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Determinants of household's modern cooking and lighting energy transition in rural India – Exploring household's activities and its interactions with other households

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Abstract

The majority of rural Indian households remain dependent on unreliable, inefficient and harmful household energy technologies. Rural households make their energy decisions with respect to the Water-Energy-Food security (WEF) Nexus jointly, however, previous research initiatives have analyzed household energy access problem in isolation. By analyzing household's activities and its interactions with other households, this paper identified the factors that impact household's transition to modern energies of different kinds. For the analysis, it utilized logit and zoib (zero-one-inflated beta) regression techniques on the household survey data set from the Uttar Pradesh province of India. The results showed that regular non-agricultural income of household's male member increases the probability of household's modern cooking energy and modern lighting transition by 8.6% and 13.6%, respectively. It was found that household's higher agricultural dependence and resource endowments (more labor and cattle) lead to higher share of traditional bioenergy consumption in the total cooking energy mix. Proximity to markets and high household income were observed to positively influence household modern cooking and lighting transition. Local institutions such as local bio-energy markets and barter trade for labor-bioenergy was observed to have significant influence on household energy choice. Results also showed that government's policy instrument such as household connection to government LPG scheme is associated with 20.5% increased probability of household using modern cooking energy as its primary cooking fuel. Results also indicated that social factors such as higher female education and young age of household head are associated with household's increased modern cooking energy consumption in its total cooking energy mix.

Keywords: Nexus, Determinants, Energy use, ZOIB, Logit

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1 Introduction

A majority of rural Indian population is dependent on traditional bioenergy for household thermal applications and kerosene for lighting. It is estimated that around 836 million people in India are dependent on traditional biomass-based cooking energy such as fire wood, crop residues and animal dung (Rehman et al. 2012). Moreover, recent studies indicate that during 1999-2000 to 2009-2010, there has been an increase in firewood consumption by the rural population (Sehjpal et al. 2014). Further, about 45% of India's 168 million rural households are un-electrified and lack access to modern lighting (Harish et al. 2014). This means that despite of several government efforts) on improving energy access, majority of rural Indian population continues to be dependent on traditional and dirty energy sources.

1.1 Water- Energy-Food Security Nexus and sustainable development

Access to modern household energy services, which include access to clean cooking and electricity, is important for the sustainable development (Guta et al. 2015). It is recognized that energy production and utilization have complex linkages with food security, land and water use, and other economic activities of households (Mirzabaev et al. 2015). For instance, in India, around 64% of the rural population depends on firewood for cooking energy needs (Hiloidhari et al. 2014) affecting their time allocation for livelihoods and their productivities (Barnes and Floor 1996, van der Kroon et al. 2013, Heltberg 2004). Further, around 26% of the Indian rural population depends on cattle dung and crop residues for household's energy needs (Hiloidhari et al. 2014), annually consuming around 300 to 400 million tons of cattle dung or cooking, (Rasul 2014) affecting fertilizer supply for agricultural production (ibid). On the other side, promotion of efficient modern energy such as biogas-based cooking or power generation could allow for increased use of animal dung as fertilizer, thereby strengthening food security. Crop residues can also be used for biomass gasifier-based power generation, but this can also result in scarcity of crop residues for cooking energy or scarcity of crop residues for livestock feed, resulting in tradeoffs. Traditional use of biomass for cooking or kerosene for lighting also has detrimental health effects through indoor air pollution (Lim and Seow 2012, Duflo et al. 2008), which further leads to low productivities amongst the households, thereby effecting their livelihoods. Energy also plays a very crucial role for water utilization in food production. For instance, in India, 63-70% of its irrigation needs are met by pumping ground water (Rasul 2014, Shah et al. 2006). In 2003–04, around 12.8 million electric water pumps with a total load consumption of 51.84 gigawatts (GW) consumed 87.09 billion kilowatt-hours of electricity for ground water irrigation in India (ibid). However, supply and quality of power is a big issue across India (Palit et al. 2013, Sinha et al. 2006) with power being available for only few limited hours and that too in the night time in rural areas. Groundwater market is another important aspect of Nexus, where the small and marginal farmers are dependent on large landholders (pump owners) for irrigation water and pay significantly higher costs. On the other side, modern decentralized energy technologies such as solar or bioenergy-based pumps can provide cheap, clean and reliable power and facilitate efficient water utilization, thereby strengthening food productivity and food security.

1.2 Energy transition theories

To achieve sustainable development goals through improved energy access, it is very important to understand that how rural households take decisions related to their energy choice. The theory of energy ladder was an early approach for explaining the energy choice of households, which is based on the correlation between household wealth and the uptake of modern energy sources (Davis 1998, Barnes and Floor 1996, van der kroon et al. 2013). However, using empirical evidences, several newer studies have challenged the theory of energy ladder (Masera et al. 2000, Heltberg 2004). Fuel Stacking is the newer approach for explaining the choice of household energy use, which says that fuel switching by households is not uni-directional i.e. households may not completely switch from one fuel to another and instead use additional energy type without completely abandoning the energy type which it was using early (ibid). There is a rich literature which have utilized the above theories (Isaac and van Vuuren (2009), Devi et al. 2009, P. Komala et al. 2014, Burke and Dundas 2014, Sehjpal et al. 2014, Alem et al. 2016, Rahut et al. 2016). Under the framework of consumer utility maximization by households, these studies found that the energy choices of households are greatly influenced by various technical and socioeconomic factors such as household's income level, size, education, occupation, gender, poor household access to clean energy sources, low household standard amongst others. Howells et al. 2010, Srivastava et al. 2012 and Lee et al. 2015 further discussed the impact of institutions, information failures, other external factors that influence the household energy decisions. Ekholm et al. 2010 extended the scope of fuel choice study in India by considering heterogeneity of consumers and modeled determinants for household energy choices considering different consumer groups. While the above discussed studies were country specific studies, Bahera et al. 2015 studied the household energy use phenomenon across different countries of South Asia viz India, Bangladesh and Nepal. While most studies on household energy choice studies have used data for a single cross-section of households at a point in time, Burke and Dundas 2014 instead used national-level longitudinal data to identify factors associated with household energy transition while controlling for country-level sources of persistent unobserved heterogeneity. In the settings of South Asia, the paper observed that while higher incomes are linked to usage of modern energy sources, however, they are not associated with significant reduction of bio-energy. Secondly it observed that greater female labor force participation is associated with reduction in household bio-energy use, which means that the opportunity cost of woman's time is of importance for the household energy transition. Alem et al. 2016 analyzed energy choice determinants in the context of Ethiopia. The major innovation of this paper is that while most studies are based on cross sectional data which does not controls unobserved heterogeneity and analysis of changes over time, this paper utilizes a panel multinomial logit approach. The results of this research showed that household expenditure, price of energy commodities and household education play an important role in determining fuel choice. Ekholm et al. 2010 gave another approach for analyzing household energy use patterns. It argued that if the preferences are locally non-satiable and the utility function is continuous, a problem of minimizing costs to yield the similar amount of utility arrives at the same consumption choice and thus is an alternative formulation to the consumer choice problem.

There have been diverse attempts in analyzing the energy choice of the households. However, most of the available studies suffer from a gap, that while analyzing household traditional biofuel consumption, they concentrated on the consumption side of household only (following consumer-utility maximization principle) but missed to consider the supply side of household (for instance, household bio fuel production) and interconnection between different household activities, and with other households. This is crucial as rural household is both the supplier and consumer of bioenergy. For example, household's decision to use cattle dung cake for cooking energy is not just the question of maximizing its consumption utility but is also dependent on its time allocation for livelihood generation or is also dependent on its decision to use cattle dung as fertilizer input. There is a water-energy and food production (WEF) nexus around the household and the household takes its energy related decisions not in isolation but based on its food production and natural resource utilization. Recent literature has highlighted the lack of a holistic approach in understanding the energy transition of households. Kowsari and Zerriffi 2011 has argued that the previous studies have adopted techno-economic approach, psychological approach and sociological approaches in understanding the energy transition of rural households but the integrated approach that combines all the above approaches have been very limited or missing. Mirzabaev et al. 2015 argued that the application of Water-Energy-Food Security (WEF) Nexus approach, which analyzes household's activities and interconnections, can be used as an integrated approach to understand household behavior on energy consumption.

Analyzing household's activities and their interactions, this paper attempts to identify the drivers that impact household's transition from traditional energies to modern energies of different kinds, and provides recommendations on the strategies that can aid in household's modern energy transition. More specifically, it analyzes the technical, economical, behavioral, psychological, social, anthropological and environmental factors that drive households to make transition from traditional energies to modern energies of different kinds?

