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Exploring Clean Energy Transitions: Socio-Economic Perspectives of Tribal Households in Maharashtra

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Abstract
This study examines the energy consumption patterns of urban and rural tribal households in Nandurbar District, Maharashtra, focusing on socio-economic, demographic, and behavioral factors. The study covers 600 households across eight villages, it explores energy choices, fuel usage trends, and the impact of indoor air pollution on health. The study also analyzes the alignment of household energy choices with the Energy Ladder Model. Government initiatives like the Pradhan Mantri Ujjwala Yojana (PMUY) have improved energy access, but their effectiveness is limited by affordability issues, distribution challenges, and lack of awareness about the health benefits of cleaner energy sources. Access to affordable modern energy is crucial for improving living standards, as it impacts health, productivity, and environmental sustainability. Tribal households primarily rely on solid biomass for cooking, which harms health and productivity. The study identifies factors influencing energy consumption, such as income, family size, education, and location. It provides empirical data, case studies, and policy evaluations to assess the success of current interventions. The study uses the Linear regression model to explore factors influencing the transition to LPG. It finds that both common and location-specific factors affect the shift. In regions with high use of solid fuels, income links to LPG adoption are weaker. The duration of LPG usage is also an important factor driving the transition over time. Most tribal households rely on firewood, with over half using it as their only fuel. Although some also use LPG, it's mostly a secondary fuel because many families can't afford it. The findings suggest that targeted subsidies, community-specific interventions, and improved supply systems are essential to overcoming energy access challenges and promoting cleaner energy adoption across diverse contexts.

Keywords: Clean energy, LPG, Sustainability, Transition, and Tribal households.

I. Introduction

Access to affordable, reliable, sustainable, and modern energy is a critical component of achieving sustainable development, as highlighted in Sustainable Development Goal 7 (UNDP, 2015). In 2021, 2.3 billion global population relied on inefficient cooking technologies, compromising health, socio-economic opportunities, and environmental degradation. Access to clean cooking solutions increased by 7 percentage points between 2015 and 2021, with projections suggesting 77% of the global population will have access by 2030 (WHO, 2021). SDG 7 emphasizes the need for universal access to clean energy services for poverty eradication, health improvement, gender equality, and socio-economic development. Despite global efforts, disparities persist, especially in developing countries like India, where many rely on traditional, polluting fuels like wood, crop waste, animal dung, charcoal, and coal. This dependence leads to indoor air pollution, respiratory diseases, cardiovascular illnesses, and other health complications, especially for women and children exposed to high levels of smoke in confined indoor spaces. According to estimates from the Global Burden of Disease (GBD), improper use of solid fuels for cooking causes household air pollution, which results in 4 million premature deaths annually. The urban-rural divide intensifies energy access challenges. According to the National Sample Survey (78th Round, 2021), 47% of rural households still rely on traditional fuels for cooking, compared to 6.5% in urban areas. This disparity reflects systemic barriers, including limited infrastructure, high costs of clean energy technologies, and lack of awareness. The prohibitive cost of LPG connections and other clean energy technologies reinforces energy poverty and hinders socio-economic development in rural areas.

Tribal communities, particularly in rural and remote regions, face even more significant challenges in accessing modern energy services. The socio-economic marginalization and geographical isolation of these communities' result in greater disparities in

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energy access compared to the general rural population. In Maharashtra, 36 percent of rural households lack access to clean cooking fuels, but this figure is considerably higher in tribal-dominated districts. In Nandurbar, 74.5 percent of tribal households do not have access to clean cooking energy (NFHS-5, 2021). The lack of infrastructure, combined with socio-economic vulnerabilities, significantly impedes the ability of tribal households to transition to cleaner energy sources, thereby perpetuating their reliance on polluting and harmful fuels. The implications of this energy deprivation extend beyond health concerns to economic and social outcomes. Tribal communities often rely on traditional biomass fuels, not only for cooking but also for income-generating activities, such as agricultural production and handicraft making. The time spent collecting firewood and other biomass fuels takes a toll on the labor productivity of women, who are primarily responsible for managing household energy needs. This reduces the time available for other income-generating activities, education, and participation in community development. The resulting loss of productivity contributes to continued poverty and socio-economic marginalization, especially for women and children, who bear the greatest burden.

1.1 Context

The 2011 Census recorded Maharashtra's population at 11.24 crore, with 9.3% (1.05 crore) being tribal population. Nandurbar district, located in northern Maharashtra, has the highest tribal population in the state, with 69.5% of its inhabitants belonging to tribal communities. The district, spanning 5,955 sq. km, faces significant challenges in energy access, with 74.5% of tribal households lack of access clean cooking fuel (NFHS 5, 2021). This contributes to health issues like indoor air pollution, emphasizing the need for improved clean energy access.

