



Research Paper

Clean Fuel for Rural Families in India a Major Challenge: Evidence from four rounds of consumer expenditure survey

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ABSTRACT

Ensuring universal access to reliable, sustainable, and modern energy at an affordable price by 2030, is one of the major targets under the Sustainable Development Goals (SDGs) of the United Nations. Unfortunately, although the world has made tremendous progress in the last decade in ensuring access to sustainable energy in the form of electricity, mainly for lighting, until now, three billion people (39% of the total population) in the world still rely on unclean and unsafe cooking fuels. The people who rely on dirty and unsafe fuel for cooking are mostly concentrated in the rural areas of the global south. To attain the UN target of affordable, reliable, and clean energy for all by 2030, it is imperative to provide more focused attention to improve access to safe and clean cooking fuels and technologies. To begin with, it is crucial to explore the influential factors that impact rural households' choice and use of safe and clean cooking fuels. This study examined the factors affecting the choice and use of different types of fuels for cooking the rural households of India. In the process, this study relied on four rounds of data collected by the National Sample Survey Organization (NSSO) 46th(1991–92), 56th (2000–01), 63rd (2006–07), and 68th (2011–12) round. Applying the multivariate probit and two-limit Tobit estimation, this study reveals that the formal education of the spouse and household head and the economic solvency of the household are the major influential factors in influencing the cooking fuel choice and use by the rural households in India. The findings of this study suggest investing in general education and to improve the livelihoods of the rural households to rapid adoption and use of nonpolluting, clean, and modern fuel for cooking in the rural areas of developing countries.

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1. Introduction

Access to clean, and modern fuels at an affordable price significantly and sustainably determine economic development and the overall livelihood quality of the citizens. Therefore, ensuring access to modern energy and technology at an affordable price for all by 2030 is the seventh Sustainable Development Goals (SDGs) of the (United Nations, 2020). Achieving this goal of the UN can unveil a new era of prospects for billions of people by laying the foundation for poverty alleviation, and climate action for sustainable development (United Nations, 2021a). In the last decade, tremendous progress has been made in ensuring access to clean and efficient energy, such as electricity. For example, in 2010, 83% of the total population of the world was connected to electricity,

which has increased to 90% in 2019 (United Nations, 2021b). The progress on ensuring clean and modern fuel for cooking for all is comparatively low. In 2010, 57% of the total population in the world were using clean and modern fuels and technologies, in 2019, which has increased to 66% for cooking (United Nations, 2021b). It means, until now, 44% of the total population (2.6 billion) in the world relies on dirty and solid fuel for cooking (United Nations, 2021b). Thus, the overall progress to attain the UN target in terms of clean and affordable energy for all by 2030 is slow. Alarming, the use of inefficient, dirty, and highly polluting cooking fuels and technologies is responsible for nearly 4 million annual premature death in the world (United Nations, 2021b; WHO, 2020). This issue is particularly prominent in the rural areas of developing Asia, Africa, and Latin America (Bonjour et al., 2013; United Nations, 2021b). Thus the question arise as to how to ensure clean, nonpolluting, and efficient cooking fuels and technologies for all by 2030 as per the target of the UN?

To begin with, it is crucial to explore the context and factors that affect households' preference and use of clean and efficient

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as well as dirty and polluting fuels and technologies for cooking. A deep understanding of the issue can significantly contribute to developing effective policies to widen the doorway to clean and efficient cooking fuels and technologies as per the target of the UN. The objective of this study is to examine the context and factors affecting the choice and use of cooking fuels by rural households in India.

With a population of 1.37 billion, India is the second-most populous country after China (the total population of China is 1.39 billion), and one of the fastest economically emerging nations in the world (World Bank, 2021b). Since 1990, the country has been economically growing very fast. Consequently, India has made remarkable progress in ensuring clean and affordable fuel for all, particularly in the form of electricity. In 2001, 56% of the total population of India was connected to electricity, which has increased to 98% in 2019 (IRENA et al., 2021). However, the relatively slow progress of India in ensuring clean and nonpolluting cooking fuels and technologies has posed a question on whether India can achieve the target of SDG 7 by 2030. In 2000, 22% of the total population of India had access to clean cooking fuels and technologies, which has increased to 64% in 2019 (IRENA et al., 2021). It means still, 36% of the total population of India, or 493 million people of India are deprived of clean cooking fuel and technologies, who rely on solid fuels, kerosene, or biomass for cooking. In India, reliance on biomass, dung cake, and firewood is the major source of indoor air pollution (Smith, 2000; Andresen et al., 2005; Viswanathan and Kavi Kumar, 2005; Ingale et al., 2013; Rohra and Taneja, 2016). Research studies show that in addition to yearly 1.3 million premature deaths (Kanti, 2017), the average loss in productive life years is 5% in India due to indoor air pollution (Reddy and Srinivas, 2009; Rohra and Taneja, 2016).

Alarmingly, the clean cooking fuels and technology-deprived people are mostly concentrated in the rural areas of India (Khandker et al., 2010; Ranjan and Singh, 2017). For example, in India, currently, around 23% of households in the urban areas and 83.5% of the rural households, rely on firewood and biomass for cooking (NSSO, 2014). Considering the background, this study exclusively examined the choice and use of fuels for cooking by rural households in India. Though several studies examined the fuel choice behaviors at the household level in India (Berry et al., 2020; James et al., 2020; Parikh et al., 2016; Reddy, 1995), those studies were based on a micro dataset from the village and/or state, and thus, are not nationally representative. The study of Rao and Reddy's study (2007) and Farsi and Filippini (2007), however, is based on the National Sample Survey Organization (NSSO) datasets, but both studies are based on only one round of datasets. This indicates that still there is a gap in understanding the rural households' behavior regarding clean energy use for cooking at the national level.

Extracting cooking fuel choice and expenditure data of more than 136,000 households from the rural areas from four rounds of the National Sample Survey (NSS) datasets: NSS 1990–91 46th round; NSS 2000–01 round 56th; NSS 2006–07 round 63rd; and NSS 2011–12 68th rounds of India (NSSO, 1990–91; NSSO, 2000–01; NSSO, 2006–07; NSSO, 2011–12), the present study investigates the dynamics of cooking fuel choice and expenditure on different cooking fuels of rural households of India. Like India, generally in the global south, the rural–urban gap in access to clean and nonpolluting fuels for cooking is severest. Thus, the policy implications of this study can have some applicability to other economically emerging countries. The novelty of the study, to our knowledge, this study is the first that applied rigorous econometric estimation procedure to explore the fuel choice and expenditure behavior of rural households in India using four waves of nationally representative datasets. This study contributes to the existing literature in a number of ways. Using

a large nationally representative dataset span over a long period of time (1990–2012) this study reinvigorates the importance of formal education, and economic affluency in ensuring the provision of clean cooking fuels for rural families in developing countries. Furthermore, this study presents both aggregate levels and disaggregated level econometric analysis to examine the factors affecting different cooking fuel choice and reliance on it by the rural households in India. This study thus can provide deep insights into the choice and use of cooking fuels by the rural households of India, which can be used to ensure access to clean and efficient cooking fuel by the rural Indian households.

2. Fuel use for cooking by the rural Indian households

Currently, the total population of India is 1.37 billion, which makes India the second-most populous country. Importantly, India is one of the fastest economically growing nations in the world (World Bank, 2021b). Since the late 1990s, India has been experiencing strong economic growth leading to increased incomes and improved living standards of the citizens. For instance, India's annual average GDP growth rate was about 5.8% between 1990 and 2020, the GDP per capita of the country increased from about US \$364 in 1990 to about US \$1900 in 2020 (World Bank, 2021b). It is expected that the rapid economic growth of India will continue in the future, as it is predicted that Indian GDP (in terms of 2010 prices) will continue to grow by 6.2% per annum until 2031 (USDA, 2020), and the real GDP per capita will be around US \$4,247 by 2031 (USDA, 2021). In the last three decades, India also has experienced a rapid urbanization process. For example, in 1960, less than 18% of the total population lived in urban areas, whereas in 2019, 34% of the population was in the urban areas (World Bank, 2021b). It is predicted that more than 50% of the citizens will live in urban areas by 2050 (World Bank, 2021a).

The rapid economic progress and speedy urbanization of India have contributed to increasing the power generation and distribution capacity. It has enabled India to fulfill the seventh SDG goal of ensuring clean and efficient energy for all. Also, the rural–urban discrepancy in terms of access to electricity has dropped dramatically in the last few decades. In the 2009–10 financial year, the total power generation from all sources was 808.5 billion units, which has increased to 1,381.8 billion units in 2020–21 (Government of India, 2021). During this time, the annual average growth of power generation was more than 5%. In 1980, at the national level, 26% of the total households in India were connected to electricity, in which the electricity connection rate in the rural area was 15%, and in the urban area, it was 63% (Agarwal et al., 2020). In 2020, more than 98% of the households in India, are connected to electricity (Agarwal et al., 2020; Government of India, 2020; IRENA et al., 2021). In 2020 while 99.2% of the total population in the urban areas of India had access to electricity, it was 97.6% for rural areas (Agarwal et al., 2020; Government of India, 2020). Overall, India is highly successful in ensuring electricity, clean energy for all.

The progress of India in ensuring clean cooking fuels and technology for all is also tremendous (Mani et al., 2021; Parikh et al., 2016). For example, in 1994, more than 90% of the households in the rural area, and more than 40% of the households in the urban area, were relying on traditional biomass (firewood, chips, dung cake, and crop residues) for cooking (Ramamurthi et al., 2016). In 2012, nearly 80% of the households in the rural areas and a little more than 15% of the households in the urban areas were using traditional biomass for cooking (Ramamurthi et al., 2016).

The policy of the government of India in ensuring access to liquefied petroleum gas (LPG), however significantly and drastically changed the entire scenario. In 2016, the ministry of petroleum and natural gas, of India introduced “Pradhan Mantri Ujjwala

Yojana (PMUY) scheme, intending to make clean cooking fuel such as LPG available for the rural and economically backward households were using traditional biomass for cooking. Under the scheme, a target was set to release 80 million LPG connections to rural and poor households by March 2020 (Government of India, 2016). In this scheme, the beneficiary receives deposit-free access to LPG supplies and a stove free of charge. The impact of this program has generated stunning results. In 2011, 29% of households were using LPG as their major fuel for cooking, of which 11% of rural households and 65% of urban households were using LPG as their primary fuel for cooking (Mani et al., 2021). In 2020, overall 71% of the total households in India were using LPG as their primary cooking fuel, in which 61% of the rural households and 95% of the urban households were using LPG as their primary cooking fuel (Mani et al., 2021).

Despite the tremendous progress in ensuring access to modern and clean fuels for cooking, still 15% of the total households of India, in which 20% rural households and 2% urban households completely rely on traditional biomass for cooking (Mani et al., 2021). Moreover, still, now, 19% of rural households and 14% of urban households mixed traditional biomass with clean cooking stoves and LPG for cooking (Mani et al., 2021). In addition to rural–urban difference, the regional difference in choice and reliance on clean fuels for cooking in India is also wide. For example, in 2020, more than 50% of the households in Odisha, Jharkhand, Bihar, West Bengal, and Madhya Pradesh were relying on traditional biomass stacking with LPG for cooking, where is Delhi, Andhra Pradesh, Haryana, Punjab, and Maharashtra, almost all of the households rely on only LPG for cooking (Mani et al., 2021).

