NAVIGATING THE TRANSITION TOWARDS CLEANER ENERGY - AN EMPIRICAL STUDY OF ENERGY STACKING BEHAVIOUR IN NEPAL

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Abstract

The literature on energy transition from developing countries has largely centred around the testing of the Energy Ladder Hypothesis (ELH), suggesting that as a household's disposable income increases, consumers typically transition toward cleaner fuel options. In reality, energy consumption patterns in these countries reveal a prevalence of fuel stacking. In this context, the study investigates patterns of household fuel choices and identifies the factors that contribute to a complete shift towards cleaner energy consumption. This study is based on the microdata from the Household Risk and Vulnerability Survey, Full Panel 2016–2018. This paper employs panel multinomial logit approach to analyse the factors influencing the combinations of household fuel choices. The study reveals that households with higher income, smaller household size, shorter distances to market, and lesser engagement in agriculture and livestock rearing demonstrate a higher likelihood of adopting cleaner fuel mixes.

JEL Classification: C25, Q42, O13
Keywords: Clean Energy; Energy Ladder Hypothesis; Energy Transition; Fuel Stacking; Multinomial Model; Panel Data

1. INTRODUCTION

In the global pursuit of transition to cleaner energy sources, an in-depth examination of individual households' energy consumption patterns provides crucial insights into the challenges hindering the world's move towards clean energy. Notably, households in developing countries remain heavily reliant on traditional biomass fuels, such as firewood, agricultural residues, and animal waste, to meet their energy needs. These biomass fuels, categorised as dirty, emit harmful pollutants when burnt, contributing to air pollution and surpassing the pollutant levels released by fossil fuels. Unfortunately, approximately 2.8 billion people globally, constituting one-third of the population, still rely on traditional biomass fuels (IEA, 2006). Nepal exemplifies this reliance, as nearly 4 million out of 5.4 million households depend on traditional biomass, including firewood, for cooking (CBS, 2011).

The human cost of using biomass fuels is substantial, affecting health, the environment, and economic development. The combustion of biomass results in household air pollution (HAP), contributing to approximately 3.2 million deaths in 2020, with over 237,000 of these fatalities occurring among children under the age of five (WHO, 2014). Heart disease, stroke, and lower respiratory infections are prevalent health risks associated with household air pollution, disproportionately affecting women, who often bear the brunt due to their predominant role in cooking and household activities. Beyond health implications, the economic burden of burning biofuels extends to hindering women's participation in income-generating activities, as collecting biomass fuels becomes an additional time-consuming task (Farabi-Asl et al., 2019). These social challenges, coupled with the environmental concerns surrounding biomass use, including but not limited to deforestation, land degradation, and air pollution, raise a pressing need to transition to cleaner energy sources.

Cleaner fuel options such as electricity, gas, ethanol, and biogas are gaining attention globally. Efforts are

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underway to shift populations to cleaner cooking methods like Liquified Petroleum Gas (LPG), electric stoves, biogas, and bioethanol. Among these, gas stoves emerge as the most economically viable and scalable option, particularly in countries like Nepal. While not the ultimate solution, gas stoves offer a comparatively lower health and environmental cost than traditional biomass fuels, providing a practical interim solution for those currently grappling with the adverse consequences of dirty fuel usage. Despite the evident benefits of cleaner cooking solutions, questions persist about why households continue to use dirty fuels.

This paper aims to address the aforementioned question by empirically analysing why households are reluctant to adopt cleaner cooking fuel choices. The literature review in Section 2 primarily examines the two established hypotheses on the determinants of household fuel choice: the energy ladder and energy stacking hypotheses. Section 3 then goes on to illustrate how rural households tend to stack fuels, categorises households into clusters based on their observed fuel choices, and explains the rest of the variables, the data sources, and the empirical methodology. The results are discussed in Section 4, followed by the conclusion discussed in Section 5.

2. LITERATURE REVIEW

2.1. Energy Ladder Hyothesis

The transition to cleaner energy consumption and sustainable technologies is often explained using the 'Energy Ladder' model. According to this model, households mimic the behaviour of a utility-maximising neoclassical consumer (Hosier & Dowd, 1987). This implies that as a household's disposable income increases, consumers typically transition to cleaner fuel options, leaving behind the inferior or polluting ones (Leach, 1992). The energy ladder model illustrates a three-step discrete progression in household fuel usage. In the initial stage, households predominantly use low-cost, inefficient, and environmentally harmful fuels like biomass. In the second stage, with a rise in household income, they transition to "intermediate" fuels such as kerosene, coal, and charcoal to meet their energy needs more effectively. Finally, in the third phase, as incomes reach sufficient levels, households adopt cleaner energy sources like LPG and biogas, marking a move away from previously used fuels.