Nandurbar also has one of the lowest literacy rates in Maharashtra (64.38%), with a noticeable gender disparity 72.98% male and only 55.37% female literacy. Low education levels, especially among women, hinder the adoption of cleaner energy technologies. The district's Human Development Index (HDI) of 0.604 also lowest in the state which reflects limited access to basic services like education, healthcare, and clean energy, reinforcing the vulnerability of tribal communities and their reliance on traditional energy sources. The district's governance under the Panchayats Extension to Scheduled Areas (PESA) Act, 1996, it offers a unique opportunity to study the role of local governance in addressing energy access, sustainability, and economic development. The combination of a high tribal population, limited access to clean energy, low literacy rates, low HDI, and local governance under PESA makes Nandurbar an essential location for studying energy use patterns in tribal households, with potential insights into improving energy access and promoting sustainable development in similar communities.

II. Literature Review

2.1 Overview of Previous Research

Previous studies on clean cooking transitions often focus on socio-economic factors like income and education, which are outside the control of clean technology proponents (Lewis & Pattanayak, 2012; Jagadish & Dwivedi, 2018). There is a lack of behavior modification theories applied, especially after adopting clean cooking solutions (Thompson et al., 2018). Energy is crucial for development and economic progress, influencing various sectors (Guozhu Li et al., 2009). The ladder theory suggests that wealthier households shift from traditional fuels to cleaner cooking options like LPG or natural gas (Leach, 1992; Barnes et al., 2005). Khandker et al. (2012) discovered that energy poverty in urban families is proportional to economic status, whereas in rural India, even non-poor households are energy poor. In India's rural areas, liquefied petroleum gas (LPG) is by far the most widely used clean cooking fuel. Yet, according to data from the 2011 Indian Census, just 11% of rural households use LPG as their primary cooking fuel; the remaining 89% heat their homes each day by burning solid fuels including wood, coal, and dung (Tripathi et al., 2015).

Many studies show that household income is positively correlated with the adoption of sustainable energy sources such as electricity and gas, while poorer households in developing nations rely on unclean energy like firewood, agricultural waste, and animal dung (Danlami et al., 2016; Mensah & Adu, 2013; Ozcan et al., 2013; Couture et al., 2012). Research by Onoja (2012) found that family income negatively influences firewood use, while Oyekale et al. (2012) found a positive correlation between firewood consumption and household income. Other studies indicate that higher per capita expenditure encourages non-solid fuel usage (Heltberg, 2003; Abrahamse & Steg, 2009). House ownership also influences energy choice. Homeowners are more likely to adopt cleaner energy sources (Couture et al., 2012; Laureti & Secondi, 2012), though some studies suggest homeowners may prefer charcoal over firewood (Pundo & Fraser, 2006). The number of household appliances increases

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energy consumption, particularly with electric heaters, irons, and water heaters (Louw et al., 2008). However, subsidies for energy-efficient appliances promote conservation (Wang et al., 2011).

Energy cost significantly affects energy choices, with rising firewood prices leading to a shift towards cleaner energy (Mensah & Adu, 2013; Couture et al., 2012). However, some studies contradict this, showing increased fuelwood consumption despite higher costs (Oyekale et al., 2012). Household fuel switching is influenced by energy costs, with some studies finding that rising LPG and electricity prices deter clean energy adoption (Osiolo, 2010). Marital status and household structure also impact energy consumption. Families with children use more solid fuels, while married households tend to consume less kerosene (Laureti & Secondi, 2012; Nnaji et al., 2012). Gender dynamics further affect energy use, with some studies suggesting male-headed households favor fuelwood (Abebaw, 2007; Mekonnen & Kohlin, 2008), while others indicate that female-headed households are more likely to adopt cleaner fuels (Mensah & Adu, 2013; Danlami et al., 2016). Age is often negatively correlated with clean energy adoption. Older household heads are less likely to transition to sustainable energy sources (Nlom & Karimove, 2014; Suliman, 2010). Similarly, research shows that younger household heads are more open to fuel switching (Mensah & Adu, 2013; Ozcan et al., 2013). Education plays a crucial role in energy choices. Higher education levels correlate with increased adoption of clean energy (Nlom & Karimove, 2014; Eakins, 2013). Studies indicate that educated household heads are less likely to use firewood and more likely to adopt LPG (Oyekale et al., 2012). Furthermore, greater education levels reduce household spending on coal and solid fuels (Eakins, 2013; Abebaw, 2007).

2.2 Research Gap

Previous research focuses on solar, electricity and neglecting crucial energy sources such as fuelwood, kerosene, and LPG. However, these studies ignore the impacts of social, cultural, economic and environmental factors on clean energy use. There is hardly any study which focuses on the different determining factors of energy use depending on location (i.e. near to city and interior area). The present study attempts the same.

Although NFHS 5 provides valuable insights into key variables related to clean energy use among households but there are some other important variables that the present research includes. The present study attempts to fill these gaps by exploring additional factors such as ***(geographic location, distance, social culture, accessibility, affordability, environmental awareness, sustainable livelihood, decision-making, time spent in the kitchen, time taken to collect fuel, perceptions, proximity to natural resources, and government schemes)***.