Overall, despite tremendous global progress in the last decade, more than 27 million (2% of 1.37 billion) people of India is not connected to electricity, and nearly 400 million people (29% of 1.37 billion) still rely on traditional biomass or mix traditional biomass with other fuel for cooking. Including India, a total of 770 million population of the world have no access to electricity, and 2.5 billion have been deprived of clean cooking fuel (IEA, 2021). Indoor air pollution due to the use of traditional biomass for cooking is the cause of the death of 2.5 million globally in a year (IEA, 2021). The yearly per capita economic costs of using traditional biomass and polluting cooking fuel are US \$ 1000/person, which is equivalent to US\$ 2 trillion/year, in which US \$ 0.8 trillion for the loss of productivity of women, US\$ 0.2 for environmental degradation, and US \$ 1.4 trillion for health care (IREA et al., 2021). Only in India, in 2019, indoor air pollution was the cause of 0.61 million death, and the economic loss due to loss in production from morbidity and premature death due to indoor air pollution was 0.49% of GDP, equivalent to US \$ 14 billion (Pandey et al., 2021).

Ironically, as most of the clean energy-deprived households reside in the rural areas of Asia and Africa (IEA, 2021), to formulate effective policies to ensure clean energy for all, it is essential to explore the aspects that affect the selection and use of clean as well as dirty fuels for cooking and household chores. This study, using information collected during the 1990-to-2012 period, examined the factors affecting the choice and expenditure on cooking fuels by the rural households in India. The findings of the present study can shed light on the priority investment area to ensure clean fuels for cooking for India by 2030.

Ensuring the right to use clean and modern energy for all by 2030 as per the SDG of the United Nations can positively and significantly influence economic development and the quality of life. While the global progress in ensuring access to clean and modern technology for cooking fuels was on the right track until 2019, the recent COVID-19 induced pandemic has negatively impacted global progress. This is because, many countries diverted

resources from energy and other sectors to the health sector, and also the COVID-19 induced economic turmoil has diminished poor households' ability to pay for modern and clean cooking fuels and lighting (IEA, 2021). It is estimated that ensuring clean and modern technology and cooking fuels by 2030 requires an investment of US \$ 43 billion per year (IEA, 2021). Otherwise, under the business-as-usual scenario, globally, including India, some 670 million people will remain without access to electricity and 2.1 billion without access to clean cooking fuel and technology (IEA, 2021). Although the present study is focused on the rural households of India, the policy implications of this study can be used to devise useful investment strategies to ensure clean fuels for the energy-deprived households in the rural areas in developing Asia and Africa. In the next section, testable research hypotheses are derived after reviewing available empirical literature.

3. Factors affecting choice and use of dirty and clean cooking fuels and research hypotheses

Several studies have investigated households' preferences and use of cooking fuels. In this study, we have confined our literature review to three important aspects: choice and the use of cooking fuels against (1) income and wealth; (2) formal education of the spouse and household head; and (3) the demographic composition of a household.

3.1. Wealth and income and cooking fuel choice by the rural households

It has long been argued that households' income and wealth are the major determinants of cooking fuel preference, which is widely known as the energy ladder hypothesis (Leach, 1975, 1987, 1992). According to the hypothesis, as income increases, households progressively move from dirty (e.g., traditional biomass), to clean fuels (e.g., LPG) for cooking and lighting. Later, several quantitative research studies have established a strong positive connection between households income and wealth status and the preference and use of clean cooking fuels and technologies, and a contrasting relationship with the use of traditional biomass and dirty fuels for cooking (Behera et al., 2015; Mottaleb et al., 2017a; Pachauri et al., 2004; Pachauri and Jiang, 2008; Rahut et al., 2014, 2016).

In India, despite the significant progress in ensuring clean cooking fuels and technologies, in 2020, at least 15% of the total households were relying completely on traditional biomass and solid fuels, the share was 20% for the rural Indian households (Mani et al., 2021). Following the energy ladder theory, we have developed the following hypothesis:

Hypothesis 1 (H1): Economically affluent households in rural India are more inclined to choose clean cooking fuels, such as electricity, LPG, and natural gas, and spend more on clean fuels compared to others.

3.2. Human capital and cooking fuel choice and use

The education level of spouses and household heads strongly and significantly influence the household's choice and use of clean fuels for cooking (Heltberg, 2005; Israel, 2002; Mottaleb et al., 2017b; Mottaleb and Rahut, 2021; Pandey and Chaubal, 2011; Rao and Reddy, 2007; Reddy and Srinivas, 2009). There are a few reasons why the education level of household heads and spouses is positively and significantly correlated with the preference and reliance on clean cooking fuels and vice versa. Firstly, in general, the level of education and income are positively and highly correlated. In general, higher educated enhances the

opportunity of employment and lucrative earnings from other than the farm sector, higher incomes, augments households' acquiring power for clean cooking fuels. Secondly, education also enhances awareness about the hazards of using solid and traditional biomass for cooking and indoor air pollution (Heltberg et al., 2000b; Israel, 2002; Pachauri and Jiang, 2008; Rao and Reddy, 2007). This awareness can also influence households to choose and use clean cooking fuels. Thirdly, the opportunity costs of the collection of traditional biomass and firewood are relatively higher for the educated household heads and spouses than others (Mani et al., 2021). It can also negatively affect the decision to and reliance on biomass and firewood for cooking for the educated household heads and spouses.

The family composition and households' demographic structure also affect the choice and use of different types of cooking fuels (Behera et al., 2015; Pandey and Chaubal, 2011; Rahut et al., 2016; Reddy and Srinivas, 2009). For example, it is found that there is a positive assertion between the number of household members and the reliance and choice of traditional biomass for cooking (Pandey and Chaubal, 2011). This is because, more family members can provide more labor for free for the collection of firewood and biomass (Deweese, 1989; Heltberg et al., 2000a; Nepal et al., 2011; Pandey and Chaubal, 2011). In addition, in developing countries, women are mostly responsible for cooking and thus for collecting biomass and firewood for cooking (Mottaleb et al., 2017a). Thus, the rural households with more female family members are more likely to rely on and use firewood as well as biomass for cooking. Based on the reviewed literature, we developed the following testable hypothesis regarding cooking fuel preference and reliance on it by the rural households in India:

Hypothesis 2 (H2): Although formal years of schooling of the spouse and household head positively affect the preference and use of clean cooking fuels, households with more family members are more likely to depend on biomass and fuelwood for cooking.

4. Materials and methods

4.1. Data

This study relies on data collected by the National Sample Survey (NSS) Organization, India, from the NSS 46th round collected in 1990–91; NSS 56th round collected in 2000–01; NSS 63rd round collected in 2006–07, and NSS 68th round collected in 2011–12. Details of the sampling procedure and data collection process can be seen in National Sample Survey Organization NSSO (1991, 2007, 2002, 2014). From 28,533 surveyed households in the 46th round (1990–91), 13,739 households (48.2%) were from rural areas. In the NSS 56th round (2000–01), the total surveyed households were 81,500, of which 30,562 households (37.5%) were from the rural areas (Table 1). In the NSS 63rd round (2006–07), a total of 63,729 households were surveyed, of which 33,146 households (52%) were from the rural areas (Table 1). Finally, in NSS 68th round (2011–12), a total of 101,662 households were surveyed, of which 59,695 households (59%) were from the rural areas (Table 1).

During the data curation stage, it is noticed that the information on fuel use and expenditure on it was incomplete for a few households. We dropped those households from this study. Consequently, this study is based on information collected from 134,852 households residing in the rural areas of India, and the NSSO collected data in four rounds (Table 1).

4.2. Empirical estimation procedure: modeling choice and reliance on different fuels for cooking

Based on the literature review and our hypotheses, several factors, such as income, human capital, households' demographic structure, and many other factors, can affect the choice and expenditure on different types of cooking fuels. To econometrically explore the issues affecting the preference and reliance on cooking fuels by type by the sampled rural households, we develop the following empirical model:

$$y_i = \alpha_0 + \sum_{s=1}^3 \varphi_s(EDS)_s + \sum_{h=1}^3 \theta_h(EDH)_h + (HCI)_i \lambda_i + \beta_1 \ln(PCX)_i + \sum_{i=1}^3 \psi_i(PEX.quartile)_i + \beta_2(MNL)_i + \beta_3(SML)_i + \beta_4(CST)_i + \sum_{d=1}^5 \gamma_d(RGN)_d + \zeta_i \quad (1)$$

In Eq. (1), the variables EDS_s and EDH_h are the education level of the spouse and head that include, a dummy for primary level schooling (≤ 5 years); a dummy for education level up to high school (6–10 years), and a dummy for the education level more than 10 years (11 years and above), where no formal schooling is the base ($=0$). HCI is a vector of independent variables that include the age of the spouse and head, and a sex dummy of the household head, which assumes a value of 1, if the household head is a female and 0, otherwise; and the size of the household (number of family members). $\ln(PCX)$ is the monthly per capita total consumption expenditure in Indian Rupees (Rs.) in the natural log form. This variable is treated as a proxy for income. The variable $PEX.quartile$ includes four expenditure quartiles (Q1–Q4) dummies constructed based on monthly per capita total expenditure, where the lowest expenditure quartile (Q_1) is the base (poorest group = 0). The variable MNL is a dummy variable that assumes a value of 1, if the household owned less than one hectare of land, or else, 0; SML is a dummy variable that assumes a value of 1, if the family-owned 1–2 ha of land, otherwise 0.

Existing literature reveals a strong signal for the tenacious social and economic inequalities based on caste system in different scales of the livelihoods citizens in the rural areas in India (Borooh, 2005; Desai and Dubey, 2012; Zacharias and Vakula-bharanam, 2011). Studies are, however, scanty, particularly on the association between caste and the choice and use of cooking fuels in India. To examine the issue, we include a variable CST , which is a dummy variable that assumes a value of 1 if the household belongs to the scheduled tribe or scheduled caste or backward caste, and 0 otherwise. RGN includes five dummies for six regions of India, where the base region is the West Indian States ($=0$). Region dummies are included to capture the regional heterogeneity in preferring and using cooking fuels in India (Mani et al., 2021). Furthermore, to capture the impacts of interactions of the caste of the households, and the land ownership status (if any), three multiplicative dummies are included in the model as:

- Dummy for schedule tribe/caste/backward caste household (yes=1) X \ln (monthly per capita expenditure (Rs.));
- Dummy for marginal household (yes=1) X \ln (monthly per capita expenditure (Rs.)); and
- Dummy for the smallholder households (yes=1) X \ln (monthly per capita expenditure (Rs.)).

In Eq. (1), α_0 is a scalar and λ_i , β_i , γ_i , φ_s , θ_h , ψ_i and γ_d are the parameters to be assessed, and ζ_{im} is the random error term.

In Eq. (1), Y_i is a vector of dependent variables that represents both choice and expenditure on different cooking fuels by

Table 1
 Sampled rural and urban households by the NSS rounds in India.
 Source: Authors' calculation based on National Sample Survey Organization NSSO (2007, 2002, 1991, 2014).