2 Methodology

2.1 Data Source

The Indian province of Uttar Pradesh (UP) was selected for this study, as amongst all Indian provinces, this province has the highest dependency on traditional bio-energy based household cooking (NSSO 2015), has one of the lowest electrification rates (Census of India 2011), and is agricultural dominant economy with more than 66% of its economy engaged in agriculture (University of Allahabad 2015). A field research (household and village surveys) was conducted in Uttar Pradesh in year 2015 and the following sampling procedure was adopted to select the surveyed households. UP has a population of 199.58 million (Government of Uttar Pradesh website). Considering confidence interval of 95% for the research outcomes, sample size came out to be around 400. Considering the variance of socio economics and energy systems in the province, homogenous clusters of districts were first identified, and 4 districts were selected from different clusters. From each selected district, 2 villages were randomly selected. Then utilizing systematic sampling technique as suggested by Levy & Lemeshow 2008, around 40-70 households were randomly selected from each village, depending on the village size. This way, around 400 households were surveyed from 8 villages. Figure 1 presents the map of the UP. They surveyed districts are also depicted in the map. The field research collected information on household demography, income sources, expenditures, asset endowments, agricultural production, and energy use. Village surveys were also conducted to understand villages' energy supply-demand and socio-economic characteristics.

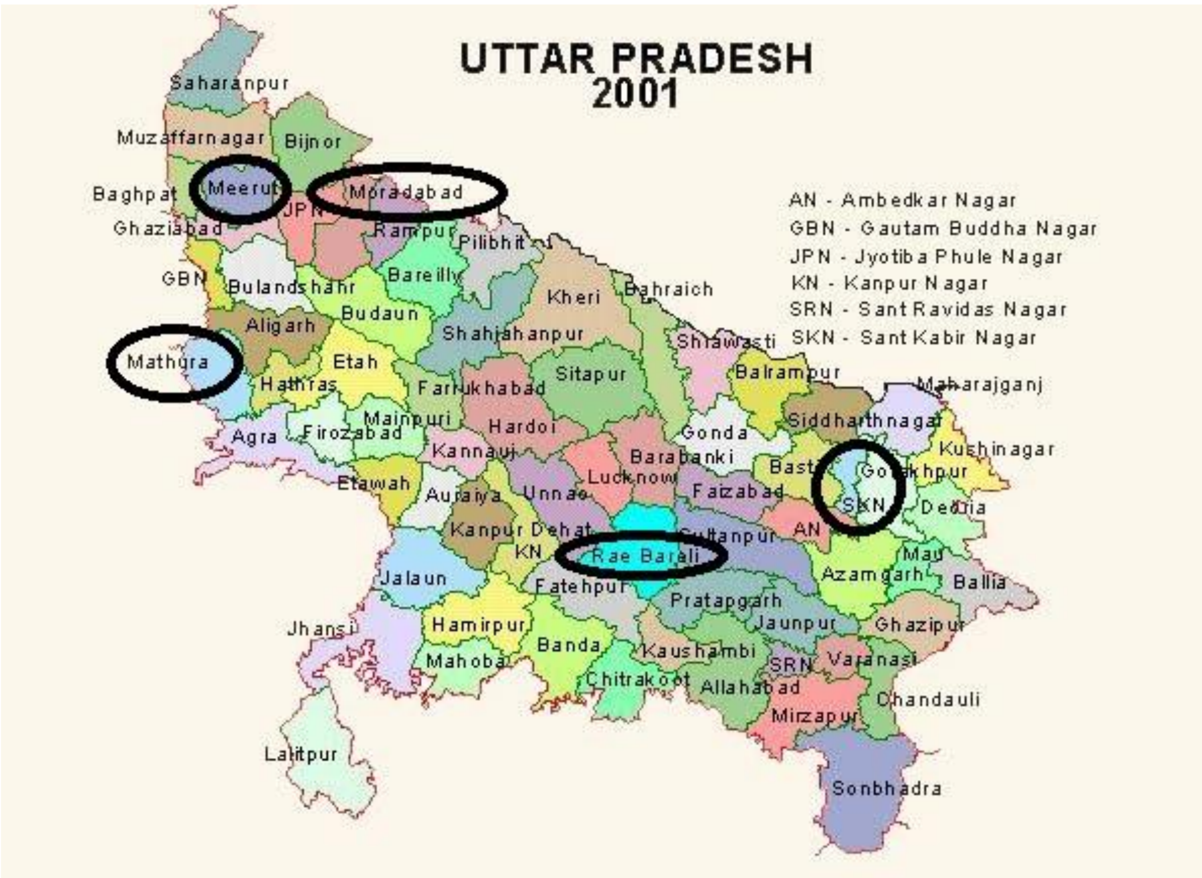

Figure 1: Map of Research Area (Uttar Pradesh with the surveyed districts)

Source: ORGI, Ministry of Home Affairs, Government of India

Note: In addition to 4 selected districts, few households were also surveyed from Meerut district (neighboring district of Moradabad due to extensive hailstorm in Moradabad district)

2.2 Conceptual framework

Figure 2 presents the conceptual framework that is used in this research to analyze the factors impacting household (hh) energy choice behavior. It has 3 major depictions. Firstly, at the core, there is a household which is not isolated but interacts with other households and local markets. Secondly, it shows that the household takes its energy decisions jointly with its decisions on food production and natural resource utilization. The analysis of this WEF (Water-Energy-Food Security Nexus) nexus requires the analysis of household's activities and their interactions (Mirzabaev et al. 2015). To analyze these household's activities and their interactions, research utilizes the integrated approach as suggested by Kowsari and Zerriffi 2011. Mirzabaev et al. 2015 had also argued that the application of Water-Energy-Food Security (WEF) Nexus approach can be considered as the above mentioned integrated approach to understand household's energy use. Kowsari and Zerriffi 2011 combines the following 3 approaches to form an integrated approach for analyzing household energy use behavior: 1) physical-technical-economic models (PTEM) which include economic models that assume household to take energy decisions based on its utility maximizing behavior and technology models where changes in household energy usage pattern arise from the change in energy technologies, 2) psychology based approaches which suggest that household energy use decisions involve complex behavioral and social processes, 3) Sociological and anthropological model involving institutions and external factors in household's decisions. Thirdly, the conceptual framework shows that there could be several factors/ drivers which influence household's activities and their interdependencies, and influence household's decision process for its energy choice. Utilizing the above discussions, following factors are identified which can impact household's energy use: technological factors (such as surplus of bio-energy for household), economic factors (such as household's livelihood opportunities), sociological factors (such as impact of local institutions and policies), psychological factors (such as caste of household or mentality of household head) and environmental & health factors (such as respiratory diseases in house). These factors are depicted in figure 2 and are further elaborated in the subsequent section.