2.3 Research Questions

1. What are the main sources of energy and consumption patterns in the study region?
2. Does socio-economic factors (***Income, Education, Gender, Occupation, Family size etc***) influence the energy consumption in tribal households?
3. Is there a significant rural-urban conversions or divergence in energy consumption patterns among tribal households?

2.4 Research Objectives

1. To identify trends and map out the clean energy sources used among the scheduled tribe population.
2. To identify the socio-economic and behavioral factors that influence energy usage in tribal households

III. Methodology

This study aims to analyze energy consumption patterns and socio-economic dynamics in tribal households in Nandurbar district, Maharashtra. The study used a stratified random sampling techniques, dividing the sample into two strata: households near to city and interior areas. This approach covers 600 households evenly split among these strata. The sampling is conducted with a 95% confidence level and a 5% margin of error, focusing specifically on selected areas within the Nandurbar district known for its tribal population and forest areas.

A mixed-method approach was used, with 600 households selected based on factors like income, education, and access to government schemes. Data collection involved structured surveys, in-depth interviews, and focus group discussions. Surveys focused on energy consumption, costs, types of energy sources, health impacts, and access to energy-efficient options. Interviews with tribal members, community leaders, and government officials provided deeper insights into socio-cultural factors and barriers to energy access.

3.1 Sample Design

For this study, first selected, a district with a large tribal population. Then, picked two blocks in

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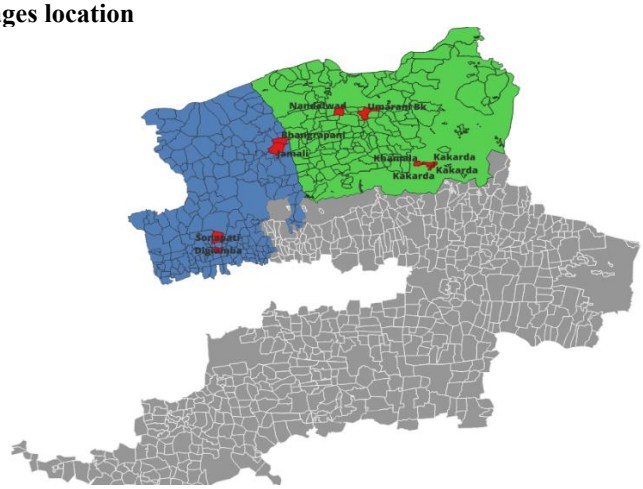
that district, known for their tribal population and forest areas. Next, randomly chose eight villages from these blocks, making sure to include both interior and near to city villages. In these blocks, selected four interior villages that are more than 50 km apart and four villages near the city that are within the 5 km radius. For the selection of sample households Proportion to Population Method has been used.

The study collected data from 600 sample households out of 2488 households which is nearly 24.1 percent of total households. These 600 sample household devided with 300 from interior villages and 300 from near to city villages.

3.2 Data Collection

The study conducted in Nandurbar district from January 2022 to March 2022 aimed to investigate the socio-economic conditions and energy usage patterns of tribal households across both urban and rural areas. The data collected provides insights into the population distribution, household characteristics, and the proportion of the tribal population in various villages across the district. In the urban areas, the selected villages included Umarani Bk (90 sample households) and Nandalwad (82 sample households) in Akrani block, as well as Dighi Amba (52 sample households) and Sonapati (76 sample households) in Akkalkuwa block. These villages are located within a 0-5 km radius of the tehsil, with tribal populations ranging from 98% to 100%. The total sample size for urban areas was 300 households, providing a representative sample for analysis. Similar to the rural areas of Nandurbar district included the villages of Khamala (70 sample households) and Kakarda (104 sample households) in Akrani block, as well as Jamali (64 sample households) and Bhangrapani (62 sample households) in Akkalkuwa block. These villages are situated more than 50 km from the tehsil and also have a high tribal population, ranging from 98% to 100%. A total of 300 households were surveyed in the rural areas, allowing for a comparative assessment of the socio-economic and energy-related challenges faced by these remote tribal communities. The study's findings are based on a total sample size of 600 households, evenly distributed between urban and rural areas.

District map and villages location



3.3 Data Analysis Tools

Primary data was systematically collected from tribal households in Nandurbar district, while secondary data sources, including government reports, energy statistics, and scholarly publications on rural energy policies, were utilized to enhance contextual understanding. The study rigorously examines key variables such as energy access, socio-economic determinants, health implications, environmental awareness, and the effectiveness of government interventions. Quantitative data obtained from structured surveys was analyzed using STATA for statistical robustness, whereas qualitative insights from interviews and focus group discussions were thematically analyzed to capture nuanced perspectives. Given its geographic focus, the findings of this study are specific to Nandurbar district and may have limited generalizability to other tribal regions in Maharashtra.

