Determinants of household cooking fuel choices in India

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Certificate of Examination

This is to certify that the dissertation titled “Determinants of household cooking fuel choices in India” submitted by Ms. Preeti(Reg. No. MS15048) for the partial fulfilment of BS-MS dual degree programme of the Institute, has been examined by the thesis committee duly appointed by the Institute. The committee finds the work done by the candidate satisfactory and recommends that the report be accepted.

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Dated:15 June,2020

Declaration

The work presented in this dissertation has been carried out by me under the guidance of Dr. Baerbel Sinha at the Indian Institute of Science Education and Research Mohali.
This work has not been submitted in part or in full for a degree, a diploma, or a fellowship to any other university or institute. Whenever contributions of others are involved, every effort is made to indicate this clearly, with due acknowledgement of collaborative research and discussions. This thesis is a bonafide record of original work done by me and all sources listed within have been detailed in the bibliography.

Preeti
(Candidate)

Dated: 4-5-2020

In my capacity as the supervisor of the candidate's project work, I certify that the above statements by the candidate are true to the best of my knowledge.

Dr. Baerbel Sinha
(Supervisor)

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Notation (abbreviations)

1. LPG : liquified Petroleum Gas
2. VOC's: Volatile Organic Compounds
3. INR : The Indian Rupee
4. MJ : Megajoules
5. Kg : Kilograms

CONTENTS

Abstract

This study attempts to understand the factors that drive the adoption of cleaner cooking fuels in rural Punjab and Haryana. We find that family size is an important determinant of per capita cooking fuel consumption. Larger families consume less cooking energy than smaller families. Smaller families generally tend to have average sized pots whereas bigger families need bigger pots and utensils, which consume less energy when consumption is normalized to the amount cooked. Hence more energy is needed to cook the food for a person living in a small family and more wastage tends to occur with individuals and small families. The drop in the per capita cooking energy consumption with increasing family size is called the economy of scale.

While studying stove stacking behavior we find that landowning families with lower disposable income use more biofuel and less LPG whereas those with more disposable income use less biofuel and more LPG. LPG and biofuel consumption are inversely related to each other. This indicates that in cases where biofuel is available and free, income becomes an important driver of fuel choices. The increase of LPG energy usage for landowning families with larger cooling bills somehow satisfies the concept of 'energy ladder theory'. This theory proposes that increase in income leads to people leaving traditional fuels and moving to modern clean fuels.

For landless families both biofuel and lpg consumption appear to be independent of the disposable income, however, the average LPG and biofuel cooking energy consumption of households are inversely related to each other. This interesting phenomenon deserves further study. Landless families appear to violate the 'energy ladder theory' showing that increasing income does not necessarily lead to adoption of clean cooking fuels, while even those with little disposable income can adopt clean cooking fuels. It is possible that parameters not recorded such as cattle ownership which results in free access to cow dung cakes impact the cooking fuel choices of landless families. The landless families without cattle, have to pay for their cooking fuel in any case, even if they buy firewood or dung cakes. So if the prices of LPG is cheap, those who anyways have to buy their fuel, might chose to switch to the more convenient LPG fuel.

Chapter 1

Introduction

There are 2.7 billion people around the world that use traditional biomass to fulfill their cooking and heating requirements (Yao et al,2012). In 2011, three-fifth of households in India relied on biomass as well as coal for cooking (Census of India 2011,Office of the Registrar General and Census Commissioner, India & Ministry of Home affairs,Government of India ,2013). Majority of Rural parts of India, a developing country, uses traditional biomass fuels like dungcake, wood and crop residue, coal for cooking whereas LPG remains primary choice in urban parts of India.

A large amount of black carbon, greenhouse gases like methane, carbon dioxide, trace gases like carbon monoxide, nitrogen oxides, sulphur oxides and volatile organic compounds (VOCs) are emitted from burning of biomass fuels.(Habib et al,2004,Reddy and Venkatraman et al,2002,).

The estimated the emissions of such species are maintained as a scientific database which includes sources of a chemical specie over a period of time for over a specific region. To establish an emission inventory, the first step to identify sources and look at amount of species released by a source. There are various methodologies and approaches reported in literature ,that are adopted to report estimations of various species over a vast range. Precise estimations provide better inputs for air quality models, as well as helps government to form better socio- economic policies

1.1. Black carbon : Estimations reported in literature

Black Carbon is an important air pollutant and comprises a notable portion of particulate matter. It is emitted from gas and diesel engines and burning of biomass.South Asia region emits 2.54 Tg of Black Carbon Out of which 600 Gg/year is emitted by India

(Streets et al 2000). It is estimated that India emits 901.11 ± 151.56 Gg/ year black carbon out of which 423.52 Gg/year comes from residential sector (Paliwal et al 2016). However, there are contradictory estimates of residential sector black carbon emissions ranging from 220 Gg/year (Habib et al 2004) to ~ 420 Gg/ year (Dickerson et al 2002, Reddy and Vekantraman 2002).

Above estimations tell us that there is a huge disparity between in calculated emissions. Surveys Such as National Health Surveys used in Estimations made by Habit at el , are decades old and use questionnaire which does not account for practice of stove stacking in India. Stove stacking means that the same household uses several stoves at the same time and decides which one to use for every individual cooking task. Subsequent estimations appear to be provided by scaling up to the growing population without collecting fresh activity data to account for different stoves usage and solid fuels used.

1.2. Volatile Organic compounds and its emission factors

Volatile Organic compounds are compounds that have a vapour pressure greater than 0.01kPa at 298K and low boiling points (323K to 533K) at 1.013 bar pressure. Globally ~1300 Tg (Goldstein and Galbally, 2007) of VOCs are emitted every year in atmosphere . Pandey et al l 2004 estimates 4.6 Tg/Year of Non methane VOCs emissions from residential cooking sector of India.

VOC's have negative effect on human heath as well as air quality and climate. Benzene is known to have carcinogenic effect on human body. Continuous exposure to toluene and xylenes cause irritation in respiratory track, dizziness, headache and sore eyes (Sarah Johnson,2012 Environmental Health (2012). It also impacts climate by undergoing reactions that lead to formation of tropospheric ozone and secondary organic aerosols.

Emission factor is mass of a specie released per unit of mass of carbon burnt. It is reported that emission factor of gaseous compounds depends on combustion efficiency of fuel.

Following emission factors of VOCs contributing to secondary organic aerosol formation and ozone formation have been reported in literature.

