 2 reviews the extant literature and provides background information for the three countries. Sections 3-4 present the data and empirical strategy. Section 5 discusses the results. Section 6 concludes with a summary of the results and policy implications.

[1] CIS – Commonwealth of Independent States.

2. Literature review and countries' background information

2.1. Literature review

There is no universally agreed definition of 'clean' cooking fuel. Conventionally, the term is used to refer to cooking solutions that do not generate indoor air pollution (e.g., particulate matter and carbon monoxide) or, if that occurs, the air pollution concentration is significantly low. Also, such cooking practices do not contribute to outdoor air pollution in the form of black carbon emissions.

There is a wide range of factors that influence households' choice of cooking fuel. Prominent factors include socio-economic factors, taste and preference for energy choice, technological change in energy sources, energy carrier availability, and/or shifts in the supply of energy options and their prices (Alem et al. 2014; Alem et al., 2016; Brooks et al., 2016; Gebreegziabher et al., 2018). Cooking with solid fuels is intertwined with structural elements, such as established traditions, income-generating practices, gender norms, and a sense of belonging. These factors profoundly dominate households' decision to continue using solid fuels despite the availability and adoption of modern alternatives (Malakar, Greig, and van de Fliert 2018). Hanna and Oliva (2015), in their study found that an increase in income does not help households switch to a better cooking source, and many of the target households switched to a worse but more readily available source—assets in the form of livestock that produced a cheap source of dung for use as fuel.

Socioeconomic factors studied in the literature often include: household income and size; household head's age, education, and gender; household location (rural or urban). Income is one of the main determinants of fuel choice. The impact of income on fuel choice is explained by the energy ladder hypothesis (Leach 1992), which states that as income increases, households use more reliable, cleaner, and efficient fuel (Fig. 1). Household income is usually measured as total consumption expenditure per capita.

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

Households' location in rural or urban areas largely determines access to fuels. For example, biomass is more accessible in rural than in urban areas. Fuel availability and accessibility are important for the choice of cooking fuel (Alem et al., 2016; Gupta and Köhlin 2006). Clean fuels such as natural gas and electricity are not widely available and accessible to households in developing countries due to the lack of infrastructure. The availability of cleaner cookstoves, such as LPG, electric, or gas cookstoves, is another important determinant (Brooks et al., 2016). A systematic literature review on the determinants of

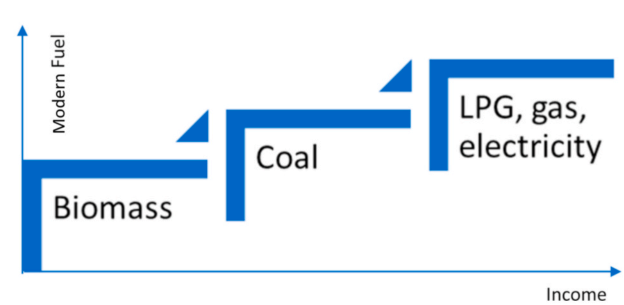

Fig. 1. Energy ladder. Own elaboration using Amoah (2019)

cooking fuel choice is provided in the literature (Lewis and Pattanayak 2012; Muller and Yan 2018; Timilsina 2014). Fuel price is also an important determinant of fuel demand. However, not many studies include fuel prices in their empirical analysis due to data scarcity (Alem et al., 2016).

Most literature studying the choice of cooking fuel uses the multinomial logit method (MLM). The multinomial logit model allows us to accommodate the use of more than one fuel type, which causes fuel stacking behavior (Muller and Yan 2018). This is important because many households use a combination of several cooking fuels and cookstoves.

The empirical literature on cooking fuel choice in India is abundant (Brooks et al., 2016; Menghwani et al., 2019; Ravindra et al., 2019). Cooking fuel preferences in India in general are significantly determined by socioeconomic and cultural factors (Ravindra et al., 2019). Affordability is a great factor in guaranteeing widespread uptake of LPG use in India, especially in rural areas (Gould and Urpelainen 2018; Kumar et al. 2016). Recent programs, such as Pradhan Mantri Ujjwala Yojana (PMUY)[2], facilitating LPG access and subsidies for the poor promoting the use of LPG among wider circles of the population, but affordability of refilling remains an impediment to complete transition to clean fuels (Gould and Urpelainen 2018). In most countries, cooking fuels include traditional solid fuels, such as wood and charcoal, as well as cleaner fuels, such as LPG, electricity, and natural gas. The choice of solid fuel raises most concerns, as such fuel causes both indoor and outdoor pollution.

The studies that uncover the determinants of household fuel demand for cooking in the Kyrgyz Republic and Kazakhstan are scarce. For the Kyrgyz Republic, only a few studies present a profile of household energy consumption and households' fuel choice (Gassmann and Tsukada 2014; Sabyrbekov and Ukueva 2019). Sabyrbekov and Ukueva (2019) argued that high income itself does not guarantee the use of clean energy, but rather results in the consumption of multiple fuels. Conversely, access to gas and education leads to the transition to clean energy. The study by Sabyrbekov and Ukueva (2019) focuses on total household energy demand, while the focus of our paper is on the energy demand for cooking. To the best of our knowledge, no studies have explored the determinants of household energy demand for cooking in Kazakhstan. Previous studies have presented an energy consumption profile of households in Kazakhstan using a household living conditions survey conducted in 2013, covering 12,000 households (Kerimray et al., 2018).

2.2. Overview of countries' fuel demand

Having been subsidized for over three decades, Liquefied Petroleum Gas (LPG) is now a predominantly clean cooking fuel in urban India. Currently, 94% of households have LPG connections, according to Pradhan Mantri Ujjwala Yojana (PMUY) (Patnaik et al. 2019). In Kazakhstan and the Kyrgyz Republic, natural gas or electricity are treated as a predominantly used clean cooking fuel.

In Kazakhstan 40% of surveyed households use electricity, 29% use natural gas, 25 % use LPG, and only 6% of surveyed households use solid fuels for cooking (Table A3.2 in Appendix A). In contrast, in the Kyrgyz Republic, 37% of surveyed households use solid fuels, 14% use LPG, and 47% use electricity (Table A3.3 in Appendix A). Widespread power cuts in the Kyrgyz Republic (Dikambayev 2019) may explain why households do not completely switch to electricity for cooking. In contrast, power outages in Kazakhstan are rare. In general, studies agree that quality of access to electricity is an important determinant of household choice of fuel, even if electricity access is provided (Sedai et al., 2021).

In India, there are specific programs for the transition to clean energy use at the household level. The most prominent effort by the Indian government in terms of improving access to clean cooking energy is the PMUY, launched in 2016. It has provided subsidized LPG connections to over 70 million households in 700 districts (Ministry of Finance of India 2019). Previously, the government has also attempted to improve access to LPG by expanding the distributor network in rural areas through the Rajiv Gandhi Gramin LPG Vitaran Yojana. This scheme helped increase the share of rural distributorship from 14% since its launch in 2009–2010 to over 40% in 2016–2017 (Dubey 2017). However, the government's strategy for increasing LPG usage must go beyond expanding the distribution of connections: it must also promote the sustained use of LPG as a primary cooking fuel. Fewer than 5% of the sample households used LPG exclusively (Jain et al., 2015). Only 22% of the sample households reported using LPG, yet more than one-third of them did not use it as their primary cooking fuel, indicating a high level of fuel stacking behavior (Patnaik et al., 2017).

In Kazakhstan and the Kyrgyz Republic, official strategic documents target the development of the supply-side energy infrastructure, while, to the best of our knowledge, there are no specific programs aimed at promoting the transition to clean energy use at the household level. Through fuel and energy development strategies and green economy development programs that envisage the development of energy-generating capacity via the construction of new power plants, governments facilitate the use of renewable energy sources, promote energy efficiency and use of energy-saving technologies. In Kazakhstan, there has been substantial progress in providing access to a gas network over the last seven years. The share of the population with access to a piped gas network increased from 30% in 2013 to 52% in 2019 (KazTransGas 2019). Completion of construction of the Saryarka gas pipeline in 2019 is expected to provide natural gas access to the gas-deficient Central Kazakhstan, which has a population of 2.7 million people (Karimova 2019). The Kyrgyz Republic government, in turn, aims to ensure access to natural gas to 60% of the population by 2030 (Gazprom 2015). Increased access to the gas network will likely contribute to natural gas transition in Kazakhstan and the Kyrgyz Republic; however, more support may be needed for low-income households to ensure affordability and greater adoption of natural gas. In Kazakhstan, despite the availability of the network gas in a neighborhood, some households continue to rely on coal due to the relatively high cost of connection, the high cost of a gas boiler, or for other reasons. Moreover, there are no specific programs in Kazakhstan aiming to subsidize the cost of connecting to a gas pipeline or purchasing a gas boiler. Other measures adopted in some countries include a ban on coal-burning by households (particularly in urban areas), which was found to be particularly effective in reducing the air pollution level (Dockery et al., 2013). For Kazakhstan and the Kyrgyz Republic, applying a coal ban as a policy instrument may require financial support programs for low-income households.