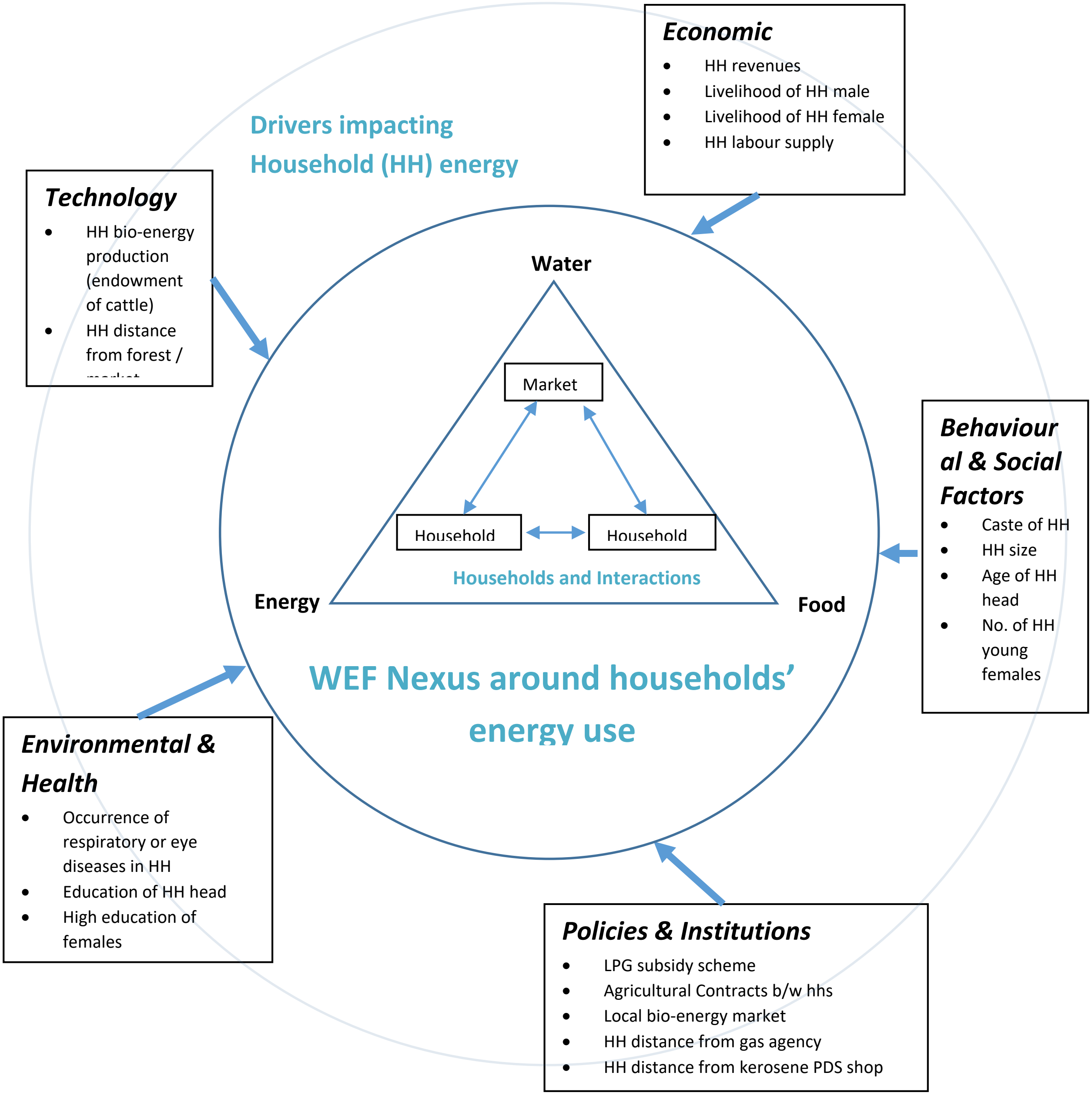

Figure 2: Conceptual Framework for analyzing the household (hh) energy choice behavior

2.3 Econometric Models for analyzing determinants of energy transition

Different econometric techniques are used to analyze the factors that impact households' transition to modern energies for cooking and lighting. Factors influencing household's decision to use modern cooking energy as primary cooking energy, and household's decision to use modern lighting, are analyzed using separate Logit models. Additionally, ZOIB (Zero-One inflated beta regression model) is used to analyze the factors that are associated with the high proportion of modern input cooking energy (in MJ) in the total input cooking energy usage (in MJ) of the household. Zero inflate and One inflate model are byproducts of ZOIB. Zero inflate model for modern cooking energy analyzes the factors that are associated with zero proportion of modern cooking energy (in MJ) in total input cooking energy usage (in MJ) of household, while one inflate model for modern cooking energy analyzes the factors that are associated with 100% proportion of modern cooking energy (in MJ) in total input cooking energy usage (in MJ) of household. Consideration was made to construct ZOIB model for modern lighting energy to analyze the factors that are associated with high proportion of modern input lighting energy (in MJ) in the total input lighting energy usage (in MJ) of the household. However, widespread stealing of electricity grid supply, as observed in the field research, makes the ratio of modern lighting to total lighting energy usage of household, an unreliable regressor and is therefore not included in the research.

In the conceptual framework, discussions were made on the various drivers that may impact the energy usage decisions of the household. Utilizing the same discussions, following list of independent variables have been identified, as discussed in table 1 below. Continuing with the discussions in conceptual framework, table also highlights the category (driver category) that the chosen independent variable falls in. The primary category of the selected variable is highlighted by grey color, and the secondary variable category is depicted by light gray color. Some variables may be used only for a specific model. The variables marked with single asterisk are not included in the logit model analyzing household's modern lighting transition as the reason could be their little expected correlation with dependent variable or their possible high correlation with another independent variables, and this will be discussed along with the explanation of variables in the next section. The variables marked with double asterisk are not included in the logit and zoib model analyzing household's modern cooking energy transition because of the same above discussed reasons. Subsequent section presents the explanation of the independent variables along with the results of the model.

Table 1: Independent variables for the analysis of modern energy transition of the household (hh)

		Category of variables influencing energy transition					
S.NO	**Independent variables for model**	Technical	Economical	Social, Behavioural and cultural	Policies and Institutional	Health & Environmental	Households' interactions
1*	Number of cattles with hh (**CT**)						
2	HH's distance from nearest market (**MD**)						
3	Annual hh revenues (**RV**)						
4	Regular non-agricultural livelihood of hh male (**NL_m**)						
5	Annual regular non-agricultural labor days of the hh females (**NL_f**)						
6	HH size (**HS**)						
7	HH's caste (**CS_{hh}**)						
8*	High education of hh female (**ED_{fm}**)						
9*	HH head's years of education (**ED_{hd}**)						
10	HH head's age (**AG**)						
11	HH dwelling type (**DW**)						
12**	Presence of young women in hh (**NF**)						
13**	Years of education of hh's highest educated member (**ED_{hh}**)						
14**	Caste of village chief of the hh (**CS_{vc}**)						
15*	HH's purchase price of dung cake in local market (**DP**)						

		Category of variables influencing energy transition					
S.NO	**Independent variables for model**	Technical	Economical	Social, Behavioural and cultural	Policies and Institutional	Health & Environmental	Households' interactions
16	Agricultural contracts of hh (**AL** $_f$)						
17*	HH's possession of LPG stove through government scheme (**PD**$_l$)						
18**	HH's distance from PDS kerosene shop (**PD**$_k$)						
19	Occurrence of respiratory or eye problems in hh (**HT**)						

* this is not included in the logit model for modern lighting energy.
**this is not included in the logit and zoib model for modern cooking energy.
Note: Dark shades represent the main category of independent variables & light shade represent their secondary category if applicable.

While selecting suitable variables for these model, household's farm size was also thought to be an important variable, but since household's farm size was observed to be correlated with annual household revenues, it has been excluded from the list of selected variables. Since household's distance to forest is negatively correlated to household's distance to market, therefore the same has also been excluded from the list of selected variables. Also, the household's distance to gas agency is positively correlated with household's distance to market as probability of gas agency in the main markets is high, therefore it has also not been included in the variable list.

Representation of the econometric models used in the analysis

Based on the above discussions, following econometric models have been formulated:

Logit Model 1:

$$\text{Logit (MC)} = \alpha + \beta 1\,(\text{CT}) + \beta 2\,(\text{MD}) + \beta 3\,(\text{RV}) + \beta 4(\text{NL}_{\text{m}}) + \beta 5(\text{NL}_{\text{f}}) + \beta 6(\text{HS}) + \beta 7(\text{CS}_{\text{hh}}) + \beta 8(\text{ED}_{\text{f}}) + \beta 9(\text{ED}_{\text{hd}}) + \beta 10(\text{AG}) + \beta 11(\text{DW}) + \beta 12(\text{DP}) + \beta 13(\text{AL}_{\text{f}}) + \beta 14(\text{PD}_{\text{l}}) + \beta 15(\text{HT}) \quad (3.1)$$

Where MC is household's utilization of modern cooking energy as its primary cooking fuel

Logit Model 2:

$$\text{Logit (ML)} = \pi + \gamma 1\,(\text{MD}) + \gamma 2\,(\text{RV}) + \gamma 3(\text{NL}_{\text{m}}) + \gamma 4(\text{NL}_{\text{f}}) + \gamma 5(\text{HS}) + \gamma 6(\text{NF}) + \gamma 7(\text{CS}_{\text{hh}}) + \gamma 8(\text{ED}_{\text{hh}}) + \gamma 9(\text{DW}) + \gamma 10(\text{AL}_{\text{f}}) + \gamma 11(\text{PD}_{\text{k}}) + \gamma 12(\text{CS}_{\text{vc}}) + \gamma 13(\text{HT}) \quad (3.2)$$

Where ML is household's utilization of modern lighting energy

Zoib Model 1:

$$\text{ZOIB (RMC)} = \mu + \delta 1\,(\text{CT}) + \delta 2\,(\text{MD}) + \delta 3\,(\text{RV}) + \delta 4(\text{NL}_{\text{m}}) + \delta 5(\text{NL}_{\text{f}}) + \delta 6(\text{HS}) + \delta 7(\text{CS}_{\text{hh}}) + \delta 8(\text{ED}_{\text{f}}) + \delta 9(\text{ED}_{\text{hd}}) + \delta 10(\text{AG}) + \delta 11(\text{DW}) + \delta 12(\text{DP}) + \delta 13(\text{AL}_{\text{f}}) + \delta 14(\text{PD}_{\text{l}}) + \delta 15(\text{HT}) \quad (3.3)$$

Where RMC is ratio of household's modern cooking energy utilization (MJ) in its total cooing energy mix (MJ)

Like Zoib model 1, Zeroinflate1 and Oneinflate1 models have been formulated with the same variables.

3 Results and discussions

Household characteristics

Before discussing the model variables and model results, descriptive statistics of major household characteristics are presented in Table 2 below.

