Ecology, Economy and Society–the INSEE Journal 9 (2): 1812.1-1812.39, July 2026

RESEARCH PAPER

Patterns and Key Determinants of Clean Cooking Fuel Adoption in Tamenglong District, Manipur

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Abstract: This study examines cooking-fuel use patterns and the determinants of clean-fuel adoption in households in Tamenglong District, Manipur, a remote and socio-economically marginalized region. Using a cross-sectional survey of 500 households across three subdivisions and employing a multinomial logit model, the study analyses the factors that determine households' reliance on firewood and use of mixed (firewood-dominant or liquefied petroleum gas (LPG)-dominant) fuel for cooking. Findings indicate that firewood remains the primary cooking fuel for 57% of households, while 43% use LPG either exclusively or in combination with biomass. Fuel stacking is widespread, particularly among middle-income households, reflecting a "bulky-middle effect". Income, education, employment status, the gender of the energy decision-maker, and spatial location relative to distribution centres emerge as significant determinants of LPG adoption. Decision-making by female heads of households and higher educational attainment strongly increase the likelihood of LPG use. Importantly, the study highlights that beyond economic and infrastructural constraints, traditional kitchen practices exert a powerful cultural influence. Households that adhere to traditional hearth-based cooking continue to prefer firewood due to its multifunctional role in food preparation, preservation, and socio-cultural practices. The results underscore that for policy interventions to be effective, they must move beyond initial provisioning

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Dates: 20 Sep 2026 (submission), 4 May 2026 (acceptance), 31 Jul 2026 (publication)

DOI: https://doi.org/10.37773/ees.v9i2.1812

Published by Indian Society for Ecological Economics (INSEE), c/o Institute of Economic Growth, University Enclave, North Campus, Delhi 110007.

ISSN: 2581–6152 (print); 2581–6101 (web).

of access to LPG and address affordability, last-mile delivery, and culturally embedded practices.

Keywords: Cooking Energy, Household Energy Transition, Fuel Choice, Fuel Stacking, Traditional Kitchen Practices.

1. INTRODUCTION

Despite the global commitment under Sustainable Development Goal 7 (SDG 7) to achieve universal access to clean energy by 2030, around 2.3 billion people worldwide still rely on health-hazardous fuels for cooking (IEA 2023). In India, about 95% of households now have access to liquefied petroleum gas (LPG), facilitated largely through the Pradhan Mantri Ujjwala Yojana (PMUY) (Mani *et al.* 2020). PMUY has significantly expanded LPG access amongst low-income households (Asharafa and Tol 2024; Gill-Wiehl *et al.* 2020), claiming to have established over 103.3 million LPG connections in Phase 2.0 of the scheme (Press Information Bureau 2025). However, nearly 660 million people continue to rely on solid biomass, primarily firewood, for cooking (IEA 2021), effectively living in energy poverty (Manasi and Mukhopadhyay 2024). Studies point to persistent challenges, such as gaps in the implementation of regional subsidies and sustained LPG adoption (Gupta *et al.* 2020; Kar *et al.* 2019; Ranjan and Singh 2020). The COVID-19 pandemic further weakened the progress of the energy transition, with domestic LPG consumption, including subsidies, declining by 1.5% as of March 2023 (PPAC 2023; United Nations 2022).

These challenges are particularly acute in the Northeast Region (NER) and a few other states, including Uttar Pradesh, Bihar, and Rajasthan, where access to clean energy remains limited. This is especially evident amongst Schedule Tribe (ST) households, which are disproportionately disadvantaged (Asharafa and Tol 2024; Dabadge *et al.* 2018). Such a persistent lack of access not only reinforces households' continued reliance on biomass but also contributes to a substantial health burden from household air pollution (Sharma *et al.* 2023; Swain and Mishra 2020). Achieving SDG 7 will therefore require not only improved access but also a sustained and affordable transition to clean energy sources (Gunnarsdottir *et al.* 2021).

Understanding household energy practices is central to the clean energy transition, as everyday fuel choices reflect broader economic, social, and cultural realities. Energy consumption patterns are often driven by cost minimization strategies, with households prioritizing the most affordable fuel options within their budgetary constraints (Ekholm *et al.* 2010). This behaviour aligns with the rational choice theory, which posits that households make decisions based on utility maximization and cost efficiency (Daioglou *et al.* 2012). These insights—broadly linked to the conventional energy ladder hypothesis[1]—suggest a positive relationship between rising income and the adoption of cleaner fuels (Heltberg 2003), confirming income as a key determinant of household energy choice (Abdul-Wakeel Karakara and Dasmani 2019; Campbell *et al.* 2003; Daioglou *et al.* 2012; Muller and Yan 2018; Remigios 2014; Srivastava *et al.* 2012; Weiss de Abreu *et al.* 2021). Empirical evidence from India (Pandey and Chaubal, 2011), Tanzania (Choumert-Nkolo *et al.* 2019), and Bhutan (Rahut *et al.* 2016) shows greater uptake of LPG amongst higher-income households. Similarly, a study in northern China (Demurger and Fournier 2011) shows a reduction in biomass fuel use with an increase in income. Consistent with this pattern, urban households, benefiting from higher economic status and better infrastructure, are more likely to transition to modern fuels (IEA 2021; Khandker *et al.* 2012).

In contrast, energy use in rural households rarely follows a linear transition from traditional to modern fuels. Instead, fuel stacking—the simultaneous use of multiple fuels, such as firewood, LPG, and electricity—is a widespread practice (Ai *et al.* 2021; Debebe *et al.* 2023; Guta 2012; Masera *et al.* 2000; van der Kroon *et al.* 2013). This reflects the continued dominance of biomass, with firewood remaining the primary and most accessible energy source in rural areas. The *Indian Residential Energy Survey* (IRES) confirms this rural–urban divide in energy type prevalence (Mani *et al.* 2021). Similar disparities can be observed elsewhere, including China (Mainali *et al.* 2012; Pachauri and Jiang 2008), underscoring the role of regional and infrastructural factors in shaping household energy choices. Consistent with the multidimensional nature of household energy use (Kowsari and Zerriffi 2011; Manasi and Mukhopadhyay 2024; Tikadar and Swami 2025), household fuel choices and usage are influenced by the interaction of broader economic and sociocultural factors and institutional, technological, accessibility, affordability, and policy contexts (Nathan and Hari 2020; Sovacool 2014). Therefore, income alone does not fully explain household fuel choices.

Rural and remote communities often face structural barriers, including limited market penetration and inadequate supply chains, financial

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[1] The energy ladder model describes fuel switching in three stages: households initially rely on biomass fuels such as wood, dung, and crop residues, then shift to transition fuels like kerosene and charcoal, and eventually adopt cleaner fuels such as LPG, natural gas, and electricity as incomes and living conditions improve.

constraints, and high shadow fuel prices, which collectively shape household energy decisions (Hiemstra-van der Horst and Hovorka 2008; Muller and Yan 2018; Guta *et al.* 2022). Thus, fuel transition challenges in rural households are multifaceted and linked to contextual socio-economic-behavioural complexities. Various studies attest to the limited role of income in influencing LPG adoption amongst PMUY beneficiaries in rural Odisha (Swain and Mishra 2020) and across rural Indian households (Malakar 2018), where use of multiple fuels is often prevalent (Sabyrbekov and Ukueva 2019).

Beyond income, other household-level socio-economic factors mediate energy decisions (Gupta and Köhlin 2006; Heltberg 2003; Karimu *et al.* 2016; Muller and Yan 2018; Twumasi *et al.* 2021). The characteristics of the household head, including attainment of formal education (Acharya and Sadath 2018; Dutta and Sahu 2022; Muller and Yan 2018; Ogwumike and Ozughalu 2015; Zhang *et al.* 2023), occupational status (Choudhuri and Desai 2020; Twumasi *et al.* 2021; Zheng *et al.* 2023), age (Gupta and Köhlin 2006), and gender (Adusah-Poku *et al.* 2022; Sharma and Dash 2022), significantly shape household energy choices. This indicates that various factors may reduce the likelihood of clean-energy adoption while increasing reliance on lower-quality fuels. Gender-specific patterns are particularly pronounced, with female-headed households exhibiting a greater propensity to adopt clean fuels than male-headed households (Dutta and Sahu 2022; Gould and Urpelainen 2020; Sharma and Dash 2022; Yan *et al.* 2024). However, contrasting evidence from Karimu *et al.* (2016) and Aryal *et al.* (2019) underscores the contextual variability of these influences. Furthermore, gendered energy-use patterns are often determined by other household characteristics, reinforcing the complexity of these interactions.

