Climbing Energy Ladder or Fuel Stacking in Indian Households: A Multinomial Logit Approach

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1 Introduction

Access to affordable clean energy is one of the Sustainable Development Goals outlined by the UN (Goal 7). Lack of adequate and affordable energy services often leads the households to vicious cycle in which people who lack access to clean and modern energy are often trapped in a re-enforcing cycle of deprivation, lower income and unhealthy living conditions. Access to clean and modern forms of energy is essential to eradicate poverty, improve economic condition, generate employment opportunities and promote sustainable human development (Karekezi et al., 2012). Government of India has recognized this as a target of utmost priority due to its effect on poverty alleviation, health outcomes and environmental protection Chafe et al. (2014); MHFW Report of the Steering Committee on Air Pollution and Health Related Issues, 2015). Pradhan Mantri Ujjwala Yojana (PMUY) was launched in 2016 to safeguard the health of women and children and also to promote women empowerment through provision of LPG connections to the economically unprivileged families.

Exposure to biomass smoke has several health effects on children, which include low birth weight and neonatal deaths (Patel & Chauhan, 2020; Epstein et al., 2013). Smoke generated from combustion of fuel at household for cooking causes indoor pollution and has adverse effects on the health of household members, especially for women and children who are exposed to the smoke inside the house due to their socially determined roles (Saghir, 2004; Miller & Mobarak, 2013). Use of solid fuel is also linked to acute respiratory infections among children (Arlington et al., 2019; Patel et al., 2019). James et al. (2020), in their study, observed that two-thirds of women using biomass fuel for cooking were positively associated with self-reported

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health symptoms, which include ophthalmic, respiratory, cardiovascular and dermatological conditions and/or symptoms. Collection of fuelwood is generally done by women and children which affects their education and participation in workforce adversely (Hughes & Dunleavy, 2000). Over-collection of fuelwood causes environmental degradation and threatens environmental protection. In spite of all these harmful effects, fuelwood continues to be in use in developing countries, because it can be accessed easily without bearing any physical cost at all or at a very low cost vis-à-vis the costly clean fuels. In India, unclean fuels can also be chosen because clean fuels as an alternative are often unavailable in the specific region even if the household can afford it. The reason may further be the high cost of clean fuels and its cost of installation of associated stoves, which the household is unable to afford. But the data regarding this is very much limited for India. However, it is quite evident that households do not shift from one fuel to another in a very linear manner; i.e. there are many factors that determine the complete or partial switch of fuels, other than price of fuels or income of the household, which are considered to be the only factors behind fuel switching decision according to the 'energy ladder theory' (Leach 1975, 1992). Many households 'stack' multiple fuels, which negate all the positive effects of establishing a clean fuel connection in those households.

Many households in India rely on fuels of low quality like fuelwood, dung cake and kerosene for cooking. These fuels are used in traditional chullahs which are not energy efficient due to insufficient heat transfer and cause indoor pollution by releasing harmful gases like carbon monoxide, methane, nitrogen oxides, respirable particulate matter, etc. (Warwick & Doig, 2004). Clean fuels, on the contrary, are less polluting and are associated with better energy efficiency and convenience though with higher cost. In India, LPG for cooking is of the highest energy efficiency and convenience because the use and connection of natural gas are very limited.

There has been a major change in fuel choice in India over the last few years due to the change in lifestyle. Programmes have been launched to increase awareness, and government initiatives have been taken to encourage poor households to shift to clean fuels. LPG has been subsidized for many years, and steps have been taken by the government to improve access to LPG. But it is often seen that despite attaining connection of clean fuel sources, households are prone to use multiple fuels, effectively refuting the positive effect of clean fuels on indoor air quality. For efficient design of policy measures, analysis of the factors determining the actual choice of fuel or fuels is important. The situation is very much different in rural and urban areas. Availability of biomass at a very low direct cost is a major reason for choosing to use biomass in rural areas. But ideally it should shift to cleaner fuels if LPG connectivity is established in the household. The primary objective of the paper is to analyse the fuel stacking behaviour of rural and urban India for cooking purposes. The study tries to explore whether rural households are actually substituting biomass with clean fuels in this case. The study also aims to identify the factors that lead to simultaneous use of multiple fuels. In the urban sector, households have a wider set of choices of fuels, with easier accessibility caused by better connectivity and greater affordability. With different appliances and facilities, energy demand of urban households has increased many folds over the recent years. But the use of multiple fuels has been perceived in semi-urban and urban areas significantly. Different socio-economic parameters come into play in such fuel choices. The study also attempts to explore whether urban India behaves differently in adopting clean fuels. The present study analyses whether the households are actually switching from unclean to clean fuels or are practising stacking of multiple fuels and highlights the factors that influence their choice.

2 Conceptual Framework

In the context of residential energy consumption, the 'energy ladder' theory has been validated in many studies in the past (Baldwin, 1986; Leach & Mearns, 1988; Hosier & Dowd, 1988; Leach, 1992). The traditional energy ladder model proposes that with the increase in income and socio-economic status, the families are likely to abandon inefficient, less costly and polluting technologies, which are 'lower' in the energy ladder such as dung, fuel wood and charcoal in favour of technologies (stoves and fuels) which are higher in the 'energy ladder'. The main constraints on the transition are poor access to modern fuels and high cost of appliances for using them. The studies argued that households switch from more convenient energy forms with the increase in their disposable income. Some studies have confirmed the link between household income and fuel choice and emphasized that energy transition in rural households is largely driven by income (Hosier & Dowd 1987a, b; Davis 1998).

However, many studies oppose this idea and argue that there is no positive correlation between economic growth and modern fuel intake. Many studies have found that multiple fuels are used in many countries, especially in low-income or developing countries, across all income classes (Adamu et al., 2020; Leach, 1992; Choumert-Nkolo et al., 2019; Cheng & Urpelainen, 2014; Nansaior et al., 2011). Studies suggest that with economic growth and urbanization, total household energy use has increased in most of the developing countries but biomass continued to be an important component of the energy portfolio of the households, especially in rural areas. Though there has been a decline in the use of biomass for cooking, there is no sharp discontinuity in utilization of energy sources, as predicted by the energy ladder model.

According to some studies, fuel switching is often found not to be unidirectional in nature and people can even switch back to traditional biomass after adopting modern energy services (Herington & Malakar, 2016; Maconachie et al., 2009). Also, the appliances used in the household require different energy sources, leading to a diversified energy demand (Foley, 1995). Masera et al. (2000) opposed the view of energy ladder and criticized that the energy ladder theory is not able to explain the dynamics of fuel use of the households. According to his view, the transition from biomass to more advanced and less polluting fuels is not linear. In fact, the households follow a 'stacking procedure', which means that the traditional fuels are not always completely abandoned with the increase in socio-economic status or changed lifestyle, but they are used in conjunction with modern fuels. The study proposed an alternate 'multiple fuel' model of stove and fuel management based on the observed pattern of household accumulation of energy options using data from a four-year (1992–96) case study of a village in Mexico and from a large-scale survey from four states of Mexico. This model integrates four factors as essential in household decision making under conditions of resource scarcity or uncertainty, which are: economics of fuel and stove type and access conditions to fuels; technical characteristics of cook-stoves and cooking practices; cultural preferences; and health impacts.