National Sample Survey (NSS) round (and year surveyed)	Surveyed households			Sampled rural households considered in this study
	Total households	Urban households	Rural households	
NSS 46th round (1990–91)	28,533	14,794 (51.8)	13,739 (48.2)	13,690
NSS 56th round (2000–01)	81,500	50,938 (62.5)	30,562 (37.5)	30,389
NSS 63rd round (2006–07)	63,729	30,583 (48.0)	33,146 (52.0)	33,080
NSS 68th round (2011–12)	101,662	41,967 (41.0)	59,695 (59)	59,693

Notes: Values in the parentheses in the first column is the surveyed year. Values in the parentheses in the third and fourth columns are the percentage.

a sampled rural household *i*. Usually, in developing countries, households rely on different types of fuels simultaneously (Mottaleb et al., 2017b), which is widely known as the fuel stacking behavior of the households. The rural households of India are not an exception. For example, in 2020, while 20% of the rural households in India completely relied on solid fuels for cooking, 19% of them primarily relied on solid fuels mixed with other clean fuels (Mani et al., 2021).

To capture the factors that affect the fuel stacking and using the behavior of the rural households in India, we have classified cooking fuels used by the sampled households in three broad categories: solid and dirty fuels, such as firewood, biomass, and dung cake; kerosene and/or coal and/or other fuels, and clean fuels such as natural gas, LPG and electricity. As it is most likely that the rural households in India may choose and use different types of fuels for cooking simultaneously, to examine the factors affecting the cooking fuel choice behavior of the sampled rural households, we have estimated Eq. (1) applying the multivariate probit model estimation procedure in which the dependent variable Y_i assumes a value of 1, if a household chooses solid and dirty fuel, otherwise 0; assumes a value of 1, if household chooses kerosene/coal or other fuels for cooking, otherwise 0, and assumes a value of 1, if a household chooses clean fuels such as natural gas, LPG and electricity for cooking, or 0 otherwise.

This study also investigated the factors influencing the use intensity and dependence on different fuels for cooking. In the process, we have calculated the share of the expenditure on a particular type of cooking fuels into the total fuel expenditure of a household as follows: Symbolically:

$$\text{Share of fuel type } x_i = \frac{EX_i}{\sum_{i=1}^3 TFX_i} \tag{2}$$

where x_i is the ratio of expenditure on fuel I ($= 1, \dots, 3$) to monthly total fuel expense by a sampled household $\sum_{i=1}^3 TFX_i$ is the total fuel expenses on three broad categories of fuels (traditional biomass, coal and kerosene, and natural gas, LPG, and electricity). A higher ratio on a specific category of fuel indicates a higher level of dependency of a household on that cooking fuel.

It is important to mention here is that, not all of the sampled households spent on all types of cooking fuels. For some households, the expenditure on natural gas, LPG, and electricity is zero, and for some of the sampled households, the expenditure on traditional biomass, and firewood is zero. This is a common problem often researchers face in analyzing household data (Mottaleb et al., 2021). Due to the censored nature of data, following (Gujarati, 2004), a two-limit Tobit model estimation process has been applied.

In addition, it might be the case that the economically affluent rural households may self-select themselves in choosing and

relying on clean fuels for cooking, such as natural gas, electricity, and LPG. To control for the selection bias (if any), after estimating the fuel choice functions in Eq. (1), we estimated the generalized inverse Mill's ratio using the procedure of Vella (1998) and plugged it in when we estimated the proportion of fuel expenditure functions. The use of the multivariate probit and two-limit Tobit approach in investigating fuel use and consumption expenditure on various fuel categories is not new. These models have been extensively used in exploring households' behavior of fuel preference and use for cooking in developing countries (Mottaleb et al., 2017a; Pallegedara et al., 2021; Mottaleb et al., 2017b; Rahut et al., 2017a,b).

India has managed to achieve stunning economic progress in alleviating poverty and in ensuring clean fuels for all since the '90s. Considering the rapid economic and structural changes of India, Eq. (1) is estimated separately for rounds 1990–91, 2000–01, 2006–07, and 2011–12.

5. Results and discussion

5.1. Descriptive findings

5.1.1. Descriptive statistics of variables used in the study

Background information of the sampled rural households in the form of explanatory statistics is presented in Table 2. The sampled households were divided based on whether or not they have spent on the dirty fuels, such as firewood biomass and cow dung, and/or kerosene, coal and other fuels and/or clean fuels such as natural gas, LPG, and electricity for cooking (Table 2). As the sampled households rely on different types of fuels for cooking, the classification of the households is not mutually exclusive. The classification is based on the incidence of expenditure. It shows that 99% of households reportedly used (spent on) solid fuels like firewood, biomass, and dung cake. Further, 86% of the sampled households reportedly used kerosene or coal, and 70% used gas and electricity for cooking. This illustrates the simultaneity of the use and dependence on various categories of fuels by the same family. In South Asia, generally, rural families use kerosene or electricity for lighting and firewood for cooking.

It shows that in rural India, less than 11% of the households sampled, were headed by a female head, and the average age of a household head is 46 years, with a spouse aged 33 years. On average, a sampled household consisted of five family members. Among the sampled household heads, 41% were illiterate, 22% had below primary schooling, 15.8% had secondary schooling, and 21% had completed higher than the secondary level of schooling. As opposed, 16% of the spouse of the head had up to a primary level of education, less than 10% of them had up to a secondary or higher level of schooling. Interestingly, it shows that

Table 2

Basic characteristics of households and fuel use.

Source: Authors' calculation based on National Sample Survey Organization NSSO (1991, 2007, 2002, 2014).

Fuel type	All	Dirty fuels		Clean fuels
		Firewood, biomass, cow dung	Kerosene, coal, & other fuels	Natural gas, LPG, and electricity
No. of observations	136,852	135,876	117,327	95,169
% Female headed household	10.6	10.6	10.4	10.7
Age, household head	46.2	46.3	46.2	47.2
Household size (no. of family members)	4.9	4.9	4.9	4.9
% Household head educated up to primary level (yes = 1)	21.9	22.0	22.7	21.9
% Household head educated up to secondary level (yes = 1)	15.8	15.8	15.8	17.4
% Household head educated above secondary level (yes = 1)	21.0	20.9	18.5	26.4
Age, spouse	33.2	33.4	33.4	34.3
% Spouse educated up to primary level (yes = 1)	16.0	16.1	16.3	17.5
% Spouse educated up to secondary level (yes = 1)	9.7	9.7	9.5	11.8
% Spouse educated above secondary level (yes = 1)	9.4	9.4	7.7	12.5
Monthly per capita expenditure (Rs.)	1,102.3	1,098.0	980.8	1,328.4
% Households in the first expenditure quartile (Q1 = 1)	25.0	25.1	27.6	17.2
% Households in the first expenditure quartile (Q1 = 2)	25.0	25.1	26.6	23.5
% Households in the first expenditure quartile (Q1 = 3)	25.0	25.1	24.9	27.8
% Households in the first expenditure quartile (Q1 = 4)	25.0	24.8	20.8	31.5
% Marginal households (land holding is \leq 1 ha)	71.4	71.3	71.8	69.2
% Small holder households (land holding is 1-2 ha)	12.4	12.5	12.7	12.6
% Low caste households (belong to schedule tribe/caste or backward caste), yes = 1	67.2	67.3	68.5	65.8
% Household from West Indian States (yes = 1)	9.6	9.6	9.6	11.8
% Household from North East Indian States (yes = 1)	14.2	14.1	14.1	13.3
% Household from Central Indian States (yes = 1)	6.4	6.4	6.8	6.9
% Household from East Indian States (yes = 1)	20.7	20.8	23.7	13.2
% Household from South Indian States (yes = 1)	23.9	23.9	23.7	29.3
% Household from North Indian States (yes = 1)	23.2	23.2	21.0	22.8

Notes:

West Indian states: Goa, Gujrat, Maharashtra, Dadra and Nagar Haveli, Daman and Diu, Pondichery.

North-East Indian states: Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura

Central Indian states Madhya Pradesh; Chattishgarh,

East Indian states Bihar, Jharkhand, Odisha, West Bengal,

South Indian states: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Lakshadweep

North Indian States: Hariyana, Himachal Pradesh, Jammu& Kashmir, Punjab, Rajasthan, Uttar Pradesh, Chandigarh, and Uttaranchal.

the household heads with a relatively higher level of education, spend relatively more on clean fuels, such as electricity and liquified petroleum gas (LPG) for cooking than other households. In contrast, the households headed by a relatively less educated head, spend relatively more on solid fuels, such as biomass and kerosene. These findings highlight the importance of formal education on clean energy transition and confirm the findings of previous studies (Mottaleb et al., 2017a; Pallegedara et al., 2021; Rahut et al., 2017b).

The mean monthly per capita consumption expenditure of a person in rural India was of Indian rural families was Rs. 1102 (Table 2). For the households with positive expenditure on electricity and LPG for cooking, the per capita monthly consumption expenditure was Rs. 1328 (Table 2). The monthly per capita total consumption expenditure for the households with positive expenditure on kerosene was Rs. 1098, and it was Rs. 980 for the households with positive expenditure on traditional biomass

and firewood (Table 2). The descriptive statistics of Table 2 lend support to our hypothesis (H1) that there is a positive assertion between economic status and the use of clean cooking fuels and vice versa. Using the monthly total consumption expenditure in Rs. (per capita), we constructed four expenditure quartiles. It shows that from expenditure quartile Q4, more than 31% of sampled households used natural gas, LPG, and electricity for cooking, nearly 21% of them used kerosene and coal, and nearly 25% of them used traditional biomass and firewood for cooking (Table 2). In contrast, among the households in the poorest expenditure quartile (Q1), 17.2% of them used natural gas, LPG, and electricity for cooking, nearly 28% used kerosene and coal, and 25% used traditional biomass and firewood (Table 2). These descriptive findings show that wealth is an influential factor in determining cooking fuel choice and use in India, in which relatively wealthy households are more likely to prefer and use clean fuels for cooking and vice versa.

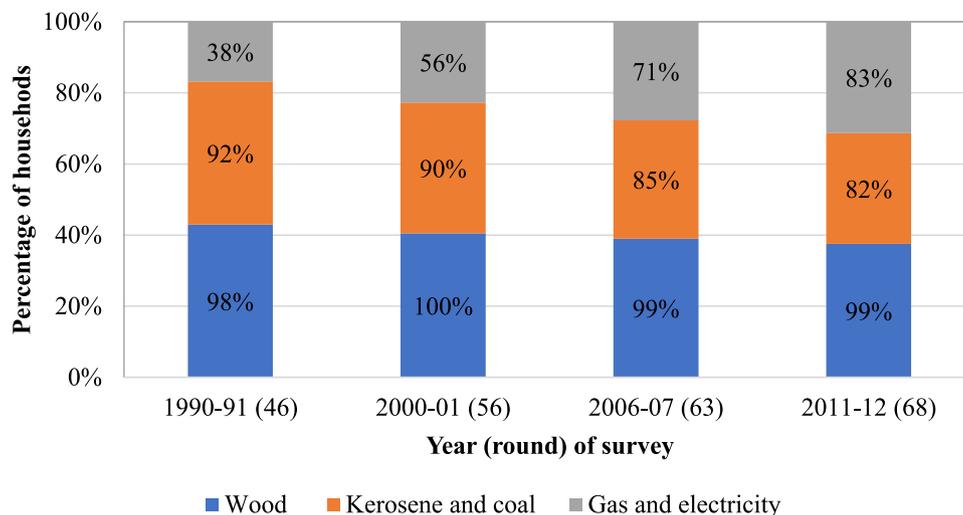


Fig. 1. Temporal changes in fuel use by rural households in India.
Source: Authors' calculation based on National Sample Survey Organization NSSO (1991, 2007, 2002, 2014).