3. Data and descriptive statistics

3.1. India

To study the factors affecting cooking fuel choices we use household-level information collected through three different household surveys in India, Kazakhstan, and the Kyrgyz Republic. The data for India derives from the household consumer expenditure survey conducted by the National Sample Survey Organization (2012). We use the latest wave of this survey (68th round), collected during 2011–2012. This nationally representative survey covered all geographical areas of the country, collecting information on a total of 101,662 households. In addition to household and demographic characteristics, the survey collected detailed information on consumption expenditure on various items, including different categories of fuel. The survey also has information on households' primary cooking fuel. In the sample, 29.6% of rural and 74.6% of urban households reported LPG as their primary cooking fuel (Table A1.1 in Appendix A). To maintain comparability across the

[2] PMUY is a program launched by the Prime Minister of India, Narendra Modi, on 1 May 2016 to distribute 50 million LPG connections to female-headed households below the poverty line.

selected countries, we focus on only 87% of households for further analysis, considering only those households that have access to electricity. The sample for analysis includes a total of 85,601 households (55.3% rural and 44.7% urban) (Table A2.1 in Appendix A). The average size of a household is 4.5 members. Around 33% of households had at least one regular salary earner; 84% of households lived in their own house; and 37% reported access to free fuel, comprising free collection from common property resources.

3.2. Kazakhstan

For Kazakhstan, we use data from the Household Fuel and Energy Consumption Survey for 2017, collected by the Committee of Statistics of the Republic of Kazakhstan (2017). This is the first survey implemented by Kazakhstan to collect data on fuel use. The distribution of the cross-sectional dataset (21,000 households) across five regions of Kazakhstan is in proportion to the population distribution. The survey includes information on household energy choice for cooking, type of settlement, year of housing construction, housing area, number of residents, consumption of fuel types and energy, and other information related to the user's equipment for space heating, cooking, and water heating. The limitation of this dataset is that it does not have information related to the socioeconomic and demographic characteristics of households. Around 66% of the total sample is drawn from an urban area (Table A1.2 in Appendix A). The average size of a household is approximately 3 members; the average area of the house is 69 m^2. Of the total sample, 59% live in apartments. Access to free fuel is reported by only 4% of the sample.

3.3. The Kyrgyz Republic

For the Kyrgyz Republic, data from the 2016 Life in Kyrgyzstan survey are used. This survey was conducted by the Leibniz Institute of Vegetable and Ornamental Crops (IGZ), the Food and Agriculture Organization of the United Nations (FAO), the International Food Policy Research Institute (IFPRI), and the University of Central Asia (International Data Service Center 2016). Data include widespread information on a household level and are representative at the national level. The survey includes around 3000 households. However, due to missing data, the initial sample size is reduced to 2521 households. Overall, the sample size may vary depending on the availability of data for the outcome and explanatory variables.

Along with the characteristics of the household and household head, information on household expenditure on the main energy types is used. In particular, the survey records household expenditure on electricity, coal, petrol, and gas. Also, the survey includes information regarding how often power supply was disrupted during the last 12 months. However, it does not identify the quantity of energy consumed. Price information for each region for each type of energy source was used to convert expenditure into the physical quantity of each energy type. However, there is no available information with detailed data on energy prices at a regional level: hence energy prices for the regional level are obtained using the consumer price index for the item 'energy, gas, and other types of fuel' for each region and the average price at a national level. Petrol is excluded in our estimation since it is mainly used for transportation and not for cooking or heating purposes. The sample consists of 62% of rural households (Table A1.3 in Appendix A). The average household size is approximately 5 persons. The average number of rooms in the dwelling unit is 3.6. Around 71% of the sample is represented by male-headed households, and 52% of the heads have acquired education up to the secondary level.

4. Empirical strategy

Due to the difference in the variables collected in each of the surveys, we model household fuel choice for cooking for each country using close but slightly differentiated explanatory variables. Uncovering households' cooking fuel choices is empirically challenging. As highlighted by other studies despite policies aiming to improve the availability of cleaner fuel (natural gas and LPG), demand-side issues concerning its adoption and sustained and exclusive use remain an issue in developing countries (Kumar et al. 2016). Given that household adoption and sustained use of clean cooking fuel is a function of economic and social determinants, it needs more attention (Lewis and Pattanayak 2012). In our paper, we model two cooking fuel choices: the dominant fuel which is the primary source of cooking, and the fuel stacking behavior of the households. We, therefore, model a combination of dirty fuel with clean cooking fuel.

4.1. Identification of dominant cooking fuel

We model the dominant cooking fuel in the case of India and the Kyrgyz Republic using Eq. (1). Our dataset for these two countries includes information on the most dominant cooking fuel used in the household. However, this information is lacking in the dataset used for Kazakhstan. We model the most used fuel using multinomial logit regression. The multinomial logistic regression model is an extension of binary logistic regression. It is effective when there is polychotomous categorical dependent variable. In India, the choice of dominant fuel takes the value from 1 to 4 for categories LPG (base category), solid fuel, kerosene and others (including electricity). In case of the Kyrgyz Republic the value of the dependent variable varies from 1 to 4 for solid fuel, gas pipeline, gas cylinders, and electricity (as a base category). In the case of Kazakhstan, the dependent variable varies from 1 to 5 for solid fuel, LPG, electricity and natural gas mix, only natural gas, and only electricity. The explanatory variables are divided into six categories: household characteristics, convenience, affordability, accessibility, built-in environment, and tenure status. The details of the indicators used in each categories are discussed in Table 1.

$$\begin{aligned} Pr\,(fuel\ type) \ = \ & \beta_0 + \sum_i \gamma_i household\_char_i + \sum_j \delta_j conveniencePk_j \\ & + \sum_k \eta_k affordability_k + \sum_l \theta_l accessibility_l \\ & + \sum_m \lambda_m built\_environment_m + \sum_n \mu_n tenure\_status_n + \varepsilon \end{aligned} \tag{1}$$

Table 1
Classification of variables used in the models.

Classifications	Variables used for each country		
	India	Kazakhstan	The Kyrgyz Republic
Household characteristics	Education of the head of the household Age of the head of the household Gender of household head Household size Social group	Household size	Education level of household head Gender of household head
Convenience/ Multiuse	Free fuel	Heating system Free fuel	Heating system
Affordability	Salaried income MPCE	Fuel prices	Fuel prices MPCE
Accessibility	Access to LPG	Access to natural gas	Access to natural gas
Built environment		Apartment	Number of dwelling rooms
Tenure status	Ownership of the house		Ownership of the house
Quality of services/fuel			Power outage

The factors affecting adoption and sustained use of cooking fuel in the regression are classified into the six broad categories (Table 1).

4.2. Identification of multiple fuel use

To study the fuel stacking behavior of households we need to study the distribution of fuel choice for cooking across households. For this, we construct the dependent variable as a combination of the clean fuel with dirty fuels. A mix of fuels is identified based on the pairwise fuel consumption matrix for each country (Tables A3.1–A3.3 in Appendix A). In India, out of 47,000 households around 1,200 households in rural areas use LPG with kerosene; for urban areas, the figure is 10,776 out of 37,705 households. The matrix reports a high incidence of LPG and wood combination in rural India—i.e., 12,335 households. In Kazakhstan, the incidence of LPG in combination with electricity is 1,131, and a combination of LPG and solid fuel is used by 910 households out of 9,514 in rural areas. A similar trend is observed in fuel combinations in the urban sample. In the Kyrgyz Republic, the most dominant combination of fuel is coal and electricity, used by 1323 and 471 households out of 1,556 and 953 households, respectively, in the rural and urban samples.