Fuel stacking behaviour is observed in many studies (Uhunamure et al., 2017; Heltberg, 2005; Hiemstra-Van der Horst & Hovorka, 2008). Some studies identified that fuel price plays a crucial role in determining the choice of fuel (Hosier & Kipondya, 1993). According to Murphy (2001) and Masera et al. (2000), culture and traditions also restrain complete transition to modern fuels for those who often practise traditional methods of cooking. Availability and ease of use also play crucial role for the choice of fuel (Gupta & Köhlin, 2006). According to Rahut et al. (2014), several factors influence the choice of clean energy for cooking, apart from income, e.g. age, education and gender of the household head, access to electricity, location, etc.

Choice of fuel sources and the underlying factors have been discussed in the context of residential energy consumption in India in many studies. Viswanathan and Kumar (2005) discussed the pattern of cooking fuel use in India for the years 1983–2000 and determined the factors determining the particular choices. Ravindranath and Ramakrishna (1997) conducted a regional-level study in some parts of South India, determined the efficiency of eleven cooking devices and estimated the quantity of eight fuels required to cook a 'standard' meal in those fuel–device combinations through thermal efficiency and controlled cooking tests. The study also analyses the environmental implications of these different options and discusses the potential and barriers to these options. Pandey and Chaubal (2011) discussed different factors behind the choice of clean fuel use for cooking purposes. Joon et al. (2009) explored the role of income and other socio-economic characteristics in determining the choice of fuels through a survey conducted in rural Haryana, India. Reddy (2003) identified different technological options for comparing costs and energy-saving potential and rate of return for the residential consumers. Comparison of average total cost of energy, including capital costs of equipment and appliances used to avail energy services, would enable the residential sector to improve energy services and reduce CO_2 emissions through improvement in energy efficiency. An energy efficiency scenario analysis is done in this study showing that significant energy saving can be achieved through improvement in efficiency, which can increase energy security as well as benefit low-income households. Reddy (2004) discusses the interdependence of energy and poverty and impacts of household energy use on livelihood and gender issues. Pachauri and Jiang (2008) compare the household energy transitions in China and India through the analysis of both aggregate statistics and nationally representative household surveys. Ekholm et al. (2010) present a model with focus on cooking fuel choices and explore response strategies for energy poverty eradication in India. Alternate future scenarios are developed to explore the effect of different policy mechanisms such as fuel subsidies and micro-financing on the diffusion of modern and efficient energy sources in India. O'Neill et al. (2012), in their study, pointed out that urbanization, along with changes in consumption preference due to income growth, would be a major factor of determining the fuel choice. Gould et al. (2020) found the perception of the chief wage earner and female education to be strongly positively associated with LPG ownership for two states of India, Kerala and Rajasthan. Sharma et al. (2020) suggested that willingness to pay for LPG is much less than the market price in India. They opined that apart from income, distance for collection of clean fuel, taste of meal and season are important determining factors for the choice of household cooking fuel. Choudhuri and Desai (2020) pointed out that the use of clean fuel in the household is also determined by women's access to salaried work and control over household expenditure decisions.

Most countries have initiated campaign to encourage households to shift from indoor polluting fuels to energy-efficient clean or less polluting fuels in order to reduce adverse health, social and environmental impact. Household indoor pollution (HAP) has caused millions of premature deaths and loss of healthy life years globally (Chafe et al. 2014). Millions of cases of chronic bronchitis, tuberculosis, cataract among adult Indian women and stillbirths in India are associated with the household indoor air pollution generated from biomass used for cooking (Sehgal et al. 2014). But research (Modi et al. 2005) found that for the countries with more than 75% of population living below US$2 per capita income, non-biomass energy consumption is higher (in a scale of 50–400 kgoe per capita) as compared to countries with 40–75% population earning less than $2 per day. In spite of the inconveniences generated from biomass energy use, biomass is often found in Indian households as the primary fuel for cooking. A study by the World Bank found that inter-fuel substitution has taken a significant pace within urban households in Hyderabad, a city in India, in the last twenty years, and that is partly due to the government policies that encourage to subsidize household fuels. But the study also concludes that these subsidies, which were primarily aimed to assist the poor, are misused to the benefit of high-income households (ESMAP, 1999). Ravindra et al. (2019) conducted a case study in Punjab, India, and found that up to 2010–11, only 2% of the rural households shifted from solid biomass to cleaner fuels. Their study does not support the energy ladder hypothesis, and they found several socio-economic factors to play crucial roles in shaping the fuel choice. Hanna and Oliva (2015), using data from a field experiment in India, examined the effects of a transfer programme that provided rural poor households with greater levels of assets and cash and did not observe a shift to cleaner cooking fuels.

The paper attempts to explore the extent of biomass use along with other fuels for cooking in Indian households and the reasons behind such choice of fuel. Households in developing countries are found to use fuels of low quality. Such fuels are, in fact, characterized in microeconomics as 'inferior' goods. In the case of cooking in India, the fuel range is large, among which LPG is with the highest efficiency and cleanliness, followed by kerosene and biomass (firewood, agricultural waste, crop residue or dung cake) in traditional cook-stoves. Improved cook-stoves with higher efficiency and lower emissions have, however, been introduced to alleviate pollution externalities. They would obviously come in between kerosene and biomass.

The household decision to complete or partial energy transition is quite complex and multidimensional, which includes many different factors apart from income and assets of the household. There is a need to look beyond income as the prime driving force behind fuel switching (Van der Kroon et al., 2013). The decision-making regarding fuel switching depends on household characteristics, cultures and practices, external political and institutional context and the household's capability which includes income, women empowerment, etc. This study wants to capture the factors driving the decision of use of single or multiple fuels in a comprehensive and structured manner and identify policy priority areas for fuel switching behaviour. In this context, internal factors such as human capital, women participation in the workforce, household characteristics such as age, labour force participation and income and some external factors like access to fuels and price levels of fuels would play important roles in determining the fuel choice. Some studies have used multinomial logit model for analysis of fuel choice (Rao & Reddy 2007; Jumbe & Angelsen, 2011; Danlami et al., 2019; Liao et al., 2019). This study intends to utilize the model to explain the factors which influence the household to use multiple fuels or to practise stacking behaviour.