Among the households sampled, 71.4% were categorized as marginal farm households, that owned less than one ha of land, and a little more than 12% of the sampled rural households were classified as the smallholder farm households that owned 1–2 ha of land (Table 2). More than 67% of the sampled rural households belonged to low caste, or backward caste, or schedule tribe. Table 2 shows that the highest incidence of cooking using gas and electricity was among the households in the South Indian states, 29.3%, followed by households in North Indian states (22.8%). Interestingly, the highest incidence of using biomass, cow dung, and firewood for cooking was also among the sampled households from South Indian states (23.9%), followed by the north Indian states (23.2%). The highest incidence of using kerosene and coal for cooking was observed among the households in East Indian states (23.7%) and South Indian states (23.7%).

5.1.2. The trend in the incidence of energy use

A presentation of the sampled households cooking fuel expenditure patterns by the years sampled demonstrates that the percentage of rural households using traditional biomass and firewood for cooking was the same during 1999–2021 (Fig. 1). Almost all of the sampled households included in the four rounds of surveys have used traditional biomass and firewood for cooking. The percentage of households using kerosene and coal for cooking has declined by 10 percentage points from 92% in 1990–91 to 82% in 2011–12 (Fig. 1). Importantly, the share of the households that used electricity, gas, and LPG for cooking has increased drastically over the periods sampled. In 1990–91 less than 40% of the total sampled rural households used electricity, gas, and LPG for cooking, which had increased to more than 80% in 2011–12 (Fig. 1). This big jump in the use of clean cooking fuels by the rural households in India is probably because of the results of the rapid economic growth of the country since 1990, in which the per capita GDP, as well as the living standard of the country, have increased significantly.

5.1.3. Reliance on different fuels source for cooking

In India, not only the incidence of using clean fuels for cooking has increased over the years, but also the reliance on clean cooking fuels such as electricity has increased over the periods sampled. In Fig. 2, the share of monthly total fuel expenditure by the type of fuels has been presented, in which, it shows that among the rural households in India, reliance on traditional

biomass and firewood for cooking has declined substantially, whereas the reliance on clean cooking fuels has increased drastically. For example, in 1990–91, out of total energy expenditure, 70% was only on traditional biomass, including firewood, which had declined to 53% in 2011–12 (Fig. 2). In contrast, in 1990–91, a representative rural household in rural India spent only 11% of its total energy expenditure on electricity and gas for cooking, and in 2011–12 the share had increased to 37%. Interestingly, the share of expenditure on kerosene and coal for cooking has also declined from 19% in 1990–91 to 10% in 2011–12 (Fig. 2). Overall, Fig. 2 demonstrates that during 1990–2012, the sampled rural households in India have reduced their reliance on traditional biomass and firewood, kerosene, and coal for cooking, however, their reliance on clean fuels such as electricity and gas for cooking has increased significantly. This fuel use behavior is probably linked with the improved livelihoods and increased awareness of the households concerning the rapid economic progress of India.

5.1.4. Wealth and fuel expenditure pattern

In Fig. 3, the share of expenditure on three types of cooking fuels by the expenditure quartiles is presented separately for four sampled rounds. The share of expenditure on traditional biomass and firewood for the poorest households belonging to the first expenditure quartile (Q1) is almost constant around 70%, however, their expenditure share on clean cooking fuels such as electricity and gas has increased over the period sampled (Fig. 3). In contrast, the expenditure share on traditional biomass and firewood by the richest households belonging to the fourth expenditure quartile (Q4) has reduced drastically over time, but the share of expenditure on clean cooking fuels has increased significantly. For example, in 1990–91, the share of expenditure on traditional biomass for the households belonging to the fourth expenditure quartile was 58%, which reduced to 36% in 2011–12 (Fig. 3). In contrast, the share of expenditure on clean cooking fuels such as electricity and gas has increased from 19% in 1990–91 to 58% in 2011–12 for the richest households (Fig. 3). Overall, Fig. 3 demonstrates that relatively richer households increasingly rely more on clean fuels for cooking, although the poor households still rely more on traditional biomass and firewood for cooking. The findings confirm that the economic status supports families to consume more clean fuel (electricity and LPG) and less wood and biomass, which supports our second hypothesis (H2).

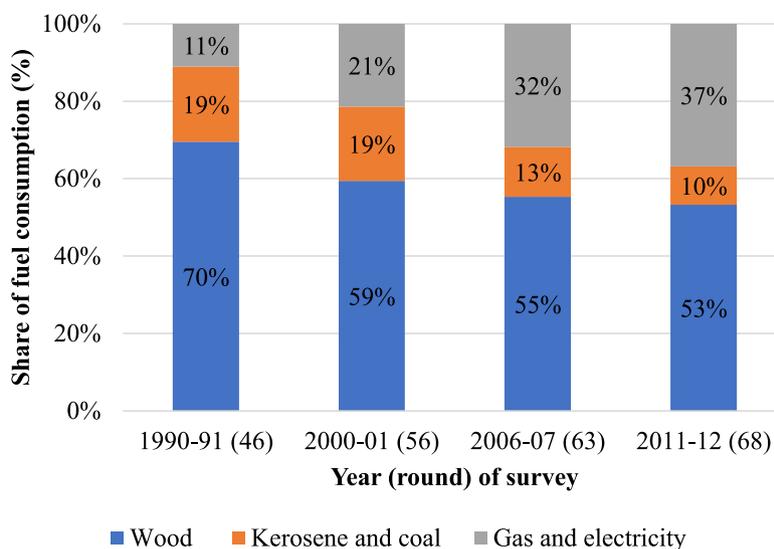


Fig. 2. Share of fuel consumption across the years.
 Source: Authors' calculation based on National Sample Survey Organization NSSO (1991, 2007, 2002, 2014).

5.2. Econometric findings and discussion

5.2.1. Factors affecting cooking fuel choice: findings from the multivariate probit model analysis

The estimated functions applying the multivariate probit model estimation procedure, explaining the factors affecting preferences for cooking fuels by the sampled rural households in India, are presented in Table 3. The functions are estimated and reported separately for every sampled round (Table 3). The dummies for education levels of the household head are significant negative in the functions explaining the choice of traditional biomass and firewood (yes=1), while consistently positive and highly statistically significant in the function explaining the choice of clean fuels, such as natural gas, LPG and electricity (Table 3). The education level dummies of the spouse also are significant and positive in the estimated functions explaining the household's clean cooking fuel preferences, such as electricity and gas, across the years sampled (Table 3). In general, the findings in Table 3 provide strong support to our first hypothesis (H1), that education is the strong determinant of cooking fuel preference by the rural households in India. The findings of this study support the findings of other empirical studies (Behera et al., 2015; Gregory and Stern, 2014; Hou et al., 2017; Huang, 2015; Mensah and Adu, 2015; Rahut et al., 2017; Reddy and Srinivas, 2009).

Interestingly, the size of the coefficient of the education level dummies has increased over the level of education, while gradually decreasing over the years sampled in explaining the choice of clean cooking fuels such as natural gas, LPG, and electricity (Table 3). For example, in NSS round 46 (1990–91), for the household head with a primary level of education, the log odd of preferring clean cooking fuels increased by 37% (exp of 0.32) than the household head with no education (Table 3), but the for the household head with more than the secondary level of education dummy, the log odd of preferring clean fuels for cooking has increased by 105% (exp of 0.72) than the household head with no education. Similarly, in NSS 68 round (2011–12), for the household head with a primary level of education, the log odd of preferring clean cooking fuels increased by 27% (exp of 0.24) than the household head with no education (Table 3), but the for the household head with more than the secondary level of education dummy, the log odd of preferring clean fuels for cooking has increased by

40% (exp of 0.34) than the household head with no education (Table 3). It indicates the log odds of preferring clean cooking fuels progressively increase with the level of education of the household head, however, the importance of heads' education in preferring clean cooking fuels has been declining. This is probably because of the improved living standards due to rapid economic growth and the strong support of the government in ensuring clean cooking fuels for all in India. The same pattern is also found with the level of education of the spouse and the preference for cooking fuels. Importantly, it is found that the dummies for the primary level and middle school level education for the spouse are statistically positive and significant in explaining the preference for traditional biomass and firewood in 46th and 68th rounds (Table 3). It indicates the benefits of women's education in preferring cooking fuel choice are only observed after a threshold level of education which is middle school level in India.

The coefficient of the $\ln(\text{monthly per capita expenditure Rs.})$ is negatively associated with the use of kerosene and coal but positively associated with the use of clean cooking fuels across the years sampled (Table 3). Our result provides strong support to our first hypothesis (H1). The finding is also similar to other empirical findings (e.g., Baiyegunhi and Hassan (2014), Cayla et al. (2011), Farsi and Filippini (2007), Huang (2015), Khandker et al. (2010), Kwakwa et al. (2013), Mensah et al. (2016), Mensah and Adu (2015)). Economically solvent households are more likely to prefer clean cooking fuels and less likely to use kerosene oil, and coal. The findings in Table 3, also demonstrate a strong positive and nonlinear relationship between wealth status and choice of cooking fuels. It shows that log odd of preferring clean cooking fuels by the richest households (Q4) is always higher than the log odd of preferring clean cooking fuels by the poorest households (Q1, which is the base). It lends further support to our hypothesis (H2) that wealth is a crucial determinant in the cooking fuel choice decision of the rural households in India.

The findings of this study (Table 3) show that the age of the head and spouse are positively associated with the choice of clean cooking fuels. The coefficient of the female-headed dummy is positive and significant at 1% level in the function explaining the choice of clean cooking fuels across the years sampled. It shows that women are more concerned about the health of their family members than their male counterparts. Our result

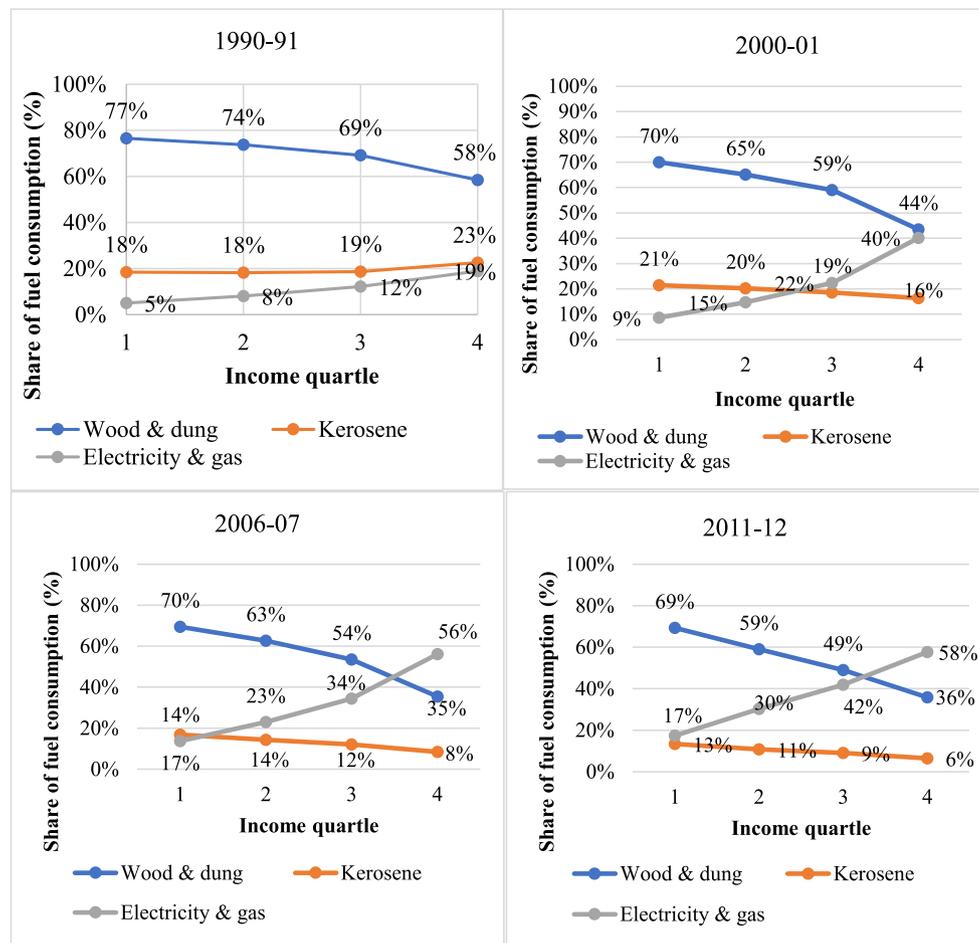


Fig. 3. Expenditure share on different fuels by the years sampled.
Source: Authors' calculation based on National Sample Survey Organization NSSO (1991, 2007, 2002, 2014).

is similar to some other research findings, which finds a positive association between clean energy and female head (e.g., Behera et al. (2015), Farhar (1998), Parikh (1995), Viswanathan and Kavi Kumar (2005)).