Table 1: Emission Factors for various fuels and stoves

	Flaming et al,2018	Flaming et al, 2018	Flaming et al,2018	Flaming et al,2018	Stockwell et al,2016	Stockwell et al, 2016	stockwell et al, 2015	Verma et al, 2019	Verma et al, 2019	Verma et al,2019	Verma et al,2019	Verma et al, 2019
	Dungcake-Chulha	Wood chulha	Mixed fuel-Chulha	Dungcake-Angithi	Dungcake-Chulha	Wood-Chulha	Wood open cooking	Wood-Chulha	Coalballs-Chulha	Crop Residue-Chulha	Dungcake-Chulha	Mixed fuel-Chulha
Aromatic												
C_6H_6	1.03 (0.33)	0.373 (0.149)	0.723 (0.218)	0.769 (0.175)	1.96 (0.45)	1.05 (0.19)	2.58 (2.68)	9.07 (2.09)	34.47 (18.73)	17.55 (5.53)	13.18 (20.3)	11.0 (8.95
C_7H_8	0.483 (0.273)	0.221 (0.085)	0.297 (0.077)	0.860 (0.167)	1.26 (0.05)	0.241 (0.160)	0.290 (0.311)	0.86 (0.47)	6.13 (3.42)	0.86 (0.68)	1.19 (1.04)	0.84 (0.37)
C_2H_4	1.86 (0.48)	0.626 (0.284)	1.13 (0.38)	1.77 (0.35)	4.23 (1.39)	2.70 (1.17)	nm	nm	nm	nm	nm	nm
C_3H_6	0.807 (0.235)	0.286 (0.202)	0.417 (0.091)	1.61 (0.33)	1.47 (0.58)	0.576 (0.195)	nm	nm	nm	nm	nm	nm
m/p C_8H_{10}	6.36 (1.26) × 10^{-2}	2.78 (1.56) × 10^{-2}	4.03 (0.98) × 10^{-2}	0.148 (0.030)	0.601 (0.294)	9.57 (7.99) × 10^{-2}	0.265 (0.380)	0.98 (0.96)	2.24 (0.49)	0.46 (0.44)	0.98 (0.74)	0.82 (0.66)
Oxygenates												
C_2H_4o	0.805 (0.279)	0.334 (0.199)	0.447 (0.119)	1.70 (0.75)	1.88 (1.63)	0.541 (0.362	0.792 (0.439)	nm	nm	nm	nm	nm
C_4H_8O	4.28 (1.50) × 10^{-2}	1.90 (1.29) × 10^{-2}	2.68 (1.05) × 10^{-2}	0.108 (0.047)	5.40 (2.19) × 10^{-2}	8.28 (6.27) × 10^{-3}	nm	nm	nm	nm	nm	nm
C_3H_6O	0.705 (0.219)	0.365 (0.226)	0.416 (0.108)	2.05 (0.52)	1.63 (0.38)	0.524 (0.256)	nm	nm	nm	nm	nm	nm
2-Butanone	0.172 (0.057)	8.00 (6.18) × 10^{-2}	0.103 (0.038)	0.498 (0.151)	0.262 (0.109)	0.232 (0.286)	8.04 (4.98)	nm	nm	nm	nm	nm
Furan	0.109 (0.041)	5.98 (3.37) × 10^{-2}	6.81 (2.19) × 10^{-2}	0.379 (0.093)	0.534 (0.209)	0.241 (0.024)	0.228 (0.162)	nm	nm	nm	nm	nm
2-Propenel	0.186 (0.060)	0.127 (0.069)	0.127 (0.059)	0.295 (0.245)	nm	nm	nm	nm	nm	nm	nm	nm
Furfural	8.55 (6.05) × 10^{-2}	4.28 (5.51) × 10^{-2}	8.22 (5.09) × 10^{-2}	0.316 (0.133)	nm	nm	nm	nm	nm	nm	nm	nm
CH_3OH	2.09 (1.14)	2.03 (2.01)	1.18 (0.40)	4.23 (3.40)	2.38 (0.90)	1.92 (0.61)	nm	nm	nm	nm	nm	nm
C_2H_50H	4.08 (5.93) × 10^{-2}	2.18 (2.00) × 10^{-2}	5.63 (6.69) × 10^{-2}	7.62 (9.08) × 10^{-2}	0.563 (0.589)	0.128 (0.017)	nm	nm	nm	nm	nm	nm
MVK (C_4H_6O)	0.129 (0.040)	6.59 (4.56) × 10^{-2}	6.31 (2.76) × 10^{-2}	0.280 (0.147)	nm	nm	nm	nm	nm	nm	nm	nm

C_4 Alkenes								nm	nm	nm	nm	nm
1-Butene (C_4H_8)	0.158 (0.047)	6.32 (4.59) × 10^{-2}	8.38 (1.83) × 10^{-2}	0.366 (0.096)	0.399 (0.331)	0.726 (0.904)	nm	nm	nm	nm	nm	nm
i-Butene (C_4H_8)	0.133 (0.057)	3.46 (2.50) × 10^{-2}	6.40 (1.86) × 10^{-2}	0.353 (0.158)	0.281 (0.091)	0.846 (1.113)	nm	nm	nm	nm	nm	nm
trans-2-Butene (C_4H_8)	4.45 (1.60) × 10^{-2}	2.00 (1.27) × 10^{-2}	2.38 (0.70) × 10^{-2}	0.151 (0.055)	0.151 (0.010)	6.78 (5.98) × 10^{-2}	nm	nm	nm	nm	nm	nm
cis-2-Butene (C_4H_8)	3.38 (1.19) × 10^{-2}	1.51 (0.95) × 10^{-2}	1.80 (0.52) × 10^{-2}	0.107 (0.047)	0.102 (0.016)	5.51 (4.76) × 10^{-2}	nm	nm	nm	nm	nm	nm
C_5 Alkenes												
3-Methyl-1-butene(C_5H_{10})	1.46 (0.48) × 10^{-2}	5.74 (4.49) × 10^{-3}	7.30 (1.94) × 10^{-3}	3.82 (0.88) × 10^{-2}	5.58 (3.50) × 10^{-2}	7.43 (5.79) × 10^{-3}	nm	nm	nm	nm	nm	nm
2-Methyl-1-butene(C_5H_{10})	2.71 (1.28) × 10^{-2}	9.96 (10.9) × 10^{-3}	1.19 (0.42) × 10^{-2}	7.70 (3.99) × 10^{-2}	nm	nm	nm	nm	nm	nm	nm	nm
2-Methyl-2-butene(C_5H_{10})	2.51 (1.26) × 10^{-2}	6.40 (4.78) × 10^{-3}	1.10 (0.47) × 10^{-2}	9.17 (4.70) × 10^{-2}	nm	nm	nm	nm	nm	nm	nm	nm
1-Pentene (C_5H_{10})	4.17 (1.59) × 10^{-2}	9.65 (6.55) × 10^{-3}	2.13 (0.60) × 10^{-2}	0.122 (0.033)	0.168 (0.086)	1.43 (0.94) × 10 2	nm	nm	nm	nm	nm	nm
trans-2-Pentene (C5H10)	1.74 (0.65) × 10^{-2}	8.89 (5.77) × 10^{-3}	8.69 (2.22) × 10^{-3}	5.14 (2.70) × 10^{-2}	0.115 (0.035)	1.05 (0.83) × 10^{-2}	nm	nm	nm	nm	nm	nm
cis-2-Pentene (C_5H_{10})	1.00 (0.36) × 10^{-2}	5.55 (3.62) × 10^{-3}	4.98 (1.26) × 10^{-3}	2.50 (1.28) × 10^{-2}	5.14 (0.76) × 10^{-2}	8.69 × 10^{-3}	nm	nm	nm	nm	nm	nm

1.3. Properties of Different types of Stoves used in India

When a fuel is burnt, 100 percent of fuel does not get converted to energy. The amount of energy transmitted to the pot in which the meal is cooked depends on the stove efficiency on which fuel is burnt and thermal efficiency of fuel. The stove efficiency differs for every stove and fuel. The calorific value varies from fuel to fuel and depends on the moisture content which is not standardises in the real world. Literature reports following values for efficiency of LPG stove and traditional Chulha and calorific values of LPG, dungcake and firewood.