3 Methodology and Data Source

The study uses multinomial logit model to explore the fuel stacking behaviour in India for the rural and urban sectors separately. The multinomial logit model is applied in this study to identify the socio-economic determinants of the following fuel choices for cooking, namely only biomass, LPG and no biomass, kerosene and no biomass, biomass with other fuels. In multinomial logit model, all the logits for each dependent variable are estimated simultaneously, and the effect of explanatory variables and parameters of the model on the dependent variables are captured efficiently. In this model, log of the odds of outcomes is modelled as a linear combination of the explanatory variables and relative odds of one alternative being chosen over a second which should be independent of the existence of an un-chosen third alternative.

Multinomial logit model is an extension of logit model. Unlike the logit model, dependent variable in multinomial logit model has more than 2 categories, say, 'M' number of categories. One value of the dependent variable is designated as reference category. The probability of falling into other categories is compared to the probability of falling into the reference category.

Therefore, if the first category is the reference, then, for $m = 2, \ldots, M$,

$$\ln \frac{P(Y_{i=m})}{P(Y_{i=1})} = \alpha_m + \sum_{k=1}^{K} \beta_{mk} X_{ik} = Z_{mi}$$

Therefore, for $m = 2, \ldots M$,

$$P(Y_{i=m}) = \frac{\exp(Z_{mi})}{1 + \sum_{h=2}^{M} \exp(Z_{hi})}$$

And for the reference category,

$$P(Y_{i=1}) = \frac{1}{1 + \sum_{h=2}^{M} \exp(Z_{hi})}$$

The model assumes that stalking behaviour depends on household size, price of alternative fuels, socio-economic characteristics of the household, such as religion, age of the household head, educational attainment of the household head, occupational category of the household, expenditure decile group in which the household falls into, land cultivation by the household, gender of the household head and social group (caste) of the household. The study uses the latest published consumption expenditure data by NSSO for the year 2011–12 to capture the use of energy services in the household sector.

4 Results

4.1 Energy Profile of Household Sector

Energy services in households are required for a variety of purposes to meet the energy need of the household, such as lighting, heating, cooking and use in electrical appliances. Based on the purpose, household energy services include fuelwood, dung cake, agricultural residues, coal, charcoal, kerosene, liquefied petroleum gas (LPG) and electricity. This study is limited to the analysis of energy services for the purpose of cooking only and is concentrated on the energy services and associated cost that are relevant to cooking food for the household.

India is the second largest populous country in the world. With this huge population, energy needed for the domestic sector is quite large. While the increasing volume of population causes increase in the total demand for energy, the degree of urbanization and growth in income as a result of development cause shifts in the pattern of fuel consumption. With the considerable diversity in geographical and agroclimatic zones, the energy consumption pattern varies according to place and season. Firewood historically dominates cooking energy choice in almost all the states in rural India irrespective of the income level.

At the all-India level, the share of households using firewood as primary fuel for cooking (77% in 2011–12) varies from around 92% for the lowest expenditure class to around 46% in the highest expenditure class in the rural sector (Fig. 1). For the urban sector, LPG use has been increased by a significant amount in 2011–12 as compared to 1993–94. However, biomass use in urban sector is limited to low-income households in 2011–12 (Fig. 2).

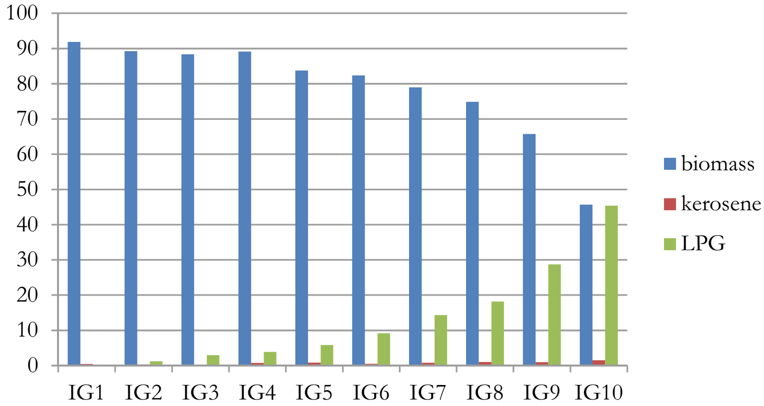

Fig. 1 Percentage of households depending on biomass, kerosene and LPG as their primary fuel for cooking in rural India across income classes (2011–12). *Source* NSSO 68th round, 2011–12

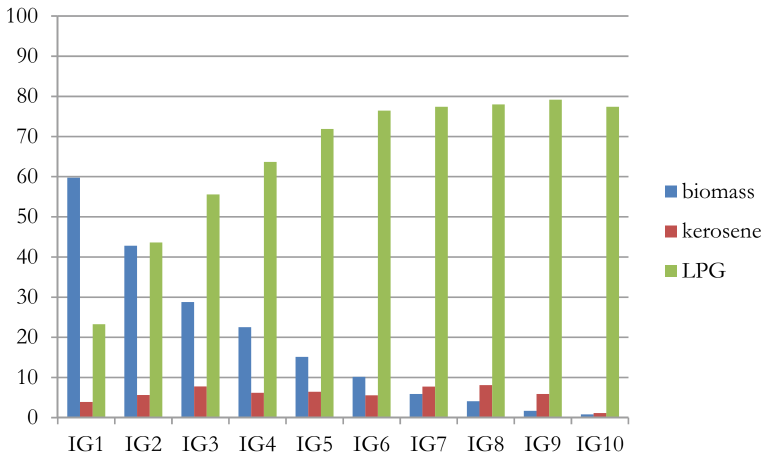

Fig. 2 Percentage of households depending on biomass, kerosene and LPG as their primary fuel for cooking in urban India across income classes (2011–12). *Source* NSSO 68th round, 2011–12

Though percentage of households depending on biomass as primary fuel for cooking has decreased significantly from 90% in 1993–94 to 77% in 2011–12 in rural sector, it is still much higher than the official head-count ratio of poverty (26%) (Fig. 3). Moreover, the per capita consumption of biomass is higher in higher-income households in the rural sector (Fig. 4). Average consumption of biomass was quite high in rural areas as compared to urban areas in 2011–12. In every income class in rural and urban India, average consumption of LPG is lower as compared to biomass (in calorific values of end-use energy) (Fig. 4). This is partially due to the fact that LPG can provide more useful heat value than firewood if we compare the same

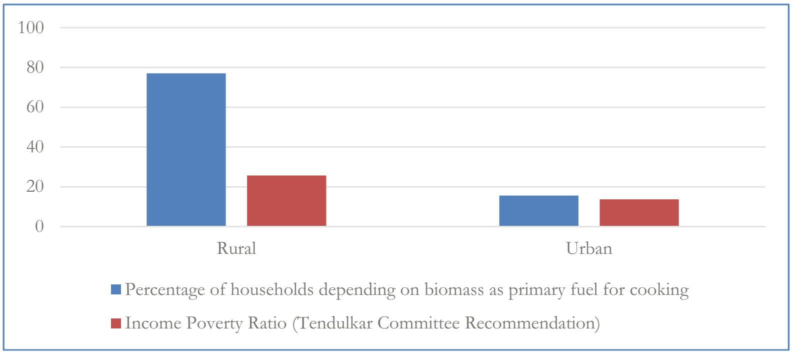

Fig. 3 Percentage of households depending on biomass as primary fuel for cooking and income poverty ratio (Tendulkar Committee Recommendation). *Source* Author's calculation and GOI documents