Table 2: Descriptive Statistics (Characteristics of the households)

Household characteristics	Mean	Std. Dev.	Min	Max
Annual Revenues (Ten thousand Rs)	22.39	28.51	1.19	319.62
Annual dung cake consumption (kgs)	1728.57	1035.38	0	6000
Annual firewood consumption (kgs)	874.47	723.01	0	4560
Annual crop residues consumption (kgs)	169.59	287.89	0	2400
Annual LPG consumption (kgs)	55.28	75.77	0	504
Monthly energy consumption from renewable sources and battery (MJ)	19.42	52.82	0	356.40
Monthly kerosene energy consumption (MJ)	107.69	46.39	0	305.52
Number of cattles (Nos)	1.48	1.58	0	11
Distance from nearest market (km)	6.57	3.03	1	11
Regular non-agricultural based livelihood of HH male (Yes/ No)	0.39	0.49	0	1
Annual regular non-agricultural labour days of the hh females (days)	11.25	45.71	0	365
Household size (nos)	6.84	2.95	1	18
Upper caste of the hh (Yes/No)	0.31	0.46	0	1
High education (graduation) of hh female (Yes/ No)	0.14	0.35	0	1
Household head's years of education (years)	5.51	5.52	0	19
Household head's age (years)	49.71	12.77	18	82
Dwelling type permanent (Yes/ No)	0.82	0.38	0	1
Number of young women in hh (Nos)	1.20	1.03	0	5
Years of education of highest educated member (years)	10.21	4.98	0	19
Upper caste of village chief of hh (Yes/ No)	0.29	0.46	0	1
Purchasing price of dung cake in household's local market (Rs/ kg)	5.54	1.63	1	8
Agricultural contracts of households (days per year)	19.82	31.77	0	200
Possession of LPG stove through government scheme (yes/ no)	0.40	0.55	0	4
Distance from PDS kerosene shop (kms)	1.70	2.11	0	6
Occurrence of respiratory or eye problems in HH (yes/ no)	0.10	0.30	0	1
Source: Author's household surveys				

Determinants of household's modern energy transition

Table 3 and Table 4 below presents the results (significance level as well as marginal effects) of the logit model 1 and zoib model 1 respectively that analyze the factors impacting household transition to modern cooking energies. Table 5 presents the results of the logit model 2 that analyzes the factors impacting household transition to modern lighting energies. These are followed with the discussions on the results.

Table 3: Results of the logit model 1 analyzing modern cooking energy transition of the household

S.No	Variables	Logit Regression		Marginal effects in Logit Regression	
		Coef.	P>z	Coef.	P>z
1	Number of cattles with HH (CT)	-0.240	0.147	-0.0160	0.139
2	Distance of hh from nearest market (MD)	-0.225	0.003**	-0.0150	0.001**
3	Annual Household (HH) Revenues (RV)	0.022	0.008**	0.0015	0.005**
4	Regular non-agricultural based livelihood of HH male (NL_m)	1.293	0.005**	0.0860	0.003**
5	Annual regular non-agricultural labor days of the hh females (NL_f)	-0.003	0.471	-0.0002	0.469
6	HH size (HS)	-0.149	0.072*	-0.0099	0.065*
7	Caste of the hh (CS_{hh})	0.589	0.247	0.0392	0.244
8	Higher education of hh female (ED_{fm})	0.966	0.094*	0.0643	0.086*
9	Household head's years of education (ED_{hd})	0.082	0.052*	0.0055	0.045**
10	Household head's age (AG)	0.014	0.465	0.0009	0.464
11	Dwelling type (DW)	0.228	0.744	0.0152	0.743
12	Price of dung cake in local market (DP)	0.452	0.003**	0.0301	0.002**
13	Agricultural contracts of household females (AL_f)	-0.030	0.093*	-0.0020	0.091*
14	Possession of LPG stove through government scheme (PD_l)	3.073	0.000***	0.2045	0.000***
15	Occurrence of respiratory or eye problems in HH (HT)	0.510	0.535	0.0339	0.534
*** significant at 1% level, ** significant at 5% level, * significant at 10% level					

Table 4: Results of the Zoib model 1 analyzing modern cooking energy utilization of the household

S.No	Variables	Zoib Regression		Marginal effects in Zoib		Zero Inflate Regression		One Inflate Regression	
		Coef.	P>z	dy/ dx	P>z	Coef.	P>z	Coef.	P>z
1	Number of cattles with HH (CT)	-0.118	0.031**	-0.0046	0.038**	0.231	0.259	-1.089	0.028**
2	Distance of hh from nearest market (MD)	-0.083	0.000***	-0.0032	0.000***	0.133	0.152	-0.230	0.122
3	Annual Household (HH) Revenues (RV)	0.004	0.017**	0.0002	0.023**	-0.009	0.779	0.014	0.250
4	Regular non-agricultural based livelihood of HH male (NL_m)	0.265	0.034**	0.0106	0.036**	-1.464	0.014**	0.018	0.983
5	Annual regular non-agricultural labor days of the hh females (NL_f)	-0.001	0.467	0.0000	0.466	0.502	0.994	-0.174	0.990
6	HH size (HS)	-0.077	0.001***	-0.0030	0.001***	0.044	0.692	-0.233	0.201
7	Caste of the hh (CS_{hh})	0.083	0.521	0.0033	0.526	-0.902	0.166	-1.013	0.258
8	Higher education of hh female (ED_{fm})	0.347	0.016**	0.0149	0.029**	-0.210	0.833	0.120	0.885
9	Household head's years of education (ED_{hd})	0.026	0.025**	0.0010	0.029**	-0.011	0.860	0.096	0.233
10	Household head's age (AG)	-0.013	0.023**	-0.0005	0.024**	0.005	0.812	0.072	0.060
11	Dwelling type (DW)	0.082	0.701	0.0031	0.695	-0.158	0.831	-0.712	0.592
12	Price of dung cake in local market (DP)	0.161	0.000***	0.0063	0.000***	0.149	0.458	-0.257	0.196
13	Agricultural contracts of household females (AL_f)	-0.004	0.297	-0.0001	0.290	0.011	0.238	0.004	0.904
14	Possession of LPG stove through government scheme (PD_l)	0.723	0.000***	0.0283	0.000***	-181.409	0.994	1.261	0.115
15	Occurrence of respiratory or eye problems in HH (HT)	0.190	0.452	0.0079	0.477	-0.141	0.845	-1.426	0.334
*** significant at 1% level, ** significant at 5% level, * significant at 10% level									

Table 5: Results of the logit model 2 analyzing modern lighting transition of the household

S.NO	Variables	Logit Regression		Marginal effects of Logit Regression	
		Coef.	P>z	Coef.	P>t
1	Distance of hh from nearest market (MD)	-0.328	0.000***	-0.0312	0.000***
2	Annual Household (HH) Revenues (RV)	0.033	0.000***	0.0031	0.000***
3	Regular non-agricultural based livelihood of HH male (NL_m)	1.427	0.000***	0.1356	0.000***
4	Annual regular non-agricultural labor days of the hh females (NL_f)	0.009	0.002**	0.0009	0.002**
5	HH size (HS)	-0.138	0.076*	-0.0131	0.072*
6	Number of young females in hh (NF)	0.104	0.613	0.0099	0.613
7	Caste of the hh (CS_{hh})	-0.058	0.887	-0.0055	0.887
8	Education years of highly educated hh member (ED_{hh})	0.020	0.648	0.0019	0.648
9	Dwelling type (DW)	0.374	0.535	0.0355	0.535
10	Agricultural contracts of household females (AL_f)	-0.013	0.106	-0.0012	0.105
11	HH distance from kerosene PDS shop (PD_k)	0.020	0.800	0.0019	0.800
12	Upper Caste of Village Chief (CS_{cv})	0.746	0.063*	0.0709	0.059*
13	Occurrence of respiratory or eye problems in HH (HT)	-0.061	0.918	-0.0058	0.918
*** significant at 1% level, ** significant at 5% level, * significant at 10% level					

<u>Explanation of model variables and the discussions on the results</u>

This section discusses the results of the econometric models. For each of the independent variables used in the model, firstly its brief explanation is presented, followed by the discussion on its econometric results.

Number of cattles with household (hh): This is the number of cows/ buffalos (male or female) with the household. This variable clarifies that how a household takes energy related decision with respect to its agricultural production, for example whether it prefers to use its cattle dung for producing dung cakes (traditional bio-energy) or biogas for cooking energy or use it as farm fertilizer, depending on its farm needs, taste characteristics and energy needs. The results of logit model 1 does not shows any significant correlation between household's number of cattles and its cooking energy utilization. However, results of zoib model 1 suggest that within 95% confidence interval, if household is using modern cooking energy, then every increase in the number of household cattles is associated with 0.46% decrease in the proportion of household's modern cooking energy usage (in MJ) in its total cooking energy mix (in MJ), while keeping all other variables constant. Within 95% confidence interval, one inflate model suggests that higher number of household cattles is negatively associated with 100% proportion of modern cooking energy (in MJ) in its total cooking energy usage (in MJ). The results of logit and zoib model indicate that the number of household cattles is not definitely associated with the modern cooking energy transition of household but larger number of cattles and hence greater amount of cattle dung production motivates household to use lesser amount of LPG based cooking and compensate it with the dung cake-based cooking. The possible reasons could be that if the household has more number of cattles, then it may have cattle dung surplus then what may be required in its farm, or it find using dung based cooking more rationale then using it as farm fertilizer as it already gets subsidized urea and NPK (Nitrogen-Phosphorous and Potassium) fertilizers from the government, or it views crop production as side business with livestock rearing being the main livelihood so it is not much worried about crop production, or household needs to cook feed for the large number of livestocks for which it needs high amount of dung based cooking. It is to be noted that the household with cattle dung surplus could have shifted to biogas, however during the field research, it was observed that the biogas technology is perceived as failed technology by the households and they didn't want to experiment with the same.