Table 2: Thermal efficiency and calorific values (Habib and Vekantraman,2004)

Type of stove	Type of fuel used	Thermal Efficiency (SD) (%)	Calorific Value (SD) (MJ/kg)
LPG	Propane	57(4.8)	45.9
Traditional chulha	Dungcake	11.07 (2.0)	11.8(2.0)
Traditional Chulha	wood	13.2 (2.2)	16.2(1.7)
Traditional Chulha	Crop waste	11.8 (3.0)	15.2(2.8)

1.4. Fuel Carbon content

Fuel carbon content is the carbon content of the fuel as the percentage of its mass. Its used to calculate the emission factors using the carbon mass balance method. Carbon content of propane is reported as 0.82 kg_{Carbon}/kg_{fuel}, wood as 0. 5 kg_{Carbon}/kg_{fuel} and rice husks as 0.39 kg_{Carbon}/kg_{fuel} (J.Jetter,2012)

1.5. Determinants of sustained use of LPG as household cooking fuel in India

The practice of using unclean fuels have adverse negative impacts on human health and environment. Hence, there needs to be a transition from use of dirty fuels to clean fuels. There are several determinable factors reported in literature like income (Ouedraogo 2006,Baiyegunhi and Hassan 2014)), household expenditure (Gupta and kohlein 2006) , price of clean fuels(Farsi et al.2007,Zhang and Kotani 2012), education(Farsi et al 2007), lifestyle(Baiyengunhi and Hassan et al 2014), and access of fuels(Gupta and Kohlein 2006) that are affect switching from dirty fuels to clean fuels. However, there are several other factors that play a major role to undergo the transition that vary as per socio - economic structure of country.

To provide alternatives to people to undergo the transition, Government of India launched scheme named ‘Pradhan Mantri Ujjawala Yojana’ in year 2016 which increased LPG coverage rate to 94.3 percent in May 2019 . However, for year 2019, average refill rates of PMUY consumers of the scheme was 2.98 cylinders per year which is far lower than rate of 6.73 cylinders per year by Non PMUY consumers of LPG cylinders per year. (Report of Comptroller and Auditor General of India on Pradhan Mantri Ujjawala Yojana,Comptroller and Auditor General of India,2019). which means that beneficiaries did not shift entirely on LPG fuel and do not become primary and exhaustive consumers of LPG, and continued using other fuels like biomasss simultaneously.

A Study concludes that PMUY beneficiaries switching to primary consumers of LPG is not dependent of their income and due to factor of having fresh LPG connections. The other factor affecting primary use of LPG fuel is easy access and availability of biomass by either cattle owned by family or accessibility due to presence of sources of firewood in particular region, for examples areas surrounded by forests. It hinders the users to switch exclusively to LPG fuel as it is economical and they don’t have to pay for dung obtained from their cattle or firewood collected from forests or availability of free biomass fuel.

Lesser sustained use of LPG is reported in families whose income is from agricultural lands. Similar case is observed with family with daily-wage workers. (Mani S, 2020).

To look at emissions made from residential cooking sectors, it is first necessary to look at factors that are responsible for prevalent use of unclean fuels. Determining the various parameters between clean and unclean fuel can help to model the fuel usage on country level and provide input for emission models. This study aims to find parameters that play a role for choices made by people for clean and unclean fuels and can be considered for switching from unclean fuels to clean fuels.

Chapter 2

Material and Method

2.1. Data collection

2.1.1. Data collected from Surveys

The table below indicates the number of random houses from the villages with more than 500 households, that were surveyed in order to collect Data.

Table 3: Location, names of villages and number of households surveyed.

Name of Village	Longitude	Latitude	Number of houses surveyed	District , State
Nadampur	76.1168° E	30.2537° N	26	Sangrur, Punjab
Kamalpur	75.3033° E	31.2463° N	29	Sangrur,Punjab
Jhuneri	75.9797° E	30.2184° N,	32	Sangrur,Punjab
Kheri	75.8811° E	30.1905° N,	31	Sangrur,Punjab
Tepla	76.9477° E	30.3064° N	24	Ambala ,Haryana
			142	

This data collection was done by students enrolled in course HSS636 : Climate change and sustainable development,as part of coursework. The villages were selected randomly by running random function of Excel on Census database of the villages, and households were selected by generating random pairs of latitude and longitude coordinates spread out over the village.

Following were the questions that were asked about cooking practies during surveys and responses were recorded.

Table 4: : Questions asked during surveys conducted

	Questions	Possible Selected Answers
2.1.1.1	How many people live in this house ?	
2.1.1.2	How many times do you cook per day?	One/two/three
2.1.1.3	How much time does it take to cook breakfast,lunch and dinner?	0.5/1/1.5/2 hour
2.1.1.4	Which stove do you use primarily for cooking ?	LPG stove/traditional biomass stove/Improved stove/kerosene stove/biogas stove/sigdi
2.1.1.5	Which stove do you use secondarily for cooking?	LPG stove/traditional biomass stove/Improved stove/kerosene stove/biogas stove/sigdi
2.1.1.6	For how long does one LPG Cylinder lasts	
2.1.1.7	Are you vegetarian ?	Yes/No
2.1.1.8	What primary fuel do you use in traditional biomass stove?	Firewood/Dungcake/Crop residue/other
2.1.1.9	What secondary fuel do you use in traditional biomass stove ?	Firewood/Dungcake/Crop residue/other
2.1.1.10	For how many months do you use Primary stove?	1/2/3/4/5/6/7/8/9/10/11/12
2.1.1.11	What is weight of fuel used in traditional biomass stove for one time cooking ?	
2.1.1.12	For how many days per month and how frequently do you use secondary stove?	Days per month or days per week
2.1.1.13	What special dishes do take long to cook and what stove do you use for cooking them?	Chicken/saag/fish/others
2.1.1.14	What is frequency of cooking dishes that take long time to cook?	Once a week /twice a week/ others
2.1.1.15	For how many months do you rely on traditional stove for cooking	1/2/3/4/5/6/7/8/9/10/11/12
2.1.1.16	How high is your electricity bill in Summers? Mention the amount	
2.1.1.17	How high is your electricity bill in Winters ? Mention the amount	

2.1.1.17	Do you own land	Yes/no

Chapter 3

Results and Discussion

3.1. Changes in LPG usage as estimated from country level statistical parameters

3.1.1. Domestic LPG sales data

To look at pattern of rate of LPG consumption in India, LPG sales numbers from annual reports of Indian PNG statistics of year 2014-15, 2017-18 were taken. [Government of India Ministry of Petroleum and Natural gases,.Indian PNG statistics 2014-15 (2015) ,Indian PNG statistics 2017-18 (2018) Retrieved from petroleum.nic.in]

It reports the Sales in Tonnes as shown in Table 5.