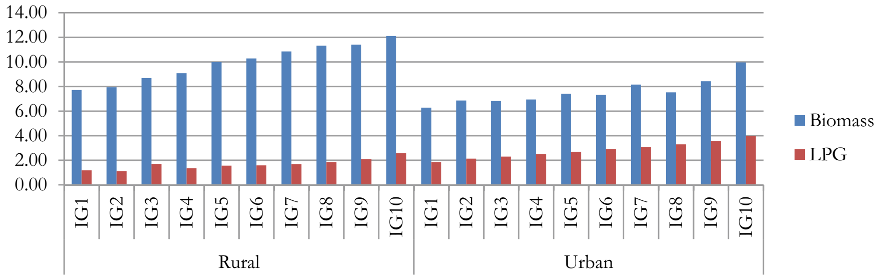

Fig. 4 Average consumption of cooking fuels in rural and urban households across income decile groups in 2011–12 (kgoe per month). *Source* NSSO 68th round, 2011–12

amount of end-use energy of the two sources. The data clearly indicates that the households who have LPG connectivity still use biomass in significant proportion of their cooking energy; the 'energy ladder model' is not essentially followed in India. On the contrary, with increases in income, households continue to use of unclean inefficient fuels and often increase their consumption due to income effect of higher real income. However, we have observed significant difference in the pattern of fuel use among the rural and urban sectors. Access to clean cooking energy sources in urban areas is generally driven by affordability, as cleaner fuels are sufficiently available. The issue of availability is a problem in rural areas, especially in far flung hilly areas. The penetration of cleaner fuels in urban areas has gained significant momentum.

The pattern of fuel use in cooking varies spatially as well. Figure 5 depicts the rural and urban scenarios in the major Indian states in 2011–12, which suggests that the reliance on traditional energies for cooking was quite high in rural areas in most of the states. In urban areas, people have shifted from the use of traditional fuels for cooking in majority of the states. However, biomass use in urban areas is high in Orissa, Chhattisgarh, Kerala, Madhya Pradesh, Uttar Pradesh, Tripura and Bihar

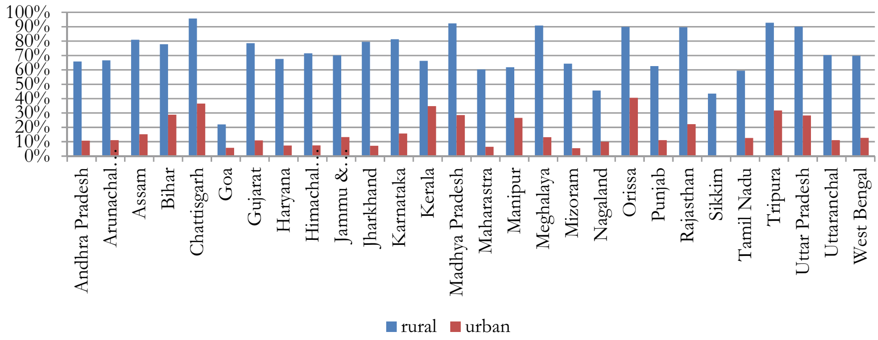

Fig. 5 Biomass distribution as primary fuel for cooking across the Indian states for rural and urban sector (2011–12). *Source* NSSO 68th round, 2011–12

among other states. But in rural areas, even in 2011–12, majority of households depend on biomass as their energy source for cooking in majority states and the degree of reliance is also quite high. Reliance on biomass as energy for cooking is comparatively lower in rural areas of Tamil Nadu, Punjab, Kerala and Andhra Pradesh among the large states.

In brief, a large section of the Indian population (around 162 million households according to Census 2011) relied on traditional energies to satisfy cooking energy needs in 2011. Rural areas are more dependent on traditional energies, and this is irrespective of the income levels of households and geographic location. Poor households in urban areas rely on traditional energies, while richer families tend to use cleaner fuels such as LPG and kerosene. Access to modern cooking fuel is severely limited in rural areas. As this is a common problem in most major states, major national policy initiatives are required to bring in changes in the cooking fuel use pattern. Transition to modern and clean cooking fuels can have significant implications for the supply side of the industry. High reliance on traditional energies has significant social costs including costs due to health effects on women and children. As rural households across all expenditure classes rely significantly on traditional energies for cooking, the issue of access to clean energies assumes greater importance, because affordability alone cannot explain such widespread reliance on polluting energies.

A more in-depth analysis shows that though biomass is largely used in rural areas as primary fuel, in majority of the cases, it is not used as the only fuel for cooking. NSSO data shows that households spend simultaneously on biomass, kerosene, LPG and other fuels. The use of more than one fuel is very common. Biomass, dung cake and crop residue can be obtained without incurring any cost in India, especially in rural areas. The study explored the distribution of energy services utilization in physical units and found out that only 3.75% of rural and 1.64% of urban households rely solely on biomass as a cooking fuel while biomass with other fuels is used in 85.44% of rural and 23.66% of urban households (Table 1).

Table 1 Utilization of multiple fuels for cooking in Indian households (%)

	Rural	Urban
Only biomass	3.76	1.64
LPG but no biomass	3.73	45.26
Kerosene but no biomass	5.84	21.63
Biomass with other fuels	85.44	23.66
Data unavailable	1.24	7.82

Source NSSO 68th round, 2011–12

5 Household Characteristics

Table 2 describes the sample household characteristics. All the households who reported primary fuels for cooking have been considered for the analysis. The average household size is 4.6 in rural areas, whereas the same is 4.1 in urban areas. Since LPG and kerosene prices vary largely across region, LPG and kerosene prices are estimated as the imputed average prices of fuel, whereas average prices (per kg for LPG and per litre for kerosene) are estimated for different income classes across states. Household characteristics also vary widely. Among the households, 84.42% are Hindu and 11.03% are Muslim in rural areas, whereas 80.42% are Hindu and 13.55% are Muslim in urban areas. In rural areas, the age of household head is on an average more than that in the urban areas. The share of household heads, whose age is below 35, is 25.42% in rural areas and 30.31% in urban areas. Around 38% people in rural areas are illiterate as compared to 15.35% in urban areas. Only 9% of people in rural areas have attained education at higher secondary level and above, while the share is 34.4% in urban areas. In both the areas, household head is generally a male member. In India, there is a large number of social groups, such as caste. 32.58% of the people in rural areas and 17.74% of them in urban areas fall into either Scheduled Caste or Scheduled Tribe category. Distribution according to occupational class shows that in rural areas, 34.42% are self-employed in agriculture, 21.44% are casual labour in agriculture, 13.11% are casual labour in non-agriculture and only 8.93% are regular wage/salary earners. In urban areas, 41.52% households are regular wage/salary earners and 34.42% are self-employed. It is clear that household characteristics vary widely across rural and urban region and so is the pattern of fuel choice, as discussed in the earlier section. We need to explore how these characteristics are influencing the fuel stacking behaviour of the household.