***Household's (HH's) distance from nearest market (in kms)**:* The market is the place where regular gathering takes place for the sale and purchase of agricultural products, livestock products, labor market and other commodities such as energy technologies or other market products. With proximity to markets, households are expected to have more employment opportunities and hence more opportunity cost of time, and this variable clarifies the influence of household's opportunity cost of time on household's energy choice. Within 99% confidence interval, results of logit model 1 and logit model 2 suggests that this variable is statistically significant and negatively correlated with modern cooking energy transition as well as modern lighting energy transition. This means that if household is remotely located then it has lesser probability of shifting to modern cooking and modern lighting energy. Marginal effects in logit model 1 and logit model 2 suggests that with every 1 km increase in market distance, the probability of household using modern cooking energy as primary cooking fuel decreases by 1.5%, and the probability of household using modern lighting decreases by 3.1% respectively, while holding all other variables constant. Within 99% confidence interval, results of zoib model 1 suggests that if household is using modern cooking energy, then every 1 km increase in market distance from the household, is associated with 0.32 % decrease in the proportion of household's modern cooking energy usage in its total cooking energy usage, holding all other variables constant. There could be several reasons behind this behaviour. The following table 6 presents the average wage rates for different labour categories (off farm agricultural and non-agricultural) in different surveyed villages which are located at different distances from the market. The table shows that the households (villages) which are closer to the markets/ district headquarters have more opportunities of non-agricultural employment depicted by column e and have higher wages (column c and d), which makes their opportunity cost of time higher and this demotivates them to spend time on traditional energy collection and therefore they shift to modern energy.

Table 6: Correlation between household's market distance and its employment opportunities

a	b	c	d	e
Surveyed Villages	Distance of village from the market (kms)	Male off-farm agricultural wage in village (Rs/ day)	Female Off farm agricultural wage in village (Rs/day)	Non-Agricultural male labour days per HH per year (days) #
Vil-1	7	150	100	265.2
Vil-2	3	180	120	364.7
Vil-3	11	150	70	243
Vil-4	9	150	70	341
Vil-5	1	250	180	133.83**
Vil-6	5	200	150	137.89
Vil-7	10	200	180	236.21*
Vil-8	3	200	150	280.7

Source: Author's own field surveys

Note: * This is an exception because it is close to the touristic city of Vrindavan, so there are growing development in the areas

** this village has wealthy and large landlords with nuclear families which put more emphasis on education on youths, that's why non-agricultural male labour per HH is low

Average number of males per HH in Uttar Pradesh is 2.2 (as per field research)

Further, households with proximity to markets were observed to have high tendency to use personal solar, battery banks and rechargeable battery lights (field research observations). This is because they have high interactions with the market, have more business contacts, have greater bargaining opportunities, they are more up to date with the market developments, and they have lesser transaction costs in market purchase. Further, households which are far from market/ district centre and have electricity lines passing through their areas, have more tendency for power stealing because such villages are less likely to get surprise checks from electricity department, and this demotivates them to buy modern lighting technologies such as solar etc. Households which are close to market or district headquarter have more opportunities of non-agricultural labour which means they have regular income/ handy cash for getting LPG/ electricity connection and paying their regular fees, whereas households in remote villages are majorly dependent on agriculture and have unpredictable incomes which are dependent on farm output. Moreover, gas agency or electric utility offices are generally closer to District Head Quarter, therefore households living closer to district head quarter have greater pursuing opportunity for the gas or electricity connection and have lesser transportation costs for cylinders. During the field surveys, it was observed that households which were staying away from gas agency had to pay Rs 30 per cylinder for the transportation of gas cylinder where the cost of recharging LPG cylinder (14 litres) was Rs 450.

Annual household (hh) revenues (in the unit of ten thousand Rs): This is the sum of annual household revenues from its agriculture (crops and livestock), off farm labor (agricultural and non-agricultural), salaried job, business and remittances. The results of logit model 1 shows that within 95% confidence interval, every 10,000 Rs increase in annual household revenues increases its probability of using modern cooking energy as its primary cooking energy type by 0.15 %, while holding all other variables as constant. Within 95% confidence interval, results of ZOIB model 1 shows that if household is not meeting its 100% cooking energy demand with modern cooking energy, then every 10,000 Rs increase in its annual revenues is associated with 0.02% increases in the proportion of household's modern cooking energy usage in its total cooking energy mix, while keeping all other variables constant. Results of logit model 2 shows that within 95% confidence interval, every 10,000 Rs increase in annual household revenues, increases the probability of household using modern lighting energy by 0.31%, while holding all other variables as constant. There could be several reasons behind this behaviour. With growing wealth, household can afford modern energy fuels or systems (such as LPG (Liquified Petroleum Gas), solar panels for electricity, etc.) and their recurrent costs. For instance, to get an LPG connection, household needs to pay an upfront cost of around Rs 4500 and thereafter must pay around Rs 32 per litre for LPG gas. Similarly, the power storage batteries cost upto Rs 75 per Ah capacity. Further, if the household lives in remote location, then getting modern energy systems (i.e. LPG connection/ lighting system could be even costlier and will demotivate the household from shifting to modern cooking or lighting energy. In addition, using modern energy system is also considered as show of supremacy by wealthy households. The positive correlation between modern cooking energy usage and household income in context of rural India and other parts of the world has also been documented by several studies in the literature, for instance Rahut et al. 2014, Sehjpal et al. 2014, Isaac and van Vuuren (2009), Baiyegunhi and Hassan 2014, Bahera et al. 2015. Further, Lay et al. 2012 in a setting of Kenya observed the positive correlation between household transition to modern lighting (such as solar home system) and household income.

***Regular non-agricultural based livelihood of any of the household (hh) male*:** This is a categorical variable, which takes value of '1' if at-least one of the household male is involved in regular and stable non-agricultural livelihood such as government job, private job or a regular business, whereas it takes value of '0' if none of the household male is involved in such activities. This variable explains that how different types of livelihoods impact household energy choices. The results of logit model 1 show that within 95% confidence interval, presence of atleast one household male with regular non-agricultural work, increases the probability of household using modern cooking energy as its primary cooking energy type by 8.6 %, while holding all other variables constant. Within 95% confidence interval, ZOIB model 1 shows that when household is not meeting its 100% cooking energy demand with modern cooking energy, then presence of household male with regular non-agricultural employment is associated with 1.06% increase in the proportion of household's modern cooking energy usage in its total cooking energy mix, keeping all other variables constant. Within 95% confidence interval, the zero-inflate model 1 shows that absence of household male in non-agricultural regular work is associated with probability of household using 0% of modern cooking energy for its cooking energy demand. Results of logit model 2 shows that within 95% confidence interval, presence of household male with non-agricultural regular employment, increases the probability of household using modern lighting energy by 13.56%, while holding all other variables constant. There could be several reasons in support of the above results. These households have regular and higher wage job, therefore that they have regular and predictable income to pay for energy systems and energy services, unlike households dependent on agriculture. During the surveys, average wage of a regular salaried job male was observed to be around Rs 370/ day whereas with other livelihoods it was lesser and unpredictable (for instance Rs 245 / day and Rs 177/ day for irregular non-agricultural labour and irregular agricultural labour respectively). This means that households which have their members involved in regular non-agricultural work opportunities have higher opportunity cost of time or give more value to the household leisure and this demotivates them from spending time for traditional energy collection and therefore shifts to modern energy. Further, such households have males which work in factories, offices, enterprises or have close association with markets so they have greater market information of new technologies such as solar and have greater market interaction and lesser transaction costs to purchase modern energy as gas agencies or solar shops or battery shops are majorly located in the market areas. Another reason for greater consumption of LPG by such households could be that females in such households have to make quick food in the morning for the males who leave early morning for work. Further, as such households are less involved in agriculture, they have less opportunities with animal dung and agricultural residues. In the case study of Madhya Pradesh, India Sehjpal et al. 2014 observed the same phenomenon that the households where primary livelihood of male members involves regular and stable job, had greater tendency to shift to modern cooking energy as its primary cooking energy type. Figure 3 below shows the association of modern energy usage and household's regular non-agricultural work opportunity. It shows that out of the total number of households which use LPG as primary cooking fuel, around 80% of them have at least one male worker involved in regular non-agricultural job. Similar results are for households with personal big solar systems and HHs with personal battery backup system.