Table 5: Amount of domestic LPG consumed by India

Year	Total domestic LPG sales in ‘000’ tonnes
2010-11	12368.68
2011-12	13295.91
2012-13	13568.03
2013-14	14411.60
2014-15	16040.39
2015-16	17181.72
2016-17	18871.4
2017-18	20351.70

3.1.2. Estimated population numbers

Projected population numbers for Year 2011 to 2017 were taken from Estimations Provided by Ministry of Health and Family Welfare which takes Census of 2010 as base year and projects births and deaths. [National commission of population, Census of India 2011 Population Projections for India and states 2011-2026 (November 2019) retrieved from nhm.gov.in]

Table 5: Projected population numbers

Year	Projected Population ‘000’
2011	1210855
2012	1226731
2013	1242607
2014	1258483
2015	1274359
2016	1290235
2017	1304457

3.1.3. Rate of per capita per year LPG consumption versus time

Average Amount of LPG consumption by one person per year in India is calculated by using following formula, For Year 2011 to 2017.

Equation 1: Per capita LPG consumption

Per Capita LPG consumption: Total Domestic LPG sold / Projected population

The data representing per capita LPG consumption and year is plotted, with consumption on X-Axis and Year on Y-Axis.

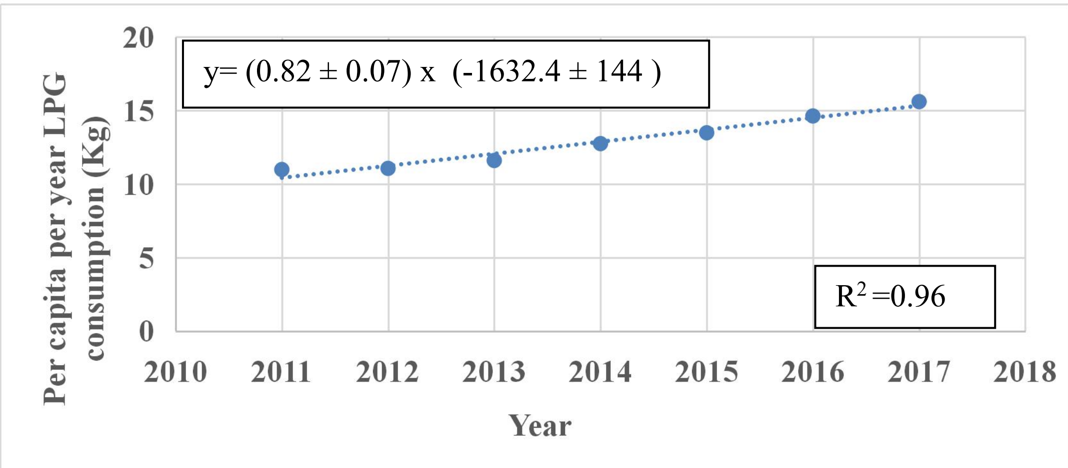

Figure 1 : Per capita per year LPG consumption VS time

3.1.4. Percentage change in per capita per year LPG consumption versus time

Percentage change in per capita per year LPG consumption in two consecutive years is calculated by using formula as following.

Equation 2 : Percentage change in consumption

*Percentage change ={(Difference in per capita consumption for two consecutive years)/(Per capita consumption for receeding year) }*100*

The data representing Percentage Change and Year is plotted.

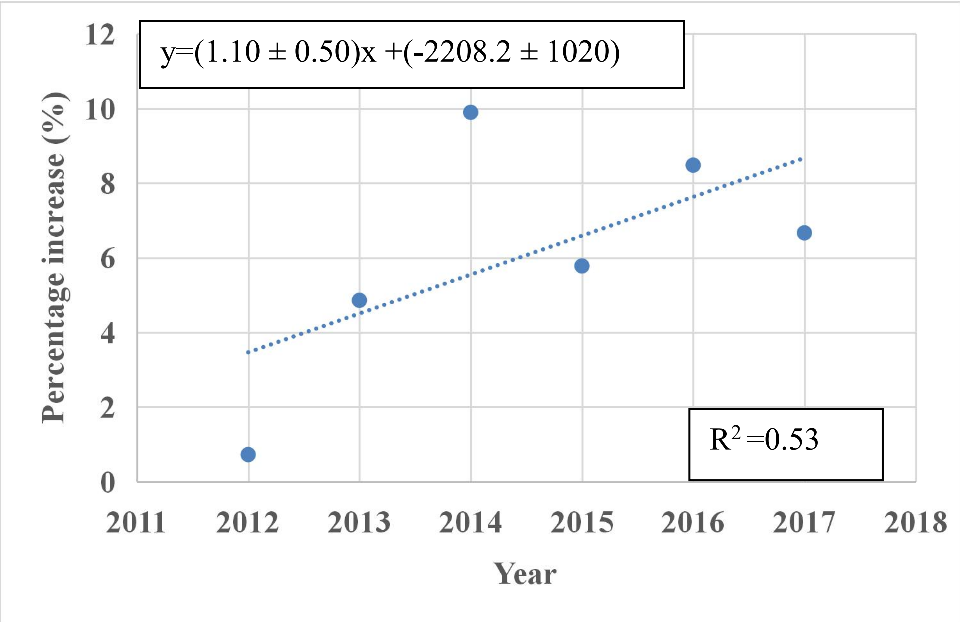

Figure 2 : Percentage increase vs time

3.2. Determinants of per capita LPG cooking energy as estimated from household level surveys

3.2.1. Establishing the relationship between per capita LPG consumption, number of members in family and family income – primary data

Per capita per day LPG consumption is calculated by using responses from questionnaire. The following table indicates the households from different villages that are used for preparing the data.

Table 6 Primary data of village Jhuneri

Household Number	Number of Family members	Response recorded to question 'For How many month does one LPG cylinder last '	Summer bill (Maximum bill)	Winters bill (Minimum bill)	Do you own agricultural land? 1= yes 0=no
Jhuneri					
HH1	5	3 months	6500	2000	1
HH2	2	No LPG	200	0	1
HH3	10	1 month	7500	4500	1
HH4	10	1.5 months	2000	1000	0
HH5	4	2 months	6000	4000	0
HH6	5	4 months	11000	3000	1
HH7	6	3.5 months	2500	1000	1
HH8	6	2 months	3000	1800	1
HH9	5	1 months	5500	3000	1
HH10	4	1.5 months	3500	2000	0
HH11	4	1.5 months	6500	5500	0
HH12	12	3 months	5000	2000	1
HH13	6	1.5 months	5500	2500	0
HH14	4	1.5 months	3500	3000	1
HH15	6	3 months	7500	3250	0
HH16	4	2 months	3500	1500	0
HH17	4	6 months	7500	2500	0
HH18	8	1 month	8000	5000	1
HH19	4	No LPG	2200	400	1

HH20	3	1.5 months	8000	2000	1
HH 21	9	20 days	7000	1500	1
HH22	4	2 months	2500	2000	0
HH23	6	20 days	1000	500	0
HH24	4	No LPG	7500	2500	1
HH26	8	1 month	700	400	0
HH27	4	4 months	7000	2500	0
HH29	3	2 months	6500	1500	1
HH30	8	1month		1000	1
HH31	5	2 months		4000	0
HH32	4	4 months	5500	2500	0
HH33	5	1.5 months	13500	7000	1
HH34	5	3 months	4000	1750	1