The model associates wood with inferior economic status, suggesting a strong correlation between income levels and fuel choices (Hosier & Kipondya, 1993). Cross-country comparisons also indicate a positive correlation between economic growth and the adoption of modern fuels, implying a shift from biomass as countries industrialise (Masera, Saatkamp & Kammen, 2000). While many empirical studies confirm the income-fuel choice relation, the correlation is not as strong as presumed by the Energy Ladder (Arnold et al., 2006). A central argument made by the energy ladder hypothesis is that of unidirectional fuel switching, i.e., a move up to a new fuel is simultaneously a move away from the fuel used before (Heltberg, 2004).

2.2. Energy Stacking Hypothesis

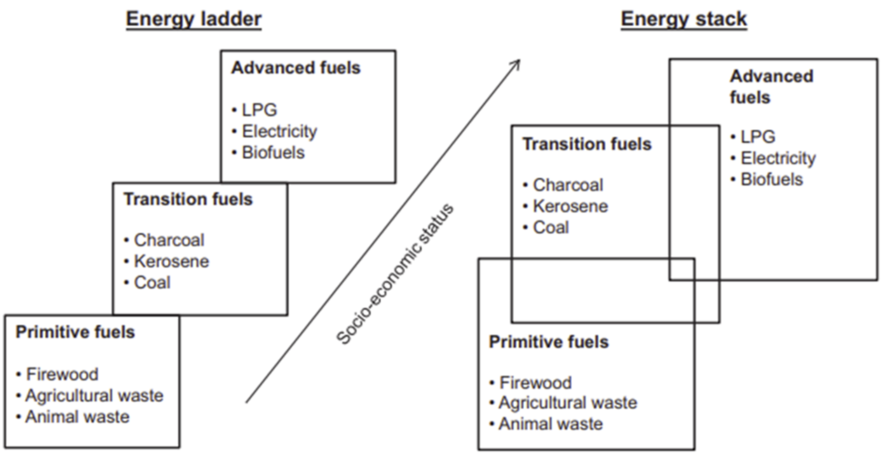
In reality, as income levels rise, especially in developing countries like Nepal, households typically don't fully transition from one fuel source to another (Campbell et al., 2003; Arnold et al., 2006). Instead, they employ a bidirectional approach known as 'energy stacking,' wherein they concurrently use various combinations of clean and dirty fuel mixes (Masera, Saatkamp & Kammen, 2000). Furthermore, it is imperative to acknowledge that the transition in fuel selection is not strictly unidirectional, as individuals may revert to traditional biomass despite prior adoption of modern energy sources (Arnold et al., 2006; Maconachie et al., 2009). Notably, Wickramasinghe (2011) identified instances where households in semi-urban areas of Sri Lanka, having initially embraced LPG, subsequently returned to utilising fuel wood in response to a substantial escalation in LPG prices. Likewise, the economic blockade in Nepal in 2015 had similar adverse effects on household fuel choices, leading households to resort to the use of firewood for cooking (Acharya & Adhikari, 2021).

Therefore, more often than not, energy stacking is driven by the need for a reliable energy supply, protection against income fluctuations, external economic shocks, and fuel shortages (Arnold et al., 2006). Nevertheless, studies also highlight that household fuel choices are influenced by a combination of economic and non-economic factors technical characteristics of fuels, and cultural preferences (Masera, Saatkamp & Kammen, 2000). Factors such as irregular income flows, fuel supply problems, price fluctuations, and cultural traditions contribute to fuel stacking behaviour (Hosier & Kipondya, 1993).

Much of the literature generally assumes the existence of an energy ladder and thus employs a discrete choice approach to analyse the determinants of the 'main' fuel choice in isolation (Heltberg, 2005; Narasimha & Reddy, 2007). While this approach is suitable for identifying a household's 'main' fuel, it oversimplifies the complexity of household fuel mix decisions. Therefore, the paper acknowledges that household fuel choices are not mutually exclusive and that households often use multiple fuels alongside their 'main' fuel.