Disparities in energy consumption are evident across rural and urban areas (Dash and Chinara 2022), with residential location also exerting a significant impact on energy access and choice (Daioglou *et al.* 2012; Pachauri and Jiang 2008). Twumasi *et al.* (2012) report that households located far from LPG distribution centres are less likely to adopt LPG, instead favouring traditional biomass fuels. Additionally, energy use is deeply embedded in sociocultural traditions, with established practices, habits, and preferences shaping consumption patterns (Crosbie 2006; Rehfuess *et al.* 2010). Households adhering to such traditions may develop a preference for inexpensive but hazardous fuels—especially considering their economic constraints and limited access to LPG (GNESD 2014)—thereby hindering the transition to clean energy (Ochieng *et al.* 2020; Ouedraogo 2006; Ravindra *et al.* 2019; Hiemstra-van der Horst and Hovorka 2008). While these studies identify key determinants such as income, access, and sociocultural practices, they are largely based on evidence from more accessible mainland regions. The operation of these factors in geographically remote, infrastructure-deficient, and culturally distinct areas, such as Tamenglong District in Manipur, remains insufficiently explored.

Despite extensive research on household energy use in India, studies specifically focusing on rural cooking fuel use in the NER remain limited. Early work, such as Bhatt and Sachan (2004), identified firewood as an accessible energy source amongst tribal communities but did not examine the underlying region-specific determinants of fuel choice. Major national surveys such as the IRES (Agrawal *et al.* 2020) provide limited coverage of the NER, excluding states beyond the Assam valley. Similarly, studies on LPG adoption have largely focused on the mainland plains (Mani *et al.* 2020; Patnaik *et al.* 2018), overlooking persistent energy poverty in the NER.

Although studies such as Gupta *et al.* (2020) and Manasi and Mukhopadhyay (2024) highlight that the north-eastern states exhibit some of the highest levels of energy poverty, and Dabadge *et al.* (2018) acknowledge the challenges in PMUY implementation in the NER, their analyses lack region-specific depth. Notably, 54% of households in the NER still rely on biomass, compared with the national average of 40.6% (Ministry of Health and Family Welfare 2022). The region accounts for only 6.8% of PMUY LPG connections, the second-lowest share nationally (Ministry of Petroleum and Natural Gas 2025), despite the high concentration of poor and marginalized tribal households. Moreover, within the NER, intra-regional disparities are striking: Manipur receives just 0.2% of the region's PMUY connections, and Tamenglong District accounts for only 2.1% of the state's connections (Ministry of Petroleum and Natural Gas 2025). These patterns underscore how remoteness, weak infrastructure, and indigenous contexts remain underexplored in the existing literature.

Taken together, the existing literature confirms the significance of key determinants in cooking fuel decisions but offers limited information on how these factors operate within remote and marginalized regions such as the NER. In areas such as Tamenglong District, these factors are mediated by the rugged terrain, inefficient LPG delivery systems, reliance on forest-based resources, and culturally embedded cooking practices. This paper does not seek to identify entirely new determinants, but it demonstrates how the established factors acquire distinct characteristics and policy relevance when shaped by the region's unique geographical, infrastructural, and sociocultural conditions.

Against this backdrop, this study offers a district-level, context-sensitive analysis that addresses important gaps in the understanding of the region's specificities in clean-energy adoption and informs more tailored policy interventions. It captures both the continued reliance on traditional fuels and the practice of fuel stacking, offering a nuanced perspective on the energy transition process, which is becoming increasingly common in rural households. While grounded in a localized context, the study also contributes to the broader discourse on the sustainable energy transition by highlighting how household-level characteristics shape fuel choices in socio-economically and geographically marginalized regions. In particular, the study aims to examine the pattern of cooking fuel use and assess the determinants of cooking fuel choices amongst households in Tamenglong District.

With these research objectives, the study seeks to identify the challenges associated with transitioning from traditional to modern energy sources in the region. The study attempts to answer the following key questions: What is the pattern of energy use amongst rural households in the mountainous regions of Tamenglong District? What factors influence their fuel adoption decisions? What are the primary challenges hindering the transition to clean cooking fuel in the region? The paper is structured as follows: Section 2 outlines the data collection methods and the methodological approach. Section 3 presents the results. Section 4 provides a discussion of the key findings, followed by policy recommendations and suggestions for future research in Section 5.

2. METHODS AND DATA

The study was conducted in Tamenglong District, located in the western part of Manipur, a state in northeast India. The district is predominantly inhabited by indigenous tribal communities, including the Zeme, Liangmei, Rongmei, and Inpui tribes. Administratively, the district is divided into three subdivisions: Tamenglong, Tamei (Tamenglong North), and Tousem (Tamenglong West) (Figure 1). Amongst these, Tousem is significantly more remote and less connected to essential services and infrastructure, making travel to the district headquarters especially challenging.

Geographically, the district features steep hills and dense forests, which cover nearly 90% of its area. It is situated at an elevation of 1,260 m above mean sea level, and the only major transport connection to the state capital, Imphal (located 147 km away), is the hilly Khongsang–Tamenglong Road (National Highway [NH] 53). The physical isolation—coupled with poor road conditions, which worsen during the rainy season due to frequent landslides—contributes to the district's infrastructural limitations and to its

Figure 1: Map of Tamenglong District, Manipur

Source*:* Author's own work based on Maps of India (2026)

being regarded as one of the most marginalized and socio-economically backward areas in Manipur.

The local economy is primarily agrarian, with about 74% of the population engaged in cultivation or agricultural labour. Strong cultural and economic ties to the land define the region's identity and shape certain household practices, including energy use.

The district's limited connectivity poses significant infrastructural challenges in accessing basic services, including clean modern energy. Despite the implementation of subsidy-based clean energy schemes, such as the PMUY, the district is characterized by low uptake of modern clean fuels, such as LPG, and heavy reliance on traditional biomass fuels for daily cooking. These conditions make Tamenglong District a highly relevant site for examining household fuel choice in a marginalized and vulnerable energy context.

We employed a cross-sectional research design to identify the key determinants of household fuel choice. We conducted a household survey using semi-structured questionnaires; primary data were collected through face-to-face interviews across the three subdivisions of Tamenglong District, namely Tamenglong, Tamei, and Tousem.

The study adopted a non-probability, convenience sampling due to logistical, geographical, and accessibility constraints in the rural subdivisions. A total sample of 508 households was initially surveyed to ensure adequate coverage and sufficient representation of the socio-economic and geographic heterogeneity across subdivisions and villages. This was reduced to 500 households after excluding the incomplete responses. While the sampling design does not permit strict statistical generalization, the sample size is sufficiently large to allow robust descriptive statistics and exploratory econometric analysis.

We were careful in selecting multiple villages within each subdivision to reflect the heterogeneity in income groups and energy users. The final sample of 500 households was distributed as follows: 150 from Tamei, 201 from Tamenglong, and 149 from Tousem. Of these, 261 households (52%) were PMUY beneficiaries, while the remaining 239 households were non-beneficiaries. The distribution of PMUY beneficiary households was 36 from Tamei, 154 from Tamenglong, and 71 from Tousem. Furthermore, the chosen sample size reflects a balance between statistical precision and complexities in the management of survey operations, survey cost, and non-sampling errors—consistent with established guidance on conducting household surveys in developing countries (United Nations Statistics Division 2005).

Primary data were collected between October 2022 and January 2023 using a semi-structured questionnaire designed to capture information on household socio-economic characteristics, energy access, and energy-use practices, with a focus on cooking fuel. Face-to-face interviews were conducted primarily in participants' homes to ensure both participant comfort and accuracy of their responses. The primary respondents were women, who were chiefly responsible for household chores such as cooking and had in-depth knowledge of daily energy use. In addition to the survey responses, field observations and survey diaries were also maintained to supplement and contextualize the analytical findings of the study.