Table 7: Primary data of village Kamalpur

HH1	5	1.5 months	10000	3500	1
HH2	3	3 months	4000	3000	1
RANDOM	5	1 month	1500	750	1
HH4	10	No LPG	7000	4000	1
HH5	6	2 months	5500	3500	0
HH6	7	5 months	5000	2000	1
HH7	4	2 months	3000	1500	0
HH8	8	1 month	2500	1500	0
RANDOM	3	5 months	4000	2000	1
HH10	6	25 Days	1200	500	0
HH11	5	1 month	10000	7500	1
HH12	7	1.5 months	4500	0	1
HH13	2	5 months	4000	1150	0
RANDOM	6	1 month	0	0	0
HH15	9	20 Days	5000	4000	1
HH16	3	No LPG	5000	1300	1
HH17	4	2 months	1000	500	0
HH18	5	1 months	6000	2500	1
HH20	5	1.5 months	3000	600	1
HH21	5	2 months	5000	4500	0
HH24	6	1.5 months	4500		1
HH23	7	No LPG	10000	6000	0
HH26	16	1.5 months	6000	3000	1
HH27	4	3 months	2200	650	1

HH28	6	1.5 months	4000	3000	1
HH29	5	2 months	6000	1700	1
HH30	6	5 months	0	0	1
HH31	8	1.5months	3000	2000	1
HH32	5	4 months	2000	500	0

Table 8 : Primary data of village Kheri

HH1	5	1 .5month	5000	3500	1
HH2	8	1.5months	4000	1500	0
HH3	5	1 months	7000	5000	0
HH4	3	40 days	7500	2200	0
HH5	5	1 months	10000	2000	1
HH6	4	3 months			1
HH7	7	1.5 months	8000	3000	1
HH8	10	1 month	6500		1
HH9	7	1 month	6500	3000	1
HH10	5	2 months	4000	1500	0
HH11	4	1.5 months	2200	900	1
HH12	6	2 months	4000	1900	0
HH13	3	2 months	1800	1000	0
HH14	7	2 months	10000	2000	1
HH15	10	1 months	7800	5080	1
HH16	4	1 months	2800	600	1
HH17	8	2 months	4500	1250	1
HH18	4	1.5 months	5500	2000	0
HH19	5	No LPG	4500	1500	1
HH20	4	2 months	1250	800	1
HH21	5	1.5months	5000	4000	0
HH22	4	3 months	1500	1100	0
HH23	5	3month			0
HH24	10	2 months	4500	2500	1
HH25	4	4 month	500	0	1
HH26	2	3 months	7000	1250	0
HH27	4	3 months	1600	400	0
HH28	10	1.5 months	10500	5500	1
HH29	5	1 month	5000	1500	1
HH30	5	1 month	9000	3000	1
HH31	8	1 month	9000	2500	1

Table 9 : Primary data of village Nadampur

HH2	6	15 days	7500	2500	1
HH3	4	2 months	3000	1500	0
HH5	4	3 months	1500	500	1
HH4	9	28days			1
HH6	11	1 month	9500	6500	1
HH7	6	1.5 months	8000	1400	1
HH8	4	2 months	9500	1500	0
HH9	6	2 months	0	0	0
HH10	5	2.5 months	0	0	0
HH11	6	2 months	1000	700	0
HH12	5	2.5 months	5000	300	0
HH13	6	1 month	3500	1500	1
HH14	4	2 months	2500	1750	1
HH15	5	1.5 months	9000	5000	1
HH16	4	2.5 months	850	550	0
HH17	4	NO LPG	0	0	0
HH18	5	2months	4000	1000	1
RANDOM	6	2 months	4900	3000	1
RANDOM	3	2 months	2500	625	1
Random near HH22	8	1.5 months	6500	2500	0
HH21	3	1 month			0
HH23	10	3 months	5000	2000	1
HH24	5	1.5 months	3500	1500	1
HH25	7	2 months	2800	1900	1
HH26	5	3 months	3000	2000	1
HH27	5	28 days	2500	1000	1

Table 10 : Primary data of village Tepla

HH1	10	15 day	450	250	0
HH3	5	1 month	1500	1200	0
HH2	6	1.5 months	2000	750	1
HH4	5	1 month	400	200	0
HH5	5	1 month			0
HH7	4	3 months			0
HH8	7	1 month	900	350	0
HH9	5	3 months	800	400	0
HH10	11	1month	600	500	0
HH11	5	1 month	1500	1500	0

HH12	6	1 month	1200	650	0
HH13	5	1.5 months	500	500	1
HH14	4	1.5 month	6000	350	0
HH15	9	15days	400	200	1
HH17	4	1 month			0
HH18	4	1 month	2500	600	0
HH19	6	2.5month	400	200	0
HH21	5	1 month	600	400	0
HH22	5	1 month	350	300	0
HH23	7	2 months	8000	2000	0
HH24	6	2.5 months	400	200	0
HH25	5	1.5 months	1200	400	0
HH26	6	3 months	900	450	0
HH27	7	15 days			0

3.2.2. Establishing the relationship between per capita LPG energy consumption and number of members in family – data processing and results

Primary data records the period for which one LPG cylinder lasts. Number of cylinders used per month by family is multiplied by 12 to obtain the total number of LPG cylinders used in a year. The amount of LPG gas in one cylinder is 14.2 kg. Per capita per year LPG consumed is Amount of LPG used in an year divided by number of family members. Per capita per day LPG consumed is calculated by dividing per capita per year LPG consumption by 365.

Equation 3 : Per capita per day LPG consumed (Kg/day)

*Per capita per day LPG consumed = (number of cylinders used per year * 14.2)/ number of family members / 365)*

Per capita per day amount of LPG consumed in household is converted to amount of cooking energy consumed by individual through LPG fuel. Amount of energy provided by a fuel is function of specific heat of fuel and type of stove on which fuel is used. For LPG fuel and gas stove, specific heat is 46.1 MJ/Kg and stove efficiency is 0.5. Hence per capita per day cooking energy consumption in a household is calculated using following equation.

Equation 3: Per capita per day energy consumed via LPG (MJ/day)

*Energy consumption via LPG = Amount of LPG burnt * 46.1 MJ/kg * 0.50*

Individual household LPG cooking energy consumption is plotted against size of family for families owning agricultural land and families who do not on agricultural land. Individual data points are binned for family size 3 or less than 3, 4,5,6, separately, 7 and 8 together, and 10 or more than 10 together. To form bins, average value of multiple data points falling in one bin is taken and it represents one single point. Error bars representing variability in binned data points are plotted.

The plot shows that for both landless and land owning families, larger families consume less per capita per day LPG cooking energy when there is an increase in family size. There are large household to household variations due to confounders such as income (which may determine the total amount of food cooked) and use of biofuel as alternate fuel. However, there appears to be a trend that could possibly be due to the economics of scale.