In this context, this paper categorises household fuel mix choices into four distinct groups, based on their fuel purchases and the primary cooking fuel used over a year. This approach will more accurately reflect how households make fuel use decisions. This study is among the first to analyse the fuel stacking patterns of rural Nepali households. Given the data availability, this paper aims to identify the major factors influencing fuel stacking within the context of cooking fuel usage in Nepal. Particularly, the study aims to analyse patterns of rural household cooking fuel stacks and investigate the determinants contributing to a complete shift toward cleaner energy consumption.

Figure 2.1: *The Energy Transition Process*



Source: (Schlag, 2008)

3. METHODOLOGY

3.1. Data and Variable

The study utilises microdata from the Household Risk and Vulnerability Survey (HRVS), Full Panel 2016-2018, provided by the World Bank Group. This dataset incorporates all of the necessary variables, including household fuel consumption behaviour, household expenses, and the other required household socio-economic characteristics. The microdata covers 6,000 households across 400 communities in non-metropolitan areas. For this survey, 50 out of the 75 districts in Nepal were selected based on the size of their household population using a random Probability Proportional to Size (PPS) sampling method.

The microdata indicates that rural households in Nepal use an array of cooking fuel sources, including firewood, animal waste, agricultural waste, coal, kerosene, liquid petroleum gas (LPG), and biogas. For the analysis, these cooking fuels are categorised into three subgroups—dirty, transitional, and clean fuel—following the classification outlined by Schlag et al. (2008). Solid fuels such as firewood, animal waste, and agricultural waste, which are burnt in inefficient and highly polluting stoves, are classified as dirty fuels. Kerosene and coal are classified as transitional fuels, while LPG and biogas are classified as clean fuels. This study considers biogas as the cleanest fuel, even though it uses solid fuels as input, because it efficiently uses recovered waste in a non-smoke-generating manner.

Based on observed household fuel consumption patterns and the aforementioned definitions, four combinations of fuel mixes are further developed.

These combinations reflect how rural Nepalese households typically stack multiple fuel types within a single kitchen.

3.2. Construction of Fuel Mix Clusters

Cluster 0 contains households that exclusively use dirty fuels, specifically solid fuels like firewood, animal waste, and agricultural waste.

Cluster 1 contains households that use both components of dirty and transitional fuels, such as kerosene oil or coal, alongside dirty fuel choices, such as firewood, animal waste, and agricultural waste.

Cluster 2 contains households that simultaneously use transitional, clean, and dirty cooking fuels. To maintain the exclusivity of clusters, the study ensures that these households have purchased and used all three types of cooking fuel within the same year.

Cluster 3 contains households that exclusively use advanced fuels, such as liquid petroleum gas (LPG) or biogas, or households that use LPG as the main source but have purchased kerosene in the past year. In this cluster, no household has purchased dirty fuel at any point of the year.

These clusters are structured to ensure that each household belongs to only one cluster. The optimal number of clusters was determined using the elbow method, a technique in clustering analysis that involves plotting the within-cluster sum of squares (WCSS) for various numbers of clusters and identifying the "elbow" point where the WCSS begins to level off. In this case, the WCSS levelled off at four clusters. Categorising households into these four mutually exclusive clusters based on observed fuel choices enables analysis within a discrete choice framework. These four clusters serve as the dependent variable for this analysis.

In terms of explanatory variables, the study primarily uses the level of household income, the foundation of their dwelling, household size, the gender of the household head, distance to the market, whether the household head is literate or not, and whether the family has participated in agricultural activities. The summary statistics table 3.2.1 given other side provide a description of how these variables are quantified.

The log of income is a continuous variable that is derived from the summation of household expenditure. As income increases, a shift towards cleaner fuel mixes is anticipated, though a complete transition is not expected. While income is a significant factor in fuel transition (Heltberg, 2005), other socio-economic and cultural factors may play a more influential role. (Sehjpal et al., 2014)

Table 3.2.1: *Summary Statistics*

Descriptive Statistics	count	mean	min	max
Cluster	16,950	0.92	0	3
Log of Income	16,950	11.9	9.4	15.2
Foundation of Dwelling	16,802	0.25	0	1
Household Size	16,949	4.6	1	22
Gender of Household Head	16,929	0.4	0	1
Household Head Read/Write	16,932	0.5	0	1
Distance to Market	16,950	1.12	0	312
Participation in Agriculture	16,437	0.65	0	1
Livestock	16,950	2	0	40

Source: Author's Description

For the purpose of the study, the foundation of dwelling is used as a proxy for measuring the socioeconomic status of the given household. The foundation of dwelling is a binary variable where 0 denotes that household i lives in wooden and mud-bonded houses, while 1 denotes they live in pillared and cemented houses in the year. In rural areas, a house made of pillars and cement signifies greater social standing and reach. Therefore, it is expected that a high social standing is correlated with the adoption of cleaner fuel choices (Narasimha & Reddy, 2007).