To ensure content validity, the questionnaire was reviewed by subject matter experts for relevance and clarity. Pre-testing was conducted in January 2022 with a sample of 50 households to refine the wording and format of the questions, ensuring that they were comprehensible and culturally appropriate. The reliability of the questionnaire was assessed using Cronbach's alpha, which yielded a value of 0.75, indicating this measure's acceptable internal consistency (Cronbach 1951).

A key revision from the pilot study was the income variable, as most respondents engaged in informal, seasonal work and struggled to report precise monthly earnings. To address this, the mean income of the pre-test sample was used to construct an income range within two standard deviations. This approach is supported by Pachauri (2004) and Deaton (2019), who advocate for a context-specific income classification based on preliminary survey insights. This allowed respondents to identify their income group more easily and thus improved response accuracy.

2.1. Model Specification and Variables

To assess the determinants of household cooking fuel choice, the study employed a multinomial logit model (MNL). The dependent variable, Fuel Choice, was classified into three mutually exclusive categories based on primary and secondary cooking fuel use combinations, as reported in the household survey. This classification draws on the concept of primary and secondary fuel use—outlined by Masera *et al.* (2000)—distinguishing between fuels used for cooking main meals, typically larger in quantity and with a longer time in use (Kojima 2021; Silwal and McKay 2015), and those used complementarily for lighter meals, such as snacks or tea.

The field data show that LPG is the only clean cooking fuel used, while firewood remains the predominant fuel in most households. These patterns are consistent with findings from the 2020 IRES (Mani *et al.* 2021), which identified LPG and firewood as the two cooking fuels most used across Indian households. This classification captures both regular and occasional practices, reflecting the full spectrum of household fuel use. It thus incorporates both traditional fuel dependence and fuel-stacking practices, a key feature of rural energy transition.

The three categories are defined as follows:

> 0 = Firewood_only (reference category): Households relying exclusively on firewood for all their cooking needs
>
> 1 = Firewood_dominant: Households primarily using firewood but supplementing it with other fuels (e.g., LPG, kerosene, electricity [cook-stoves])
>
> 2 = LPG_dominant: Households primarily using LPG for cooking, either exclusively or with secondary fuels (e.g., firewood, kerosene, electricity [cook-stoves])[2]

[2] Households that use LPG exclusively were also classified under Category 2 (LPG_dominant) due to their smaller proportion (0.8%). Similarly, households that

The general form of the multinomial logistic regression is given by Equation (1):

$$\log\left(\frac{P(Yi=j)}{P(Yi=0)}\right) = \beta_{jo} + \sum_{(k=1)}^{k} \beta_{jk} X_{ki} + \varepsilon_i, \qquad j = 1, \ldots, J \text{ .....(1)}$$

The probability form is expressed as:

$$P(Yi = j) = \frac{\exp(\eta_{ji})}{1+\sum_{m=1}^{J} \exp(\eta_{mi})}, \qquad P(Yi = 0) = \frac{\exp(\eta_{ji})}{1+\sum_{m=1}^{J} \exp(\eta_{mi})} \text{ .... (2)}$$

Specifications of the model for 0 = Firewood_only, 1 = Firewood_dominant, and 2 = LPG_dominant are as follows.

The log-odds equation for Firewood_dominant versus Firewood_only can be written as:

$$\log\left(\frac{P(Yi=1)}{P(Yi=0)}\right) = \beta_0 + \sum_{k=1}^{8} \beta_{1k} X_{ki} + \varepsilon_i \text{.....(3)}$$

Similarly, the log-odds equation for LPG_dominant versus Firewood_only can be written as:

$$\log\left(\frac{P(Yi=2)}{P(Yi=0)}\right) = \beta_0 + \sum_{k=1}^{8} \beta_{2k} X_{ki} + \varepsilon_i \text{ ....(4)}$$

where $i = 1, 2, \ldots, N$ indexes the households.

$\sqrt{\beta_{1k}}$ and $\sqrt{\beta_{2k}}$ are are the estimated coefficients for the *k*-th independent variables in Firewood_dominant and LPG_dominant versus Firewood_only, respectively. $\log\left(\frac{P(Yi=1)}{P(Yi=0)}\right)$ and $\log\left(\frac{P(Yi=2)}{P(Yi=0)}\right)$ are the log-odds of being Firewood_dominant and LPG_dominant relative to Firewood_only, respectively. Table 1 presents the description of the variables included in the MNL model.

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use LPG with electricity as a secondary fuel (9.4%) were also included in this category to mitigate estimation issues associated with sparse data, such as large standard errors and convergence failures. The final distribution of the dependent variable is as follows: 20.2% Firewood_only, 36.4% Firewood_dominant, and 43.4% LPG_dominant.

Table 1: Variables Used in the Study and Their Description

Variable	Type	Description
Household income (in Rs.)	0 = ≤.10,000 (Low) 1 = 10,001–20,000 (Lower middle) 2 = 20,001–30,000 (Middle) 3 = 30,000–40,000 (Upper middle) 4 = ≥ 40,001 (High)	Monthly household income categorized into five groups. This grouping also aligns with policy-relevant income brackets and is expected to determine affordability and fuel choice.
Household size	No. of family members	Number of family members currently living in the house. Larger households may have different cooking fuel needs and demands.
Gender of the EDM	0 = Male 1 = Female	The EDM is the primary household member who decides on the type of fuel to use. Gender roles may shape preferences and priorities.
Education of the EDM	0 = No schooling 1 = Primary 2 = Secondary 3 = Higher secondary 4 = Degree and above	The level of education attained by the EDM is assumed to affect access to information, awareness, and the ability to adopt cleaner fuels.
Employment status of the EDM	0 = Subsistent farmer 1 = Casual labour 2 = Self-employed 3 = Salaried	The employment status of the EDM determines the household's purchasing power and its capacity to adopt modern, cleaner fuels.
Area of residence	0 = Outside a 10-km radius 1 = Within a 10-km radius	The geographical location of the household, referring to its distance from the main town area, affects physical access to modern clean fuels; for example, proximity to LPG distribution centres.
Traditional kitchen practices (TKP)	0 = High 1 = Medium 2 = Low	TKP is measured using nine equally weighted items, grouped into three levels.* Each increase in level corresponds to three additional items. Such practices are assumed to influence fuel choice.
Land ownership	No. of acres	The size of the land owned by the household indicates its asset base and potential access to biomass resources.

Abbreviation: EDM = energy decision-maker

Note: * The construction of the traditional kitchen practices (TKP) measure is grounded in the pilot study; information on kitchen practices was collected through open-ended questions. This approach allowed respondents to describe their practices in detail, ensuring that the measure captured the full range of culturally specific behaviours instead of relying on pre-defined assumptions. The qualitative responses were then systematically analysed, coded, and consolidated into nine key indicators: slow-cooking techniques; preference for smoky flavours; space heating; insect repelling; prevention of fungal and mould growth; food preservation using smoke and heat; preparation of animal feed; adherence to traditional beliefs (e.g., use of fire or protection against negative spirits); and hardening of materials and wooden house structures through smoke deposition (tar). Together, these indicators represent the major dimensions of TKP in the study context and are directly related to the use of fire in household practices.

Source: Authors' analysis

Prior to data collection, ethical approval was obtained from the university's institutional review board to ensure compliance with social science research standards. The participants were fully briefed on the study's purpose, their role, and their right to voluntary participation; they provided informed consent orally due to their low literacy level. All personal information remains confidential to protect the participants' privacy throughout the study.

3. RESULTS

3.1. Household Demographic Details

Amongst the households surveyed, nearly 89% belonged to low- to middle-income categories, and only 11% were in the high-income categories. Land ownership was relatively widespread, with 76% owning land suitable for plantations—often used as a source of firewood—ranging from 1 to 50 acres. Additionally, 81% of the households reared livestock—including chickens, ducks, turkeys, goats, cows, buffaloes, dogs, and pigs—primarily for self-sustenance, income generation, or both. However, ownership of durable goods was limited; only 28% owned items such as vehicles, refrigerators, washing machines, grinding machines, and television sets, indicating modest levels of material wealth despite owning land and livestock.

Household socio-demographic characteristics are presented in Table 2.