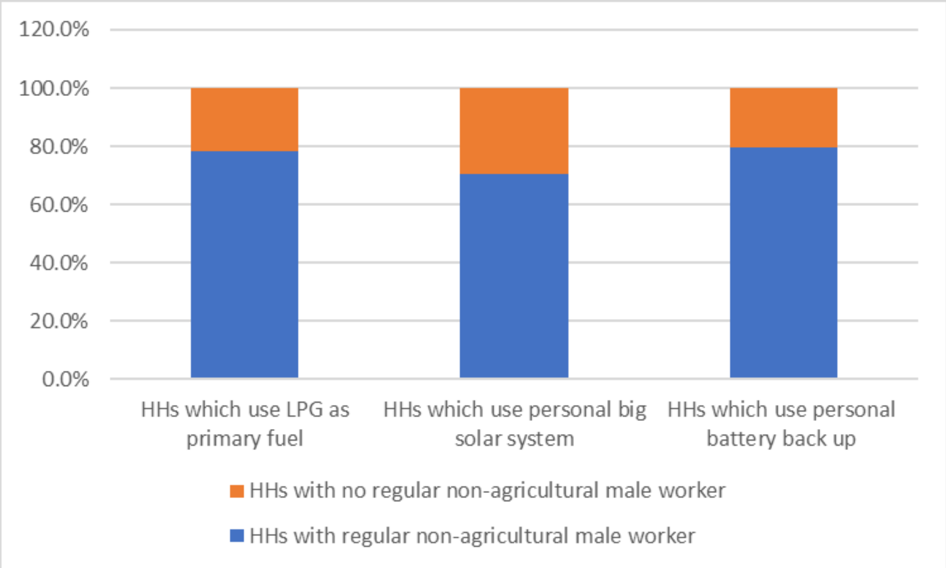

Figure 3: Household's energy usage and its non-agricultural work opportunities

Source: Author's own field surveys

Annual regular non-agricultural labor days of the household (hh) females: This is the summation of annual number of days that household's females spend on non-agricultural labor job. The results of logit model 1 and zoib model 1 indicates that the non-agricultural work of household female has no significant relation with its modern cooking energy transition. The possible reasons are as follows. Firstly, it can happen that even if a household female is involved in non-agricultural employment, but other household females are still house wives and they take care of traditional energy collection. Secondly, non-agricultural labour employment for females in the surveyed villages were observed to be limited to teachers, cooks, cleaners, maids in the local areas and with these jobs they are not exposed to markets and the information on modern energy technologies. Thirdly, it was observed that the household males associate food cooked in traditional energy with better taste and household females care more for the taste of males rather than the ill effects of traditional cooking on their own health. On the other hand, results of logit model 2 indicates that within 95% confidence interval, each one-day increase in the non-agricultural labour days of household female, increase the probability of household utilization of modern lighting by 0.1%, while holding all other variables constant. The possible reasons could be that such household female who work as maid in rich household see its master's family enjoying TV or better light or fan service, and then she demands similar energy services at her own home. Unlike the case of modern cooking energy where household male opposes female's demand due to his taste preference, he doesn't oppose the demand to purchase modern lighting or electricity system.

Household size *(in numbers):* This is the size of household in numbers. This variable clarifies that how labor endowment of household impacts its energy choice. Results of logit model 1 suggests within 90% confidence interval, every 1-member increase in household size, decreases its probability of using modern cooking energy as primary cooking energy source by 0.99%, while holding other variables constant. Zoib model results indicates that within 99% confidence interval, every 1-member increase in household size is associated with 0.30% decrease in the proportion of household's modern cooking energy usage in its total cooking energy usage, while holding all other variables constant. Logit model 2 suggests that within 90% confidence interval, every 1-member increase in household size decreases the probability of household using modern lighting by 1.3%, keeping all variables constant. There could be the following reasons for the above discussed results. If the household is bigger in size, than it has higher cooking and lighting energy demand, and this makes it difficult to cash purchase LPG or modern electricity system for meeting its demand. Second reason could be that such household has greater number of females or children or males which can aid in the collection of traditional energy, or with joint families it gets more quota from the government for the purchase of kerosene for lighting. Another reason could be that the bigger families are the joint families who also have grandparents. During the survey, it was observed that grandparents (old people) have the perception that the food cooked in traditional energy has better taste, is good for the health and therefore they insist for the food cooked in LPG or modern biogas stove. Further, this behaviour may be the result of the internal politics in the household (eg. joint families), for example, there could be a case that there are several brothers in a joint family and some of them have different preferences on spending money, for instance, one brother spends more money on alcohol and the other brother wants to purchase a solar power system, however, the second brother thinks that If he invests in some modern energy system then why should the family of another brother (spending money on alcohol) enjoys the benefits of modern energy and therefore this demotivates him to invest in some modern energy system.

Household's (HH's) caste: This category includes '1' for upper caste households and '0' for lower caste household. The objective of this variable is to analyze the importance of household's social status in its cooking and lighting energy choice behavior. Following castes are included in the upper caste: Brahmins (Intellectuals), Rajputs (Kshatriya or the fighters), Vaishnava (Merchants). In Uttar Pradesh, with its caste appeasement politics, government put "Jaat" community under backward castes as government gives lot of social benefits to the backward castes. However, in other states, "Jaat" is not included in backward caste. In the field research, Jaats were observed to be amongst the economically forward castes and therefore they have been included in the upper caste in this research. Following castes are included in the backward caste/ non upper castes as observed in the survey: Scheduled Castes (Dalits), Yadavs (Cattle herders), Pal (Cattle herders), Bhagel (Cattle herders), Valmiki (Sweeper), Sunar (Gold Smith), Lauhar (Iron Smith), Kurmis (Farmers), Rajbhars (backwards). Muslims have also been included in the lower castes because of their low economic status as observed in the research and because of their demand to the government to get included in lower caste. In the field research, 116 households out of 380 households were the upper caste HHs. The results of logit model 1, logit model 2 and zoib model 1 don't show any significant correlation between household caste and household transition to modern cooking energy or modern lighting energy. Table 7 could be a reason for that. As per the field research, upper caste households have higher endowment of livestocks, private trees and farm areas, so they have greater and easier access to wood, dung and crop residues. They further have access to cheap labour from lower caste households who process the biofuels and take some percentage of bioenergy as fees for the labour. All the above reasons, along with taste consideration of food cooked in traditional cook stoves motivates upper caste household to continue using traditional cooking energy. For modern lighting, since upper caste households have more clout in the region, they openly steal grid power and manage to get government funded solar street lights in front of their houses.

Table 7: Characteristics of upper caste and lower caste households

Household characteristics	Lower Caste HH	Upper Caste HH
Private tree per hh (Nos)	12.1	37.2
Farm size per hh (acres)	0.94	3.71
No. of cattles per hh	1.08	2.44
Source: Author's own field surveys		

High education of household (hh) female: This is a categorical variable which takes the value of "1" if the highest education of any household female is graduation or above and it takes the value "0" otherwise. This variable is not included in logit model 2 (modern lighting transition) because this model already includes the variable on "education years of highest educated member" and including "high education of household female" would result in correlation errors. Whereas for cooking energy transition, impact of education of household female and household head are required to be analyzed separately and moreover household heads are generally household males and therefore little correlation is expected between them. Results of logit model 1 suggests that within 90% confidence interval, presence of household female with graduation degree increases the probability of household using modern cooking energy as primary cooking energy by 6.4%, while holding all other variables constant. Results of Zoib model 1 suggests that when household is not meeting its 100% cooking energy demand with modern cooking energy, then within 95% confidence interval, the presence of household female with graduation degree is associated with 1.4% increase in the proportion of household's modern cooking energy usage in its total cooking energy mix, while holding all other variables constant. While Sehjpal et al. 2014 in their study in Madhya Pradesh province of India observed the education level of household male and female insignificant for its modern energy transition, Pundo and Fraser 2006 in its study in Kenya observed the education level of household female significant for its modern energy transition which is in line with this finding. The reason for the result could be that when there is a highly qualified female in the household, she understands the ill effects of traditional cooking energy and with her respect in the household, she convinces other household members to switch to modern cooking energy.