In addition, the vector of explanatory variables includes household characteristics such as household size, gender and education status of the household head, involvement of household members in agriculture, and the number of livestock owned. The variable indicating whether the household head can read and write is a dummy variable where 0 denotes illiteracy and 1 denotes literacy. Similarly, the gender of the household head is a dummy variable where 0 denotes male and 1 denotes female head of household. A smaller household size is expected to have an increased likelihood that the household will shift towards cleaner fuel choices; the expectation remains the same when the household head is female and educated.

Furthermore, the study expects that the household member's involvement in agriculture and household livestock rearing acts as a disincentive for shifting away from dirty fuel mixes. A household's involvement in agriculture is calculated as the ratio of members who work in the agriculture sector to the total number of members who are of active working age. The convenience of collecting firewood while grazing livestock and the ready availability of agricultural and animal waste renders the transition to cleaner fuel choices somewhat unnecessary for rural households. The study counts animals as livestock owned only if their dung can be used to produce fuel or if the animals require grazing. Therefore, it is expected that as the proportion of household involvement in agriculture and the number of cattle a household owns increases, households are less likely to adopt cleaner fuel choices. This goes hand-in-hand with distance to the market.

A longer distance to the market serves as a disincentive for households to adopt cleaner cooking energy and likely justifies why many households are reluctant to shift away from using agriculture and animal waste as cooking fuel (Aminu et al., 2024). Consequently, it is expected that distance to the market will have a negative correlation with the choice of cleaner fuels. In this study, distance is measured by the average hours it takes for a household member to reach the nearest market. Time is used instead of distance in kilometres because the rugged terrain of rural Nepal means that the standard unit for distance does not consistently reflect the actual time and effort required to travel. Additionally, distance to the market is used to assess the level of remoteness of households and how their behaviour changes as remoteness increases. For the median household, the average time taken to reach a market is 30 minutes; however, for households above the 75th percentile, the time taken increases exponentially.

3.3. Limitations

It is important to note that the observed data spans only three years, limiting the ability to discern a clear transition (refer to figure A1, A2 & A3 in the appendix). Over a more extended period, a more pronounced shift in household fuel consumption may become evident. While the study focusses solely on rural households, it does not account for geographical variations in consumption behaviours, as geographical coordinates could not be retrieved. Additionally, variables such as fuel prices are not considered, which might result in omitted variable bias.

3.4. Model and Estimation Methods

Given that the dependent variable is categorical, a panel multinomial logit model (MLM) is estimated to assess the impact of income and other relevant variables on cooking fuel choice in rural Nepal. The theoretical framework of the multinomial logit model posits that each household (*i*) is faced with different combinations of fuel choices (*j*) over a yearlong period (*t*). It is assumed that a household receives a certain level of utility from each fuel mix choice, and the household makes a choice that is expected to maximise its household utility. In this study, each household is expected to choose an independent alternative from the aforementioned four combinations during a certain year (*t*).

The utility function of a household cooking fuel (U_{ijt}) for a given fuel mix type (X_j) in period t be expressed as:

$$U_{\text{ijt}} = \alpha_{ij} + \beta_j X'_{it} + \epsilon_{\text{ijt}} \quad (1)$$

Here, X'_{it} represents a vector of independent variables, each of which will be described below. Household fixed effects α_{ij} capture time-invariant unobservable characteristics at the household level, β_j represents a vector comprising estimated parameters, and ϵ_{ijt} represents the error term, following an independent and identically distributed (IID) extreme valued distribution. With this background, the probability of a household i choosing fuel mix j at time t, conditional on X'_{it} and α_{ij} can be represented as:

$$P[\text{j, t}/X'_{it}] = \frac{exp^{\beta_j X'_{it}}}{1 + \sum_{j=0}^{m} exp^{\beta_j X'_{it}}} \quad (2)$$

In this context, j corresponds to the number of available fuel mixes within the choice set, and only when j equals 0, it refers to the reference fuel mix. The vector of independent variables (X'_{it}) can be represented as:

$$\beta_j X'_{it} = \beta_1 \text{I}_{\text{it}} + \beta_2 \text{FD}_{\text{it}} + \beta_3 \text{A}_{\text{it}} + \beta_4 \text{L}_{\text{it}} + \beta_5 \text{HHS}_{\text{it}} + \beta_6 \text{HHG}_{\text{it}} + \beta_7 \text{HHEDU}_{\text{it}} + \beta_8 \text{DM}_{\text{it}} \quad (3)$$

Within this framework, I_{it} symbolises the logarithm of income for household i in year t. FD_{it} denotes the foundation of the dwelling. A_{it} signifies the proportion of household members involved in agriculture, and L_{it} stands for the number of cattle a household owns that can produce dung in the year t.