Table 2: Descriptive Statistics of Household Socio-Demographic Variables

Variable	%	Min.	Max.	Mean	Standard deviation
Household income (in Rs.)	100	1	5	2.61	1.230
Low (up to 10,000)	19.2				
Lower-middle (10,001–20,000)	33.6				
Middle (20,001—30,000)	25.2				
Upper-middle (30,001–40,000)	10.8				
High (40,001 and above)	11.2				
Land assets (acre)	75.6	1	50	12.60	11.141
Livestock	100	0	1	0.81	0.389
Yes (1)	81.4				
No (0)	18.6				
Durable goods	100	0	1	0.28	0.449
Yes (1)	28				
No (0)	72				
Family type	100	1	2	1.47	0.5
Nuclear (1)	53				
Joint (2)	47				
Household size	100	1	17	6	2.052
EDM gender	100	`1	2	1.48	0.5
Male (1)	52.4				
Female (2)	47.6				
EDM education	100	1	5	2.87	1.254
Illiterate (1)	13.6				
Primary (2)	30.2				
Secondary (3)	27				
Senior secondary (4)	14.2				
Higher education (5)	15				
EDM employment status	100	1	4	2.34	1.167
Subsistence farmer (1)	37.6				
Casual labour (2)	10.4				
Self-employed (3)	32.8				
Salaried (4)	19.2				
Area of residence	100	1	2	1.53	0.499
Within 10 km (1)	46.6				
Outside 10 km (2)	53.4				

Source: Primary field survey data, authors' analysis

Table 3: Descriptive Statistics of Household Fuel Consumption

Fuel used	%	Mean	Standard deviation
Primary cooking fuel	100	1.43	0.496
Firewood (1)	56.8		
LPG (2)	43.2		
Secondary cooking fuel	100		
Firewood (1)	51.4	1.62	0.751
LPG (2)	36.8		
Charcoal (3)	1.8		
Electricity (cook-stoves) (4)	9.8		
Kerosene (5)	0.2		
Fuel for lighting	100	1.07	0.435
Electricity (1)	96.8		
Kerosene lamp (2)	1.2		
Solar lamp (3)	0.8		
Solar battery (4)	0.6		
Paraffin candle (5)	0.6		
Fuel for water heating	100	1.26	0.455
Firewood (1)	74.2		
Electric cooker (2)	25.2		
Electric induction (3	0.6		
Fuel for space heating	100	1.15	0.355
Firewood (1)	85.2		
Charcoal (2)	14.8		

Source*:* Primary field survey data, authors' analysis

3.2. Details of Household Fuel Use

The households in the study utilized various locally available fuels for cooking, lighting, water heating, and space heating (Table 3). The majority of households (57%) reported using firewood as their primary cooking fuel, indicating a significant reliance on biomass. The rest (43%) reported LPG as their primary cooking fuel. As a secondary fuel, firewood remained dominant (51%), with LPG (37%) also widely used. A smaller proportion of households used electricity (cook-stoves) (10%), charcoal (2%), and kerosene (0.2%) as supplementary cooking fuels.

For lighting, almost all households relied on electricity (97%), while a small fraction reported using kerosene lamps (1%), solar lamps (1%), solar batteries (1%), and paraffin candles (1%) during the survey. For heating water, the majority used firewood (74%), followed by electric cookers (25%) and electric cook-stoves (1%). For space heating, firewood remained dominant (85%), with charcoal used by 15%. Space heating is essential in the region due to high precipitation during the monsoon and low temperatures in winter. Households in the lower-income groups typically used firewood for both cooking and heating, while households in the higher-income groups used charcoal exclusively for heating. The limited use of charcoal is due to its high cost (Rs. 800 per bag, typically packed in a 50 kg rice sack) and its limited availability, as it is purchased from a few local producers.

3.3. Pattern of Cooking Fuel Use

A distinct local energy management practice observed during the survey highlights the challenges of inadequate access to clean energy. To optimize fuel use, households typically employ a sequential cooking method: water is first heated using firewood or an electric rice cooker (when electricity is available); rice is then cooked on an LPG stove in a pressure cooker, using the preheated water to save time and reduce LPG consumption. Snacks and teas are also prepared on an LPG stove, while curries that require longer cooking are prepared on an open fire. Boiled water is practically essential for low-income households, as it helps save fuel and thereby reduces fuel costs and cooking time. These practices reflect fuel stacking (Debebe *et al.* 2023; Masera *et al.* 2000), where a primary fuel is used for cooking main meals and a secondary fuel for lighter and quicker preparations (Kojima 2021; Silwal and McKay 2015). Ravindra *et al.* (2019, p. 1031) used the phrase "short-term quick services" to describe the use of LPG as a secondary fuel in Indian households.

Table 4 indicates an energy-use pattern consistent with the energy ladder hypothesis. There is zero representation by the low-income households under household type C, and, likewise, zero representation from high-income households under household type A. This indicates a strong correlation between low income and high usage of traditional non-clean biomass fuels and between high income and the adoption of modern clean fuels. A key finding is that approximately 70% of the households fall under household type B, demonstrating widespread energy stacking across income groups. The data reveal a "bulky-middle" effect, whereby middle-income households dominate mixed fuel use, while low- and high-income groups form smaller proportions. This underscores that fuel stacking is primarily a middle-income phenomenon.

Table 4: Descriptive Statistics of Household Cooking Fuel Use Combinations by Income Group (%)

Household income (in Rs.)	Household type			
	A	**B**	**C**	**Total**
≤ 10,000 (Low)	10	9	0	19.2
□ 10,001–20,000 (Lower-middle)	8.6	22	3	33.6
□ 20,001–30,000 (Middle)	1	21.6	2.6	25.2
□ 30,000–40,000 (Upper-middle)	0.6	8.2	2	10.8
≥ 40,001 (High)	0	8.8	2.4	11.2
Total	20.4	69.4	10.2	100

Note*:* Household types: A = exclusive use of non-clean fuels; B = mixed fuel use (both traditional and clean fuels); C = exclusive use of clean fuels.

Source*:* Primary field survey data, authors' analysis

Amongst the surveyed households, 261 (52%) were PMUY beneficiaries (Table 5). PMUY coverage varies considerably across subdivisions. Tamenglong records the highest coverage (59%) and exhibits relatively higher LPG adoption, though mixed fuel use remains widespread. In contrast, Tamei (14%) and Tousem (27%) report lower coverage, with negligible or no exclusive clean fuel use.

Fuel-use patterns, even amongst PMUY beneficiary households, reveal that the majority (78%) practised mixed fuel use, while exclusive clean fuel (primarily LPG-based) use was rare (10%) and confined to Tamenglong and Tamei. A small but notable share (12%) still depended solely on non-clean fuels, especially in Tousem; despite having active LPG connections, several households do not use them. Overall, only 39% of PMUY beneficiary households used subsidized LPG as their primary cooking fuel, while about 50% relied on it as a secondary fuel.

Table 5: Cooking Fuel Use Combinations Amongst PMUY Beneficiary Households by Subdivision (%)

Subdivision	Household type			
	A	**B**	**C**	**Total**
Tamei	1.1	10.6	1.9	13.8
Tamenglong	3	47.5	8.4	59
Tousem	7.2	19.9	0	27.2
Total	11.5	78.2	10.3	100

Note*:* Household types: A = exclusive use of non-clean fuels; B = mixed fuel use (both traditional and clean fuels); C = exclusive use of clean fuel.

Source*:* Primary field survey data, authors' analysis

The analysis indicates that exclusive LPG adoption remains limited, with fuel stacking persisting despite PMUY coverage. In rural areas, households combine the readily available firewood from private and community forests with LPG, which, though less accessible, is valued for its efficiency. This mix allows households to optimize energy use according to access, cost, and convenience.

Subdivisional variation reveals policy implementation gaps. While Tamenglong records relatively better outcomes, the weaker performance of Tamei and Tousem reflects their remoteness and poor connectivity. These patterns point to the challenges of extending scheme benefits to less-accessible areas and raise concerns about whether the initial LPG connections provided by the PMUY translate into sustained adoption. More broadly, they highlight that household fuel choices are shaped not only by conventional factors such as income but also by a set of household-level characteristics.