The coefficient of the family size is positive and significant for all sources of fuel. The coefficient and sign of the small and marginal land holding dummies are mixed and largely insignificant in explaining energy choice (Table 3). The coefficient of caste dummy (scheduled caste, tribe, and backward class) is positive and significant for the use of electricity and gas in all three rounds except for the 46th round (1990–91), while it is negative for the choice of kerosene and coal. We also interacted the caste dummy with the monthly per capita expenditure and found a negative relation with the use of clean energy, indicating that backward or schedule caste and richer households are less likely to use electricity and gas for household purposes. Regional dummies were included in the model to control for the regional differences. The result shows that households in western India (which is base=0), prefer more to use clean fuels for cooking than the households in other regions (Table 3).

Table 4 shows the correlation of coefficients of the error terms of three types of cooking fuel choices: traditional biomass and firewood (dirty fuels); kerosene and coal, and clean cooking fuels, such as natural gas, LPG, and electricity. The coefficients of correlation between firewood and kerosene are positive and significant, while it is negative and significant between firewood and kerosene with electricity. The significant correlation among different types of cooking fuels (Table 4) justifies the application of

the multivariate probit model estimation process for estimating the cooking fuel choice function.

5.2.2. Estimating households' dependency on different types of cooking fuels: Results from the two-limit tobit model estimation procedure

Table 5 presents the estimated functions applying the two-limit Tobit model estimation procedure, explaining the reliance of households on three types of cooking fuels: dirty fuel (traditional biomass and firewood), kerosene and coal, and clean fuels (natural gas, LPG, and electricity). The level of education dummies of the household head and spouse is positive and significant in explaining the share of expenditure on clean cooking fuels (natural gas, LPG, and electricity), whereas negative and significant in explaining the share of expenditure on dirty fuels (traditional biomass and firewood) (Table 5). The findings strongly support our hypotheses (H1 and H2) that relatively more educated households rely more on clean cooking fuels (spend more on clean fuels for cooking) and vice versa.

The coefficient of $\ln(\text{monthly per capita expenditure in Rs.})$ is negative and significant in the function explaining the share of expenditure on dirty fuels, but positive and significant in explaining the share of expenditure on clean fuels (Table 5). The finding strongly supports our hypothesis that economic affluence is a major determinant of expenditure share (reliance) on different types of fuels, in which relatively economically affluent households rely more on (spend more) clean cooking fuels, such as natural gas, LPG, and electricity. The expenditure quartile dummies Q2, Q3,

Table 3
 Result from the multivariate probit model: Explaining the choice of fuel by rural families.
 Source: Authors' calculation based on National Sample Survey Organization NSSO (1991, 2007, 2002, 2014).

Dependent variables: Choice of fuel												
Type of fuels	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas
NSS rounds	46th (1990–91)			56th (2000–01)			63rd (2006–07)			68th (2011–12)		
<i>Household head's level of education dummies (no education is the base = 0)</i>												
Household head is educated up to primary level (dummy, yes = 1)	−0.30*** (0.08)	−0.032 (0.04)	0.32*** (0.03)	−0.30*** (0.11)	0.05 (0.03)	0.20*** (0.02)	0.28 (0.33)	−0.0035 (0.06)	0.029 (0.05)	−0.14** (0.06)	−0.01 (0.02)	0.24*** (0.02)
Household head is educated up to middle school level (dummy, yes = 1)	−0.49*** (0.10)	−0.13** (0.06)	0.51*** (0.04)	−0.53*** (0.12)	0.08** (0.04)	0.33*** (0.03)	−0.37*** (0.08)	−0.095*** (0.03)	0.22*** (0.03)	−0.18*** (0.07)	−0.02 (0.02)	0.26*** (0.02)
Household head is educated to secondary level and above level (dummy, yes = 1)	−0.49*** (0.11)	−0.22*** (0.06)	0.72*** (0.05)	−0.45*** (0.13)	−0.11*** (0.04)	0.51*** (0.03)	−0.63*** (0.08)	−0.25*** (0.03)	0.39*** (0.03)	−0.29*** (0.07)	−0.15*** (0.02)	0.34*** (0.02)
<i>Level of education dummies of the spouse (no education is the base = 0)</i>												
Spouse is educated up to primary level (dummy, yes = 1)	0.40*** (0.12)	0.14*** (0.05)	0.14*** (0.04)	−0.03 (0.10)	0.02 (0.03)	0.15*** (0.03)	−0.039 (0.33)	−0.037 (0.07)	0.14*** (0.05)	0.26*** (0.06)	−0.09*** (0.02)	0.23*** (0.02)
Spouse is educated up to middle school level (dummy, yes = 1)	0.46** (0.19)	0.29*** (0.09)	0.38*** (0.06)	0.17 (0.16)	−0.025 (0.04)	0.32*** (0.04)	0.21* (0.11)	0.0040 (0.03)	0.14*** (0.03)	0.16** (0.07)	−0.09*** (0.02)	0.35*** (0.03)
Spouse is educated to secondary level and above (dummy, yes = 1)	−0.12 (0.15)	−0.13 (0.09)	0.56*** (0.08)	−0.34*** (0.11)	−0.27*** (0.05)	0.46*** (0.05)	0.27** (0.11)	−0.22*** (0.03)	0.36*** (0.05)	0.095 (0.07)	−0.28*** (0.02)	0.48*** (0.03)
ln(monthly per capita expenditure in Rs.)	0.043 (0.19)	0.057 (0.09)	0.14* (0.07)	0.18 (0.28)	−0.40*** (0.07)	1.10*** (0.09)	0.037 (0.12)	−0.60*** (0.05)	1.04*** (0.08)	0.074 (0.15)	−0.26*** (0.04)	0.76*** (0.07)
<i>Expenditure quartile dummies: poorest households belong to first quartile Q1 is the base</i>												
Household in the second expenditure group Q2 (dummy, yes = 1)	0.086 (0.11)	−0.074 (0.06)	0.25*** (0.04)	0.57*** (0.15)	0.11*** (0.04)	0.17*** (0.03)	0.23** (0.11)	−0.01 (0.04)	0.16*** (0.03)	0.16** (0.07)	−0.12*** (0.03)	0.13*** (0.03)
Household in the third expenditure group Q3 (dummy, yes = 1)	0.047 (0.12)	−0.090 (0.07)	0.49*** (0.05)	0.53*** (0.13)	0.063 (0.05)	0.31*** (0.04)	0.12 (0.12)	−0.14*** (0.04)	0.25*** (0.05)	0.083 (0.08)	−0.23*** (0.03)	0.24*** (0.04)
Household in the fourth expenditure group Q4 (dummy, yes = 1)	−0.42*** (0.16)	−0.34*** (0.09)	0.59*** (0.07)	0.41** (0.16)	0.032 (0.07)	0.36*** (0.07)	−0.28* (0.16)	−0.31*** (0.06)	0.22*** (0.08)	−0.022 (0.10)	−0.46*** (0.04)	0.18*** (0.06)
Age, household head	0.01*** (0.00)	0.001 (0.00)	0.01*** (0.01)	0.01* (0.00)	0.002** (0.00)	0.003*** (0.00)	0.01*** (0.00)	0.002* (0.00)	0.003*** (0.00)	0.02*** (0.00)	−0.0002 (0.00)	0.01*** (0.00)
Age, spouse	0.01*** (0.00)	0.003** (0.00)	0.003** (0.00)	0.012*** (0.00)	0.0020** (0.00)	0.002*** (0.00)	0.009*** (0.00)	0.002*** (0.00)	0.0022*** (0.00)	0.01*** (0.00)	0.001** (0.00)	0.0030*** (0.00)
Female-headed household (dummy (yes = 1))	0.10 (0.10)	0.014 (0.07)	0.15*** (0.05)	0.29** (0.13)	−0.02 (0.04)	0.22*** (0.04)	0.095 (0.10)	−0.01 (0.04)	0.19*** (0.04)	0.13 (0.08)	−0.05 (0.03)	0.24*** (0.03)
No. of family members	0.17*** (0.03)	0.053*** (0.01)	0.077*** (0.01)	0.15*** (0.04)	0.02*** (0.01)	0.09*** (0.00)	0.18*** (0.03)	0.0034 (0.00)	0.093*** (0.00)	0.08*** (0.02)	0.02*** (0.00)	0.075*** (0.00)
Marginal household, landholding ≤ 1 ha (dummy, yes = 1)	−1.38 (1.19)	−0.20 (0.45)	−0.45 (0.34)	3.10* (1.62)	0.87** (0.42)	1.05** (0.43)	0.66 (0.74)	−0.36 (0.27)	−0.10 (0.31)	2.57** (1.02)	1.16*** (0.26)	−0.25 (0.37)
Small farm household, landholding 1.01 to 2 ha (dummy, yes = 1)	−0.79 (1.61)	−0.41 (0.61)	−0.90* (0.47)	0.30 (1.56)	0.60 (0.59)	−0.25 (0.56)	1.01 (1.11)	−0.58 (0.37)	0.034 (0.44)	1.49 (1.40)	0.95** (0.38)	0.15 (0.50)
Schedule tribe/caste/ backward caste household (dummy, yes = 1)	−1.25** (0.59)	−0.12 (0.33)	−0.51* (0.26)	1.07 (0.74)	−0.67** (0.30)	1.48*** (0.29)	−0.56 (0.67)	−1.11*** (0.26)	0.83*** (0.31)	0.019 (0.52)	−0.42** (0.20)	0.73** (0.29)
Dummy for schedule tribe/caste/ backward caste household (yes = 1)X ln (monthly per capita expenditure Rs.)	0.22** (0.11)	0.0012 (0.06)	0.048 (0.05)	−0.16 (0.11)	0.11** (0.05)	−0.28*** (0.05)	0.10 (0.09)	0.18*** (0.04)	−0.15*** (0.05)	0.013 (0.07)	0.076*** (0.03)	−0.14*** (0.04)
Dummy for marginal household X ln (monthly per capita expenditure Rs.)	0.26 (0.20)	0.046 (0.08)	0.088 (0.06)	−0.47* (0.25)	−0.14** (0.06)	−0.16** (0.07)	−0.14 (0.10)	0.035 (0.04)	0.0082 (0.05)	−0.35*** (0.14)	−0.15*** (0.03)	0.044 (0.05)
Small farm household dummy X ln (monthly per capita expenditure Rs.)	0.15 (0.28)	0.080 (0.11)	0.18** (0.09)	0.079 (0.24)	−0.080 (0.09)	0.041 (0.09)	−0.13 (0.16)	0.096* (0.05)	−0.0063 (0.07)	−0.19 (0.19)	−0.11** (0.05)	−0.010 (0.07)
<i>Region dummies: West Indian states are the base</i>												
Households from a northeast Indian state (dummy, yes = 1)	0.083 (0.12)	0.048 (0.06)	−0.99*** (0.05)	0.057 (0.11)	0.096** (0.04)	−1.04*** (0.04)	−0.34*** (0.11)	0.066* (0.04)	−0.61*** (0.04)	−0.41*** (0.06)	0.23*** (0.02)	−0.83*** (0.03)
Households from a north Indian state (dummy, yes = 1)	0.19 (0.14)	−0.061 (0.08)	−0.30*** (0.05)	0.17 (0.17)	−0.056 (0.06)	0.015 (0.04)	0.14 (0.21)	0.054 (0.05)	0.095** (0.05)	0.21** (0.10)	0.64*** (0.03)	−0.16*** (0.04)
Households from a central Indian state (dummy, yes = 1)	0.13 (0.10)	0.51*** (0.07)	−1.48*** (0.05)	0.26** (0.12)	0.83*** (0.05)	−1.45*** (0.03)	−0.094 (0.11)	1.10*** (0.05)	−0.90*** (0.03)	0.23*** (0.08)	1.32*** (0.03)	−1.06*** (0.03)
Households from an east Indian state (dummy, yes = 1)	0.09 (0.10)	0.03 (0.06)	−0.33*** (0.04)	0.21** (0.10)	0.10*** (0.04)	0.04 (0.03)	−0.09 (0.09)	0.01 (0.03)	0.58*** (0.04)	0.01 (0.07)	0.38*** (0.02)	0.42*** (0.04)