Using MLM we model the factors affecting different fuel mixes for three countries. We modeled the probability of adoption of a particular combination of fuels for all three countries (Eq. (2)). Here the dependent variable is the ordinal value assigned to each pair of fuels. The explanatory variables included are as in Eq. (1).

$$
\begin{aligned}
Pr\,(fuel\ combinations) = \beta_0 &+ \sum_i \gamma_i household\_char_i \\
&+ \sum_j \delta_j conveniencePk_j + \sum_j \eta_j affordability_j \\
&+ \sum_k \theta_k accessibility_k + \sum_l \lambda_l built\_environment_l \\
&+ \sum_m \mu_m tenure\_status_m + \varepsilon
\end{aligned} \tag{2}
$$

In India, the list of regressors includes—log of monthly per capita expenditure (MPCE), education characteristics, age of household head, the gender of household head, household size, a dummy variable for households which have at least one regular salary earner, and information about social groups, access to free fuel, and access to LPG.

In Kazakhstan, the list of regressors includes—prices of fuel, dwelling characteristics such as a total area of the dwelling unit and whether a household resides in an apartment/dormitory versus a separate house, access to natural gas, access to free fuel, and the type of a heating system installed in the premises of a household. The household survey does not have information on the prices of fuels and therefore we use regional prices (16 regions).

Finally, in the Kyrgyz Republic, the list of regressors includes gender, age and education level of the household head, the number of dwelling rooms, access to LPG and natural gas, and the type of heating system installed in the premises of the household.

The dataset contains no direct information on pairwise fuel consumption by the households, therefore, the outcome variable for Model 2 is generated by categorising households according to their responses on the use of every single category of fuel. We assume that this new reclassification does not violate the independence of irrelevant alternatives axiom. Based on the variables selected in the Model 2, we do not find any case of reverse causality. The results from Model 2 were verified by employing a binary logit model with (only) clean fuel and clean plus solid fuel as the binary outcome in the dataset (Appendix C Table C1).

5. Results

Tables B1.1–B1.3 of Appendix B report the marginal effects from multinomial logit regressions for each country separately. Results on the determinants of major cooking fuel and mixes of cooking fuels for India are presented in Tables B1.1a and B1.1b, for Kazakhstan in Table B1.2a and B1.2b, and for the Kyrgyz Republic in Tables B1.3a - B1.3d.

5.1. Access to cleaner fuels

In the case of India though our sample is limited to the households that have access to electricity, we still find that the households use solid fuels because electricity is more expensive than solid fuels and the households may not have continuous supply of electricity. However, households with access to gas, in particular access to LPG in India are less likely to use solid fuels for cooking. We also find that in the Kyrgyz Republic the households having access to natural gas, and LPG are less likely to use solid fuels for cooking. Hence policies promoting natural gas and LPG infrastructure development will likely reduce the consumption of solid fuels in our sample countries.

5.2. Convenience/multiuse: same heating fuel

In cold countries such as Kazakhstan and the Kyrgyz Republic, the heating system installed at the premises of a household can determine the choice of cooking fuel. This is because the same stove could be used for cooking and heating in the winter time. Here, we test how a heating system installed in the premises of the households affects their choice of cooking fuel in Kazakhstan and the Kyrgyz Republic.

In rural areas of Kazakhstan, any heating system has a positive and significant effect on the use of solid fuels, though the probability of choosing a solid fuel stove is highest in settlements that use a coal-based individual oven for heating. The positive effect is less pronounced in urban areas, where the effect of heating systems on the likelihood of using a solid fuel stove is positive but not significant. The effect of heating systems on LPG use is diverse across regions and heating systems. The significant impact of the heating system on the choice of cooking fuel shows the importance of providing access to clean energy not only for cooking but also for heating in promoting the use of clean fuels for cooking in cold countries.

In the Kyrgyz Republic, the use of coal and wood for heating increases the probability of using the same dirty fuels for cooking in both urban and rural areas. The use of electricity for heating increases the use of gas cylinders and electricity as the dominant fuel for cooking. Heating based on piped gas decreases the use of gas cylinder as a dominant fuel for cooking. The piped gas infrastructure in the Kyrgyz Republic is available mainly in the area of the capital city, demonstrating its presence and significance in urban areas. These findings suggest that access to clean energy types for heating promotes the use of clean energy for cooking because of convenience.

5.3. Economic factors

Per capita expenditure, access to free fuel, and energy prices are included as economic factors that can affect the choice of cooking fuel. Our results show that households with higher expenditure per capita (in India) or larger dwelling unit areas (in Kazakhstan) are less likely to use solid fuels for cooking and are more likely to use clean fuels (i.e., electricity and gas). These results are in line with other studies that find households that tend to switch to clean fuel sources as their incomes increase, supporting the energy ladder hypothesis (Alem et al., 2016; Jaime et al. 2020).

The availability of free fuels is associated with lower fuel expenditure. This may reflect the fact that poor households mainly rely on human resources to collect wood and dry leaves in mostly rural areas. The availability of the data allows us to compare India and Kazakhstan. In general, the availability of free fuel increases the probability of using all fuel types in rural and urban areas in India. In Kazakhstan, it increases the probability of choosing LPG in rural areas and solid fuel and electricity and gas mix in urban areas, while it reduces the probability of choosing electricity and gas mix in rural areas and natural gas in urban areas.

Our results show that energy prices have a significant impact on the choice of cooking fuel. Studying the impact of energy prices is important, as they could be used to promote clean fuels. The results on energy prices are not reported for India due to data limitations. Average regional energy prices are used as a measure of energy prices in Kazakhstan and the Kyrgyz Republic. Households located in regions with higher coal prices are more likely to use clean fuels: electricity in both rural and urban areas of Kazakhstan, natural gas in rural Kazakhstan, and gas cylinders in the urban Kyrgyz Republic. Similarly, households in Kazakhstan and the Kyrgyz Republic located in regions with lower gas prices are more likely to consume clean fuels such as natural gas and are less likely to use solid fuel ovens. Interestingly, households living in regions with higher electricity prices are more likely to use electric stoves. However, they are less likely to use solid fuel stoves in the Kyrgyz Republic and rural Kazakhstan. That contradicts the general perception that higher prices reduce the consumption of a product. However, it should be mentioned that despite the positive impact of electricity prices on electric stove usage, electricity prices in the Kyrgyz Republic and Kazakhstan are regulated by the government. Also, built-in infrastructure and living conditions limit fuel substitution. In general, using average regional energy prices presents a limitation for this study, showing the impact of prices at the regional rather than at the household level.

5.4. Built environment

In India, the house-ownership affects the fuel choice of the households. Households are more likely to use solid fuels for cooking if they own a house. This may be because households that own a house have more independence choosing fuel. For example, households in rural India, which are mainly involved in agriculture (both livestock and agriculture), live in their own house and use crop residues as fuel for cooking their food and boiling cereals for livestock. This type of setup mostly has a *chulha* (a stove made of clay) in the courtyard.

In Kazakhstan, households who reside in apartments are more likely to choose natural gas and are less likely to choose solid fuel and LPG, which are predominantly used by households who live in detached houses. In the Kyrgyz Republic, the number of dwelling rooms has a positive and significant effect on the use of coal and wood in urban areas, though reducing the probability of choosing gas in rural areas. That is likely to be because solid fuel is used for heating purposes, therefore, the greater the number of dwelling rooms in the unit, the higher the probability of using solid fuel for cooking as well.

5.5. Household characteristics

The gender of the head of the household affects the choice of cooking fuel. Households with male household heads are more likely to use electricity and other clean fuels in India. In contrast, in the Kyrgyz Republic, households with male heads are less likely to use piped gas in urban areas. The pertinent literature attributes the difference between the decisions made in male- and female-headed households to the difference in preferences and opportunity cost of time. In general, female-headed households are likely to be prone to interventions related to better access to clean energy and are more likely to switch to clean energy relative to male-headed households (Karimu et al. 2016; Rahut et al. 2016). Interestingly, the findings for the Kyrgyz Republic are consistent with other studies while the results for India are, surprisingly, at odds with the literature.

The age of the household head affects the choice of cooking fuel. In urban areas of the Kyrgyz Republic, such households are more likely to use gas and less likely to use LPG.

The education of the household head is a strong determinant of fuel demand in India and the Kyrgyz Republic. Households with more educated household heads are less likely to use coal, wood, and kerosene as a dominant cooking fuel in India. Likewise, in the Kyrgyz Republic, such households are more likely to use clean fuel such as electricity in rural areas and are less likely to use coal and wood in both rural and urban areas. Our results show that education can lead to fuel switching. This result is aligned with other studies that show that the probability of using cleaner fuel sources increases with education (Alem et al., 2016; Karimu et al. 2016; Paudel et al. 2018).