Household head's (HH's) year of education: This variable captures the number of years of education of household head. For example, if household head is 5th grade pass, then he/ she has 5 years of education. This variable is not included in logit model 2 (modern lighting transition) because it already includes the variable "education years of highest educated household member" and including this variable would have resulted in correlation errors. Results of Logit model 1 shows that within 90% confidence interval, household head's high education has positive influence on household's transition to modern cooking energy, and each one-year increase in household head's education increase the probability of household shifting to modern cooking energy as its primary cooking energy type by 0.55%, while holding all other variables constant. Result of Zoib model 1 indicates that when household is not meeting its 100% cooking energy demand with modern cooking energy, then within 95% confidence interval, every one-year increase in household head's education is associated with 0.1% increase in the proportion of household's modern cooking energy usage in its total cooking energy usage. With higher education, household head is aware of the harmful effects of indoor pollution and this motivates him to switch to modern cooking energy. Other reason could be that with high education, the livelihood opportunities increase for the household head and with growing incomes, household can now afford modern cooking energy. Also, with high education and growing livelihood opportunities, opportunity cost of household head's time increases, and this demotivates household in spending time on bioenergy collection. Other reason could be that highly educated household head want to give good education to his/ her children and want them to spend time on education rather than bioenergy collection.

Household head's (HH's) age: This is the household head's age in year. Older household head is expected to have old thinking and misconceptions on cooking energy usage as discussed in chapter -2 and the same behaviour is expected to be analysed with this variable. While logit model 1 (modern cooking energy) does not gives any significant results, results of zoib model 1 indicates that within 95% confidence interval, if household is using modern cooking energy, then every one-year increase in the household head's age is associated with 0.05% decrease in the proportion of household's modern cooking energy usage in its total cooking energy mix, while keeping all other variables constant. During the household surveys, it was observed that locals perceive food cooked in traditional bioenergy more healthier and tastier and that the smoke from the traditional cook stove kills the germs in the food. This perception was more prominent amongst elder people. During the field research, one local unqualified doctor (quack) even said that eating food cooked with modern cook stoves gives acidity. All these misconceptions stem out from old thinking of the people and therefore households led by elderly male or female prefer to cook food in traditional cook stoves.

Household's (HH's) dwelling type: This is the housing type of the household. This takes value "0" when the housing is a temporary structure such as an open hut or mud house with thatched roof, and it takes the value "1" when the housing is a permanent structure such as house made with concrete. The temporary housing structure of the household may demotivate household in making investments in modern energy systems, and the same behaviour is expected to be tested with this variable. Both logit and zoib model indicate insignificant correlation between dwelling type and the cooking energy and lighting energy choice of the household.

Household's (HH's) purchase price of dung cake in local market: This variable deal with the local bioenergy energy markets and the endowment of natural bioenergy resources locally and their institutions. The price of cattle dung cake (in Rs/ kg) in the local market is used as its proxy because in the field research, cattle dung was observed to be the most important bioenergy fuel and if there is a scarcity of cattles and forests/ private trees in or near the village, the price of dung cake in the local market is expected to be high and this may motivate the households to shift to modern cooking energy. The same behavior is expected to be tested with this variable. Within 95% confidence intervals, both logit and zoib model results show positive correlation between price of dung cakes in local market and transition to modern cooking energy. The marginal effects on logit model 1 suggests that with every 1 rupee increase in the price of dung cake in local markets, the probability of household's utilization of modern cooking energy as primary cooking fuel increases by 3.01%, while holding all other variables as constant. The marginal effects on zoib model 1 suggests that when household is using modern cooking energy, then with every 1 rupee increase in the price of dung cake in local market increase the proportion of modern cooking energy in total cooking energy usage of household by 0.63%, while holding all other variables constant. The above results can be explained by table 8 below. It shows that if the price of dung cakes in the local market is high (row A), then there is lesser number of cattles per HH in these villages (row B) and there is a scarcity of other resources such as wood (row C and D), and this pushes households to look for alternate energy sources for cooking. For instance, villages Vil-1 and Vil-2 have scarcities of cattles as well as wood resources but have higher percentage of households using LPG cooking gas as their primary cooking fuel.

Table 8: Correlation between household (hh) energy usage and local bioenergy markets

S.No	Characteristics of HHs in the villages	Surveyed Villages							
		Vil-1	Vil-2	Vil-3	Vil-4	Vil-5	Vil-6	Vil-7	Vil-8
A	Cattle dung cake price in local market (Rs/kg)	5-7	5-7	4-5	4-5	-	1.5-2	1.5-2	1.5-2
B	Livestock per HH (excl. calves) [Nos]	0.79	0.82	1.45	1.87	2.9	1.7	1.9	1.5
C	Private trees per HH (nos)	3.63	0.71	26.2	56.1	3.2	5.2	4.5	35.73
D	Access to forests/ wastelands (Yes/ No)	No	No	Yes	Yes	No	No	Yes	No
E	% of HHs which use LPG as primary cooking energy	32%	31%	10%	17%	67%	19%	10%	5%
Source: Author's own field surveys									

Agricultural contracts of household (hh): This variable captures the interactions between rich households (large farms) and poor households (agricultural laborers). These interactions also lead to barter trade of energy commodities between households where, for instance, poor households work in the farms of rich households and get crop residues or dung cakes or wood residues as labor wage or as bonus over labor wage. In the field research, household females were observed to be majorly involved in off-farm agricultural labor as they have lesser wage compared to males. The number of females (between 15 to 59 years of age) per household has therefore been used as a proxy to this variable. Within 95% confidence interval, results of logit model 1 indicates that with every increase of 1 household female in the family, the probability of household using modern cooking energy as primary cooking energy decreases by 0.20%, while keeping all other variables constant. One of the reasons could be that with more agricultural labour contracts, household females get greater interaction with large farms who discard their agricultural residues and these females collect them and this surplus crop residues demotivate this household to cash purchase modern LPG gas. Secondly, since they are not paid in cash but in bio-energy residues, they don't have sufficient cash to buy modern energies. While zoib model 1 also suggests negative correlation, but the results are not significant. The results of logit model 2 does not suggests any significant correlation, as household males might have more say in the selection of modern lighting energy who have more association with the markets and have more exposure to market developments.

Household's (HH's) possession of LPG stove through government PDS (public distribution scheme): Under this PDS scheme, government provides subsidized LPG to households. However, to get this connection, household is required to pay a high initial connection fees of Rs 4500. Whereas, households who don't have LPG connection under the government PDS scheme, must buy LPG from black market at almost double price as compared to PDS price. Therefore, the households who possess LPG stove from government PDS scheme are expected to use LPG as primary cooking fuel compared to other households who may only use it as secondary fuel or don't use it at all. The same hypothesis is assessed in the model. Within 95% confidence interval, results of both logit model 1 and zoib model 1 indicate the significant positive correlation. The marginal effects in logit model 1 indicate that the connection to PDS scheme increases the probability of household using modern cooking energy as primary cooking energy by 20.45%, while holding all other variables constant. Marginal effects in zoib model indicates that when household is not using 100% modern cooking energy, then the connection to PDS scheme is associated with 2.83% increase in the proportion of household's modern cooking energy usage in its total cooking energy usage, while holding all other variables constant. The major barriers which block the households from getting government LPG stove connection are: high connection cost (Rs 4500 per connection), distance from gas distribution agencies and the associated transportation costs of gas cylinders.

Occurrence of Respiratory or eye diseases in the household (hh): The usage of traditional bio-energy for cooking and kerosene for lighting cause indoor pollution which further causes Tuberculosis, other respiratory or eye related diseases amongst household members. During the household surveys, households were asked if they have any of such diseases. However, it was observed that household confirms any such diseases only when diagnosed by doctors and if there is no diagnosis, they take any disease very lightly and they don't talk about it. Moreover, it was observed that they generally go to doctors at a very advanced stage of disease as medical services are very expensive. So, it may also happen that household females or males may be suffering from such health problems, but they don't know about it and that's why they did not reveal the same during the surveys. This question in the survey was crucial as it could help in understanding whether respiratory and eye related health problems in the household motivate household to shift to non-polluting energy sources or not. This is a categorical variable which takes the value "1" if any of the household member suffer from Tuberculosis, other respiratory or eye related diseases, and it takes the value "0" otherwise. Results of both logit models and zoib model don't indicate any significant correlation between household health and choice of energy source. The reasons could be that households are unaware of the harmful impacts of the indoor pollution caused by traditional bio-energy or kerosene, and there are also local perceptions that food cooked in traditional bio-energy is tasty and good for health as discussed in chapter 2. Further locals also believed that smoke caused by traditional bioenergy drive away the mosquitos from the home. So, this local perception neglects the harmful impacts of traditional bio-energy base cooking. In the surveys, there were 36 households which mentioned about the above health problems amongst their females, whereas only 2 households confirmed the above problems amongst household males. So, these problems were more amongst household females. It may happen that household heads (decision makers) who are generally males, are not aware of the harmful impacts of traditional cooking on females or even if they are aware, they are not much bothered about the female health in the household. Thirdly, as every household receives 3 liters of subsidized kerosene from the government, it demotivates them to shift to modern lighting energies.