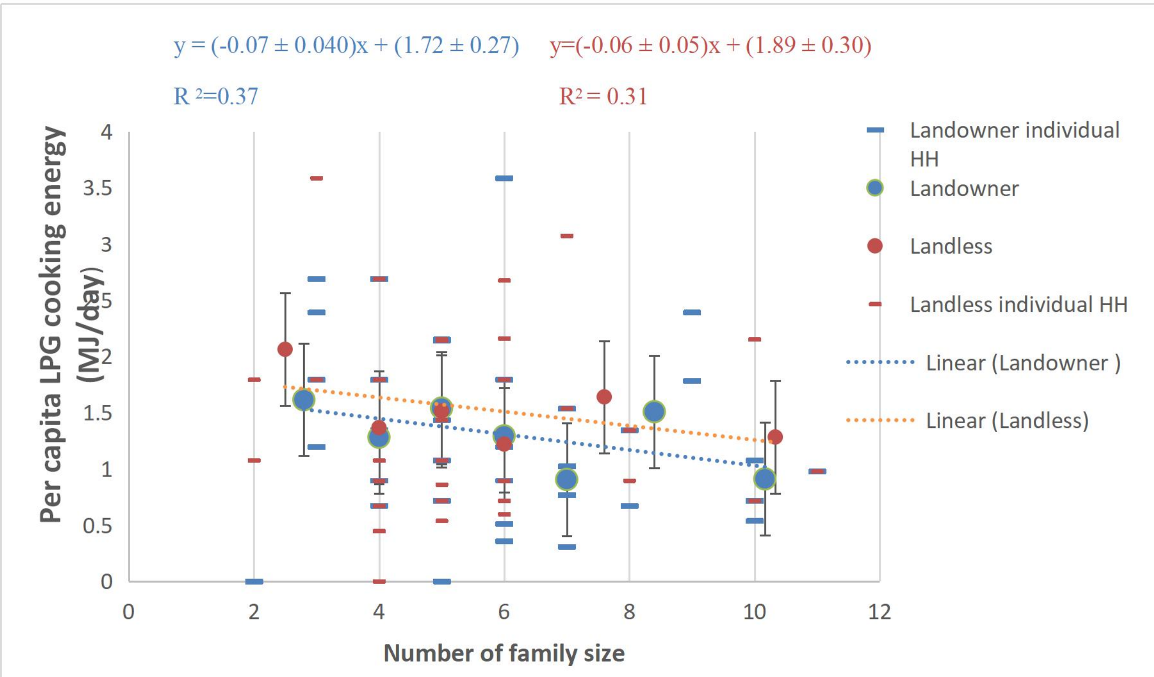

Figure 3 : Per capita per day LPG cooking energy VS size of family

3.2.3. Establishing relationship between per capita LPG cooking energy consumption and household income as estimated by the cooling bill

Cooling bill refers to amount that is difference between the maximum electricity bill and minimum electricity bill that comes throughout the year for one family. It is used as a proxy for income while obtaining results.

Per capita per day LPG consumption as mentioned in equation 4, is plotted as function of per capita cooling bill for a month. Per capita cooking bill is calculated by dividing cooling bill by number of family members in household.

Individual values of per capita LPG energy consumption and cooling bill per person are plotted in a form of scatter plot for both landless and land owning families. The cooling bill ranges from Rs. 0 to Rs. 2785, hence the data is binned depending on range of cooling bill. To form bins, average value of multiple data points falling in one bin is taken and it represents one single point. Data representing per person cooling bill is binned for ranges bill less than 100 , Rs. 101-200, Rs 201-400, Rs 401-600, Rs 601-1000, and greater than or equal to Rs 1000 are represented by single point for every individual range.

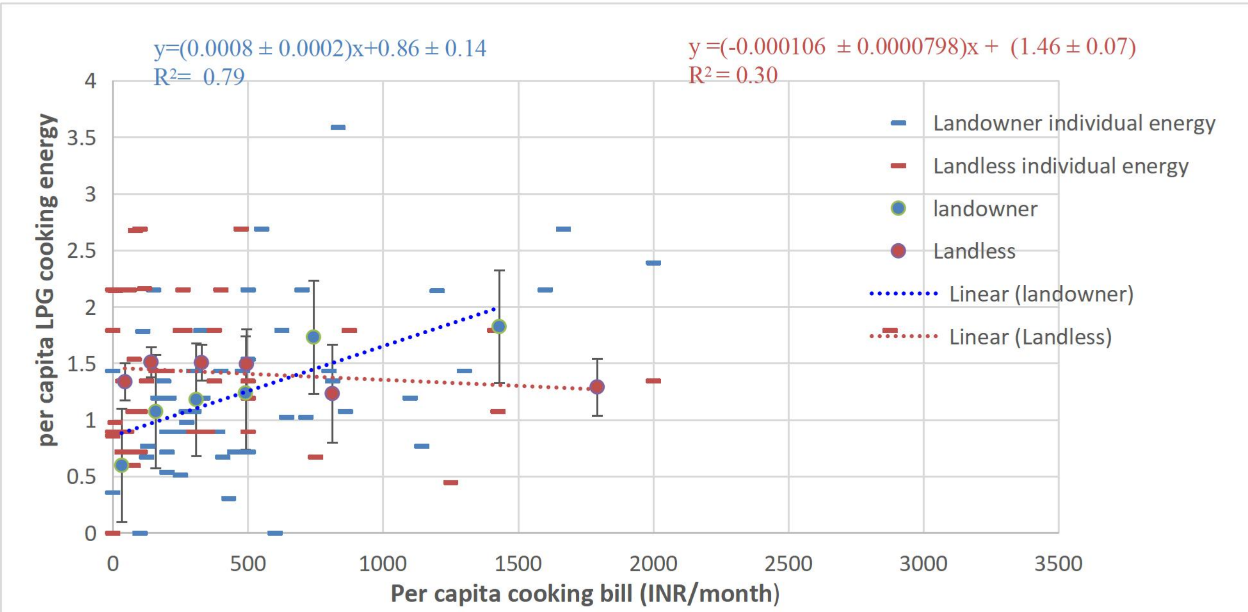

Figure 4 : Per capita per day LPG cooking energy consumption VS cooling bill

The graph shows that for land owning families with increase in cooling bill, that is proxy for income, there is increase in consumption in LPG cooking energy. However, for landless energy, there is no indication that income is the primary determinant of LPG consumption. Landowners have free access to biofuel from their land, it is hence understandable that those with less disposable cash would chose to use free biofuel rather than LPG which has to be paid. However, landless farmers could also have free access to biofuel if they own cattle. Unfortunately, cattle ownership was not recorded in the questionnaire, so we cannot investigate whether the landless household continuing with biofuel use are cattle owning households. Landless household with no land or cattle ownership often spend even for procuring biofuel such as firewood and cow dung. It is possible that a transition to LPG is easier for such households. However, this hypothesis cannot be investigated with the available data.