Household size affects the choice of cooking fuel. Larger households are more likely to use coal and wood in India and more likely to use cleaner fuels such as electricity in urban areas. In Kazakhstan, larger households are more likely to use electricity in rural and urban areas and less likely to use LPG in rural areas and mixed types of fuel in urban areas. In the Kyrgyz Republic, larger households are less likely to use electricity in rural and urban areas and more likely to use coal and wood in urban areas. The results for India and the Kyrgyz Republic are consistent with the literature that shows that household size hurts the consumption of clean fuels and has a positive effect on the consumption of dirty fuels (Paudel et al. 2018). That is typical for developing countries, as larger households require more cooking fuel; hence, to reduce costs, they use cheaper fuels such as coal and wood. This is in contrast to the findings for Kazakhstan, where we find opposite results, pointing at the positive effect of household size on the probability of choosing cleaner fuels.

5.6. Quality of access to electricity

Not only the connection to electricity, but rather quality of access to electricity may have significant impact over the household behavior in selection of fuel (Sedai et al., 2021). Using available variable on the frequency of disruption of power supply from the dataset for the Kyrgyz Republic MLM models are estimated. Results in Tables B1.3b and B1.3d indicate that inclusion of power outage variable does not alter our estimation results. Households with more frequent power supply disruptions in rural area have higher probability to use more coal and wood for cooking, while lower probability to use gas cylinders and electric stoves. Households residing in urban area facing more frequent power supply disruption increase consumption of gas cylinders. Within the fuel combination choice model, quality of access to electricity has statistically significant impact on combination of coal with gas and with electricity. In particular, increasing frequency of power supply disruptions decrease probability of using gas and coal, while increasing coal and electricity combinations. Overall, these findings indicate that quality of electricity is important for choice of cooking fuel by households.

5.7. Fuel stacking

The results from the fuel stacking model for India show that higher income tend to reduce the fuel stacking. The demand for pairwise combination of LPG with other fuels is significantly lower when households have higher incomes. In contrast, higher incomes in Kyrgyz Republic tend to increase the fuel stacking behavior, in particular increasing the probability of choosing the natural gas and coal mix. That is likely related to the type of the heating system installed in the premises of a household. Availability of the coal-based heating stove induces the use of coal apart from natural gas for cooking, while on the other hand it reduces the probability of choosing natural gas and electricity as a cooking fuel mix. Similarly, in Kazakhstan, coal-based heating system also promotes fuel stacking behavior, and in particular increases the probability of using LPG and coal fuel mix for cooking, whereas it reduces the transition to the use of cleaner fuels for cooking, such as natural gas and electricity. That further confirms our earlier finding that heating system largely affects the choice of cooking fuel and moreover it leads to fuel stacking behavior.

Access to free fuel has a positive and significant effect on the probability of choosing LPG and wood fuel mix in India, which further supports our finding on the impeding effect of the free fuel on the transition to the use of cleaner cooking fuel among households. Similarly access to free fuel has an impeding effect on the use of cleaner fuels, such as natural gas and electricity in Kazakhstan. Fuel prices also play a significant role in fuel stacking. For instance, higher electricity prices increase the probability of using gas and coal as a fuel combination for cooking in the Kyrgyz Republic, while higher coal prices reduce the probability of using LPG and coal for cooking in Kazakhstan.

6. Concluding remarks

This study provides a comprehensive analysis of the role of infrastructures such as access to clean fuels (in India, Kazakhstan, the Kyrgyz Republic) and heating systems (in Kazakhstan, the Kyrgyz Republic) in the choice of dirty and clean cooking fuels. The study uses household survey data from India, Kazakhstan, and the Kyrgyz Republic over the periods 2011–2012, 2017, and 2016, respectively, and applies MLM to study the determinants of the choice of clean and dirty cooking fuels.

Limited gas pipeline networks and instability of the electricity supply may have an important impact on household preferences. Therefore, the development of infrastructure and increased affordability of cleaner types of fuel, as measured by access to natural gas or LPG in the sample countries, are important factors for the transition to clean energy. Also, we find that the choice of fuel for cooking depends on the heating system installed in the premises of the households in cold countries such as Kazakhstan and the Kyrgyz Republic. This suggests that the transition to clean fuels for cooking should unambiguously take into account the heating system used by a household. Economic factors play a substantial role, in particular, households with higher per capita expenditure and higher income are inclined to move from solid fuel to LPG, natural gas, and electricity. That confirms the energy ladder hypothesis that suggests that households move away from dirty fuels to cleaner fuels as their incomes rise.

According to a report by the Steering Committee on Air Pollution and Health Related Issues MOHFW (2015), air pollution inside houses, primarily due to burning of solid fuels contributed to more than 1 million deaths in 2010, thus making it the second-biggest health risk factor in India. According to the International Energy Agency, 2021 despite the recent success in expanding coverage of LPG in rural areas, 660 million Indians haven't fully switched to clean cooking fuels. Economy and convenience are the important factors affecting the sustained and complete switching to the clean fuels for cooking. At this point of time it is required that the government should intervene through factors making the clean fuel affordable and at the same time running awareness campaigns to discourage households from burning solid fuels even if they come for free. Fuel prices and subsidies can play a crucial role in sustained use of clean fuel, however the unavailability of such information in the datasets remain a limitation of this study.

In cold climate countries such as Kazakhstan and the Kyrgyz Republic, the heating season lasts for more than six months in a year, with average winter temperatures of -8°C to -10°C in some regions. Heating comprises nearly 60% of the end-use energy demand of households in Kazakhstan (UNDP 2012a). Most of households' energy expenditure is related to heating fuel. In this regard, finding and purchasing enough fuel for heating is of greater concern for households than cooking fuel. Generally, households will tend to use one stove for multiple purposes (originally for heating). The top surface of the heating stove is generally used for heating water and cooking during the wintertime.

In the Voluntary National Review of the Republic of Kazakhstan (Ministry of National Economy of the Republic of Kazakhstan 2019), Kazakhstan reported a 100% electrification rate, and thus fulfillment of SDG 7: "Ensure access to affordable, reliable, sustainable and modern energy for all". Despite 100% electrification, households in Kazakhstan rely on solid fuels, i.e., 30% of surveyed households using solid fuels mainly for heating purposes. Thus, the electrification rate indicator may not be sufficient to address complex challenges with ensuring affordable access to sustainable fuel. The indicator of SDG 7 should not only take into account the electrification rate, but should include the share of households relying on clean fuels and fuel stacking.

Also, current government efforts to provide wider access to cleaner affordable fuels have to be sustained, possibly even accelerated and expanded to cover more areas. A gas pipeline network could be constructed in densely populated areas of Kazakhstan while ensuring LPG supply in remote and distant locations where a gas pipeline is not possible. Additionally, in the case of the Kyrgyz Republic, efforts should be focused on reducing electricity outages to restore trust in electricity as a reliable source of energy. Transition to cleaner fuels requires substantial investment, but the health benefits may outweigh the costs. The governments of Kazakhstan and the Kyrgyz Republic could consider programs to subsidize the cost of a gas connection or a gas boiler, particularly for rural low-income households. In wealthier urban areas with significant air quality issues associated with solid fuel use, a gradual coal ban can be considered, with subsidy programs for low-income and vulnerable populations. Such programs are in place in India, and the experience could be integrated in Kazakhstan and the Kyrgyz Republic.

Our paper poses the need for further studies. Firstly, future studies could look at questions related to the energy ladder and fuel stacking in heating—in particular, whether households are stacking up or down the energy ladder, similar to Choumert-Nkolo et al. (2019). As fuels used in cooking and heating are largely related, both in Kazakhstan and the Kyrgyz Republic, such studies could further contribute to the discussions on how this joint use affects the fuel choices and help in energy transition. Secondly, raising awareness of health damage due to air pollution is crucial; hence future studies could uncover the effects of energy demand on the health of different groups of the population. Thirdly, transition to cleaner fuels empowers women as it reduces cooking time and has health benefits, and so understanding gendered issues of cooking and heating fuel choices will uncover the benefits of the transition to clean fuel use. In general, gender-related studies are limited for the sample countries, and such studies will shed light on a host of issues pertinent to these countries.

Author statement

Zhanna Kapsalyamova: Conceptualization, Methodology, Software, Writing – review & editing, Formal analysis, Data curation. Ranjeeta Mishra: Methodology, Software, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. Aiymgul Kerimray: Visualization, Investigation, Writing – review & editing, Formal analysis. Kamalbek Karymshakov: Data curation, Writing – original draft, Writing – review & editing, Formal analysis. Dina Azhgaliyeva: Writing – original draft, Writing – review & editing, Validation, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.112539.