3.4. Key Determinants of Cooking Fuel Choice

The multinomial logistic regression model was estimated with Firewood_only as the reference category. The likelihood ratio (LR) chi-square test indicates that the model is highly significant overall ($p < .001$). McFadden's pseudo R^2 suggests that the model explains a substantial share of the variation in household cooking fuel choice, demonstrating strong explanatory power. The Hausman–McFadden test further supports the independence of irrelevant alternatives assumption, confirming the suitability of the multinomial logit specification.

Table 6 presents the results of the MNL model, which examines the determinants of household cooking fuel choices in Tamenglong District. The dependent variable distinguishes between three categories, namely firewood-only households (reference group), firewood-dominant households (those engaging in fuel stacking with firewood as the primary source), and LPG-dominant households (those primarily dependent on clean fuels). By adopting firewood-only households as the baseline, the model estimates the likelihood of households transitioning towards either firewood-dominant or LPG-dominant usage patterns.

We report the results in two complementary forms: the log-odds coefficients and the average marginal effect (AME). The former indicates the direction and magnitude of the effect of each predictor on the odds of belonging to either the firewood-dominant or the LPG-dominant group, relative to the firewood-only group. The AME for the same category provides a more intuitive interpretation, indicating the percentage point increase in the probability of LPG use associated with the predictor

Table 6: Multinomial Logistic Regression of Household Cooking Fuel Choice (N = 500)

Variable (base category = Firewood_only)	Firewood_dominant		LPG_dominant	
	Coefficient (1)	AME (dy/dx) (2)	Coefficient (3)	AME (dy/dx) (4)
Household income (in Rs., ≤Rs.10,000: Ref)				
□ 10,001–20,000	0.666* (0.361)	−0.001 (0.068)	1.254** (0.593)	0.084 (0.063)
□ 20,001–30,000	2.040*** (0.631)	0.035 (0.078)	3.114*** (0.782)	0.164** (0.068)
□ 30,001–40,000	0.142 (0.875)	−0.163 (0.100)	1.951* (0.999)	0.222*** (0.083)
≥□ 40,001	14.342 (552.421)	0.021 (0.097)	16.050 (552.421)	0.263*** (0.096)
Household size	0.032 (0.080)	0.004 (0.010)	0.011 (0.103)	−0.001 (0.008)
Gender_EDM (Male: Ref)				
Female	1.010** (0.389)	0.018 (0.050)	1.577*** (0.495)	0.080* (0.042)
Education_EDM (No schooling: Ref)				
Primary	0.926** (0.429)	0.062 (0.064)	1.142* (0.624)	0.047 (0.059)
Secondary	1.757*** (0.485)	0.138** (0.067)	1.909*** (0.661)	0.053 (0.061)
Higher secondary	3.626*** (1.163)	0.215*** (0.080)	3.951*** (1.261)	0.088 (0.071)
Degree and above	2.411* (1.290)	0.050 (0.109)	3.719*** (1.375)	0.203*** (0.086)
Employment_EDM (Subsistence farmer: Ref)				
Casual labour	0.572 (0.493)	−0.054 (0.079)	1.359** (0.672)	0.114 (0.072)
Self-employment in non-farm	0.050 (0.640)	−0.285*** (0.067)	2.427*** (0.694	0.336*** (0.061)
Salaried	−0.041 (0.687)	-0.159* (0.088)	1.233 (0.807)	0.175** (0.076)
Area of residence (Outside 10 km: Ref)				
Within a 10-km radius	1.545*** (0.474)	−0.026 (0.052)	2.790*** (0.540)	0.183*** (0.044)
TKP (High: Ref)				
Medium	−0.306 (0.458)	−0.013 (0.058)	0.664 (0.586)	0.045 (0.047)
Low	0.951* (0.576)	−0.090 (0.065)	2.511*** (0.717)	0.189*** (0.054)
Land ownership	0.003 (0.017)	0.000 (0.002)	−0.003 (0.021)	−0.000 (0.001)
Constant	-2.911*** (0.858)	—	-7.024*** (1.214)	—

Model summary
No. of observations = 500
LR χ^2 (38) = 452.91
Probability > χ^2 = 0.0000
Pseudo R^2 = .4300

Note: Standard errors are in parentheses. ***p < .01, **p < .05, *p < .10. AME = average marginal effect.

Source: Primary household survey data, authors' analysis variable, say income level. Further, although we have presented them in the same table for economy of reporting, we emphasize the importance of treating the firewood-dominant and LPG-dominant outcomes as analytically distinct. This means the determinants of fuel stacking (firewood-dominant) and clean fuel transition (LPG-dominant) may not operate in the same way.

The regression results highlight a set of socio-economic and contextual factors that influence household cooking-fuel adoption in Tamenglong District. Household income emerges as the most decisive determinant of the transition to clean cooking fuels. Compared with the poorest households (earning ≤ Rs. 10,000 annually), those in the higher income brackets exhibit significantly higher odds of being in the LPG-dominant category, with the AME indicating 16% to 26% increases in the probability of clean-fuel adoption. This demonstrates a clear energy ladder effect, whereby increases in income enhance the affordability of LPG refills and associated appliances. At intermediate income levels, however, households are more likely to fall into the firewood-dominant category, reflecting a fuel-stacking strategy. These households acquire partial access to LPG but continue to rely heavily on firewood, underscoring that income growth alone does not guarantee a total transition to clean energy. Overall, the pattern shows an income gradient towards LPG dominance—consistent with earlier studies (Weiss de Abreu *et al.* 2021)—with any tendency towards firewood dominance peaking at lower- to middle-income levels and declining as income rises.

The gender of the energy decision-maker (EDM) also shows a notable influence on a household's cooking-fuel choices. Households in which women make decisions regarding cooking-fuel usage are significantly more likely to adopt LPG as the primary fuel. The marginal effect of female decision-making raises the probability of LPG adoption by about 8%, indicating that women's preferences, shaped by considerations of convenience, health, and time savings, play an important role in driving clean-energy adoption. Amongst female EDMs, around 67% are salaried or self-employed, which means that they have financial autonomy and agency, not just a preference, to opt for cleaner cooking fuels. There is greater prioritization of the health and time-saving aspects of clean fuels, which aligns with the findings of previous studies (e.g., Choudhuri and Desai 2020). A respondent aptly summarized this preference:

> Firewood is, in reality, costlier if we truly account for the labour and effort spent collecting it. We walk several kilometres and spend many hours, sometimes an entire day to gather just two to three loaded baskets of

firewood. Moreover, the increasing difficulty of finding dry wood adds to the burden.

Education levels of EDMs reveal a dual pattern. Households with secondary and higher secondary education levels are more likely to belong to the firewood-dominant category, suggesting that partially educated households supplement traditional fuels with LPG without fully transitioning. This outcome indicates that while some level of education improves knowledge of LPG's advantages and facilitates partial access, it does not immediately lead to the replacement of traditional fuels with LPG. This pattern illustrates how education expands awareness and aspiration, but, in the absence of sufficient income or a reliable supply infrastructure, does not result in a complete shift to clean fuels.

By contrast, households headed by decision-makers with higher levels of education (degree and above) show a distinct shift towards LPG dominance. The large and statistically significant coefficients translate into AMEs of approximately a 20% increase in the probability of LPG adoption compared with households with no schooling. This transition underscores that higher education not only increases awareness of the health and time burdens associated with biomass use but also tends to correlate with higher income, salaried employment, and urban proximity, which jointly lower the barriers to LPG adoption. In other words, education plays both a direct role by contributing to knowledge, preferences, and health awareness regarding clean fuel and an indirect role through association with socio-economic mobility and market integration.

EDM employment status shows a differentiated effect on household fuel choice. EDMs who are casual labourers are more likely to practise LPG-dominant mixed fuel use than EDMs who are subsistence farmers, with a positive marginal effect of 11 percentage points. However, the significance level is lower, indicating only a modest tendency towards LPG use. Households with heads who are self-employed in non-farm activities are 28.5 percentage points less likely to be in the firewood-dominant category than households headed by subsistence farmers. At the same time, they show a strong and highly significant positive association with LPG-dominant mixed fuel use of about 34 percentage points.