3.3. Determinants of per capita biofuel usage as estimated from household level surveys

3.3.1. Establishing relationship between per capita per year biofuel consumption and number of members in family – primary data

The table given below indicates the household numbers and questionnaire responses recorded that are used to establish data point

Table 11 Primary data of village Tepla

Household	Number of family members	Amount of fuel used for one time cooking	Number of months for which traditional chulha is used	Number of days for which chulha used in a month
HH1	10	0	0	0
HH3	5	0	0	0
HH2	6	0	0	0
HH4	5		12	30
HH5	5	0	0	0
HH7	4		8	25
HH8	7	0	0	0
HH9	5	0	0	0

HH10	11	3	12	
HH11	5	0	0	0
HH12	6		12	30
HH13	5	0	0	0
HH14	4	3	4	30
HH15	4	0	0	0
HH17	4	0		0
HH18	4	0	0	0
HH19	6		12	
HH21	5	2.5	4	30
HH22	5	0	0	0
HH23	7	3	4	20
HH24	6	3	4	25
HH25	5	0.5	12	30
HH26	5	4.5	12	30
HH27	7	0	0	0

Table 12 Primary data of village Nadampur

Household	Number of family members	Amount of fuel used for one time cooking	Number of months for which traditional chulha is used	Number of days for which chulha used in a month
HH2	6		12	8
HH3	4	1.6	12	30
HH4	9		12	30
HH5	4	4	12	30
HH6	11	3	12	30
HH7	6	3	12	15
HH8	4	2	12	30
HH9	6	10	12	30
HH10	5	1.8	12	30
HH11	6	3	12	30
HH12	5		12	30
HH13	6	3	12	30
HH14	4	1	3	10
HH15	5	3	12	30
HH16	6	2.5	12	30
hh17	4	5	12	30
HH18	5	3.5	12	30
Random	6	2	12	30
Random	3	0	0	0
HH21	3	0	0	0

Random near HH22	8	5	12	30
HH23	10		12	
HH24	5	3	12	30
HH25	7	1.5	12	30
HH26	5	2	12	30
HH27	5	2.5	12	30

Table 13 Primary data of village Kheri

Household	Number of Number of family members	Amount of fuel used for one time cooking	Number of months for which traditional chulha is used	Number of days for which chulha used in a month
HH1	5		3	10
HH2	8		12	30
HH3	5		12	1
HH4	3		12	30
HH5	5	2	3	10
HH6	4		12	30
HH7	7	2	12	30
HH8	10	3	12	30
HH9	7	2	4	
HH10	5		12	
HH11	4	4	12	30
HH12	6	2	12	30
HH13	3		1	7
HH14	7	0.3	12	30
HH15	10		12	30
HH16	4		12	3
HH17	8		12	30
HH18	4		4	
HH19	5		12	
HH20	4	3	3	30
HH21	5	3	12	30
HH22	4	3	12	30
HH23	5	2.5	12	30
HH24	10	3	12	30
HH25	4	2.5	10	30
HH26	2	2	12	30
HH27	4	0	0	0
HH28	10	5.35	12	30
HH29	5	3	12	30

HH30	5	2.5	3	30
HH31	8	3	2	10

Table 14 : Primary data of village Jhuneri

Household	Number of family members	Amount of fuel used for one time cooking	Number of months for which traditional chulha is used	Number of days for which chulha used in a month
HH1	5	0	0	0
HH2	2	2.5	12	30
HH3	10		2	
HH4	10		12	30
HH5	4	1.5	12	30
HH6	5		12	30
HH7	6	3		30
HH8	6	4	3	4
HH9	5	0	0	0
HH10	4	6	12	
HH11	4		4	8
HH12	12		12	30
HH13	6		3	4
HH14	4	2	12	30
HH15	6	5		
HH16	4		12	
HH17	4	1		30
HH18	8	2	1	7
HH19	4	2	1	3
HH20	3	4	12	
HH21	9		12	30
HH22	4	0	0	0
HH23	6	3	12	
HH24	4	2	4	8
HH26	8	1.5	12	30
HH27	4	1.5	5	30
HH29	3	2	12	30
HH30	8	3	4	
HH31	5	5	4	
HH32	4	2.5	12	30
HH33	5	0	0	0
HH34	5	2.5	11.5	30

Table 15 Primary data of village Kamalpur

Household	Number of family members	Amount of fuel used for one time cooking	Number of months for which traditional chulha is used	Number of days for which chulha used in a month
HH1	5		12	30
HH2	3	1.5	7	20
Random	5	3.5	6	30
HH4	10		12	30
HH5	6	3	4	15
HH6	7	0.5	12	30
HH7	4	3	12	13
HH8	4	0	0	0
random	3	0	0	0
HH10	6	2.5	12	10
HH11	5	0	0	0
HH12	7	0.4	12	30
HH13	2	0.3		
Random	6	0	0	0
HH15	9	10	12	30
HH16	3	0.5	4	4
HH17	4	7	3	30
HH18	5	2.5	3	8
HH20	5	0.6	12	30
HH21	5	2	4	8
HH23	7	5	4	
HH24	6	0	0	0
HH26	16		12	30
HH27	4	0.2	12	30
HH28	6	0.5	12	30
HH29	5	5	12	30
HH30	6	6	12	30
HH31	8	10	5	30
HH32	5	3	12	30

3.3.2. Establishing relationship between per capita per day biofuel cooking consumption and number of members in family

Consumption per day per person is calculated by following formula

Equation 5 : Per capita per day biofuel consumption (Kg/day)

*Per capita per day Biofuel consumption = (A * N * D*T)/ (M * 365)*

Where A is amount of biofuel used in kilograms for one-time cooking

N is number of times biofuel is used per day to cook meals.

D is number of days in a month when biofuel is used for cooking meals

M is number of members in family.

T is number of months for which biofuel is used.

Biofuel that gets converted into energy is calculate by using following equation 6 as below. As biofuel used by people is reported as mixture of wood and dungcake, a ratio of 60: 40 of dung cake to wood is assumed to be used. Therefore, this ratio is taken into consideration calculating energy consumption through biofuels.

Equation 6: Per capita per day biofuel cooking energy (MJ/day)

*Per capita per day biofuel cooking energy = (0.6*B *11.8*0.1107)+(0.4*B*16.2*0.138)*

Where B = Per capita per day biofuel consumption as calculated in equation 5.

11.8 MJ/kg = calorific value of dungcake

0.1107= Thermal efficiency of chulha when operated on dungcake

16.2 MJ/kg = calorific value of wood

0.138 = Thermal efficiency of chulha when operated on dungcake.

The cooking energy consumed per person in household in calculated for both landless and land owning families. The individual consumption is plotted against size of household. Data points for family of size 2 and 3 for both landless and land owning families are binned as one point that is average of individual points to represent one single value.

Similarly for land owning families, points at 4,5,6,7 are binned for each family size. Points at 8 and 9 are binned together and plotted against weighted average of family size , similarly for family size 10 or greater than 10, data points are binned to represent one single value.