6 Factors Affecting the Fuel Stacking Behaviour of Households

In order to understand the factors determining the choice of fuels, a multinomial logit regression has been estimated to understand the fuel stacking behaviour of

Table 2 Sample household characteristics

Characteristics of the sampled households					
Rural ($n = 59{,}695$)			Urban ($n = 41{,}963$)		
Variables	Mean	Standard deviation	Variables	Mean	Standard deviation
Number of household members	4.6	2.2	Number of household members	4.1	2.2
LPG price	31.1	5.0	LPG price	29.4	1.2
Market price of kerosene	27.7	4.8	Market price of kerosene	32.3	5.8
Monthly per capita expenditure (Rs.)	1414.5	1168.8	Monthly per capita expenditure (Rs.)	2912.7	2756.0
Percentage of households (dummy variable)					
	No. (unweighted)	% (weighted)		No. (unweighted)	% (weighted)
Religion					
Hindu	45,603	84.42	Hindu	31,456	80.42
Muslim	7043	11.03	Muslim	6093	13.55
Christian	4294	2.19	Christian	2774	3.04
Others	2754	2.36	Others	1640	2.99
Age of household head					
Less than 35 years	12,976	25.42	Less than 35 years	10,209	30.31
35–50 years	25,335	41.42	35–50 years	17,391	39.66
More than 50 years	21,383	33.16	More than 50 years	14,363	30.03
Education of household head					
Not literate	17,247	39.08	Not literate	6496	15.35
Below primary	7454	13.57	Below primary	3505	8.36
Primary	8094	13.15	Primary	4359	10.77
Secondary	17,515	25.19	Secondary	13,161	31.11
Higher secondary	4349	4.86	Higher secondary	4981	11.59
Above higher secondary	5031	4.15	Above higher secondary	9458	22.81
Whether owned land					
Yes	20,280	37.76	Yes	22,788	52.76
No	39,414	62.24	No	19,175	47.24

(continued)

Table 2 (continued)

Characteristics of the sampled households					
Rural ($n = 59{,}695$)			Urban ($n = 41{,}963$)		
Variables	Mean	Standard deviation	Variables	Mean	Standard deviation
Gender of household head					
Male	53,249	87.92	Male	36,656	88.27
Female	6445	12.08	Female	5307	11.73
Social groups					
Scheduled Caste and Scheduled Tribe	20,194	32.58	Scheduled Caste and Scheduled Tribe	9129	17.74
OBC	23,757	44.19	OBC	16,156	40.62
Others	15,734	23.22	Others	16,673	41.64
Occupational class					
Self-employed in: agriculture	16,788	34.42	Self-employed	15,647	34.43
Non-agriculture	15,294	16.06	Regular wage/salary earning	16,364	41.52
Regular wage/salary earning	10,705	8.93	Casual labour	5385	12.53
Casual labour in agriculture	4889	21.44	Others	4552	11.52
Casual labour in non-agriculture	8758	13.11			
Others	3248	6.04			

Source NSSO 68th round, 2011–12

the household through analysing the association with wide range of exogenous variables representing the household's socio-economic characteristics for rural and urban sector separately. Multinomial logit estimates the determinants of household's choice between only biomass, LPG but no biomass, kerosene but no biomass and biomass with other fuels. Biomass with other fuels is the omitted variable for both rural and urban sectors. The model captures the fuel stacking behaviour of the households and explores factors that lead to the choice of biomass as a cooking fuel.

The multinomial logit model includes independent variables, namely the number of members in the household, price of LPG, price of open-market kerosene, religion, age of the head of the household, educational level of the head of the household, monthly per capita expenditure decile group, whether land is cultivated by the household or not, gender of the head of the household, social group and the occupational category of the household. The results of the multinomial logit model for the analysis of the determinants of use of multiple fuels as cooking fuel in the rural and urban Indian context are given in Table 3. The coefficients of almost all the factors have been found to be significant at the 1% level of significance.

Results suggest that for rural area, household size plays a major role in the practice of fuel stacking. It is found that, in rural areas, larger the household size, more probability is there that the household would choose biomass with other fuels, i.e. would stack fuels, rather than choosing the option of only biomass, or LPG or kerosene. For urban sector, on the other hand, with increase in number of household members, household is more likely to prefer LPG only over other options.

Higher LPG price and kerosene prices also encourage rural households to choose mix of fuels or kerosene. In urban sector, with an increase in LPG price, the likelihood of choosing the combination of biomass and other fuels increases.

The relative log odds of choosing 'only biomass' against 'biomass with other fuels' decrease by 0.345 with a movement from Hindu to Muslim. For the Christians, households are more likely to choose only biomass over biomass mixed with other fuels. In urban areas, a religion-wise analysis shows Muslims and Christians are more likely to choose other fuels or fuel mix over LPG only as compared to the Hindu population.

For older household heads, the likelihood of a household choosing biomass mixed with other fuels increases. Similarly, in urban areas too, with increase in age of the household head, probability of choosing LPG over biomass only increases in urban areas.

With higher education attained by the household head, it is more likely that the household chooses LPG only. It can be seen that for educational attainment of below primary and primary levels, as compared to 'not literate' household heads, the probability of choosing 'only biomass' increases as compared to biomass with combination of other fuels. This may be attributed to the income effect, which allows the household to acquire more quantity of unclean fuel, but the decision of switching to expensive clean fuel is not yet taken. On the contrary, even at educational attainment of below primary and primary levels, urban households are prone to choosing 'biomass with combination of other fuels' as compared to 'only biomass'. This may be caused by unavailability of biomass or easy availability of clean fuels. In urban areas, with more education attained by household head, they are prone to choose LPG over 'biomass only' or biomass mix with other fuels.

It is also seen that as income increases, households are more likely to choose LPG (with higher coefficients) over other options. With increase in income, there is a high probability of choosing LPG over any other fuel options in the urban sector.

The households possessing own land have a higher probability of choosing biomass along with other fuels, perhaps because of the abundant supply of crop residues. In urban areas, not owning land leads to choosing 'only biomass' option as compared to 'biomass with other fuels', since they are expected to have lower assets as compared to the households who own land.