DM_{it} denotes distance to the nearest market. HHS_{it} represents household size, $HHEDU_{it}$ indicates the dummy for whether the household head is literate or not, and HHG_{it} is the dummy variable for the gender of the household head (where 0 denotes male and 1 denotes female).

4. RESULTS AND DISCUSSION

Table 4.1: *Results of Multinomial Logit Model (Baseline 0)*

VARIABLES	(1) (Cluster 0)	(2) (Cluster 1)	(3) (Cluster 2)	(4) (Cluster 3)
Log of Income	Baseline	-0.328***	2.082***	1.672***
		(0.0691)	(0.170)	(0.0544)
Foundation of Dwelling	Baseline	0.213***	1.091***	1.187***
		(0.0700)	(0.161)	(0.0467)
Household Size	Baseline	0.152***	-0.188***	-0.254***
		(0.0152)	(0.0454)	(0.0137)
Distance to Market	Baseline	-0.186***	-0.402***	-0.620***
		(0.0299)	(0.115)	(0.0334)
Livestock	Baseline	-0.282***	-0.311***	-0.215***
		(0.0176)	(0.0507)	(0.0128)
Household Member	Baseline	0.137**	0.327*	-0.165***
Participation in Agriculture		(0.0676)	(0.184)	(0.0508)
Gender of Household Head	Baseline	-0.721***	0.0928	0.218***
		(0.0850)	(0.213)	(0.0565)
Education Status of Household	Baseline	0.316***	0.590***	0.492***
Head		(0.0566)	(0.180)	(0.0462)
Constant	Baseline	2.125***	-28.37***	-19.80***
		(0.778)	(2.005)	(0.627)
Observations	16,253	16,253	16,253	16,253
Household Fixed Effect	YES	YES	YES	YES

Standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Source: Author's calculations

The maximum likelihood estimations indicate that rural households rarely switch from dirty to clean fuel, unidirectionally. The results suggest that households are more likely to concurrently use various combinations of clean, transitional, and dirty fuel mixes and that these households show considerable reluctance in choosing exclusively dirty or clean fuel mixes, regardless of income changes.

The results from Table 4.1 reveal that an increase in disposable income corresponds to an increased likelihood that households choose combinations of transitional and clean fuel relative to an exclusively dirty fuel mix, given all of the other variables in the model are held constant. This positive significance aligns with the literature that households adopt cleaner fuel combinations as their disposable income increases. However, with a similar increase in disposable income, the likelihood that households would choose a combination of dirty and transitional fuel relative to an exclusively dirty fuel mix is negative. Simply put, rural households are likely to either persist in using dirty fuels or take a leap towards cleaner options while still hoarding certain transitional fuels. This result complies with the literature that suggests households will initially shift towards cleaner fuel options with a marginal increase in their disposable income.

However, the result disagrees with the energy ladder hypothesis that households make a complete transition from dirty fuel mixes and exclusively use cleaner fuel as their income increases. It can be seen in both tables A.2 and A.3 that even with an increase in household disposable income, households are not likely to choose clean fuel exclusively when they have the option to hoard transitional fuel with clean fuel. Along the same line, households are more likely to choose a mix of transitional and clean fuels relative to exclusively dirty fuel options as their income increases. These results suggest that while households are likely to move away from burning dirty fuels as their disposable income increases, they are more likely to choose a cluster that has a combination of clean, transitional, and dirty fuel mixes instead of entirely clean fuel or entirely dirty fuel clusters.