Appendix A. Summary Statistics

Table A1.1
Distribution of households by their primary source of cooking, India.

	Rural		Urban		Total	
	Frequency	%	Frequency	%	Frequency	%
Coal, wood, crop residual	31,667	67.1	7345	19.7	39,012	46.2
LPG	13,960	29.6	27,821	74.6	41,781	49.4
Kerosene	481	1.0	1616	4.3	2097	2.5
Electricity and biogas	209	0.4	240	0.6	449	0.5
Others	901	1.9	283	0.8	1184	1.4
Total	47,218		37,305		84,523	

Source: National Sample Survey Organization (68th round); authors' calculations.

Table A1.2 Distribution of households by their source of cooking, Kazakhstan.

Fuel type	Rural		Urban		Total	
	Frequency	%	Frequency	%	Frequency	%
Solid fuel	910	9.56	393	2.93	1303	5.69
LPG	3016	31.7	2585	19.29	5601	24.45
Natural gas	1752	18.41	4388	32.75	6140	26.8
Mixed fuel (electricity and gas)	700	7.36	858	6.4	1558	6.8
Electricity	3136	32.96	5174	38.62	8310	36.27
Total	9514	100	13,398	100	22,912	100

Source: Committee of Statistics of the Republic of Kazakhstan (2017); authors' calculations.

Table A1.3
Distribution of households by their primary source of cooking, the Kyrgyz Republic.

	Rural		Urban		Total	
	Frequency	%	Frequency	%	Frequency	%
Stove (coal and wood)	969	62.28	226	23.71	1195	47.63
Gas pipe supply	7	0.45	385	40.4	392	15.62
LPG gas stove	139	8.93	124	13.01	263	10.48
Electric	441	28.34	218	22.88	659	26.27
Total	1556	100	953	100	2509	100

Source: International Data Service Center (2016); authors' calculations.

Table A2.1
Descriptive statistics for India.

Variable	Obs.	Mean	Std. Dev.	Min	Max
MPCE on fuel, log	85,619	4.999597	0.534136	0.693147	8.747828
MPCE, log	85,619	7.012084	1.056935	0.693147	12.41521
Education (base category = Below Primary)					
Primary	85,619	0.121013	0.326144	0	1
Middle and secondary	85,619	0.414441	0.492628	0	1
Diploma and above	85,619	0.159112	0.365783	0	1
Age	85,619	47.11245	13.28923	15	105
Gender of the Head (Male = 1)	85,619	0.887023	0.316567	0	1
Household size	85,619	4.578084	2.206122	1	31
House ownership	85,619	0.843913	0.36294	0	1
Regular salary earner	85,609	0.3320525	0.470966	0	1
Social groups (base category = Scheduled Caste)					
Scheduled tribes	85,611	0.142622	0.349689	0	1
OBC	85,611	0.391492	0.488087	0	1
Others	85,611	0.337807	0.472965	0	1
Access to free fuel	85,619	0.378152	0.484929	0	1
Sector (rural = 1)	85,619	1.44698	0.497184	1	2
Access to LPG	85,619	0.567491	0.495427	0	1

Table A2.2
Descriptive statistics for Kazakhstan.

Variable	Obs	Mean	Std. Dev.	Min	Max
Total area of the dwelling, m2	20,993	69.18	51.48	9.00	1000.00
Access to natural gas (=1 if household has access to natural gas)	21,000	0.41	0.49	0	1
Free fuel (=1 if household has free fuel access)	21,000	0.04	0.20	0	1
Household size	21,000	3.28	1.88	1.00	15.00
Coal log price	21,000	9.42	0.22	8.97	9.74
Natural gas log price	12,602	3.19	0.49	2.08	3.56
Electricity log price	21,000	7.37	0.25	6.57	7.70
Urban (=1 if household resides in an urban area)	21,000	0.66	0.47	0	1
Apartment (=1 if household resides in apartment or dormitory)	21,000	0.59	0.49	0	1

Source: Committee of Statistics of the Republic of Kazakhstan (2017); authors' calculations.

Table A2.3
Descriptive statistics for the Kyrgyz Republic.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Monthly per capita expenditure of household, Som	2521	3933.65	2587.57	7.00	29,923
Log of total expenditure of household on energy	2458	5.05	0.76	1.51	7.41
Access to gas (=1 if household has access to LPG)	3106	0.23	0.42	0	1
Age of household head	2521	53.97	13.45	21.00	90.00
Gender of household head (=1 if male)	2521	0.71	0.45	0.00	1.00
Household head education					
Secondary	2169	0.52	0.50	0.00	1.00
Technical	2169	0.17	0.37	0.00	1.00
Tertiary	2169	0.17	0.37	0.00	1.00
Household size	2521	5.26	2.54	1.00	17.00
Dwelling rooms	2320	3.60	1.36	1.00	12.00
Rural (=1 if household resides in a rural area)	2521	0.62	0.49	0.00	1.00
Power outage (from 1 = never disrupted; to 7 = no power supply at all)	2521	2,38	0,96	1	7

Source: International Data Service Center (2016); authors' calculations.

Table A3.1
Pairwise combination of fuel demand in India (number of households)

	Coal	LPG	Kerosene	Electricity	Wood
All India					
Coal	2995				
LPG	988	48,588			
Kerosene	2465	22,844	55,013		
Electricity	2954	48,424	54,817	85,292	
Wood	1574	17,076	40,576	48,948	49,124
Rural					
Coal	1425				
LPG	415	19,377			
Kerosene	1236	12,068	37,207		
Electricity	1406	19,334	37,097	47,201	
Wood	1009	12,335	32,365	38,380	38,513
Urban					
Coal	1570				
LPG	573	29,211			
Kerosene	1229	10,776	17,806		
Electricity	1548	29,090	17,720	38,091	
Wood	565	4741	8211	10,568	10,611

Source: National Sample Survey Organization (68th round); authors' own calculations.

Table A3.2
Pairwise combination of fuel demand for cooking in Kazakhstan (number of households)

	Solid fuel	LPG	Mixed fuel (electricity and gas)	Natural gas	Electricity
All Kazakhstan					
Solid fuel	1303				
LPG	933	5601			
Mixed fuel (electricity and gas)	135	140	1558		
Natural gas	22	7	79	6140	
Electricity	550	1720	533	1091	8310
Rural	Solid fuel	LPG	Mixed fuel (electricity and gas)	Natural gas	Electricity
Solid fuel	910				
LPG	658	3016			
Mixed fuel (electricity and gas)	90	115	700		
Natural gas	22	5	43	1752	
Electricity	412	1131	375	540	3136
Urban	Solid fuel	LPG	Mixed fuel (electricity and gas)	Natural gas	Electricity
Solid fuel	393				
LPG	275	2585			
Mixed fuel (electricity and gas)	45	25	858		
Natural gas	0	2	36	4388	
Electricity	138	589	158	551	5174

Source: Committee of Statistics of the Republic of Kazakhstan (2017); authors' calculations.

Table A.3.3
Pairwise combination of fuel demand in the Kyrgyz Republic (number of households)

	Coal	LPG	Electricity
All the Kyrgyz Republic			
Coal	1866		
LPG	376	717	
Electricity	1794	677	2375
Rural	Coal	LPG	Electricity
Coal	1390		
LPG	213	242	
Electricity	1323	205	1446
Urban	Coal	LPG	Electricity
Coal	476		
LPG	163	475	
Electricity	471	472	929

Appendix B Regression Results

Table B1.1a
Determinants of major cooking fuel choice in India, marginal effects (multinomial logit).