A female household head is more likely to choose 'only biomass' over 'biomass with other fuels' in the rural sector. They also are less likely to choose LPG over

Table 3 Results of multinomial logit model on fuel stacking

Rural				Urban			
	Only biomass	LPG but no biomass	Kerosene but no biomass		Only biomass	LPG but no biomass	Kerosene but no biomass
Household size	−0.007***	−0.112***	−0.099***	Household size	−0.068***	0.053***	−0.05***
LPG price	−0.113***	−0.371***	0.005***	LPG price	−0.024***	−0.121***	−0.068***
Market price of kerosene	−0.131***	−0.021***	0.063***	Market price of kerosene	−0.076***	0.002***	0.01***
Religion (omitted: Hindu)				Religion (omitted: Hindu)			
Muslim	−0.345***	−0.229***	0.24***	Muslim	−0.405***	−0.427***	−0.164***
Christian	1.003***	−0.254***	−0.587***	Christian	−0.047***	−0.791***	−0.755***
Others	1.556***	1.022***	0.12***	Others	0.702***	0.534***	−0.042***
Age of household head (omitted: <=35 years)				Age of household head (omitted: <=35 years)			
35–50 years	−0.308***	−0.142***	−0.121***	35–50 years	−0.497***	−0.213***	−0.15***
More than 50 years	−0.511***	−0.216***	−0.174***	More than 50 years	−0.956***	−0.352***	−0.231***
Education of household head (omitted: not literate)				Education of household head (omitted: not literate)			
Below primary	0.229***	0.146***	−0.247***	Below primary	−0.036***	0.375***	0.35***
Primary	0.053***	0.476***	−0.064***	Primary	−0.055***	0.56***	0.562***
Secondary	−0.062***	1.003***	0.254***	Secondary	−0.495***	0.891***	0.705***
Higher secondary	−0.524***	1.434***	0.64***	Higher secondary	−0.845***	1.546***	1.022***
Above higher secondary	−0.575***	1.616***	0.855***	Above higher secondary	−2.3***	1.792***	1.01***
Monthly per capita expenditure decile groups (omitted: Decile 1)				Monthly per capita expenditure decile groups (omitted: Decile 1)			
Decile 2	−0.298***	3.241***	0.076***	Decile 2	0.096***	1.151***	0.43***
Decile 3	0.251***	3.052***	0.085***	Decile 3	0.229***	1.601***	0.763***
Decile 4	0.425***	4.021***	−0.007**	Decile 4	0.138***	1.979***	0.708***

(continued)

Table 3 (continued)

Rural				Urban			
	Only biomass	LPG but no biomass	Kerosene but no biomass		Only biomass	LPG but no biomass	Kerosene but no biomass
Decile 5	0.325***	3.716***	0.517***	Decile 5	−0.232***	2.324***	0.959***
Decile 6	0.445***	4.633***	0.135***	Decile 6	−0.112***	2.726***	1.114***
Decile 7	0.439***	4.797***	0.499***	Decile 7	−0.123***	3.202***	1.433***
Decile 8	0.367***	5.033***	0.402***	Decile 8	0.527***	3.478***	1.551***
Decile 9	0.841***	5.55***	0.628***	Decile 9	−0.779***	3.786***	1.464***
Decile 10	0.583***	6.158***	0.854***	Decile 10	0.293***	4.081***	0.989***
Whether owned land (omitted: yes)				Whether owned land (omitted: yes)			
No	−0.585***	−0.391***	−0.182***	No	0.12***	−0.231***	−0.032***
Gender of household head (omitted: male)				Gender of household head (omitted: male)			
Female	0.032***	−0.18***	−0.085***	Female	−0.307***	0.046***	−0.077***
Social groups: Scheduled Caste and Scheduled Tribe=1 (omitted), OBC = 2, others = 3)				Social groups: Scheduled Caste and Scheduled Tribe=1 (omitted), OBC = 2, others = 3)			
OBC	−0.073***	0.451***	0.194***	OBC	−0.366***	0.172***	−0.006***
Others	0.075***	0.863***	0.78***	Others	−0.221***	0.792***	0.57***
Occupational class: (omitted: self-employed in agriculture)				Occupational class: (omitted: self-employed)			
Self-employed in non-agriculture	−0.185***	1.353***	0.916***	Regular wage/salary earning	0.269***	0.546***	0.429***
Regular wage/salary earning	−0.102***	1.87***	0.952***	Casual labour	0.314***	−0.914***	−0.565***
Casual labour in agriculture	0.019***	−0.296***	0.393***	Others	0.444***	0.142***	0.004**
Casual labour in non-agriculture	0.163***	0.252***	−0.028***				

(continued)

Table 3 (continued)

Rural				Urban			
	Only biomass	LPG but no biomass	Kerosene but no biomass		Only biomass	LPG but no biomass	Kerosene but no biomass
Others	0.125***	1.277***	0.554***				
Constant	4.006***	2.23***	−5.239***	Constant	1.289***	0.457***	0.445***
Number of obs		56,824		Number of obs		39,360	
Pseudo R2		0.1617		Pseudo R2		0.2033	

**Significant at 5%, ***significant at 1% level
Source Author's estimation from NSSO 68th round, 2011–12

multiple fuels. In urban areas, female household heads are more likely to choose LPG only.

It is also observed that households belonging to OBC and other castes, as compared to Scheduled Caste or Scheduled Tribe households, are more likely to choose LPG and kerosene over biomass with other fuels. Like in the rural sector, households belonging to OBC and other castes in the urban sector are more likely to choose LPG and kerosene over biomass with other fuels.

For occupational class, the categories are differently defined for rural and urban sector. Since agriculture is a crucial sector in rural India, the occupational classification of household is: self-employed in agriculture, self-employed in non-agriculture, regular wage/salary earner, casual labour in agriculture, casual labour in non-agriculture and others. On the other hand, for urban sector, the classification is: self-employed, regular wage/salary earner, casual labour and others. As compared to self-employed in agriculture, households who are self-employed in non-agriculture are more likely to choose LPG over biomass or multiple fuels in the rural sector. This may be due to the unavailability of crop residue to the latter group of households. In rural areas, for casual labours in agriculture, it is more likely that the household would choose biomass with other fuels over LPG only. In the urban sector, regular wage/salary earners would prefer LPG only as compared to other fuel options, while for casual labour it is more likely that they would choose biomass only, kerosene only or biomass mix, respectively.

7 Conclusion

The study reinforces widespread use of biomass in the rural sector. Around 77% of rural households from all income classes were using biomass as their primary fuel for cooking in 2011–12. Even the average consumption of biomass increases with income in rural areas. This essentially shows that the energy ladder model is not followed in India. With increase in income, households are using larger amounts of biomass rather than shifting to fuels like LPG. Use of biomass is very high in rural areas in states like Chhattisgarh, Madhya Pradesh, Uttar Pradesh and Odisha among large states. The factors behind the practice of fuel stacking are further explored through a multinomial logit model. Results show that in rural areas, households' preference for biomass or stacking fuel can be influenced by age and gender of the head of the household, employment status, socio-economic status and the education level of the members of the household. Prices of alternative fuels can also encourage rural households to choose a mix of fuels. The households who own land have more probability of choosing biomass with other fuels, perhaps because of the abundant supply of crop residues. On the contrary, in urban areas, households are more likely to choose LPG only over other options with increase in household size, age and educational attainment of the household head and household income. Fuel stacking behaviour of rural areas is very much led by the availability of fuelwood, dung cake or crop residue, which they can avail without incurring any cost. In urban areas, unlike rural areas, households are more likely to follow the 'energy ladder' model, where the household shifts from unclean fuels to clean fuels with increase in income or living standard.