The energy ladder hypothesis assumes that families also make a shift towards cleaner fuel sources to demonstrate increased socioeconomic status. (Masera, Saatkamp & Kammen 2000). To analyse this, the foundation of dwelling is used as a proxy for household wealth or fixed income. The model indicates positive significance, suggesting that when a household transitions from living in wooden and mud-bonded houses to pillared and cemented houses, the likelihood of progressively choosing cleaner fuel options increases significantly. This pattern is illustrated in all multinomial regression tables; it is clear that the cluster on the left of the baseline model exhibits negative significance, while the cluster on the right demonstrates positive significance in each regression table. This trend likely indicates a wealth effect, as homes with cemented pillars are associated with more affluent households.

In order to better understand the nature of substitution patterns between the fuel mix clusters, the study considers the distance from the house to the market and attempts to understand if fuel choice simply is a matter of access. The study delineated the distance to the market by the amount of time taken to travel. The negative significance in all the coefficients that are right of the baseline cluster indicates that as travel time increases, households are significantly less likely to opt for cleaner fuel alternatives. This aligns with the rationale that the convenience and accessibility of LPG gas, despite its higher cost, become more compelling when travel time is minimised. Commercial fuels such as LPG find greater popularity in areas that demonstrate shorter travel times to the market, given their ease of use compared to traditional energy sources.

In addition to this, the findings underscore a negative correlation between involvement in agricultural activities and livestock farming and the preference for cleaner household fuel choices. The study defines having livestock as owning animals whose dung can be used as cooking fuel. The result shows that increasing the number of cattle capable of producing dung for fuel usage is linked to a decreased likelihood of households opting for cleaner and transitional fuel mixes (i.e., Cluster 0 compared to Cluster 1, 2, & 3) compared to dirty fuel mixes, assuming other variables remain constant.

Similarly, an increase in the share of household members involved in agricultural activities is associated with an increased likelihood of selecting dirty and transitional fuel, holding other variables constant. This implies that households engaged in agricultural and livestock-rearing activities are more inclined to choose dirtier fuel mixes. This observation aligns with the socioeconomic landscape of Nepalese households, where traditional agriculture and rural living are predominant, with over 70% belonging to the subsistence-based traditional agricultural sector and more than 80% residing in rural regions (CBS, 2011) in Nepal (Joshi & Bohora, 2017). The prevalence of agricultural and animal waste in these areas likely nudges agricultural households to opt for these unclean fuel sources rather than cleaner alternatives. Households owning livestock may strategically decide to collect firewood when gathering fodder for their livestock feed. In this context, making biogas available to such households emerges as a favourable option for transitioning to cleaner energy fuels.

Ultimately, the choice of cooking fuel in households is also influenced by characteristics such as the gender and education status of the household head, as well as the family size. These findings align closely with existing literature. The results show that having a literate or female household head is negatively associated with the likelihood of selecting dirty fuels compared to clean fuels. Education emerges as a crucial factor influencing fuel-switching behaviour, with most studies finding positive effects on the probability of households using clean commercial fuels like LPG and kerosene. This can be attributed to the rising opportunity costs of fuel collection time at higher education levels and increased awareness of the adverse health effects associated with wood and charcoal use (Heltberg, 2004). The results also show that households with a larger family size are more likely to opt for dirtier fuel mixes over clean ones.

The increase in family size suggests an ample labour force for fuel collection, reducing the necessity to switch to modern fuels available in markets (Van der Kroone, 2016). Narasimha and Reddy (2007) further explain that larger households in developing countries often have lower incomes; hence, these households have limited ability to purchase commercial fuels. In addition, larger families require more fuel for sustenance, therefore, the need to purchase commercial clean fuel adds to their financial burden.

5. CONCLUSION

The study shows that rural Nepali households tend to concurrently use a mix of dirty, transitional, and/or clean fuels for cooking purposes. While current literature focusses on a complete shift from dirtier fuel to cleaner option, this study considers the analysis of stacked consumption of various combinations of fuels instead.

Through the estimation of a multinomial logit model on fuel-consumption behaviour, this study has highlighted the influence of income, remoteness of household, as well as household characteristics such as wealth or social standing, household member's engagement in agriculture and livestock rearing, family size, and gender and education of household head on these decisions. The findings align with the "energy ladder" concept, indicating that the shift to cleaner fuels increases with rising disposable income and improved socio-economic status. However, it is also observed that households are less likely to make a complete shift to cleaner fuel, opting instead to stack cooking fuels despite changes in income. These findings provide valuable insights for shaping effective energy policies in Nepal.