(continued on next page)

Table 3 (continued).

Households from a south Indian state (dummy, yes = 1)	0.20* (0.11)	-0.29*** (0.06)	-0.57*** (0.04)	0.27** (0.11)	-0.43*** (0.04)	-0.61*** (0.03)	0.18 (0.12)	-0.33*** (0.03)	-0.57*** (0.03)	0.043 (0.07)	0.061*** (0.02)	-0.83*** (0.03)
Constant	0.88 (1.09)	0.92* (0.49)	-1.67*** (0.38)	0.21 (1.80)	3.59*** (0.47)	-6.90*** (0.56)	1.34 (0.84)	5.11*** (0.32)	-6.62*** (0.51)	0.93 (1.12)	2.54*** (0.30)	-4.66*** (0.51)
Artho 21		0.42*** (0.03)			0.10*** (0.02)			0.13*** (0.02)			0.12*** (0.01)	
Atrho31		-0.032 (0.02)			-0.06*** (0.02)			-0.05** (0.02)			0.01 (0.02)	
Atrho31		-0.30*** (0.02)			-0.28*** (0.01)			-0.38*** (0.01)			-0.25*** (0.01)	
No. of households	13,690				30,389			33,080			59,693	
Wald χ^2 (75)		3,710.51			9824.76			10546.6			14722.14	
Prob > χ^2		0.00			0.00			0.00			0.00	
Log pseudolikelihood		-11349.2			-23828.6			-26815.9			-45721.1	

Note: Standard errors in parentheses are calculated based on clustering the standard error at the household level. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

Table 4

Correlation coefficients among three fuels used for household chores in India.

Source: Authors' calculation based on National Sample Survey Organization NSSO (1991, 2007, 2002, 2014).

Sampled rounds and years	1990-91 (46th round)	2000-01 (56th round)	2006-07 (63rd round)	2011-12 (68th Round)
Type of fuel used				
Firewood and kerosene (rho21)	0.39*** (0.03)	0.10*** (0.02)	0.13*** (0.02)	0.12*** (0.01)
Firewood and electricity (rho31)	-0.03 (0.02)	-0.06*** (0.02)	-0.05** (0.2)	0.01 (0.01)
Kerosene and electricity (rho32)	-0.29*** (0.02)	-0.28*** (0.01)	-0.36*** (0.01)	-0.25*** (0.01)
Likelihood ratio test of rho21 = rho31 = rho32 = 0: χ^2 (3)	487.6	476.2	820.5	598.4
Prob> χ^2	0.00	0.00	0.00	0.00

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

and Q4 (where Q1 is the base) are 0.13, 0.24, and 0.18 (P<0.00) in the estimated function explaining the share of expenditure on clean cooking fuels (natural gas, LPG, and electricity), whereas those are -0.11-0.23, and -0.46 (P<0.00) for the proportion of expenditure on kerosene oil and coal for the year 2011–12 (Table 5). It supports the notion that relatively wealthy households rely less on dirty fuels for cooking and vice versa. The finding of this study is similar to the findings of other empirical studies, which state a strong positive relationship between wealth and the reliance (expenditure) on clean fuels for cooking (Baiyegunhi and Hassan, 2014; Cayla et al., 2011; Farsi and Filippini, 2007; Huang, 2015; Khandker et al., 2010; Kwakwa et al., 2013; Mensah et al., 2016; Mensah and Adu, 2015; Rahut et al., 2019).

Findings of this study show that the household with older heads and large family size, rely more on both clean and dirty fuels, but rely less on kerosene and coal for cooking (Table 5). Female-headed households rely more on electricity & LPG and less on kerosene and coal (Table 5). The analysis also shows that the schedule tribe/caste/backward class depends on electricity & LPG and less on firewood & biomass, and kerosene oil. The households residing in Northeast India, Central India, East India, and North India tended to rely more on kerosene and coal, and less on clean cooking fuels compared to the households in West Indian states, which is the base (=0).

In Tables 4A and A in the annexures, we have presented the estimated functions explaining fuel choice and reliance of different cooking fuels by the rural households in India after pooling data across the years sampled. The findings in Tables 4A and A confirm the importance of formal education, economic affluency, and sex in determining cooking fuel choice and reliance on specific fuels for cooking in India. Importantly in both tables, the year dummies in the estimated functions explaining the choice of clean cooking fuels and its share of expenditure are highly significant and positive. It indicates the gradual progress of India in ensuring clean cooking fuels for the rural households of the country.

6. Conclusion and policy implications

This study is based on large nationally representative datasets span over a long period of time (1990–2012). This study first examined the cooking fuel choice by the rural Indian households applying the multivariate probit model estimation procedure. Secondly, the study examined the reliance on a specific cooking fuel of the sampled households by applying the two-limit Tobit estimation procedure. Finally, this study also presents a disaggregated level by pooling data across the years sampled. Thus, the findings of this study are more reliable and acceptable.

In this study, it is discussed that globally a significant improvement has been made in confirming access to clean energy such as electricity. For example, in 2019, 90% of the population of the world had access to electricity, which was 83% in 2010 (United Nations, 2021b). However, the progress in ensuring clean cooking fuel and technology is still at bay. Until 2019, only 66% of the total population in the world was using clean and modern fuels and technologies (United Nations, 2021b). It means, until now, 44% of the total population (2.6 billion) in the globe relies on dirty and solid fuel for cooking (United Nations, 2021b). As the world population is projected to increase until 2050, under the business-as-usual scenario, by 2050, more people will rely on dirty and solid fuels for cooking. Observing the sluggish progress, the United Nations has already warned that SDG 7 that is ensuring clean and modern fuels and technologies for all by 2030 at affordable prices, may not be achieved (WHO et al., 2018).

Indoor air pollution from the use of dirty, polluting, and solid fuels for cooking is responsible for nearly 4 million annual premature death in the world (United Nations, 2021b; WHO, 2020). The premature death related to indoor air pollution from the use of dirty cooking fuels is mostly concentrated in the rural areas

Table 5

Two-limit Tobit estimation: determinants of dependency on particular types of fuel (expenditure on fuel j/Total fuel expenditure) over time in India.

Source: Authors' calculation based on National Sample Survey Organization NSSO (1991, 2007, 2002, 2014).