IV. Results and Overview of Findings

4.1 Results

4.1.1 Socio- economic profile of the selected households

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Descriptive Statistics of the Households for Selected Variable (percentage)			
Variable	***Interior***	***Near to City***	***Total***
Gender of household head			
Female	6.3	4.7	5.5
Male	93.7	95.3	94.5
Age Group of Respondent			
18-35	42.7	33.7	38.2
36-59	46.0	54.7	50.3
60 and above	11.3	11.7	11.5
Type of Family			
Joint	10.3	4.3	7.3
Nuclear	89.7	95.7	92.7
Marital status			
Married	92.7	95.0	93.8
Unmarried	0.7	0.3	0.5
Widowed	6.7	4.7	5.7
Education Level			
No Education	54.7	58.0	56.3
Primary	22.3	15.0	18.7
Secondary	13.0	18.7	15.8
Higher	10.0	8.3	9.2
Occupation of respondent			
Agri Labor	92.3	50.7	71.5
Farmer	7.3	48.7	28
Teacher	0.3	0.7	0.5
Land Holding			
No Land	25.0	22.3	23.7
Less than 1 Acre	74.3	77.3	75.8
1 Acre and above	0.7	0.3	0.5
Income Level			
less than10 K	41.0	22.3	31.7
11k-20k	27.7	11.7	19.7
21k-30k	23.7	58.3	41.0
31k - 40k	3.7	5.3	4.5
41k-50k	1.7	1.0	1.3
51k above	2.3	1.3	1.8
LPG Connection			
Yes	39.3(N-118)	30.3(N-91)	34.8(N-209)
N0	60.6(N-182)	69.6(N-209)	65.1(N-391)
LPG Connection and Family Type (Out of 209)			
Joint	9.3	3.3	6.7
Nuclear	90.7	96.7	93.3

Source: Primary Survey

All the respondents in the study are female. In terms of household head, only 5.5% of households are headed by females, while the majority, 94.5%, are headed by males. The largest age group among the respondents is between 36 and 59 years, accounting for 50.3% of the total. A significant majority, 92.7%, belong to nuclear families. Most respondents, 93.8%, are married. Regarding educational background,

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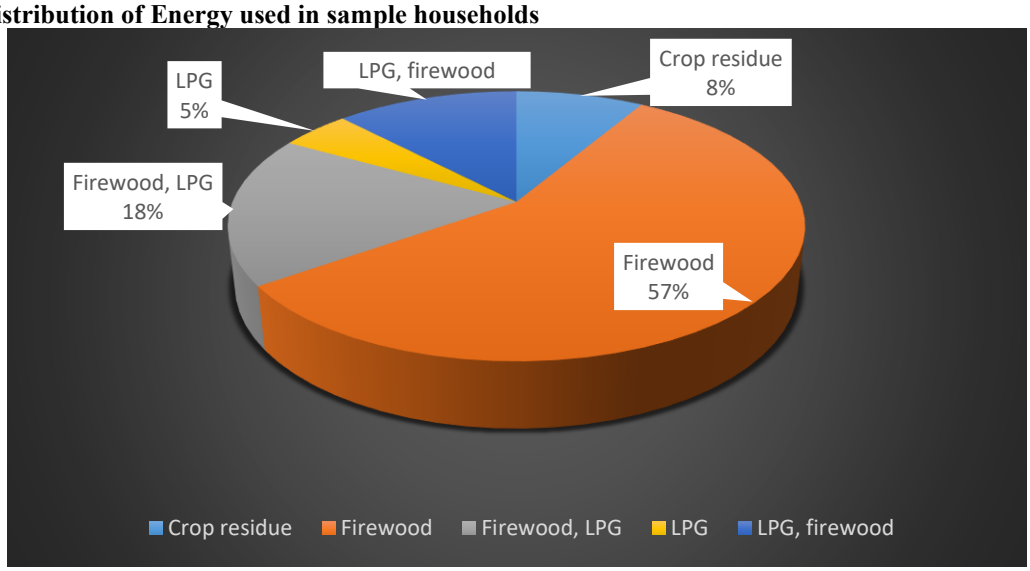
56.3% of the respondents have no formal education, while 18.7% have completed primary education. This data highlights the predominance of male-headed households, a high rate of marriage, and low levels of formal education among the female respondents. A majority of the respondents, 71.5%, are agricultural laborers, indicating a high reliance on this occupation for their livelihood. In terms of land ownership, 23.7% of the respondents do not own any land, while 75.8% possess less than one acre, reflecting limited access to land resources. Regarding income levels, 31.7% of the respondents earn less than ₹10,000, and only 1.8% have an income exceeding ₹51,000, highlighting that most respondents fall within lower and middle-income categories. This data underscores the economic vulnerability of the population, with heavy dependence on agricultural labor, minimal land ownership, and low income levels. About 34.8% of households have an LPG connection, while the majority, 65.1%, do not, indicating a significant gap in access to clean energy sources. When comparing family types, only 6.7% of joint families have LPG connections, whereas 93.3% of nuclear families have access to LPG. This highlights that nuclear families are more likely to have LPG connections compared to joint families, reflecting disparities in clean energy access based on family structure.