Variables	Rural			Urban		
	Coal, wood, crop residual	Kerosene	Electricity and others	Coal, wood, crop residual	Kerosene	Electricity and others
MPCE, log	−0.0291	−0.0430	0.148***	−0.257***	−0.190***	0.403***
	(0.0205)	(0.0654)	(0.0437)	(0.0331)	(0.0475)	(0.0560)
Education of the head of household (base category = below primary)						
Primary	−0.116*	−0.132	−0.146	0.00155	0.177	0.232
	(0.0595)	(0.165)	(0.110)	(0.0901)	(0.124)	(0.187)
Middle and secondary	−0.416***	−0.279**	−0.406***	−0.728***	−0.598***	−0.214
	(0.0452)	(0.128)	(0.0861)	(0.0746)	(0.103)	(0.146)
Diploma and above	−1.009***	−1.015***	−0.683***	−1.749***	−2.196***	−0.187
	(0.0684)	(0.220)	(0.151)	(0.123)	(0.199)	(0.184)
Age, years	−0.00345**	−0.00483	−0.00664**	−0.00554**	−0.0106***	0.00478
	(0.00146)	(0.00425)	(0.00287)	(0.00241)	(0.00336)	(0.00432)
Gender (male = 1)	−0.00110	0.127	0.457***	−0.0459	0.0131	0.426**
	(0.0576)	(0.170)	(0.136)	(0.0851)	(0.123)	(0.196)

(continued on next page)

Table B1.1a (*continued*)

Variables	Rural			Urban		
	Coal, wood, crop residual	Kerosene	Electricity and others	Coal, wood, crop residual	Kerosene	Electricity and others
Household size	0.116***	−0.0517	0.0959***	0.168***	−0.0651***	−0.0119
	(0.00882)	(0.0338)	(0.0182)	(0.0130)	(0.0225)	(0.0277)
House ownership	1.082***	−1.451***	1.608***	0.776***	−0.754***	0.203
	(0.124)	(0.167)	(0.264)	(0.0874)	(0.103)	(0.131)
Regular salary earner	0.181***	−0.559***	0.511***	0.238***	−0.276***	−0.241**
	(0.0397)	(0.118)	(0.0981)	(0.0642)	(0.0881)	(0.111)
Social groups (base category = Scheduled Caste)						
Scheduled Tribes	0.877***	0.829***	1.989***	0.495***	0.709***	0.0447
	(0.0789)	(0.199)	(0.168)	(0.141)	(0.189)	(0.242)
OBC	0.648***	0.723***	1.494***	0.689***	0.567***	0.0825
	(0.0646)	(0.167)	(0.156)	(0.120)	(0.171)	(0.210)
Others	0.909***	1.568***	2.806***	0.280**	0.667***	0.757***
	(0.0649)	(0.169)	(0.152)	(0.125)	(0.174)	(0.202)
Access to free fuel	1.541***	0.0746	0.305***	2.451***	0.798***	0.578***
	(0.0372)	(0.114)	(0.0717)	(0.0682)	(0.134)	(0.210)
Access to LPG	−8.003***	−9.580***	−8.687***	−7.991***	−9.217***	−8.216***
	(0.199)	(0.312)	(0.222)	(0.161)	(0.200)	(0.196)
Observations	47,343	47,343	47,343	38,258	38,258	38,258

Note: LPG is a base category.
Robust standard errors in parentheses ***$p < 0.01$, **$p < 0.05$, *$p < 0$.

Table B1.1b
Determinants of major cooking fuel combinations choice in India, Marginal Effects (Multinomial logit).

	LPG +Coal	LPG+ Kerosene	LPG + Wood
MPCE, log	−0.163**	−0.359***	−0.200***
	(0.0776)	(0.0141)	(0.0168)
Education of the head of household (base category=below primary)			
Primary	−0.548*	0.0165	−0.0857
	(0.304)	(0.0521)	(0.0572)
Middle and secondary	−0.389**	−0.0480	−0.443***
	(0.193)	(0.0380)	(0.0426)
Diploma and above	−0.949***	−0.310***	−0.939***
	(0.234)	(0.0442)	(0.0530)
Age	0.00468	0.000635	−2.76e-05
	(0.00562)	(0.00102)	(0.00125)
Gender (male = 1)	0.327	0.0833**	−0.0257
	(0.245)	(0.0415)	(0.0480)
Household size	0.160***	0.172***	0.197***
	(0.0339)	(0.00706)	(0.00811)
House ownership	0.457**	0.592***	0.838***
	(0.179)	(0.0321)	(0.0451)
Regular salary earner	−0.368***	0.151***	0.227***
	(0.141)	(0.0260)	(0.0320)
Social groups (base category= Scheduled Caste)			
Scheduled Tribes	−1.359***	−0.179***	−0.388***
	(0.328)	(0.0578)	(0.0637)
OBC	−1.275***	−0.00359	−0.222***
	(0.231)	(0.0475)	(0.0516)
Others	−0.478**	−0.287***	−0.992***
	(0.193)	(0.0469)	(0.0526)
Access to free fuel	−1.494	0.0333	3.946***
	(1.006)	(0.0893)	(0.0627)
Rural	0.268*	0.525***	1.442***
	(0.161)	(0.0291)	(0.0317)
Observations	48,576	48,576	48,576

Notes: Use of LPG without combination with other fuel is the base category. Standard errors in parentheses; ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table B1.2a
Determinants of major cooking fuel choice in Kazakhstan, marginal effects (multinomial logit).

Variables	Rural					Urban				
	Solid fuel	LPG	Mixed fuel (electricity and gas)	Natural gas	Electricity	Solid fuel	LPG	Mixed fuel (electricity and gas)	Natural gas	Electricity
Heating (base category = central heating)										
Autonomous (gas, electricity)	0.000901*	0.101*	0.0123	−0.176***	0.0619	0.00122	−0.0619***	−0.00249	−0.0876***	0.151***
	(0.000533)	(0.0602)	(0.0105)	(0.0208)	(0.0587)	(0.00143)	(0.0237)	(0.00953)	(0.0222)	(0.0259)
Autonomous (gas, coal)	0.200***	−0.00602	0.249***	−0.444***	0.000848	0.0546	0.0860***	−0.0508***	−0.292***	0.203**
	(0.0496)	(0.0291)	(0.0659)	(0.0192)	(0.0445)	(0.0523)	(0.0283)	(0.00460)	(0.0928)	(0.0848)
Oven (gas, electricity)	0.0107**	−0.0817	0.0312**	−0.133***	0.173***	4.57e-10	−0.00879	0.0550***	−0.190***	0.144***
	(0.00474)	(0.0576)	(0.0130)	(0.0232)	(0.0553)	(1.46e-06)	(0.0251)	(0.0163)	(0.0261)	(0.0309)
Oven (coal, other)	0.188***	−0.0489	0.0416	−0.394***	0.214***	0.154	−0.0419***	−0.0508***	−0.602***	0.541***
	(0.0429)	(0.0300)	(0.0411)	(0.0396)	(0.0521)	(0.106)	(0.0140)	(0.00460)	(0.0360)	(0.0981)
Oven (coal only)	0.272***	0.0593**	0.000631	−0.343***	0.0109	0.227	0.0512***	−0.0161	−0.585***	0.322***
	(0.0439)	(0.0271)	(0.0190)	(0.0353)	(0.0386)	(0.144)	(0.0177)	(0.0231)	(0.0329)	(0.112)
Access to natural gas	0.131***	−0.459***	0.0562**	0.296***	−0.0232	0.0301	−0.195***	0.0543***	0.268***	−0.158***
	(0.0309)	(0.0643)	(0.0231)	(0.0257)	(0.0527)	(0.0228)	(0.0169)	(0.0164)	(0.0192)	(0.0193)
Access to free fuel	−0.000424	0.0365**	−0.0439**	0.0128	−0.00504	0.0235***	0.0163	0.0403*	−0.196***	0.115***
	(0.00879)	(0.0148)	(0.0203)	(0.0263)	(0.0239)	(0.00361)	(0.0109)	(0.0221)	(0.0561)	(0.0439)
Household size	0.000387	−0.00631***	−0.00205	0.00146	0.00651**	0.000452	−0.00149	−0.00348**	−0.00115	0.00566**
	(0.00156)	(0.00241)	(0.00139)	(0.00212)	(0.00277)	(0.000869)	(0.00166)	(0.00159)	(0.00262)	(0.00262)
Coal log price	0.0573	−1.062***	−0.214***	0.181***	1.038***	0.0282	−0.333***	−0.193***	−0.296***	0.794***
	(0.0526)	(0.0763)	(0.0426)	(0.0646)	(0.0908)	(0.0360)	(0.0597)	(0.0492)	(0.0772)	(0.0843)
Natural gas log price	−0.0176	−0.000444	0.0808***	−0.0743***	0.0115	−0.0221**	0.0955***	0.198***	−0.163***	−0.109***
	(0.0126)	(0.0198)	(0.0152)	(0.0229)	(0.0276)	(0.00914)	(0.0180)	(0.0209)	(0.0269)	(0.0262)
Electricity log price	−0.135***	−0.208***	−0.145***	0.00932	0.478***	−0.00870	−0.151***	−0.250***	−0.163***	0.573***
	(0.0330)	(0.0471)	(0.0272)	(0.0464)	(0.0683)	(0.0237)	(0.0441)	(0.0373)	(0.0576)	(0.0627)
Apartment	0.00690	−0.0495***	−0.0312***	0.0622***	0.0117	0.0114***	−0.0291***	0.00917	−0.0707***	0.0793***
	(0.0104)	(0.0159)	(0.00910)	(0.0128)	(0.0184)	(0.00414)	(0.00854)	(0.00882)	(0.0165)	(0.0157)
Total area of the dwelling, m2	−5.34e-05	4.26e-05	9.50e-05**	−8.12e-05	−2.95e-06	5.31e-05	−0.000436***	4.18e-05	−7.79e-05	0.000419***
	(9.17e-05)	(0.000137)	(3.72e-05)	(7.52e-05)	(0.000142)	(5.31e-05)	(0.000102)	(3.42e-05)	(6.35e-05)	(9.47e-05)
Observations	6155	6155	6155	6155	6155	7748	7748	7748	7748	7748

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

Table B1.2b
Determinants of major cooking fuel combinations choice in Kazakhstan, Marginal Effects (Multinomial logit).