For salaried EDMs, firewood-dominant mixed fuel use shows no significant difference relative to subsistence farmer EDMs, although the marginal effect is moderately negative by about 16 percentage points. In contrast, salaried households are positively associated with LPG-dominant fuel use, with a marginal effect of 17 percentage points, indicating a meaningful increase in adoption likelihood despite the coefficients' weaker significance.

These results highlight how employment stability and income potential, especially in self-employed or salaried households, play a critical role in driving the transition to LPG adoption; households with subsistence farmers remain strongly reliant on traditional fuels.

Spatial location emerges as a strong determinant of household fuel choice in Tamenglong District, reflecting the importance of infrastructural access, market connectivity, and distribution networks in driving energy transitions. The multinomial logit results show that households residing within 10 km of the District/Town have significantly higher log-odds of being LPG-dominant relative to firewood-only households. The corresponding AME confirms this substantive effect, with an 18% increase in the probability of LPG adoption. This indicates that households closer to the district headquarters benefit from easier access to LPG distribution centres, reduced transportation costs, and more reliable cylinder delivery.

Field observations corroborate this statistical pattern, showing that rural households encounter higher transportation costs, logistical barriers, and difficulties in sustaining LPG use. A subsidized PMUY 14.2-kg cylinder priced at Rs. 1,050, on average costs around Rs. 1,131 locally (range: Rs. 1,050–1,600) and typically lasts 2.5 months for a six-member household. Hence, it needs to be supplemented with other fuel sources, such as firewood. Survey narratives reveal additional constraints:

> Sometimes, we cannot make it to the dealer's place because we spend nights working in the fields. In such cases, we give our booking details to someone with a vehicle to collect it on our behalf. However, they often fail to inform us when the stock is available, claiming it's not our turn yet.

Reliance on intermediaries to collect cylinders and delays in accessing refills explain the persistence of fuel stacking in rural settings.

Traditional kitchen practices (TKP) capture the cultural and behavioural dimensions of fuel use, beyond purely economic or infrastructural factors. TKP shows a strong and consistent association with household fuel choice. The regression results reveal that adherence to such practices significantly influences household fuel choice, and the persistence of cultural norms and cooking habits shapes energy transitions. The multinomial logit coefficients show that households with low levels of TKP—i.e., those less attached to conventional firewood-based cooking methods—are significantly more likely to adopt LPG-dominant fuel use relative to firewood-only households. In AME terms, low-TKP households exhibit an average 19% increase in the probability of being LPG-dominant compared with high-TKP households. This finding suggests that, even after controlling for income, education, and proximity to supply, cultural orientation exerts an independent influence on adoption behaviour. Households less bound by traditional practices are quicker to embrace LPG, recognizing its convenience, efficacy, and health benefits.

3.5. Determinants of Cooking Fuel Choice: PMUY Beneficiary Households

Table 7 shows the results of the multinomial logit estimates for PMUY beneficiary households, reported as log-odds coefficients and AMEs, to examine the factors influencing cooking-fuel choices. As in the overall sample (see Section 2.1), the firewood-dominant and LPG-dominant categories are treated as analytically distinct outcomes compared with the reference category of firewood-only users. These results are compared with the full sample estimates in Section 3.4.

The effect of household income is not as prominent here as it is on the full sample. The higher-income level (≥Rs. 40,001) shows a statistically significant reduction in the probability of the household remaining in the firewood-dominant category, along with a decline in LPG-dominant households. This suggests that higher-income PMUY households are less likely to rely on mixed fuel use, indicating a transition away from firewood dependence. However, the middle-income level (Rs. 20,001–30,000) has a negative marginal effect for LPG-dominant use, suggesting that refill-affordability constraints persist, leading to continued fuel stacking rather than full LPG use.

The gender of the EDM has a moderate level of influence; specifically, female-EDM households show a higher likelihood of LPG-dominant use, although the AMEs are not statistically significant. This offers a limited, but suggestive, indication of women's preference for clean-fuel uptake even in beneficiary households.

Education as a factor offers mixed results. EDMs with secondary education are seen as having some association with firewood-dominant as well as LPG-dominant use, but the marginal effects of the same are not consistently significant. This suggests that amongst PMUY beneficiary households, education can play a role in raising awareness, but it does not have a direct, independent influence on the complete shift from firewood to LPG if additional economic and infrastructural support are absent.

Employment status was found to be a relatively more influential factor. Households with a self-employed (non-farm activities) or salaried EDM demonstrate a strong and statistically significant positive marginal effect for LPG-dominant use compared with households with subsistence farmers.

Table 7: Multinomial Logistic Regression of Household Cooking-Fuel Choice Amongst PMUY Beneficiary Households

Variable (base category = Firewood_only)	**Firewood_dominant**		**LPG_dominant**	
	Coefficient (1)	**AME (dy/dx) (2)**	**Coefficient (3)**	**AME (dy/dx) (4)**
Household income (≤□ 10,000: Ref)				
□ 10,001–20,000	−0.256 (0.603)	−0.117 (0.098)	0.556 (0.905)	−0.104 (0.091)
□ 20,001–30,000	0.311 (0.895)	−0.094 (0.107)	1.200 (1.126)	−0.118 (0.095)
□ 30,001–40,000	−0.664 (1.484)	−0.266* (0.149)	1.160 (1.644)	-0.234* (0.119)
≥□ 40,001	15.454(1939.968)	−0.116*** (0.033)	17.645 (1939.968	−0.318** (0.144)
Household size	−0.183 (0.134)	−0.025 (0.015)	−0.063 (0.165)	0.013 (0.013)
Gender_EDM (Male: Ref)				
Female	0.910 (0.617)	−0.020 (0.077)	1.496* (0.785)	0.081 (0.071)
Education_EDM (No schooling: Ref)				
Primary	1.321 (0.861)	0.106 (0.100)	1.276 (1.053)	0.007 (0.077)
Secondary	1.371* (0.827)	0.044 (0.099)	1.891* (1.023)	0.077 (0.078)
Higher secondary	2.115 (1.577)	0.195 (0.125)	1.680 (1.700)	-0.036 (0.084)
Degree and above	17.272 (2067.156)	0.158 (0.128)	17.629 (2067.157)	0.068 (0.113)
Employment_EDM (Subsistence farmer: Ref)				
Casual labour	1.808 (1.190)	0.058 (0.120)	2.153 (1.419)	0.056 (0.111)
Self-employment in non-farm	15.593 (1199.573)	−0.279*** (0.091)	18.119 (1199.573)	0.435*** (0.087)
Salaried	0.361 (0.928)	−0.137 (0.122)	1.598 (1.120)	0.182* (0.110)
Area of residence (Outside 10 km: Ref)				
Within a 10-km radius	1.323*(0.784)	−0.115 (0.074)	2.707***(0.880)	0.202***(0.068)
TKP (High: Ref)				
Medium	0.157 (0.620)	−0.056 (0.074)	0.757 (0.773)	0.072 (0.057)
Low	1.517* (0.876)	−0.137* (0.083)	3.371***(1.035)	0.239***(0.071)
Land ownership	−0.021 (0.030)	−0.000 (0.003)	−0.026 (0.035)	−0.001(0.002)
Constant	0.438 (1.555)	—	−4.810**(2.018)	—
Model summary				
No. of observations = 261				
LR χ^2 (38) = 199.25				
Probability > χ^2 = 0.0000				
Pseudo R^2 = .3959				

Notes*:* Standard errors are in parentheses. ***$p < .01$, **$p < .05$, *$p < .10$.

Source*:* Primary household survey data, author's analysis

This suggests that income stability and regular cash flow remain crucial for sustaining LPG consumption.

Spatial access remains one of the strongest determinants, even amongst PMUY beneficiary households. Households located within 10 km of the main town area have a significantly higher probability of LPG-dominant use, with a large positive marginal effect. This underscores the significance of proximity to distribution centres; transportation costs continue to hinder sustained LPG use even after the provision of connections.

Finally, TKP shows a strong and consistent influence in both samples. Households that have lower adherence to traditional practices are more likely to use LPG predominantly, with statistically significant marginal effects. This again indicates the importance of cultural and behavioural constraints even within the context of PMUY.