4.1.2 Distribution of Energy used in sample households



Source: Primary Survey

The chart shows that a majority of households rely on firewood as their primary fuel source, with 340 households using it (56.7%) and 30.2% when combined with LPG. LPG, while less common as a standalone fuel, is significant when combined with firewood, used by 73 households (12.2%). Crop residue is the least utilized fuel type, with only 51 households (8.5%) relying on it. These patterns reflect accessibility, affordability, and cultural preferences for firewood over other fuel types, with LPG serving more as a secondary fuel. Overall, firewood is the most prevalent fuel source in households. These patterns reflect the accessibility, affordability, and possibly cultural preferences for firewood over other fuel types.

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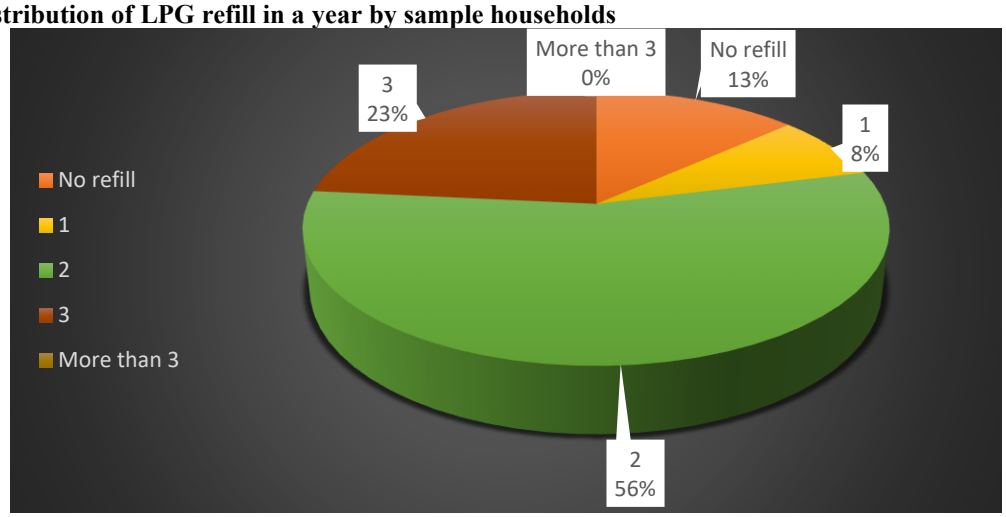
4.1.3 Distribution of LPG refill in a year by sample households

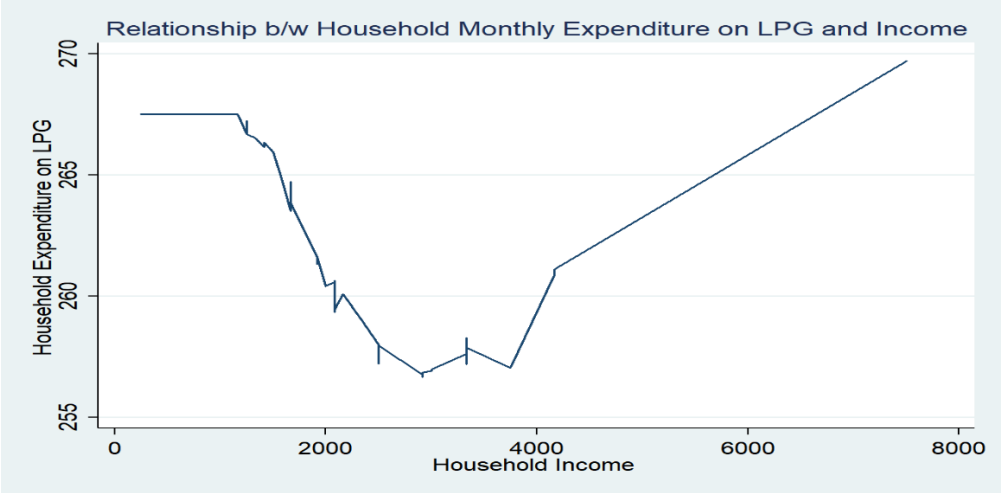


Source: Primary Survey

This chart shows that 55.5% of households require two LPG refills annually, followed by 23.4% who need three. A smaller proportion, 7.7%, requires only one refill. None require more than three refills annually, and 13.4% do not require any refills within the specified timeframe. The data suggests that most households require multiple refills, with two being the most common frequency, emphasizing the importance of efficient usage and management of LPG resources.

4.1.4 Relationship between household monthly expenditure on LPG with Income

We can observe a U-shaped curve. As the household income increases, the LPG expenditure first decreases and bottoms around the monthly Rs. 2500-3000 Income and then rises sharply again. However, the range of LPG expenditure is only Rs.255-270.