	LPG+coal	LPG+electricity	Natural gas + electricity
Urban	−0.0168	−0.0196	0.0364***
	(0.0158)	(0.0173)	(0.00796)
Heating (base category = central heating)			
Autonomous (gas, electricity)	0.000891	0.0263**	−0.0272**
	(0.000617)	(0.0121)	(0.0122)
Autonomous (gas, coal)	0.395***	−0.246***	−0.149
	(0.0950)	(0.0270)	(0.0960)
Oven (gas, electricity)	0.00735	−0.0268	0.0194
	(0.00599)	(0.0200)	(0.0206)
Oven (coal, other)	0.262***	−0.0584***	−0.204**
	(0.0949)	(0.0173)	(0.0963)
Oven (coal only)	0.428***	−0.253***	−0.175***
	(0.0631)	(0.0128)	(0.0636)
Access to natural gas	0.605***	−0.828***	0.223***
	(0.125)	(0.127)	(0.0150)
Access to free fuel	−0.0217	0.0745***	−0.0528**
	(0.0186)	(0.0271)	(0.0225)
Household size	−0.00106	−0.00308	0.00415**
	(0.00335)	(0.00367)	(0.00175)
Coal log price	−0.572***	0.280**	0.292***
	(0.121)	(0.130)	(0.0596)
Natural gas log price	−0.0156	−0.0789**	0.0945***
	(0.0273)	(0.0317)	(0.0195)
Electricity log price	−0.625***	0.646***	−0.0208
	(0.0870)	(0.0900)	(0.0323)
Apartment	0.0392**	−0.0603***	0.0211**
	(0.0200)	(0.0224)	(0.0107)
Total area of the dwelling, m2	1.94e-05	−6.06e-05	4.12e-05
	(0.000202)	(0.000207)	(5.21e-05)
Number of observations	2639	2639	2639

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

Table B1.3a
Determinants of major cooking fuel choice in the Kyrgyz Republic, marginal effects (multinomial logit).

	Urban				Rural			
	Oven (coal and wood)	Gas pipe	Gas cylinder	Electric stove	Oven (coal and wood)	Gas pipe	Gas cylinder	Electric stove
MPCE	9.29e-06*	−4.60e-06	2.30e-07	−4.92e-06	−7.09e-07	−1.58e-06	4.84e-06*	−2.55e-06
	(5.29e-06)	(4.42e-06)	(3.84e-06)	(5.65e-06)	(6.96e-06)	(1.50e-06)	(2.66e-06)	(6.96e-06)
Gender of household head (male = 1)	0.0367	−0.0656***	0.0191	0.00979	0.0357	0.000115	0.00418	−0.0400
	(0.0247)	(0.0240)	(0.0223)	(0.0260)	(0.0279)	(0.00386)	(0.0143)	(0.0286)
Age	−0.000437	0.00215**	−0.00243***	0.000721	−0.000185	0.000238	−0.000339	0.000286
	(0.000920)	(0.000944)	(0.000855)	(0.00100)	(0.000964)	(0.000164)	(0.000476)	(0.000991)
Secondary	−0.00422	0.00548	0.0272	−0.0285	−0.0961***	0.00316	0.0118	0.0811**
	(0.0377)	(0.0417)	(0.0360)	(0.0419)	(0.0313)	(0.00396)	(0.0144)	(0.0317)
Higher secondary (technical)	−0.0550	0.0570	0.0227	−0.0247	−0.0835**	−0.00194	−0.00457	0.0900**
	(0.0418)	(0.0444)	(0.0374)	(0.0467)	(0.0420)	(0.00209)	(0.0179)	(0.0429)
Graduate and above	−0.0498	−0.00637	0.0261	0.0301	−0.0591	0.0173	−0.0120	0.0537
	(0.0446)	(0.0440)	(0.0373)	(0.0493)	(0.0452)	(0.0169)	(0.0231)	(0.0462)
Household size	0.0153***	0.00209	−0.00449	−0.0129*	0.00704	−0.00112	0.00425	−0.0102*
	(0.00588)	(0.00625)	(0.00576)	(0.00729)	(0.00553)	(0.00109)	(0.00282)	(0.00575)
Electricity	−0.135***	−0.440***	0.200***	0.374***				
	(0.0364)	(0.0534)	(0.0430)	(0.0456)				
Stove (coal and wood)	0.127***	−0.472***	0.175***	0.170***	0.127***	0.000361	−0.0691***	−0.0581
	(0.0378)	(0.0416)	(0.0270)	(0.0340)	(0.0469)	(0.00510)	(0.0123)	(0.0457)
Gas	−0.00849	0.0493	−0.0264***	−0.0144				
	(0.119)	(0.111)	(0.00918)	(0.0787)				
Electricity log price	−2.990***	0.183	0.662	2.145***	−6.612***	−0.243	−0.621	7.477***
	(0.658)	(0.708)	(0.634)	(0.741)	(0.823)	(0.304)	(0.753)	(0.948)
Coal log price	0.840	0.303	1.343**	−2.486***	1.681***	0.143	0.733	−2.557***
	(0.591)	(0.682)	(0.646)	(0.672)	(0.585)	(0.245)	(0.500)	(0.640)
Gas log price	0.529*	−0.353	0.0172	−0.193	2.149***	−0.0683	−1.387***	−0.693*
	(0.318)	(0.428)	(0.334)	(0.373)	(0.325)	(0.0757)	(0.250)	(0.355)
Access to gas	−0.0968***	0.223***	0.0864***	−0.212***	−0.188***	0.00514	0.0304**	0.152***
	(0.0243)	(0.0205)	(0.0187)	(0.0246)	(0.0327)	(0.00409)	(0.0120)	(0.0327)
Dwelling rooms	0.0200**	0.0207**	0.00659	−0.0472***	0.0131	−0.00501*	−0.000494	−0.00764
	(0.00837)	(0.00888)	(0.00739)	(0.0107)	(0.00982)	(0.00299)	(0.00478)	(0.00998)
Observations	812	812	812	812	1304	1304	1304	1304

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

Table B1.3b
Determinants of major cooking fuel choice in the Kyrgyz Republic, marginal effects (multinomial logit).