NSSO rounds	46th (1990–91)			56th (2000–01)			63rd (2006–07)			68th (2011–12)		
Dependent variable: Expenditure share on	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas
Independent variables												
Household head's level of education dummies (no education is the base = 0)												
Household head is educated up to primary level (dummy, yes = 1)	-0.07*** (0.01)	-0.01** (0.00)	0.01** (0.01)	-0.03*** (0.00)	-0.00033 (0.00)	0.012*** (0.00)	0.0034 (0.01)	-0.01 (0.00)	0.01 (0.01)	-0.03*** (0.00)	-0.01*** (0.00)	0.01*** (0.00)
Household head is educated up to middle school level (dummy, yes = 1)	-0.14*** (0.01)	0.011* (0.01)	0.02*** (0.01)	-0.07*** (0.00)	-0.018*** (0.00)	0.042*** (0.01)	-0.05*** (0.00)	-0.01*** (0.00)	0.03*** (0.00)	-0.05*** (0.00)	-0.01*** (0.00)	0.034*** (0.00)
Household head is educated to secondary level and above level (dummy, yes = 1)	-0.23*** (0.01)	0.046*** (0.01)	0.07*** (0.01)	-0.14*** (0.01)	-0.0072* (0.00)	0.097*** (0.01)	-0.15*** (0.00)	-0.02*** (0.00)	0.09*** (0.00)	-0.12*** (0.00)	-0.02*** (0.00)	0.087*** (0.00)
Spouse's level of education dummies (no education is the base = 0)												
Spouse is educated up to primary level (dummy, yes = 1)	0.02*** (0.01)	0.03*** (0.00)	0.03*** (0.01)	-0.01** (0.00)	0.0051* (0.00)	0.010** (0.01)	-0.01 (0.01)	0.01 (0.00)	0.003 (0.01)	-0.02*** (0.00)	-0.0001 (0.00)	0.042*** (0.00)
Spouse is educated up to middle school level (dummy, yes = 1)	0.03** (0.01)	0.02** (0.01)	0.05*** (0.01)	-0.02*** (0.01)	0.010** (0.00)	0.028*** (0.01)	0.01 (0.00)	-0.003 (0.00)	0.03*** (0.00)	-0.04*** (0.00)	-0.01*** (0.00)	0.058*** (0.00)
Spouse is educated to secondary level and above (dummy, yes = 1)	-0.11*** (0.02)	-0.01 (0.01)	0.11*** (0.02)	-0.09*** (0.01)	-0.04*** (0.01)	0.096*** (0.01)	-0.05*** (0.01)	-0.01*** (0.00)	0.11*** (0.01)	-0.10*** (0.00)	-0.01*** (0.00)	0.12*** (0.00)
Ln(monthly per capita expenditure in Rs.)	-0.04*** (0.01)	-0.0002 (0.01)	0.06*** (0.02)	-0.16*** (0.01)	-0.05*** (0.01)	0.12*** (0.01)	-0.12*** (0.01)	-0.04*** (0.00)	0.11*** (0.01)	-0.07*** (0.01)	-0.02*** (0.00)	0.06*** (0.01)
Household in the second expenditure group Q2 (dummy, yes = 1)	0.012* (0.01)	-0.01 (0.01)	-0.01 (0.01)	0.03*** (0.00)	0.02*** (0.00)	-0.02*** (0.01)	0.002 (0.00)	-0.004* (0.00)	0.00013 (0.00)	-0.021*** (0.00)	-0.01*** (0.00)	0.04*** (0.00)
Household in the third expenditure group Q3 (dummy, yes = 1)	-0.01 (0.01)	-0.010 (0.01)	-0.0076 (0.01)	0.03*** (0.01)	0.022*** (0.00)	-0.020*** (0.01)	-0.03*** (0.01)	-0.01** (0.00)	0.026*** (0.01)	-0.067*** (0.00)	-0.01*** (0.00)	0.09*** (0.00)
Household in the fourth expenditure group Q4 (dummy, yes = 1)	-0.08*** (0.01)	-0.026** (0.01)	-0.022 (0.02)	0.003 (0.01)	0.015** (0.01)	-0.0015 (0.01)	-0.10*** (0.01)	-0.02*** (0.01)	0.065*** (0.01)	-0.12*** (0.01)	-0.02*** (0.00)	0.14*** (0.01)
Age, household head	-0.0002 (0.00)	0.001*** (0.00)	0.002*** (0.00)	-0.0004*** (0.00)	-0.0001 (0.00)	0.0011*** (0.00)	-0.001*** (0.00)	0.000080 (0.00)	0.001*** (0.00)	-0.001*** (0.00)	0.0001** (0.00)	0.0024*** (0.00)
Age, spouse	0.002*** (0.00)	-0.0004*** (0.00)	0.001** (0.00)	0.001*** (0.00)	-0.0002*** (0.00)	0.001*** (0.00)	0.001*** (0.00)	-0.0004*** (0.00)	0.0004*** (0.00)	0.0003*** (0.00)	-0.0002*** (0.00)	0.00039*** (0.00)
Female-headed household dummy (yes = 1)	0.02** (0.01)	-0.011 (0.01)	0.03** (0.01)	-0.003 (0.01)	-0.01 (0.00)	0.044*** (0.01)	-0.0036 (0.01)	-0.02*** (0.00)	0.03*** (0.01)	-0.02*** (0.00)	-0.01*** (0.00)	0.04*** (0.01)
No. of family members	0.01*** (0.00)	0.0018** (0.00)	0.004*** (0.00)	-0.002*** (0.00)	-0.004*** (0.00)	0.0019*** (0.00)	-0.004*** (0.00)	-0.004*** (0.00)	0.01*** (0.00)	0.001** (0.00)	-0.004*** (0.00)	0.002** (0.00)
Marginal household, landholding ≤ 1 ha (dummy, yes = 1)	0.08 (0.05)	-0.13*** (0.05)	0.021 (0.08)	0.29*** (0.05)	0.023 (0.03)	-0.082 (0.05)	0.26*** (0.04)	0.01 (0.03)	0.13*** (0.04)	0.39*** (0.04)	0.042 (0.03)	-0.073* (0.04)
Small farm household, landholding 1.01 to 2 ha (dummy, yes = 1)	-0.11* (0.06)	0.058 (0.05)	0.11 (0.09)	-0.12* (0.07)	0.099** (0.04)	0.10 (0.09)	-0.08* (0.04)	0.05** (0.02)	0.10** (0.04)	0.14*** (0.05)	-0.025 (0.03)	-0.060 (0.06)
Schedule tribe/caste/backward caste household (dummy, yes = 1)	-0.30*** (0.04)	-0.10*** (0.04)	0.23*** (0.06)	-0.27*** (0.04)	-0.12*** (0.03)	0.28*** (0.05)	-0.16*** (0.04)	-0.10*** (0.02)	-0.0023 (0.05)	-0.14*** (0.03)	-0.07*** (0.02)	0.11*** (0.03)
Dummy for marginal household X ln (monthly per capita expenditure Rs.)	0.063*** (0.01)	0.018*** (0.01)	-0.05*** (0.01)	0.052*** (0.01)	0.018*** (0.00)	-0.050*** (0.01)	0.03*** (0.01)	0.01*** (0.00)	-0.0043 (0.01)	0.028*** (0.00)	0.009*** (0.00)	-0.021*** (0.00)
Small farm household dummy X ln (monthly per capita expenditure Rs.)	-0.021** (0.01)	0.031*** (0.01)	-0.0027 (0.01)	-0.052*** (0.01)	0.0010 (0.00)	0.013 (0.01)	-0.04*** (0.01)	0.0004 (0.00)	-0.022*** (0.01)	-0.056*** (0.01)	-0.01 (0.00)	0.011** (0.01)
Region dummies: West Indian states are the base												
Households from a northeast Indian state (dummy, yes = 1)	0.023** (0.01)	-0.010 (0.01)	-0.023 (0.02)	0.020* (0.01)	-0.013** (0.01)	-0.015 (0.01)	0.02** (0.01)	-0.01* (0.00)	-0.018*** (0.01)	-0.018** (0.01)	0.0032 (0.00)	0.0066 (0.01)
Households from a north Indian state (dummy, yes = 1)	0.17*** (0.01)	-0.034*** (0.01)	-0.10*** (0.01)	0.22*** (0.01)	-0.06*** (0.00)	-0.089*** (0.01)	0.12*** (0.01)	-0.02*** (0.00)	-0.095*** (0.01)	0.034*** (0.00)	-0.00058 (0.00)	-0.048*** (0.00)
Households from a central Indian state (dummy, yes = 1)	0.12*** (0.01)	-0.03*** (0.01)	-0.07*** (0.01)	0.13*** (0.01)	-0.07*** (0.00)	-0.06*** (0.01)	0.09*** (0.01)	-0.07*** (0.00)	-0.04*** (0.01)	0.09*** (0.01)	-0.02*** (0.00)	-0.07*** (0.00)

(continued on next page)

Table 5 (continued).

Households from an east Indian state (dummy, yes = 1)	0.10*** (0.01)	0.03*** (0.01)	-0.020* (0.01)	0.16*** (0.01)	0.01*** (0.00)	-0.04*** (0.01)	0.16*** (0.01)	-0.01** (0.00)	-0.13*** (0.01)	0.12*** (0.00)	0.04*** (0.00)	-0.12*** (0.00)
Households from a south Indian state (dummy, yes = 1)	0.11*** (0.01)	-0.04*** (0.01)	-0.06*** (0.01)	0.08*** (0.01)	-0.05*** (0.00)	-0.01 (0.01)	0.06*** (0.00)	-0.06*** (0.00)	-0.066*** (0.01)	-0.0004 (0.00)	-0.03*** (0.00)	0.001 (0.00)
Households from a north Indian state (dummy, yes = 1)	0.13*** (0.01)	-0.030*** (0.00)	-0.018* (0.01)	0.16*** (0.01)	-0.06*** (0.00)	0.0050 (0.01)	0.17*** (0.00)	-0.10*** (0.00)	-0.068*** (0.01)	0.11*** (0.00)	-0.03*** (0.00)	-0.04*** (0.00)
Generalized inverse Mill's ratio	0.97*** (0.02)	1.13*** (0.07)	1.11*** (0.03)	0.72*** (0.04)	1.83*** (0.08)	1.31*** (0.08)	0.70*** (0.03)	0.67*** (0.03)	1.25*** (0.01)	0.94*** (0.02)	0.66*** (0.05)	1.37*** (0.02)
Constant	0.83*** (0.07)	0.14*** (0.05)	-0.13 (0.09)	1.46*** (0.07)	0.56*** (0.04)	-0.45*** (0.07)	1.32*** (0.05)	0.45*** (0.03)	-0.40*** (0.06)	1.08*** (0.05)	0.29*** (0.03)	-0.21*** (0.05)
No. of households		13,690		30,389			33,080				59,693	
Left-censored	231	1,074	8,420	132	2,894	13,373	226	5,052	9,749	387	10,505	10,141
Right-censored	221	32	36	320	7	90	150	5	172	211	5	252
Wald chi2(26)	16910.59	2084.94	4536.2	31076.5	12018.5	26435.8	22426.05	16238.7	50292.6	60827.94	16323.33	41742.07
Prob > chi2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Variance (e.expenditure share on wood)	0.05*** (0.00)	0.035*** (0.00)	0.038*** (0.00)	0.05*** (0.00)	0.02*** (0.00)	0.05*** (0.00)	0.05*** (0.00)	0.01*** (0.00)	0.05*** (0.00)	0.056*** (0.00)	0.012*** (0.00)	0.057*** (0.00)
Log likelihood	496.5	3157.4	1030.9	2395.3	12411.2	1078.5	2918.9	19770.6	1364.9	1030.1	39063.8	145.9

Note: Values in parentheses are standard errors calculated applying bootstrap estimation method replicating 1000 times. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

in developing countries (Bonjour et al., 2013; United Nations, 2021b). To ensure clean cooking fuels and technology for all by 2030, it is crucial to explore the factors influencing the demand side of the cooking fuel choice and use by the rural households in the developing countries. This study examined the factors that affect cooking fuel choice and use by rural households in developing countries, using India as a case.

With rapid urbanization and economic progress, India has made tremendous progress in ensuring electricity for all, but in the case of clean cooking fuels, still, 5% of the urban households and 39% of the households in the rural areas depend on firewood and biomass for cooking. Using nationally representative datasets and applying econometric estimation procedures, this study examined the factors affecting the cooking fuel preference and reliance by the rural households in India. The findings of this study confirm that the economic status, as well as the education of the household head and spouse considerably, controlled the decision of a household on the usage of fuel and the proportion of the expense to total household expenditure. More specifically, this study demonstrated that in the rural areas of India, economically solvent households and households headed by relatively more educated spouses and heads are more likely to prefer and rely on clean and less polluting fuels, such as electricity, LPG, and natural gas. In contrast, relatively economically poor households and households headed by relatively less-educated spouses and heads are more likely to prefer and rely on solid fuels and traditional biomass for cooking.

Based on the findings, this study strongly urged investing in the overall livelihood improvement programs and human capital in rural India. It can augment the non-farm income of rural households and thus clean fuel purchasing power of the economically backward households. The augmented nonfarm income opportunity can also reduce the use of firewood and biomass for cooking by raising the opportunity costs of the collection of traditional biomasses. On the other hand, enhanced human capital can increase the awareness of households about the health hazards of using traditional biomass for cooking. Furthermore, this study suggests investment in enhancing women's human capital in the rural areas of India. This will widen the opportunity to engage in formal income-earning activities, increasing the cost of collecting firewood, cow dung, and biomass by female family members, thus persuading households to use fuels other than firewood, biomass, and dung cake.

Almost all the rural households in India own cattle such as buffalo, and cows (Mottaleb and Rahut, 2019). Thus, there is a high potential for introducing and scaling out biogas technology in rural India. Devising and scaling up better cookers targeting the rural households in India particularly could drastically reduce the burden of indoor air pollution. Considering the COVID-19 induced

purchasing power loss of the rural households, this study also suggests continuing the government's support in ensuring LPG access to the poor and marginal households, but it is important to consider the problem of government corruption while continuing such programs.