Source: *Primary Survey*

The graph shows the relationship between household monthly expenditure on LPG and household income. Initially, at lower income levels, LPG expenditure remains stable. As household income increases to around 3,000, LPG expenditure decreases. Beyond this point, as income continues to rise, expenditure on LPG starts to increase significantly. This pattern suggests that lower-income households might be optimizing their expenses or using alternative energy sources, while higher-income households tend to spend more on LPG, possibly due to increased energy consumption and improved living standards.

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4.1.5 Linear regression: Near to City

Wood per day use In kg	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig
LPG connection : b~0	0	.	.	.	.	.	
1	-1.906	.3	-6.36	.008	-2.86	-.953	***
Respondent Age	.01	.007	1.51	.228	-.011	.032	
Occupation : base ~r	0	.	.	.	.	.	
Farmer	.063	.289	0.22	.843	-.858	.983	
Milk Supplier	-.649	.603	-1.08	.361	-2.569	1.271	
Teacher	1.215	.795	1.53	.224	-1.315	3.744	
: base Illiterate	0	.	.	.	.	.	
Primary	.189	.2	0.95	.414	-.447	.825	
Secondary	-.101	.08	-1.27	.294	-.354	.152	
Junior College	-.198	.052	-3.80	.032	-.364	-.032	**
Degree and Above	.294	.205	1.44	.246	-.357	.946	
Family size	.102	.027	3.75	.033	.015	.188	**
: base 0 - 10k	0	.	.	.	.	.	
10K - 20k	-.07	.079	-0.89	.44	-.322	.182	
20k - 30k	.179	.069	2.61	.08	-.04	.397	*
30k -40k	-.154	.428	-0.36	.743	-1.517	1.209	
40k - 50k	.18	.418	0.43	.695	-1.149	1.509	
Wealth index	.155	.036	4.33	.023	.041	.268	**
Livestock index	.147	.047	3.12	.052	-.003	.297	*
Id proof index	.007	.119	0.06	.956	-.373	.387	
Constant	4.332	.191	22.69	0	3.725	4.94	***

Mean dependent var	4.783	SD dependent var	1.186
R-squared	0.597	Number of obs	300
F-test	.	Prob > F	.
Akaike crit. (AIC)	683.339	Bayesian crit. (BIC)	694.440

*** $p<.01$, ** $p<.05$, * $p<.1$

Results shows that several factors significantly influence the dependent variable. There is a negative association with LPG connection ($p = 0.008$) and Junior College education ($p = 0.032$). Family size ($p = 0.033$), income in the 20k-30k range ($p = 0.08$), wealth index ($p = 0.023$), and livestock index ($p = 0.052$) all have positive effects. These results indicate that LPG connection, education level, family size, specific income levels, wealth, and livestock ownership are key determinants.

4.1.6 Linear regression: Interior

Wood per day use In kg	Coef.	St.Err.	t-value	p-value	[95% Conf	Interval]	Sig

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LPG connection : b~0	0	.	.	.	.	.	
1	-1.498	.442	-3.39	.043	-2.905	-.091	**
Respondent Age	.004	.002	2.04	.134	-.002	.01	
Occupation : base ~r	0	.	.	.	.	.	
Agri Labor	.663	.172	3.85	.031	.115	1.211	**
Anganwadi	-.155	.235	-0.66	.556	-.904	.593	
Farmer	.494	.215	2.29	.106	-.192	1.179	
: base Illiterate	0	.	.	.	.	.	
Primary	-.044	.052	-0.86	.453	-.208	.12	
Secondary	.057	.091	0.63	.573	-.231	.345	
Junior College	-.172	.148	-1.16	.329	-.644	.299	
Degree and Above	-.069	.334	-0.21	.85	-1.13	.993	
Family size	-.027	.009	-3.16	.051	-.054	0	*
: base 0 - 10k	0	.	.	.	.	.	
10K - 20k	-.154	.092	-1.67	.194	-.448	.14	
20k - 30k	.043	.061	0.71	.527	-.15	.236	
30k -40k	-.125	.092	-1.36	.267	-.417	.167	
40k - 50k	.473	.213	2.22	.113	-.205	1.152	
5o	0	.	.	.	.	.	
Wealth index	.213	.057	3.72	.034	.031	.395	**
Livestock index	.201	.125	1.61	.205	-.196	.599	
Id proof index	-.113	.113	-1.00	.392	-.474	.248	
Constant	5.187	.409	12.67	.001	3.884	6.489	***

Mean dependent var	4.633	**SD dependent var**	1.018
R-squared	0.698	**Number of obs**	300
F-test	.	**Prob > F**	.
Akaike crit. (AIC)	507.457	**Bayesian crit. (BIC)**	518.568

*** $p<.01$, ** $p<.05$, * $p<.1$

Key factors significantly influencing the dependent variable include a negative association with LPG connection ($p < 0.05$), a positive association with agricultural labor occupation ($p < 0.05$), a marginally significant negative effect of family size ($p < 0.10$), and a positive association with wealth index ($p < 0.05$). These results suggest that LPG connection, agricultural labor occupation, family size, and wealth are important determinants.