4. DISCUSSION

The cooking-fuel landscape in Tamenglong District reveals patterns closely intertwined with structural and spatial inequalities in access. Overall, adoption of clean cooking fuel remains limited, suggesting the district is still at an early stage of energy transition, with considerable scope for improvement. These constraints are reflected in both the general adoption patterns and the performance of government interventions. For instance, while uptake of PMUY LPG connections is noticeably higher in Tamenglong subdivision, where better connectivity facilitates access, remote areas, such as Tamei and Tousem, remain disadvantaged by poor infrastructure and weak supply chains. Such disparities reflect a spatial bias in programme implementation and raise broader concerns about energy justice. Dabadge *et al.* (2018) and Asharafa and Tol (2024) have reported that marginalized regions such as northeast India are often left behind in scheme coverage and expansion, particularly ST households. Similarly, Choudhury *et al.* (2024) observes lower clean-fuel adoption amongst ST households in general, underscoring the persistence of social and spatial inequalities in access to clean cooking energy.

Within this context, households tend to rely heavily on biomass, with firewood continuing to dominate despite some signs of an upward shift along the energy ladder. Fuel stacking is widespread, particularly amongst middle-income groups, reflecting the "bulky-middle" effect and field observations of sequential cooking practices that combined firewood, LPG, and electricity to some extent. This behaviour is evident even amongst PMUY beneficiaries; although coverage is moderate, only one-fifth of the surveyed households used LPG as their primary fuel and just 0.8% relied on it exclusively. The rest either used it as a supplementary fuel or did not use it during the survey period despite holding active connections. Such persistent fuel stacking, even under PMUY coverage, highlights the difficulty of sustaining LPG use beyond initial access (Kar *et al.* 2019). It also explains why a complete transition to clean fuels in the district remains elusive. Ultimately, Tamenglong District faces a layered challenge. Its geographical disadvantages and the socially marginalized position of its largely tribal population combine to restrict both access to and the sustained use of LPG, undermining prospects for a long-term energy transition.

The multinomial logistic regression results (Table 6) offer important insights into the household-level characteristics associated with fuel stacking, shedding light on the dynamics of energy transition, a common feature of rural household energy use. The findings underscore the pivotal role of a household's socio-economic characteristics, gendered decision-making, and the locational and cultural context in shaping household fuel choices in Tamenglong District.

Income emerges as a key driver of LPG adoption, consistent with the energy ladder theory. Those in the lowest income groups largely remain locked into exclusive firewood use, middle-income households predominantly practice firewood-dominant stacking, and higher-income households are more likely to shift towards LPG-dominant mixed fuel use. Still, exclusive LPG adoption remains limited, reflecting affordability constraints. On the other hand, the continued local availability of firewood sustains its role as a fallback fuel. These patterns confirm that income is a crucial determinant of clean-fuel adoption, which is consistent with the findings of prior studies (Ekholm *et al.* 2010; Gill-Wiehl *et al.* 2021; Weiss de Abreu *et al.* 2021); yet the persistence of fuel stacking indicates that economic resources alone are insufficient to achieve full energy transition.

The education level of EDMs is a key determinant of LPG adoption. More educated EDMs are more likely to adopt LPG-dominant fuel use and reduce reliance on firewood, reflecting greater awareness of LPG's health, convenience, and time-saving benefits (Baland *et al.* 2012; Choudhury *et al.* 2024; Zhang *et al.* 2023). Survey narratives indicate that households with lower levels of education face challenges with applying for LPG connections through the PMUY, which limits their access to clean fuel (Patil *et al.* 2021). This highlights the role of education in enabling the adoption of modern energy. Findings from Kerala and Rajasthan have shown that education shapes perceptions of LPG as being health-promoting, further supporting adoption (Gould and Urpelainen 2020). It is also important to note that education and income level are often correlated, which may partly explain the observed effect of education on fuel choice.

Employment stability is another crucial determinant. Households with salaried EDMs are more likely to transition from exclusive firewood use, as a stable and predictable income improves affordability and reduces liquidity constraints in meeting LPG-related costs. Amongst households with self-employed EDMs, however, the effects are heterogeneous. Self-employment in non-farm activities is positively associated with LPG-dominant fuel use; however, its effect is not uniform across all fuel-use categories, suggesting that such households may adopt LPG alongside traditional fuels rather than completely replacing them. In contrast, subsistence farmers and casual labourers remain more reliant on firewood due to affordability constraints. Overall, these findings indicate that socio-economic empowerment through income, education, and employment facilitates clean-fuel adoption, while households lacking these advantages continue to face multidimensional barriers to sustainable LPG use.

Beyond socio-economic factors, the gender of the household's EDM also influences clean cooking fuel choices. Female EDMs have greater agency, and in choosing clean fuel, they stand to gain the most from benefits such as improved health, increased leisure due to time savings, and general convenience. Survey narratives reinforce this finding, as women frequently highlighted the labour-intensive nature of firewood collection. These results are consistent with those of prior studies showing that women who disproportionately bear the drudgery and health risks of traditional cooking tend to prioritize clean energy when they hold decision-making power (Farsi *et al.* 2006; Gould and Urpelainen 2020; Rao and Pachauri 2017). Choudhuri and Desai (2020) similarly demonstrate that women's empowerment, particularly through engagement in salaried and off-farm employment, enhances their decision-making power and leads to greater investment in clean fuels. However, other studies suggest that male-headed households are more likely to use clean fuels than female-headed households (Motu *et al.* 2025). This indicates that women's agency alone does not guarantee clean-energy adoption, as structural constraints such as economic hardships, women's lower opportunity costs, and regional disparities in fuel access can overshadow their fuel preferences.

This analysis reveals that the spatial dimension of energy access strongly influences a household's fuel choices. Households located within a 10-km radius of the main town area are significantly more likely to fully transition to LPG use, as they have the advantage of proximity to distribution centres and refill points. Prior studies have similarly noted that rural households face higher transportation costs and logistical barriers, limiting sustained

LPG use (Patil *et al.* 2021). These barriers include the lack of home delivery facilities, requiring households to incur additional labour and expense to have cylinders collected directly from the distribution centre. In addition to the transportation costs and logistical challenges observed in the study, the locally inflated price of LPG highlights how supply-side constraints, rather than the availability of connections, lead to continued reliance on firewood. These issues are further complicated by the overwhelming political instability in Manipur. There are frequent protests and bandhs, ethnic conflicts, road blockades, and economic blockades, all of which contribute to delays in the supply of LPG cylinders to the hill districts. The main LPG bottling plant is located in Awang Sekmai (Imphal West) and belongs to Indian Oil Corporation. Highways such as the Imphal–Jiribam Road (NH 37) are critical for bringing supplies to hill districts such as Tamenglong, but when this road is blocked, the deliveries get substantially delayed or reduced.

Moreover, the persistence of fuel stacking in forest-rich regions suggests that the ready availability of biomass provides households with a fallback option, slowing the transition to exclusive clean fuel (Cabiyo *et al.* 2021; Sharma and Dash 2022). Importantly, spatial intersections with social inequalities are evidenced: Only 28% of ST households reported receiving home delivery, compared with 33% of Scheduled Caste, 35% of Other Backward Class, and 42% of General Category households (Patnaik and Jha 2020). Together, the evidence suggests that spatial disparities mediated by structural inequalities and inadequate infrastructure, market access, and resource availability continue to shape household energy transitions despite policy efforts to promote universal clean-fuel adoption.

The association between TKP adherence and fuel choice underscores the deeply embedded cultural dimension of energy use in the study area. The influence of TKP on cooking fuel preferences is deeply tied to the traditional, multifunctional role of the hearth. Beyond cooking, the hearth serves as a central social space that facilitates interaction, reinforces family cohesion, and sustains the transmission of customary practices.

In the context of Tamenglong District, cold weather, mountainous environment, the open-fire hearth is also the source of constant heat in the kitchen, which is especially beneficial for vulnerable members of the household, such as the elderly, the sick, or young children. Tamenglong District's location imposes a distinct thermal requirement as ambient temperatures are often very low. The district receives precipitation for six to eight months a year, resulting in extended periods of cold and dampness. The severe shortage of regular electricity supply in the district makes it impractical to install alternative sources of room heating, such as portable room heaters. In such a high-altitude and forested region, a constant source of indoor heating is crucial not just for comfort but also to maintain the health of the people. In this setting, the continued reliance on biomass reflects an adaptive response to environmental and infrastructural constraints rather than a mere preference.