There has been a significant increase in the use of clean fuels for cooking like LPG in India in the past years, especially after the government started promoting clean fuels through programmes like Pradhan Mantri Ujjwala Yojana, and an estimated number of 284.6 lakh LPG connections were released in 2017–18. But fuelwood is still being used in Indian households. Ensuring that households continue to use LPG or other clean cooking fuels on a sustained basis is a difficult task to accomplish. National Family Health Survey also reported that 74% of households in rural India are using wood or animal dung or agricultural waste in 2015–16. Supply-side initiatives for adoption of LPG should be matched with demand-side management, under which households need to be aware of the harmful effects of pollutants generated from combustion of solid fuels. This requires overcoming gender, behavioural and cultural barriers, which often ignores the drudgery of women. Availability of clean fuels and their affordability should also be substantially increased so that people can have access to their preferred choice of fuel.

With huge burden of population, energy demand of the residential sector of India is already very huge. The government has taken several steps to increase access to efficient fuels. India historically had provided subsidy on LPG, which is often argued to be fiscally unsustainable. Policy measures are required to provide well-monitored and well-directed subsidy through far-reaching supply chains and viable models of distribution.

Biomass is considered to be a polluting fuel because of indoor pollution generated by it. But it is an environmentally sustainable fuel which can help us to combat the adverse effects of climate change in the long run since it is renewable in nature. Research is needed to utilize these resources in environmentally sustainable manner. Using fuels in an efficient manner can reduce the burden on the ecosystem, arrest land degradation and deter over-exploitation of resources. Biomass can even be used in pollution-less devices and technologies. Biomasses in improved chullahs, biomass briquettes and biogas are safer forms of the fuel. But these technologies could not spread widely in India due to high capital cost for installation, lack of necessary infrastructure and maintenance. Efforts are needed to be taken to make these programmes commercially viable and economically attractive.

Refined energy demand estimation requires extensive information related to energy use pattern to get insights into energy efficiency, income and price elasticities of energy demand, factors influencing the purchase of appliances, fuel switching, etc. National-, state- and/or local-level data need to be collected on regular basis in order to identify the factors that drive residential energy use and improve policy response to address these issues.

Use of biomass and poverty is often considered to be very much linked in developing countries. Poor people are more dependent on forests for their livelihood. The poor people are the most vulnerable to the adverse effects of climate change and also the most affected by the climate extremes. Policies should aim to utilize the rich natural resources that we already have in a sustainable way. To pursue the process of economic development in an environmentally sustainable manner, creation of additional ecological space is important to protect a large proportion of people in the developing world from a situation of abject poverty. Proper institutional arrangement is needed to provide poor people with their basic necessities of life without affecting ecological and social sustainability.

References

Adamu, M. B., Adamu, H., Ade, S. M., & Akeh, G. I. (2020). Household energy consumption in Nigeria: A review on the applicability of the energy ladder model. *Journal of Applied Sciences and Environmental Management, 24*(2), 237–244.

Arlington, L., Patel, A. B., Simmons, E., Kurhe, K., Prakash, A., Rao, S. R., et al. (2019). Duration of solid fuel cookstove use is associated with increased risk of acute lower respiratory infection among children under six months in rural central India. *PLoS ONE, 14*(10), e0224374.

Baldwin, S. F. (1986). Bìomass stoves: Engineering design, development and dissemination, volunteers in technical assistance. *Center for Energy and Environmental Studies. Princeton University, Princeton NJ*.

Chafe, Z. A., Brauer, M., Klimont, Z., Van Dingenen, R., Mehta, S., Rao, S., Riahi, K., Dentener, F. & Smith, K. R. (2014). Household cooking with solid fuels contributes to ambient PM2. 5 air pollution and the burden of disease. *Environmental health perspectives, 122*(12), 1314–1320.

Cheng, C. Y., & Urpelainen, J. (2014). Fuel stacking in India: Changes in the cooking and lighting mix, 1987–2010. *Energy, 76,* 306–317.

Choudhuri, P., & Desai, S. (2020). Gender inequalities and household fuel choice in India. *Journal of Cleaner Production*, 121487.

Choumert-Nkolo, J., Motel, P. C., & Le Roux, L. (2019). Stacking up the ladder: A panel data analysis of Tanzanian household energy choices. *World Development, 115,* 222–235.

Danlami, A. H., Applanaidu, S. D., & Islam, R. (2019). Movement towards the adoption of non-traditional household lighting fuel energy in developing areas. *Biofuels, 10*(5), 623–633.

Davis, M. (1998). Rural household energy consumption: The effects of access to electricity—evidence from South Africa. *Energy policy, 26*(3), 207–217.

Ekholm, T., Krey, V., Pachauri, S., & Riahi, K. (2010). Determinants of household energy consumption in India. *Energy Policy, 38*(10), 5696–5707.

Epstein, M. B., Bates, M. N., Arora, N. K., Balakrishnan, K., Jack, D. W., & Smith, K. R. (2013). Household fuels, low birth weight, and neonatal death in India: The separate impacts of biomass, kerosene, and coal. *International Journal of Hygiene and Environmental Health, 216*(5), 523–532.

ESMAP. (1999). Household energy strategies for urban India, the case of Hyderabad. *Report of the Joint UNDP/World Bank Energy Sector Management Assistance Program and the Indstitute of Energy and Environmental Studies*, (214/99).

Foley, G. (1995). *Photovoltaic applications in rural areas of the developing world*. The World Bank.

Gould, C. F., Urpelainen, J., & Sais, J. H. (2020). The role of education and attitudes in cooking fuel choice: Evidence from two states in India. *Energy for Sustainable Development, 54,* 36–50.

Gupta, G., & Köhlin, G. (2006). Preferences for domestic fuel: Analysis with socio-economic factors and rankings in Kolkata, India. *Ecological Economics, 57*(1), 107–121.

Hanna, R., & Oliva, P. (2015). Moving up the energy ladder: The effect of an increase in economic well-being on the fuel consumption choices of the poor in India. *American Economic Review, 105*(5), 242–246.

Heltberg, R. (2005). Factors determining household fuel choice in Guatemala. *Environment and development economics, 10*(3), 337–361.

Herington, M. J., & Malakar, Y. (2016). Who is energy poor? Revisiting energy (in) security in the case of Nepal. *Energy Research and Social Science, 21,* 49–53.

Hiemstra-Van der Horst, G., & Hovorka, A. J. (2008). Reassessing the "energy ladder": Household energy use in Maun, Botswana. *Energy Policy, 36*(9), 3333–3344.