Finally, to ensure clean and modern fuels in South Asia by 2030, the governments in South Asia can jointly develop and invest in a South Asia energy consortium and regional power grid lines to trade electricity and gas. Also, South Asian countries can jointly invest in developing and harnessing hydropower in Nepal and Bhutan, which are still unexplored and unused in the Himalayas.

CRediT authorship contribution statement

Khondoker Abdul Mottaleb: Led the conceptualization of the research idea, Data cleaning, Analysis, Write up, Editing, Revision . **Dil Bahadur Rahut:** Contributed to the conceptualization of the research idea, Data, Analysis, Write up, Editing, Revision. **Jee-tendra Prakash Aryal:** Contributed editing and revision. **Akhter Ali:** Contributed editing and revision.

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.

Data availability

We do not have the right to upload the data, however, anonymized data and do-files will be made available to the interested reader.

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Appendix

See Tables 4A and 5A.

Table 4A

Result from the multivariate probit model: Explaining the choice of fuel by rural families (pooled data).

Source: Authors' calculation based on National Sample Survey Organization [NSSO \(1991, 2007, 2002, 2014\)](#).

Type of fuel	Dependent variables: Choice of fuel		
	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas
<i>Household head's level of education dummies (no education is the base = 0)</i>			
Household head is educated up to primary level (dummy, yes = 1)	−0.21*** (0.04)	0.0016 (0.01)	0.20*** (0.01)
Household head is educated up to middle school level (dummy, yes = 1)	−0.33*** (0.04)	−0.031** (0.01)	0.29*** (0.01)
Household head is educated to secondary level and above level (dummy, yes = 1)	−0.45*** (0.04)	−0.18*** (0.01)	0.43*** (0.02)
<i>Spouse's level of education dummies (no education is the base = 0)</i>			
Spouse is educated up to primary level (dummy, yes = 1)	0.26*** (0.05)	−0.026* (0.01)	0.17*** (0.01)
Spouse is educated up to middle school level (dummy, yes = 1)	0.20*** (0.05)	−0.030* (0.02)	0.29*** (0.02)
Spouse is educated to secondary level and above (dummy, yes = 1)	0.072 (0.05)	−0.25*** (0.02)	0.44*** (0.02)
Ln(monthly per capita expenditure in Rs.)	−0.058 (0.06)	−0.42*** (0.02)	0.63*** (0.03)
Household in the second expenditure group Q2 (dummy, yes = 1)	0.24*** (0.05)	−0.049*** (0.02)	0.18*** (0.02)
Household in the third expenditure group Q3 (dummy, yes = 1)	0.18*** (0.05)	−0.16*** (0.02)	0.34*** (0.02)
Household in the fourth expenditure group Q4 (dummy, yes = 1)	−0.055 (0.07)	−0.35*** (0.03)	0.39*** (0.03)
Age, household head	0.013*** (0.00)	0.00087* (0.00)	0.0052*** (0.00)
Age, spouse	0.0079*** (0.00)	0.0016*** (0.00)	0.0025*** (0.00)
Female headed household dummy (yes = 1)	0.14*** (0.05)	−0.030 (0.02)	0.21*** (0.02)
No. of family members	0.13*** (0.01)	0.017*** (0.00)	0.081*** (0.00)
Marginal household, landholding ≤ 1 ha (dummy, yes = 1)	0.47 (0.36)	−0.28** (0.12)	−0.26** (0.12)
Small farm household, landholding 1.01 to 2 ha (dummy, yes = 1)	0.62 (0.52)	−0.15 (0.17)	−0.17 (0.16)
Schedule tribe/caste/ backward caste household (dummy, yes = 1)	−0.29 (0.22)	−0.70*** (0.10)	−0.023 (0.09)
Dummy for marginal household X ln (monthly per capita expenditure Rs.)	0.055* (0.03)	0.11*** (0.01)	−0.033** (0.01)
Small farm household dummy X ln (monthly per capita expenditure Rs.)	−0.086* (0.05)	0.040** (0.02)	0.042** (0.02)
Region dummies: West Indian states are the base	−0.075 (0.07)	0.036 (0.02)	0.029 (0.03)
Households from a northeast Indian state (dummy, yes = 1)			
Households from a north Indian state (dummy, yes = 1)	−0.24*** (0.04)	0.18*** (0.02)	−0.87*** (0.02)
Households from a central Indian state (dummy, yes = 1)	0.21*** (0.07)	0.34*** (0.02)	−0.11*** (0.02)
Households from an east Indian state (dummy, yes = 1)	0.15*** (0.05)	1.13*** (0.02)	−1.18*** (0.02)
Households from a south Indian state (dummy, yes = 1)	0.021 (0.04)	0.23*** (0.01)	0.17*** (0.02)
Households from a north Indian state (dummy, yes = 1)	0.14*** (0.05)	−0.11*** (0.01)	−0.71*** (0.02)
Round dummies (46th round 1990-91 is the base)			
56th round dummy, 2000-01 (yes = 1)	0.59*** (0.06)	0.23*** (0.03)	0.036 (0.03)
63rd round dummy, 2006-07 (yes = 1)	0.38*** (0.07)	0.026 (0.03)	0.31*** (0.04)
68th round dummy, 2011-12, (yes = 1)	0.46*** (0.08)	0.15*** (0.04)	0.44*** (0.05)
Constant	1.47*** (0.41)	3.63*** (0.14)	−4.12*** (0.17)

(continued on next page)

Table 4A (continued).

	Dependent variables: Choice of fuel		
	atrho21	atrho32	atrho31
	0.16*** (0.01)	-0.31*** (0.01)	-0.045*** (0.01)
Correlation coefficients derived from Multivariate probit model estimation	0.16*** (0.009)	-0.30** (0.006)	-0.05*** (0.009)
Likelihood ratio test of rho21 = rho31 = rho32 = 0: χ^2 (3) Prob > chi2	2485.09	0.00	
No. of observations		136,852	
Wald Chi2(84)		45834.6	
Prob > chi2		0.00	
Log pseudolikelihood		-109319.59	

Note: Values in parentheses are standard errors calculated applying bootstrap estimation method replicating 1000 times. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

Table 5A

Two-limit Tobit estimation: determinants of dependency on particular types of fuel (expenditure on fuel j/Total fuel expenditure) over time in India (pooled).

Source: Authors' calculation based on National Sample Survey Organization [NSSO \(1991, 2007, 2002, 2014\)](#).

Dependent variable: Expenditure share on	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas
<i>Household head's level of education dummies (no education is the base = 0)</i>			
Household head is educated up to primary level (dummy, yes = 1)	-0.032*** (0.00)	-0.0074*** (0.00)	0.0099*** (0.00)
Household head is educated up to middle school level (dummy, yes = 1)	-0.065*** (0.00)	-0.012*** (0.00)	0.032*** (0.00)
Household head is educated to secondary level and above level (dummy, yes = 1)	-0.14*** (0.00)	-0.015*** (0.00)	0.089*** (0.00)
<i>Spouse's level of education dummies (no education is the base = 0)</i>			
Spouse is educated up to primary level (dummy, yes = 1)	-0.0031* (0.00)	0.0090*** (0.00)	0.030*** (0.00)
Spouse is educated up to middle school level (dummy, yes = 1)	-0.016*** (0.00)	0.0014 (0.00)	0.046*** (0.00)
Spouse is educated to secondary level and above (dummy, yes = 1)	-0.089*** (0.00)	-0.014*** (0.00)	0.12*** (0.00)
Ln(monthly per capita expenditure in Rs.)	-0.11*** (0.00)	-0.019*** (0.00)	0.077*** (0.00)
Household in the second expenditure group Q2 (dummy, yes = 1)	-0.00096 (0.00)	-0.00067 (0.00)	0.020*** (0.00)
Household in the third expenditure group Q3 (dummy, yes = 1)	-0.030*** (0.00)	-0.0050** (0.00)	0.049*** (0.00)
Household in the fourth expenditure group Q4 (dummy, yes = 1)	-0.083*** (0.00)	-0.016*** (0.00)	0.082*** (0.00)
Age, household head	-0.00091*** (0.00)	0.00023*** (0.00)	0.0019*** (0.00)
Age, spouse	0.00062*** (0.00)	-0.00028*** (0.00)	0.00049*** (0.00)
Female headed household dummy (yes = 1)	-0.01*** (0.00)	-0.01*** (0.00)	0.04*** (0.00)
No. of family members	-0.00026 (0.00)	-0.0028*** (0.00)	0.0031*** (0.00)
Marginal household, landholding ≤ 1 ha (dummy, yes = 1)	0.058*** (0.01)	0.071*** (0.01)	-0.038* (0.02)
Small farm household, landholding, landholding 1.01 to 2 ha (dummy, yes = 1)	0.011 (0.02)	0.026** (0.01)	0.026 (0.02)
Schedule tribe/caste/ backward caste household (dummy, yes = 1)	-0.057*** (0.01)	-0.062*** (0.01)	-0.031** (0.01)
Dummy for marginal household X ln (monthly per capita expenditure Rs.)	0.016*** (0.00)	0.0094*** (0.00)	-0.00094 (0.00)
Small farm household dummy X ln (monthly per capita expenditure Rs.)	-0.012*** (0.00)	-0.0084*** (0.00)	0.0050* (0.00)
Region dummies: West Indian states are the base	0.00057 (0.00)	-0.0030* (0.00)	-0.0063* (0.00)
Households from a northeast Indian state (dummy, yes = 1)			
Households from a north Indian state (dummy, yes = 1)	0.11*** (0.00)	-0.026*** (0.00)	-0.067*** (0.00)
Households from a central Indian state (dummy, yes = 1)	0.099*** (0.00)	-0.041*** (0.00)	-0.061*** (0.00)

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Table 5A (continued).

Dependent variable: Expenditure share on	Dirty fuels: Biomass, cow dung, firewood and other	Coal and kerosene	Clean fuels: Electricity and gas
Households from an east Indian state (dummy, yes = 1)	0.14*** (0.00)	0.020*** (0.00)	−0.11*** (0.00)
Households from a south Indian state (dummy, yes = 1)	0.041*** (0.00)	−0.045*** (0.00)	−0.023*** (0.00)
Households from a north Indian state (dummy, yes = 1)	0.14*** (0.00)	−0.039*** (0.00)	−0.039*** (0.00)
Round dummies (46th round 1990–91 is the base)			
56th round dummy, 2000–01 (yes = 1)	0.0100** (0.00)	0.050*** (0.00)	0.074*** (0.00)
63rd round dummy, 2006–07 (yes = 1)	0.0061 (0.00)	−0.0032 (0.00)	0.11*** (0.00)
68th round dummy, 2011–12, (yes = 1)	0.068*** (0.01)	−0.028*** (0.00)	0.059*** (0.01)
Generalized inverse Mill's ratio	0.86*** (0.02)	1.13*** (0.04)	1.31*** (0.01)
Constant	1.25*** (0.02)	0.29*** (0.01)	−0.32*** (0.03)
Var(e.woodsh)	0.053*** (0.00)	0.018*** (0.00)	0.055*** (0.00)
Observations	136852	136852	136852
Left censored	976	19,525	41,683
Right censored	902	49	550
Uncensored	134,974	117,278	94,619
Wald chi2(29)	126232.40	110919.34	334905.48
Prob > chi2	0.00	0.00	0.00
Log-likelihood	5060.45	68817.06	2422.40

Note: Values in parentheses are standard errors calculated applying bootstrap estimation method replicating 1000 times. ***, **, and * indicate significance at the 1%, 5%, and 10% levels.

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