Smoke, a by-product of biomass combustion, has several practical uses, which further justify the continued use of traditional fuels in the district. Smoke and heat help repel insects and prevent fungal and mould growth, thereby improving indoor living conditions in a humid environment. Smoke also plays a significant role in strengthening and preserving housing structures made of bamboo and wood. As one respondent noted, "Over time, the smoke from the fire helps to reinforce the house structure, making it more durable and long-lasting." Another respondent was quoted as saying, "My father-in-law insists on keeping a *nrap peng* (frame suspended from the roof above the fireplace) in our kitchen; it is essential for hardening crafted items such as bamboo baskets, head-log, axe, and blade wooden handle." This highlights how fuel use is closely linked not only to cooking but also to house maintenance and durability.

Beyond these functional roles, firewood-based cooking is closely related to food preparation and preservation, and taste preferences. Traditional practices such as roasting, smoking, and slow cooking are integral to local diets, where the flavour imparted by firewood is highly valued. As one respondent explained, "Traditional tea leaves…have a much richer taste with smoky flavour *ahuimei* (charred aroma), and meat slow-cooked on a fire stove is softer and flavourful." These preferences are not merely for the palate but are embedded in customary cooking techniques that require sustained exposure to heat and smoke. In addition, fire-based methods serve as an important means of food preservation in the absence of reliable electricity supply and cold storage facilities such as refrigerators; this further links fuel choice to both dietary practices and infrastructural constraints.

Cultural norms and symbolic meanings also shape fuel preferences. Firewood carries social and cultural significance tied to household identity and responsibility. As reflected in local perceptions, a woman "without a pile of firewood in her house represents a '*kachang pat lak mei pui*' (a woman who does not fulfil her wifely duties)." Moreover, fire itself is imbued with the meaning of life; there is a prevailing belief that "there is no life without firewood," and that the household fire should never be allowed to fully go out. At the bare minimum, a smouldering ash should always be maintained within the house as a symbol of continuity and vitality. Together, such beliefs illustrate how energy practices are embedded within broader social expectations, making transitions away from traditional fuels more complex.

Practical and technical considerations related to cooking processes also influence fuel choice. Traditional stoves are better suited to large-scale cooking in bigger households and for specific preparation methods. For example, dishes such as *nkhui* (a traditional dish prepared from fermented soybeans) need to be cooked over fire for a long time and smoked for preservation and to enhance their flavour. LPG stoves are often considered less appropriate for such cooking methods. For instance, respondents indicated that the smaller, more concentrated flame makes food burn easily, especially when large pots are used. Additionally, activities such as preparing livestock feed require substantial fuel, making exclusive reliance on LPG economically unfeasible. As one respondent explained, "Cooking food for livestock…requires large quantities of fuel. …Since we already rely on wood fuel for livestock feed preparation, we often use it for household cooking as well." These factors contribute to the continued reliance on biomass despite having LPG connections.

Hence, in Tamenglong District, firewood is not merely a fuel but an integral part of the household identity and routines, serving functions that modern clean fuels or stoves cannot easily replicate. The persistence of TKP illustrates that energy transitions are not solely driven by affordability or access but also by social norms, symbolic values, and the perceived utility of traditional systems. Culturally sensitive approaches, such as designing improved cook-stoves that retain some features of open-fire cooking or providing hybrid heating solutions, could potentially preserve the multifunctional role of TKP and thus facilitate a sustainable transition to clean fuels without diminishing traditional customs.

A comparison with PMUY beneficiary households further refines these findings, providing a more nuanced understanding of access-led policy interventions. It reveals that the choice of cooking fuel continues to be determined by a mix of economic, infrastructure, and sociocultural factors. Household income shows a limited but notable effect, suggesting a gradual shift towards cleaner fuel—though not uniformly significant across all income brackets—and highlighting a persistent affordability gap in sustaining LPG use. Further, female EDMs and those with a secondary education are modestly associated with a higher probability of LPG-dominant use—underscoring the supporting role of awareness and inclination—but do not independently drive complete energy transition. In contrast, regular cash flow and income stability enable sustained LPG usage. At the same time, physical access remains a critical constraint even after the provision of free LPG connections, affecting the ease and continuity of use. Most notably, traditional kitchen habits continue to discourage exclusive reliance on LPG, underscoring the persistence of cultural and behavioural practices even amongst PMUY beneficiaries.

Overall, the transition to clean cooking in Tamenglong District is not solely a question of access but also of sustained usability. Addressing affordability, strengthening last-mile delivery, and accounting for culturally embedded practices are essential to enable a sustainable shift away from traditional fuels. These findings suggest that PMUY partially equalizes access but does not address the structural and behavioural constraints that shape sustained adoption.

5. CONCLUSION

This study examined the socio-economic and spatial characteristics influencing a household's cooking fuel choices in rural Manipur. By analysing primary and secondary fuel use, it offers a fuller understanding of rural energy practices and priorities, capturing both the persistence of fuel stacking and the dynamics of energy transition. The findings lend partial support to the energy ladder theory, showing signs of an upward shift: 57% of households continue to rely on firewood as their primary fuel, while 43% use LPG, indicating that the district is only just beginning to transition to clean modern energy. Yet fuel stacking persists as a widespread practice, even amongst PMUY beneficiaries—with strategic fuel mixing prompted by affordability and accessibility issues—underscoring its role as a defining feature of rural energy transition.

Although government initiatives such as PMUY play a crucial role in providing subsidized LPG connections, uptake is higher in Tamenglong subdivision, where the relatively better connectivity facilitates access, but more remote areas such as Tamei and Tousem remain constrained by poor infrastructure and weak supply chains. These disparities reflect spatial biases in programme implementation and raise broader concerns about energy justice. The analysis also highlights that household income, employment stability, and the EDM's gender and education level significantly influence LPG adoption. However, spatial constraints and TKP shape behavioural fuel preferences, hindering the effective adoption of clean fuels and slowing the complete transition to modern energy, particularly in remote and hilly areas.

Policy implications point to the need for strengthening the PMUY beyond its current access-oriented design towards a sustained-usage framework. Improving refill affordability through targeted subsidies and flexible payment mechanisms remains critical, particularly for households with irregular incomes. Strengthening LPG distribution systems—by establishing micro distribution centres in remote areas, addressing the lack of reliable home delivery services in the district, and improving integration with rural infrastructure (roads, transport, and storage)—is essential to overcome last-mile constraints. At the same time, linking the PMUY with livelihood support initiatives can enhance income stability and sustained adoption. Behavioural interventions, including awareness creation and community engagement through local institutions, such as non-governmental organizations and self-help groups, are equally important to address culturally embedded practices while recognizing the multifunctional role of the traditional hearth.

Finally, the persistence of firewood usage carries broader implications for attaining the SDGs—underscoring concerns about universal access to clean fuel (SDG 7), ongoing pressures on local forests (SDG 13), and the gendered nature of biomass dependence reinforcing inequalities (SDG 5)—that are linked to community well-being. At the same time, the study is limited by its cross-sectional design, which does not capture the dynamics of seasonal variations that may influence local energy practices. Future research should adopt longitudinal approaches to ascertain the effectiveness of clean fuel consumption, including whether subsidizing LPG connections through the PMUY results in sustained use for a meaningful energy transition. The analysis can also be extended beyond cooking to other end uses often linked to fuel choice, to inform more holistic energy policies. Comparative studies across other northeast Indian states would help assess whether the observed subdivisional disparities, especially under the PMUY, are unique to Tamenglong District or reflective of broader regional patterns.

Author Contribution: IDM: Conceptualization, methodology, investigation, data curation, formal analysis, writing - original draft. KCA: Supervision, conceptualization, formal analysis, methodology, validation, writing – review and editing; MJGR: Validation, writing – review and editing

Ethics Statement: The authors hereby confirm that this study complies with requirements of ethical approvals from the institutional ethics committee for the conduct of this research.

Data Availability Statement: The data used to support this research cannot be shared openly to protect the privacy of study participants and is stated in the paper.

Conflict of Interest Statement: The authors declare no conflicts of interest.

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