APPENDIX

Table A1: *Results of Multinomial Logit Model (Baseline 1)*

VARIABLES	(1) (Cluster 0)	(2) (Cluster 1)	(3) (Cluster 2)	(4) (Cluster 3)
Log of Income	0.328***	Baseline	2.410***	2.000***
	(0.0691)		(0.180)	(0.0800)
Foundation of Dwelling	-0.213***	Baseline	0.877***	0.973***
	(0.0700)		(0.171)	(0.0735)
Household Size	-0.152***	Baseline	-0.340***	-0.405***
	(0.0152)		(0.0470)	(0.0185)
Distance to Market	0.186***	Baseline	-0.217*	-0.435***
	(0.0299)		(0.118)	(0.0428)
Livestock	0.282***	Baseline	-0.0292	-0.0674***
	(0.0176)		(0.0530)	(0.0202)
Household Member Participation in Agriculture	-0.137**	Baseline	0.189	-0.302***
	(0.0676)		(0.193)	(0.0763)
Gender of Household Head	0.721***	Baseline	0.814***	0.939***
	(0.0850)		(0.225)	(0.0937)
Education Status of Household Head	-0.316***	Baseline	0.905***	0.808***
	(0.0566)		(0.186)	(0.0657)
Constant	-2.125***	Baseline	-30.50***	-21.93***
	(0.778)		(2.110)	(0.909)
Observations	16,253	16, 253	16,253	16,253
Household Fixed Effect	YES	YES	YES	YES

Standard errors in parentheses

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

Source: Author's calculations

Table A2: *Results of Multinomial Logit Model (Baseline 3)*

VARIABLES	(1) (Cluster 0)	(2) (Cluster 1)	(3) (Cluster 2)	(4) (Cluster 3)
Log of Income	-2.082***	-2.410***	Baseline	-0.410**
	(0.170)	(0.180)		(0.168)
Foundation of Dwelling	-1.091***	-0.877***	Baseline	0.0960
	(0.161)	(0.171)		(0.161)
Household Size	0.188***	0.340***	Baseline	-0.0652
	(0.0454)	(0.0470)		(0.0456)
Distance to Market	0.402***	0.217*	Baseline	-0.218*
	(0.115)	(0.118)		(0.118)
Livestock	-0.311***	-0.0292	Baseline	0.0966*
	(0.0507)	(0.0530)		(0.0509)
Household Member Participation in Agriculture	0.327	0.189	Baseline	-0.491***
	(0.26)	(0.193)		(0.185)
1 Gender of Household Head	-0.0928	-0.814***	Baseline	0.125
	(0.213)	(0.225)		(0.213)
Education Status of Household Head	-0.590***	-0.905***	Baseline	-0.0979
	(0.180)	(0.186)		(0.181)
Constant	28.37***	30.50***	Baseline	8.569***
	(2.005)	(2.110)		(1.983)
Observations	16,253	16,253	16, 253	16, 253
Household Fixed Effect	YES	YES	YES	YES

Standard errors in parentheses

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

Source: Author's calculations

Table A3: *Results of Multinomial Logit Model (Baseline 4)*

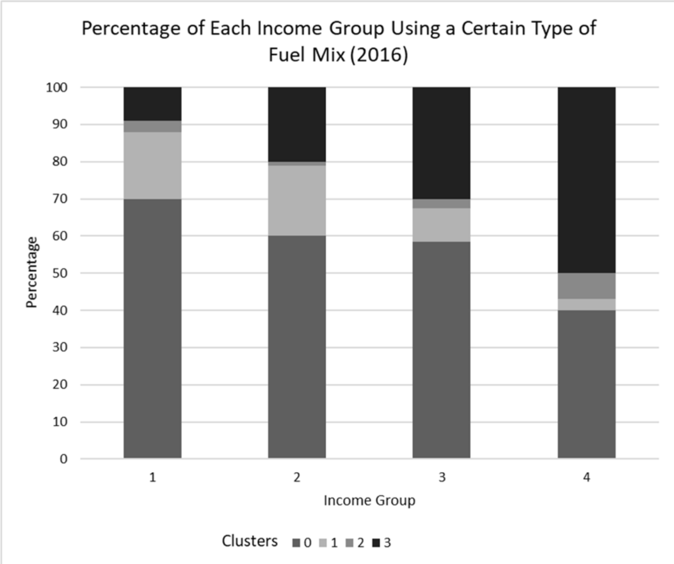
VARIABLES	(1) (Cluster 0)	(2) (Cluster 1)	(3) (Cluster 2)	(4) (Cluster 3)
Log of Income	-1.672***	-2.000***	0.410**	Baseline
	(0.0544)	(0.0800)	(0.168)	
Foundation of Dwelling	-1.187***	-0.973***	-0.0960	Baseline
	(0.0467)	(0.0735)	(0.161)	
Household Size	0.254***	0.405***	0.0652	Baseline
	(0.0137)	(0.0185)	(0.0456)	
Distance to Market	0.620***	0.435***	0.218*	Baseline
	(0.0334)	(0.0428)	(0.118)	
Livestock Ownership	0.215***	0.0674***	0.0966*	Baseline
	(0.0128)	(0.0202)	(0.0509)	
Household Member Participation in Agriculture	0.165***	0.302***	0.491***	Baseline
	(0.0508)	(0.0763)	(0.185)	
Gender of Household Head	-0.218***	-0.939***	-0.125	Baseline
	(0.0565)	(0.0937)	(0.213)	
Education Status of Household Head	-0.492***	-0.808***	0.0979	Baseline
	(0.0462)	(0.0657)	(0.181)	
Constant	21.03***	22.91***	-8.788***	Baseline
	(0.615)	(0.897)	(1.971)	
Observations	16,253	16,253	16,253	16,253
Household Fixed Effect	YES	YES	YES	YES