Years of education of household's (hh's) highest educated member: This is the highest number of years of education of any of the household member. If the highest education in the household is 10th pass, then this takes the value of 10 and likewise. This variable is only included in logit model 2. Due to its high correlation with high female education of household and household head's education year, this variable is not included in logit model 1 and zoib model 1. The results of logit model 2 does not indicate any significance with household's transition to modern lighting. The reason could be the widespread stealing of grid electricity and provision of highly subsidized kerosene to households. Although grid electricity supply is highly erratic, but households expect that the government will eventually improve its power supply. Moreover, during examination time of children, government anyway gives improved grid supply to rural areas so that the examination results of its control area improve. Because of the above reasons, even educated households are not motivated to look for better alternatives of lighting.

Presence of young women in household (hh): This variable is the number of household's female youths in the age bracket of 15 to 34 years. This variable is only included in logit model 2, but not in logit model 1 and zoib model 1. It is expected that with more number of young females, household will be more concerned about their safety and will use improved and reliable lighting for the household. For example, when these ladies go to toilet outside their house in early morning or late evening, they can carry solar lamps with them which are more reliable unlike kerosene lamps which can be extinguished by wind. Also, young females spend more time within the household and therefore they are more bothered about the lighting. The same behavior is tested in the model. However, the results of logit model 2 does not indicate its significant correlation with the household's transition to modern lighting. Easy opportunities of stealing grid electricity (although highly erratic and unreliable), false promises of local politicians of strengthening local grid electricity supply, along with the provision of highly subsidized kerosene, demotivates household to make any investments into reliable modern and clean lighting energy technologies.

***Household distance from kerosene PDS shop*:** To provide subsidized grains, sugar, kerosene etc. to rural households, government set up PDS (Public distribution system) shops in rural areas. This shop generally caters to a cluster of villages or a big village. It is expected that the household which are closer to PDS shop gets subsidized kerosene very easily and sometimes in comparatively more quantity (with good relationship with PDS shop owner). This may demotivate such household to invest in any modern lighting technology and the same behavior is tested in the model. Please note that LPG gas (under PDS scheme) is not distributed by these shops. This variable is not included in logit model 1 and zoib model 1. Results of logit model 2 does not shows any significant correlation. The reason could be that the villages which are away from PDS shops are also remote in nature and grid electricity stealing could be more widespread there. Secondly, it was observed in field research that even distantly located households (from PDS shops) were able to get around 2 liters kerosene per month from PDS shop. In a field experiment (carried out during the field research), this amount was observed to be sufficient for running 1 lamp for around 4-5 hours each day for a month. So, when used judiciously, this amount could meet basic lighting need of the household.

Caste of the village chief of the household: This is a categorical variable and it takes value "1" if the village chief of the concerned household is from upper caste and it takes value of "0" otherwise. Results of logit model 2 indicates that within 90% confidence interval, upper caste village chief of the household has positive influence on household's utilization of modern lighting energy. Marginal effects in logit model indicate that, within 90% confidence interval, if the village chief of the household is from upper caste, then it increases the probability of household using modern lighting by 7.09% while keeping all other variables constant. The reason could be as follows. During the field research, it was observed that upper caste village chief had a significant clout in the village, so they were able to unite villagers more effectively and as a result they had more influence in the local government departments and were more successful in bringing government modern lighting schemes to their villages. These schemes could be free solar lights for Below Poverty line (BPL) households, free solar street lights for the village, etc. Whereas villages with lower caste chiefs might have to deal with more internal politics due to jealousies from upper caste households and this results in failure to bring good government schemes to the village.

4 Conclusions and Recommendations

This study analyzed household's activities to identify the factors impacting household energy transition. This section summarizes the major research findings and suggests recommendations which can facilitate households' modern energy transition in UP.

Water-Energy-Food production nexus (WEF nexus) and its impact on household's modern energy transition

The results of the analysis indicate that household's agricultural production has an impact on its cooking and lighting energy choice. For instance, results showed that larger cattle endowment encourage household to consume larger quantity of traditional bioenergy (cattle dung cakes) in its cooking energy mix. The results also showed that regular non-agricultural income of household's male member increases the probability of household's modern cooking energy and modern lighting transition by 8.6% and 13.6%, respectively. Larger labor endowment (household size) was also observed to be negatively associated with household's transition to modern cooking and lighting energy. Further results also indicated that the large off farm agricultural contracts of the household discourage the household to use modern cooking energy as its primary cooking fuel and encourage the household to use larger amount of traditional bio-energy in its cooking energy mix. The unpredictabilities and the irregular incomes associated with the agricultural production, the surpluses of agricultural labor and agricultural biproducts (such as dung or crop residues) and lack of awareness on modern energies (such as biogas) are some of the reasons for this household's behavior. To overcome these challenges, it is required to create synergies between household's agricultural production and its modern energy utilization. This can be done by identifying suitable energy systems that utilize local energy resources for modern energy production (decentralized energy systems) and creating value for the local households to participate in such energy systems both as energy feedstock supplier as well as final energy consumer. Further, it also requires robust business model that makes the operation of such energy enterprise (serving the local households) sustainable while taking care of households' willingness to pay for the energy services. For local households, such arrangement can provide income augmentation, improve their purchasing power for energy as well as decrease their vulnerability to price shocks for food and energy. One such example comes from India where the company "Husk power Systems" sets up biomass gasifiers for power production (mini grids) in rural areas of Bihar. These mini grids purchase rice crop biproducts from households, use them for power generation and sell the electricity back to the households not just for their domestic consumption but also for agricultural production (such as for powering local rice dehusking mills, or pumping irrigation water, etc). This arrangement utilizes agricultural surpluses from the rural households, give them additional income that mitigates their financial challenges to buy modern energies, provide cheap and financially viable energy to the households, and provide training as well as employment to local village youths in operation of the mini grid. This company has set up around 84 such mini grids serving several thousands of people in rural Bihar in less than 4 years from the start of its operations (PWC 2016).

Government policy instruments and household's energy transition

Results showed that government's policy instrument such as household connection to government LPG PDS scheme is associated with 20.5% increased probability of household using modern cooking energy as its primary cooking fuel. However, high connection cost is one of the barriers to avail this LPG PDS scheme. Secondly, getting an LPG connection also involves significant efforts (administrative difficulties) and bribery. All this demotivates marginalized section of the rural households from taking the LPG PDS scheme connection and using LPG as their primary cooking energy source. So, government's policy instruments could have positive impacts, but they should be strengthened in a way that even the most backward and marginalized section of the rural households can avail benefit from them. Waiving off the initial LPG connection cost, opening LPG gas agencies in remote areas, easing the process of LPG connection are some of the solutions that can be explored. Results also showed that household's proximity to markets is another important factor that affects household's transition to modern energies. This is because the households living close to the markets have comparatively higher opportunity cost of time and this demotivates them from spending time on bioenergy collection. Also, proximity to markets brings proximity to market information on different technologies, which enables households to shift to modern energies. This calls for the efforts to bring marginalized communities towards the center of development and connecting them to the main stream. Government's investment on infrastructure such as roads, employment schemes, developing education & entrepreneurial skills, etc are expected to be fruitful in this regard.

Institutions and household's energy transition

The results also indicated that the local institutions such as barter trade between households (for labor and bio-energy) and local bioenergy markets impact the cooking energy utilization of household. For example, households who work in the farms of rich households and receive agricultural residues in return of their work, were observed to be having greater utilization of traditional bio-energy in their total cooking energy mix. Encouraging decentralized modern energy systems can mitigate this phenomenon, where households rich in bio-energy resources (large landlords) can sell their surplus residues to decentralized energy systems, and their money generated can be used to pay cash wage to local agricultural labors (instead of paying them in bio-energy residues). While, this will increase the paying capacity of poor households for energy services, the local sourcing of energy feedstocks will result in cheaper modern energy production thereby benefitting both rich and poor households. Results also indicated that the upper caste of village chief can impact the modern lighting transition of the village households, which is perhaps due to his/ her capability to unite locals and bring government modern energy programs to his/ her village. This signifies the importance of robust institutional models for the success of modern energy initiatives.

Social factors and household's modern energy transition

Several social factors also impact household's energy transition. For example, results indicated that the higher education of household female has a positive impact on modern cooking energy transition. So, encouragement to female education is an important driver for household's modern energy transition. Local misconceptions related to LPG and biogas and lack of awareness on modern energy technologies pose challenge to the acceptance of modern household energies. Results indicated that the household headed by low educated and old aged decision maker, has higher traditional bio-energy consumption in its total cooking energy mix. Such households therefore have greater tendency to get trapped in such misconceptions. Educational programs should therefore be undertaken in the rural areas to explain households about the harmful impacts of traditional bio-energy and the significance of modern energies.

The findings of this paper confirmed that the rural household's energy choice decisions depend on the complex linkages of its household activities and its interactions with other households. Encouragement to decentralized energy systems supported by strong business and institutional models, along with the community awareness on modern energy use, can help in households' modern energy transition.

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