	Urban				Rural			
	Oven (coal and wood)	Gas pipe	Gas cylinder	Electric Stove	Oven (coal and wood)	Gas pipe	Gas cylinder	Electric Stove
MPCE	9.22e-06*	−6.04E-06	9.09E-07	−4.09E-06	−2.00E-06	−1.76E-06	5.74e-06**	−1.98E-06
	−5.27E-06	−4.27E-06	−3.80E-06	−5.66E-06	−6.52E-06	−1.52E-06	−2.75E-06	−6.60E-06
Gender of household head (=1 if male)	0.0365	−0.0611**	0.0141	0.0106	0.0373	0.000691	0.00573	−0.0437
	−0.0248	−0.0238	−0.0222	−0.026	−0.0268	−0.00448	−0.0145	−0.0278
Age	−0.000416	0.00215**	−0.00244***	0.000708	1.72E-06	0.000188	−0.000265	7.54E-05
	−0.000922	−0.000925	−0.000851	−0.000999	−0.000925	−0.000155	−0.000478	−0.000961
Education level of household head (base category = basic education)								
Secondary	−0.00514	0.011	0.0261	−0.0319	−0.0930***	0.000436	0.0129	0.0797***
	−0.0376	−0.041	−0.036	−0.0419	−0.0299	−0.0043	−0.0151	−0.0307
Higher secondary (technical)	−0.0532	0.0565	0.022	−0.0253	−0.0931**	0.00327	−0.0146	0.104**
	−0.0418	−0.0436	−0.0374	−0.0468	−0.0409	−0.00745	−0.0176	−0.0419
Graduate and above	−0.0496	−0.00274	0.0237	0.0286	−0.0474	0.00752	−0.0152	0.0551
	−0.0446	−0.0432	−0.0373	−0.0493	−0.043	−0.0118	−0.0217	−0.0444
Household size	0.0154***	−0.000174	−0.00323	−0.0120*	0.00809	−0.00111	0.00461	−0.0116**
	−0.00586	−0.0062	−0.0057	−0.00726	−0.00526	−0.00105	−0.0029	−0.00558
Heating fuel (base category=central heating)								
Electricity	−0.145***	−0.393***	0.185***	0.352***				
	−0.0377	−0.0541	−0.0424	−0.0465				
Stove (coal and wood)	0.116***	−0.427***	0.162***	0.149***	0.128***	−0.00339	−0.0587***	−0.0655*
	−0.0394	−0.043	−0.028	−0.0369	−0.0394	−0.00346	−0.0099	−0.0385
Gas	0.000782	0.0508	−0.0305***	−0.0211				
	−0.127	−0.113	−0.0107	−0.0884				
Electricity log price	−3.018***	0.185	0.681	2.152***	−10.55***	−0.208	−0.0187	10.78***
	−0.664	−0.694	−0.626	−0.739	−0.95	−0.308	−0.852	−1.112
Coal log price	0.895	0.37	1.166*	−2.431***	4.601***	0.107	0.224	−4.932***
	−0.591	−0.681	−0.619	−0.666	−0.677	−0.244	−0.559	−0.751
Gas log price	0.539*	−0.276	−0.0528	−0.21	2.624***	−0.0718	−1.717***	−0.835**
	−0.316	−0.424	−0.329	−0.371	−0.313	−0.088	−0.275	−0.352

(*continued on next page*)

Table B1.3b (*continued*)

	Urban				Rural			
	Oven (coal and wood)	Gas pipe	Gas cylinder	Electric Stove	Oven (coal and wood)	Gas pipe	Gas cylinder	Electric Stove
Access to gas	−0.0918***	0.216***	0.0881***	−0.213***	−0.176***	0.00293	0.0266**	0.147***
	−0.0247	−0.02	−0.0184	−0.025	−0.0315	−0.00444	−0.0122	−0.0316
Dwelling rooms	0.0198**	0.0219**	0.00583	−0.0475***	0.0142	−0.00556*	0.00101	−0.00967
	−0.00836	−0.00877	−0.00736	−0.0106	−0.00951	−0.00303	−0.00492	−0.0098
Power outage	0.0111	−0.0507***	0.0219**	0.0177	0.110***	−0.00327	−0.0182**	−0.0887***
	−0.0107	−0.014	−0.0106	−0.0123	−0.0142	−0.00348	−0.00882	−0.0152
Observations	812	812	812	812	1323	1323	1323	1323

Robust standard errors in parentheses ***p < 0.01, **p < 0.05, *p < 0.

Table B1.3c
Determinants of major cooking fuel combinations choice in the Kyrgyz Republic, marginal effects (multinomial logit).

	Gas+Coal	Gas+Electricity	Coal+Electricity
MPCE	2.43e-05***	−1.23e-06	−2.30e-05***
	(4.06e-06)	(1.55e-06)	(4.35e-06)
Gender (male=1)	0.0131	−0.000879	−0.0123
	(0.0185)	(0.00834)	(0.0187)
Age	0.000120	0.000205	−0.000325
	(0.000665)	(0.000313)	(0.000673)
Education level of household head (base category = basic education)			
Secondary	0.0269	0.000575	−0.0275
	(0.0223)	(0.0129)	(0.0231)
Higher secondary (technical)	0.0317	−0.00464	−0.0271
	(0.0272)	(0.0147)	(0.0281)
Graduate and above	0.0274	0.0278*	−0.0552*
	(0.0289)	(0.0160)	(0.0300)
Household size	0.00772**	−0.00539**	−0.00232
	(0.00382)	(0.00219)	(0.00394)
Heating fuel (base category = central heating)			
Electricity	0.183***	−0.286***	0.103
	(0.0394)	(0.0737)	(0.0754)
Stove (coal and wood)	0.183***	−0.495***	0.312***
	(0.0287)	(0.0707)	(0.0733)
Gas	0.0114	−0.155*	0.144
	(0.0507)	(0.0921)	(0.109)
Electricity price, log	3.627***	−0.526**	−3.102***
	(0.564)	(0.261)	(0.564)
Coal price, log	−0.529	0.598***	−0.0688
	(0.405)	(0.208)	(0.410)
Gas price, log	−1.074***	−0.117	1.192***
	(0.208)	(0.120)	(0.211)
Dwelling rooms	0.0209***	−0.0129***	−0.00801
	(0.00613)	(0.00365)	(0.00625)
Rural	−0.0161	−0.0720***	0.0881***
	(0.0180)	(0.0120)	(0.0183)
Observations	1858	1858	1858

Robust standard errors in parentheses ***p < 0.01, **p < 0.05, *p < 0.

Table B1.3d
Determinants of major cooking fuel combinations choice in the Kyrgyz Republic, Marginal Effects (Multinomial logit) (including power outage).

	Gas+Coal	Gas+Electricity	Coal+Electricity
MPCE	2.40e-05***	−1.13e-06	−2.28e-05***
	(4.05e-06)	(1.57e-06)	(4.34e-06)
Gender of household head (male = 1)	0.0145	−0.00119	−0.0133
	(0.0184)	(0.00833)	(0.0186)
Age	0.000136	0.000198	−0.000334
	(0.000657)	(0.000312)	(0.000666)
Education level of household head (base category = basic education)			
Secondary	0.0272	0.00120	−0.0284
	(0.0220)	(0.0129)	(0.0228)
Higher secondary (technical)	0.0310	−0.00437	−0.0266
	(0.0270)	(0.0146)	(0.0279)
Graduate and above	0.0240	0.0285*	−0.0526*
	(0.0284)	(0.0159)	(0.0296)
Household size	0.00729*	−0.00529**	−0.00200
	(0.00379)	(0.00220)	(0.00392)
Heating fuel (base category=central heating)			

(*continued on next page*)

Table B1.3d (*continued*)

	Gas+Coal	Gas+Electricity	Coal+Electricity
Electricity	0.195***	−0.287***	0.0928
	(0.0376)	(0.0739)	(0.0746)
Stove (coal and wood)	0.199***	−0.493***	0.294***
	(0.0256)	(0.0708)	(0.0728)
Gas	0.00757	−0.157*	0.150
	(0.0420)	(0.0925)	(0.106)
Electricity log price	4.089***	−0.526**	−3.563***
	(0.580)	(0.262)	(0.581)
Coal log price	−0.944**	0.597***	0.347
	(0.432)	(0.207)	(0.436)
Gas log price	−1.142***	−0.122	1.263***
	(0.210)	(0.120)	(0.213)
Dwelling rooms	0.0211***	−0.0128***	−0.00826
	(0.00609)	(0.00365)	(0.00622)
Rural	−0.0106	−0.0726***	0.0832***
	(0.0182)	(0.0121)	(0.0184)
Power outages	−0.0352***	0.00263	0.0325***
	(0.00915)	(0.00450)	(0.00918)
Observations	1858	1858	1858

Robust standard errors in parentheses ***p < 0.01, **p < 0.05, *p < 0.

Appendix C Robustness

Table C1
Determinants of major cooking fuel combinations choice logit model.

Classifications	Variables used for each country		
	India	Kazakhstan	The Kyrgyz Republic
Household characteristics	(+) Gender*** (+) Age *** (+) Education*** (-) Household Size*** (+) Social group***	(+) Household size*	(-) Gender* (+) Education*
Convenience/Multiuse	(-) Free fuel***	Heating system: (-) Autonomous (gas, coal)*** (+) Oven (gas, electricity)*** (-) Oven (coal, other)*** (-) Oven (coal only)*** (-) Free fuel	(-) Stove (coal and wood)***
Affordability	(+) Salaried income*** (+) MPCE***	(+) Coal log price*** (-) Natural gas log price*** (-) Electricity log price***	(+) Fuel prices***
Accessibility		(+) Access to natural gas***	(+) Access to natural gas***
Built environment		(+) Apartment*** (+) Total area, m2	
Tenure status	(-) Own***		
Quality of services/fuel			(-) Power outage**
Location	(+) Urban***	(+) Urban***	(-) Rural***

Sign of the coefficients are in parentheses.

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