Standard errors in parentheses

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

Source: Author's calculations

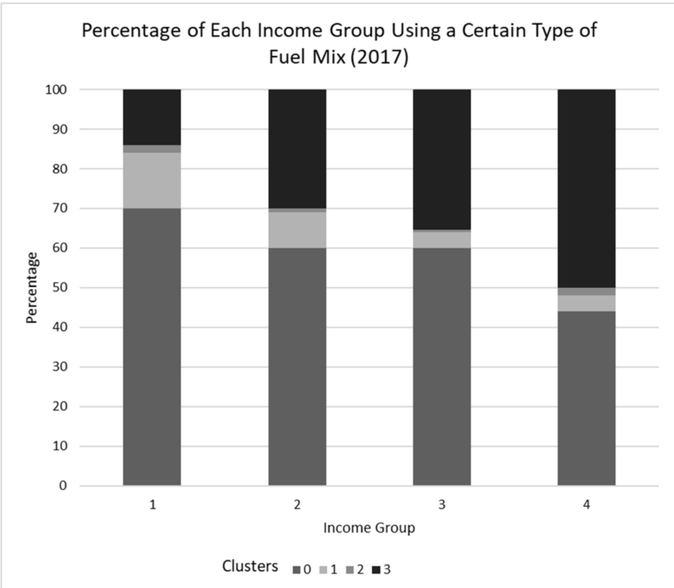
Figure A1: *Percentage of each income group using a certain type of fuel mix (2016)*



1

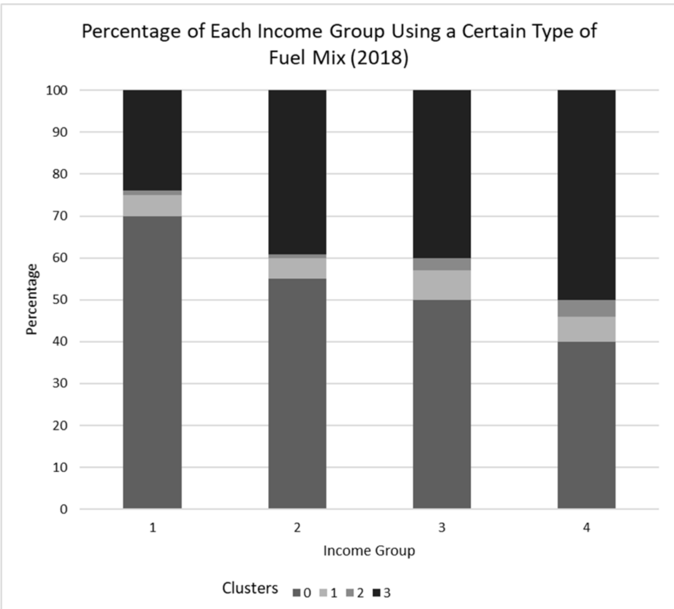
Source: Household Risk and Vulnerability Survey, World Bank Group

Figure A2: *Percentage of each income group using a certain type of fuel mix (2017)*



Source: Household Risk and Vulnerability Survey, World Bank Group

Figure A3: *Percentage of each income group using a certain type of fuel mix (2018)*



Source: Household Risk and Vulnerability Survey, World Bank Group

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