4.1.7 Linear Regression Output:

Variable	*Coef*	*St.Err*	*p-value*	*Coef*	*St.Err*	*p-value*
	Near to City			**Interior**		
LPG connection						
1	0.3	0.008	***	0.442	0.043	**
Respondent Age	0.007	0.228		0.002	0.134	
Occupation						
Farmer	0.289	0.843		0.172	0.031	**
Milk Supplier	0.603	0.361		0.235	0.556	
Teacher	0.795	0.224		0.215	0.106	

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Education						
Primary	0.2	0.414		0.052	0.453	
Secondary	0.08	0.294		0.091	0.573	
Junior College	0.052	0.032	**	0.148	0.329	
Degree and Above	0.205	0.246		0.334	0.85	
Familysize	0.027	0.033	**	0.009	0.051	*
Income						
10K - 20k	0.079	0.44		0.092	0.194	
20k - 30k	0.069	0.08	*	0.061	0.527	
30k - 40k	0.428	0.743		0.092	0.267	
40k - 50k	0.418	0.695		0.213	0.113	
Wealth Index	0.036	0.023	**	0.057	0.034	**
Livestock Index	0.047	0.052	*	0.125	0.205	
ID Proof Index	0.119	0.956		0.113	0.392	
Constant	0.191	0.000	***	0.409	0.001	***
Mean dependent var	4.783			4.633		
SD dependent var	1.018					
R-squared	0.597			0.698		
Number of obs	300			300		
Akaike crit. (AIC)	683.339			507.457		
Bayesian crit. (BIC)	518.568					

The study looks at what affects LPG adoption in households near cities and those in remote areas. The results show that people in interior regions are slightly more likely to use LPG (0.442, $p < 0.05$) than those near cities (0.3, $p < 0.01$). Age doesn't seem to play a role in LPG use. Occupation matters, especially for farmers in remote areas, who are more likely to adopt LPG (0.172, $p < 0.05$). However, jobs like teaching or milk supply don't show a significant effect. Education influences LPG use mainly near cities—households where someone completed junior college are more likely to use LPG (0.052, $p < 0.05$), but other education levels don't have a strong impact. Bigger families are more likely to use LPG, both near cities (0.027, $p < 0.05$) and in remote areas (0.009, $p < 0.1$). Middle-income households (earning ₹20k–30k) in cities are more inclined to adopt LPG (0.069, $p < 0.1$), but other income groups don't show a strong connection—possibly due to cost concerns or reliance on traditional fuels. Wealthier households are more likely to use LPG in both areas (0.036, $p < 0.05$ near cities; 0.057, $p < 0.05$ in remote areas). Livestock ownership slightly influences LPG use near cities (0.047, $p < 0.1$), but it doesn't have much effect in remote areas.

The model explains a substantial portion of the variance, with an R-squared of 0.597 near the city and 0.698 in interior areas. This suggests that the model fits the data better for interior regions. The results highlight the importance of factors like household wealth, occupation, education, and family size in influencing LPG adoption, with notable differences between urban and rural settings.

4.2 Overview of Findings

- Education has a marginally significant impact on wood use in Villages near the city. Meanwhile, education seems not to affect the consumption of wood in the interior areas of the district, indicating that it is a cultural trend with a clear preference for wood.
- The Livestock Index indicates the storing of wealth in a traditional form. Hence, their use of traditional fuels (wood) is also higher.
- Average family size has significant role in wood use between rural interior villages and those nearer to the city.
- Households with more per capita wood usage have more cases of illnesses related to indoor air pollution.
- Tribal households heavily rely on firewood. Over half 56.7% use it as their only fuel.

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Including those combining it with LPG, 86.8% use firewood, making it the most common fuel.

- LPG is used by fewer households, with only 4.7 percent using it alone. However, when combined with firewood, 34.8 percent of households use LPG, showing that it is mainly used as a secondary fuel.
- Housing predominantly consists of huts or semi-pucca structures, with only a minority of households having separate kitchens which is 9.6 percent.
- Respondent spend a considerable amount of time in the kitchen. Most 52.3 percent spend 2 to 3 hours daily, 31.8 percent spend 3 to 4 hours.
- Firewood consumption is high, with 52.7 percent of households using between 3 to 5 kilograms daily.
- Respondent spend significant time collecting firewood, with 61.5 percent spending 2 hours daily.
- Regarding LPG refills, out of 209 connections, 55.5 percent of households need two refills a year, 23.4 percent need three, and 7.7 percent need just one. and 13.4 percent of households do not need any refills.
- Affordability of LPG is a major issue, with 65.2 percent of households stating they cannot afford it.
- Meal preparation typically takes 4 hours in a day for 56 percent of households.
- In terms of social interactions during cooking, 30.2 percent spend time with daughters-in-law, 12.2 percent with children.
- Women are the main sufferers to indoor air pollution as they are the household managers managing household tasks like cooking food. They spend most of the time indoors and are involved in kitchen tasks and they spend 3 to 5 hours in kitchen every day. They are exposed to pollutants (smoke) emitted from cooking fuel and fire/high temperatures.
- Regarding medical treatment, 32.7 percent seek medical attention, with costs predominantly falling between 500 to 2000 Rupees for 85 individuals 43.4 percent.
- It is observed that energy use pattern of tribal households is highly influenced by occupational status.
- It is observed that there is correlation between income level of tribal households and clean fuel adoption.