Hosier, R. H., & Dowd, J. (1987). Household fuel choice in Zimbabwe: An empirical test of the energy ladder hypothesis. *Resources and energy, 9*(4), 347–361.

Hosier, R. H., & Dowd, J. (1988). Household energy use in Zimbabwe: An analysis of consumption patterns and fuel choice. *Household energy use in Zimbabwe: An analysis of consumption patterns and fuel choice*. 83–109.

Hosier, R. H., & Kipondya, W. (1993). Urban household energy use in Tanzania: Prices, substitutes and poverty. *Energy Policy, 21*(5), 454–473.

Hughes, G., & Dunleavy, M. (2000). *Why do babies and young children die in India?*. The World Bank: The role of the household environment.

James, B. S., Shetty, R. S., Kamath, A., & Shetty, A. (2020). Household cooking fuel use and its health effects among rural women in southern India—A cross-sectional study. *PLoS ONE, 15*(4), e0231757.

Joon, V., Chandra, A., & Bhattacharya, M. (2009). Household energy consumption pattern and socio-cultural dimensions associated with it: A case study of rural Haryana, India. *Biomass and bioenergy*, *33*(11), 1509–1512.

Jumbe, C. B., & Angelsen, A. (2011). Modeling choice of fuelwood source among rural households in Malawi: A multinomial probit analysis. *Energy Economics, 33*(5), 732–738.

Karekezi, S., McDade, S., Boardman, B., & Kimani, J. (2012). Energy, poverty, and development. In T. B. Johansson, N. Nakicenovic, A. Patwardhan, & L. Gomez-Echeverri (Eds.), *Global energy assessment—Toward a sustainable future* (pp. 151–190). Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Leach, G. (1992). The energy transition. *Energy Policy, 20*(2), 116–123.

Leach, G., & Mearns, R. (1988). *Beyond the fuelwood crisis: People, land and trees in Africa* (pp. 23–40). London: Earthscan.

Liao, H., Chen, T., Tang, X., & Wu, J. (2019). Fuel choices for cooking in China: Analysis based on multinomial logit model. *Journal of Cleaner Production, 225,* 104–111.

Maconachie, R., Tanko, A., & Zakariya, M. (2009). Descending the energy ladder? Oil price shocks and domestic fuel choices in Kano, Nigeria. *Land Use Policy, 26*(4), 1090–1099.

Masera, O. R., Saatkamp, B. D., & Kammen, D. M. (2000). From linear fuel switching to multiple cooking strategies: A critique and alternative to the energy ladder model. *World Development, 28*(12), 2083–2103.

Miller, G., & Mobarak, A. M. (2013). *Gender differences in preferences, intra-household externalities, and low demand for improved cookstoves* (No. w18964). National Bureau of Economic Research.

Modi, V., McDade, S., Lallement, D., & Saghir, J. (2005). Energy Services for the Millennium Development Goals. *Energy services for the millennium development goals.*

Murphy, J. T. (2001). Making the energy transition in rural East Africa: Is leapfrogging an alternative? *Technological Forecasting and Social Change, 68*(2), 173–193.

MHFW, N. (2015). Report of the steering committee on air pollution and health-related issues. *Ministry of Health and Family Welfare, Government of India, New Delhi.*

Nansaior, A., Patanothai, A., Rambo, A. T., & Simaraks, S. (2011). Climbing the energy ladder or diversifying energy sources? The continuing importance of household use of biomass energy in urbanizing communities in Northeast Thailand. *Biomass and Bioenergy, 35*(10), 4180–4188.

O'Neill, B. C., Ren, X., Jiang, L., & Dalton, M. (2012). The effect of urbanization on energy use in India and China in the iPETS model. *Energy Economics, 34,* S339–S345.

Pachauri, S., & Jiang, L. (2008). The household energy transition in India and China. *Energy policy, 36*(11), 4022–4035.

Pandey, V. L., & Chaubal, A. (2011). Comprehending household cooking energy choice in rural India. *Biomass and Bioenergy, 35*(11), 4724–4731.

Patel, R., & Chauhan, S. (2020). Risk of low birth weight and exposure to type of cooking fuel in India. *International Journal of Pregnancy & Child Birth for MedCrave Group, 6*(1), 8–11.

Patel, S. K., Patel, S., & Kumar, A. (2019). Effects of cooking fuel sources on the respiratory health of children: Evidence from the Annual Health Survey, Uttar Pradesh, India. *Public health, 169,* 59–68.

Rahut, D. B., Das, S., De Groote, H., & Behera, B. (2014). Determinants of household energy use in Bhutan. *Energy, 69,* 661–672.

Rao, M. N., & Reddy, B. S. (2007). Variations in energy use by Indian households: An analysis of micro level data. *Energy, 32*(2), 143–153.

Ravindra, K., Kaur-Sidhu, M., Mor, S., & John, S. (2019). Trend in household energy consumption pattern in India: A case study on the influence of socio-cultural factors for the choice of clean fuel use. *Journal of Cleaner Production, 213,* 1024–1034.

Ravindranath, N. H., & Ramakrishna, J. (1997). Energy options for cooking in India. *Energy policy, 25*(1), 63–75.

Reddy, B. S. (2003). Overcoming the energy efficiency gap in India's household sector. *Energy Policy, 31*(11), 1117–1127.

Reddy, B. S. (2004). Economic and social dimensions of household energy use: A case study of India, In Ortega, E. & Ulgiati, S. (editors): Proceedings of IV Biennial International Workshop "Advances in Energy Studies". Unicamp, Campinas, SP, Brazil. June 16–19, 469–477.

Saghir, J. (2004). Energy and poverty: Myths, links, and policy issues. Energy Sector Notes. Energy and Mining Sector Board, 4. *World Bank, Washington, DC*.

Sehgal, M., Rizwan, S. A., & Krishnan, A. (2014). Disease burden due to biomass cooking-fuel-related household air pollution among women in India. *Global Health Action, 7*(1), 25326.

Sharma, D., Ravindra, K., Kaur, M., Prinja, S., & Mor, S. (2020). Cost evaluation of different household fuels and identification of the barriers for the choice of clean cooking fuels in India. *Sustainable Cities and Society, 52,* 101825.

Uhunamure, S. E., Nethengwe, N. S., & Musyoki, A. (2017). Driving forces for fuelwood use in households in the Thulamela municipality, South Africa. *Journal of Energy in Southern Africa, 28*(1), 25–34.

Van der Kroon, B., Brouwer, R., & Van Beukering, P. J. (2013). The energy ladder: Theoretical myth or empirical truth? Results from a meta-analysis. *Renewable and Sustainable Energy Reviews, 20,* 504–513.

Viswanathan, B., & Kumar, K. S. K. (2005). Cooking fuel use patterns in India: 1983–2000. *Energy Policy, 33*(8), 1021–1036.

Warwick, H., & Doig, A. (2004). *Smoke–The killer in the kitchen.* London: ITDG.