V. Summary and Discussion

The study reveals that education has a marginally significant impact on wood use in rural villages near the city, while it does not affect wood consumption in interior areas. Traditional fuels like wood are more common in tribal households, with 56.7% using firewood as their primary fuel. LPG is used by fewer households, but combined with firewood, 34.8% use it. Households predominantly consist of huts or semi-pucca structures, with 52.3 percent spending 2 to 3 hours daily in the kitchen. Firewood consumption is high, with 52.7 percent using between 3 to 5 kilograms daily. The affordability of LPG is a major issue, with 65.2% of households stating they cannot afford it. Women are the main sufferers of indoor air pollution, as they are household managers managing tasks like cooking food. The study reveals significant health impacts related to indoor air pollution, with cough being the most common, followed by fever and bronchitis. Chronic diseases are relatively low, with asthma and pneumonia affecting 2.3 percent of individuals.

The energy use patterns of tribal households are influenced by occupational status and income level. Rural households primarily use fuelwood, but its usage is decreasing due to the availability of LPG or its free or subsidized supply by the government. Rising incomes correlate with increased food consumption and higher energy use. LPG is preferred for its convenience and cleanliness as a cooking fuel. Household energy consumption varies between urban and rural areas. Urban households consume more LPG, while rural households rely heavily on biofuels like fuelwood, charcoal, and agricultural waste. Factors such as population growth, urbanization, income levels, and appliance availability significantly influence household energy consumption. The study examines variables such as energy availability, household income, location, family size, education level, and employment type that influence household energy use. Rural households mainly use LPG for cooking, while rural households rely on LPG, agriwaste, and firewood. Urban households feel they have enough energy sources to meet their needs, while rural households report inadequacy due to frequent electricity failures.

The study also reveals a positive correlation between energy use and income, suggesting that as income rises, families transition from using lower-quality fuels to better alternatives. Fuelwood is a significant household energy source in rural regions. Agriwaste's increased use is due to its abundant and free availability. LPG usage is greater among households with higher educational levels and higher income families in the study region. Traditional cooking using agriwaste and firewood is connected to healthy and appealing cooking, used for primary staples like roti and rice in rural regions and

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for water heating in urban areas. However, the free distribution of LPG under the Ujjwala plan had a negative effect on biogas adoption in rural regions.

Overall, improved socioeconomic conditions and family size led to higher energy use. Urban residents mostly rely on LPG for cooking, while rural households use LPG, agriwaste, and firewood. Both rural and urban residents have a strong grasp of environmental preservation, energy efficiency, and energy-saving equipment, goods, and behaviors. Households tend to adopt energy-saving methods, prioritizing energy efficiency, especially when it comes to power, and monitoring their costs accordingly. Electricity usage is more sensitive to yearly income in urban families than in rural ones. Divergence in power use between rural and urban areas is caused by financial discrepancies and variations in availability. LPG is the most expensive energy source for households each year.

VI. Conclusion

The study shows that various factors affect energy use and health in tribal households. Education has a small effect on wood usage in villages near the city, but in rural areas, cultural habits seem to be the main reason for using wood. Families with livestock tend to use more wood, as it is part of their traditional way of storing wealth. Larger families use more wood, and households that rely heavily on wood tend to experience more health problems, such as cough and eye irritation, due to indoor air pollution. Most tribal households rely on firewood, with over half using it as their only fuel. Although some also use LPG, it's mostly a secondary fuel because many families can't afford it. Housing conditions are often basic, with most homes lacking separate kitchens, and people spend a lot of time cooking and collecting firewood each day. This leads to prolonged exposure to smoke, especially for women who spend more time in the kitchen. Health problems linked to indoor air pollution, like cough, eye irritation, and fever, are common. However, chronic diseases are relatively rare. Many people seek medical help for these issues, but the treatment can be costly. Finally, the study shows that the way tribal households use energy is closely tied to their income and job status, with wealthier households more likely to use cleaner fuels. Overall, the findings highlight the need for better, more affordable energy options for tribal communities and the importance of addressing indoor air pollution to improve health and well-being.

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