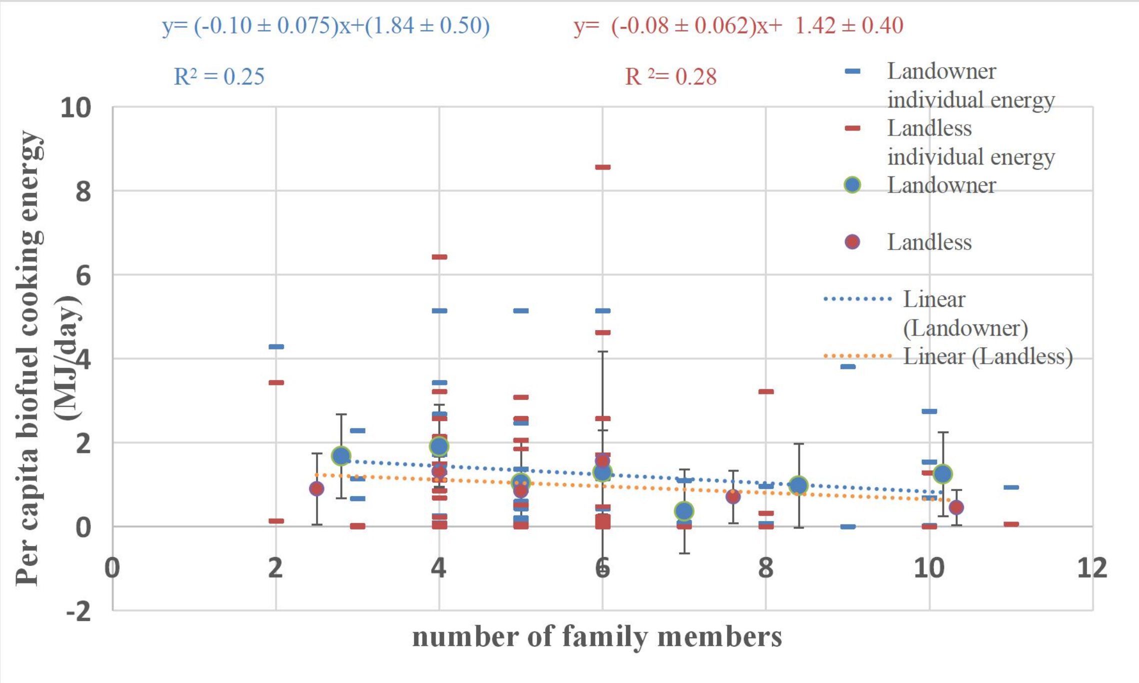

Figure 5: Per capita biofuel cooking energy VS family size**.**

The graph shows that that per capita per day biofuel cooking energy is independent of family size for both landless and land owning families. Amount of energy consumed weakly decreases with increasing number of members in a family. A similar behaviour was also observed with LPG, indicating that this trend could really be related to the economics of scale. Just like in the case of LPG there is a lot of scatter indicating family size is not the primary determinant of biofuel consumption. Instead, other factors such as income or access may play a role.

3.3.3. Establishing relationship between per capita biofuel energy consumption and cooling bill

Per capita per day Biofuel consumption as mentioned in equation 6, is plotted as function of per capita cooling bill for a month.

Individual values of per capita biofuel energy consumption and cooling bill per person are plotted in a form of scatter plot for both landless and land owning families. The cooling bill ranges from Rs. 0 to Rs. 2785, hence the data is binned depending on range of cooling bill. To form bins, average value of multiple data points falling in one bin is taken and it represents one single point. Data representing per person cooling bill is binned for ranges bill less than 100, Rs. 101-200, Rs 201-400, Rs 401-600, Rs 601-1000, and greater than or equal to Rs 1000 are represented by single point for every individual range.

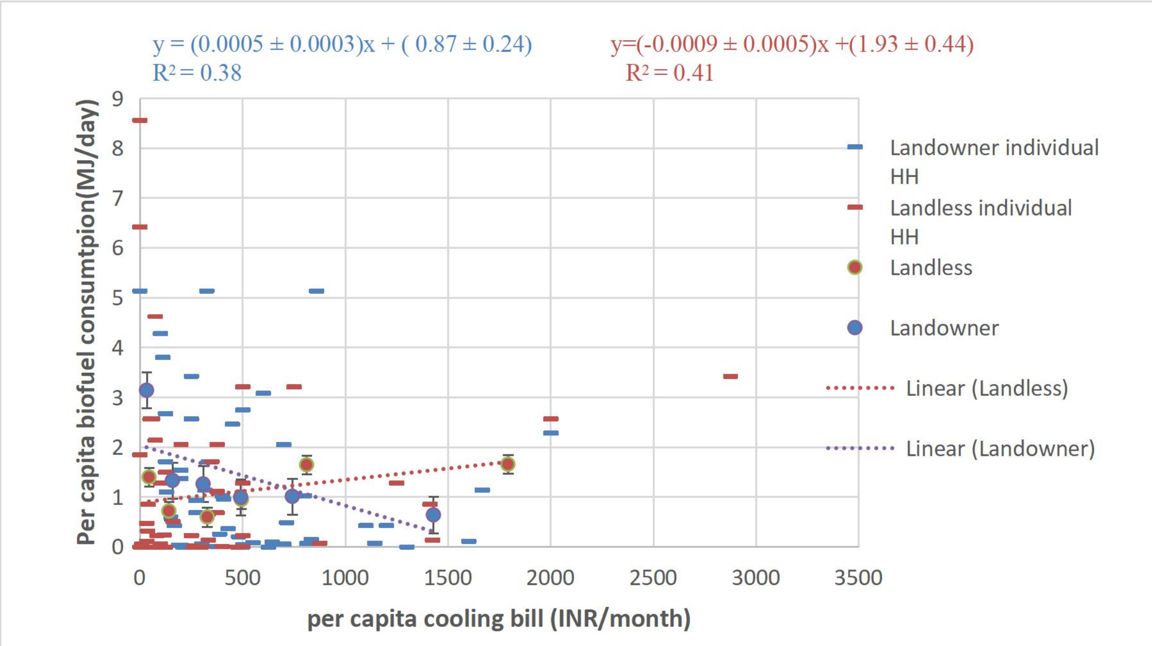

Figure 6: Per capita biofuel cooking energy VS cooling bill

The graph shows that landless families show independence of per capita biofuel cooking energy consumption with their cooling bill. A similar behavior was seen for LPG consumption as well. This seems to indicate that income is not the primary determinant of fuel choices of landless families. It is also clear that some of the landless families appear to have a higher cooking energy consumption than other households. This could be driven by the fact that some cattle owning families cook the fodder for pregnant cattle and boil much more than other households because they boil a lot of milk. On the other hand, land owning families show decrease in consumption of per capita biofuel cooking energy, when cooling bill is increased. Those same families showed an increase in LPG consumption with increase in income, indicating that income is an important parameter which drives a fuel shift from biofuel to LPG among land owning families.

3.3.4. Establishing relationship between Per capita LPG cooking energy consumption and per capita Biofuel cooking energy consumption

To look at relationship between cooking energy consumed through LPG and biofuel, a plot between Per capita LPG cooking and Per capita biofuel cooking is obtained. The points lying between 0 to 0.5 MJ/day LPG energy are binned to obtain one average value of per capita biofuel energy cooking. Similarly data points lying between 0.5 to 1.0 MJ/day, 1 to 1.5 MJ /day,1.5 to 2 MJ/day. 2.5 to 3 MJ/day and greater than 3 MJ/day are binned to obtain one value representing values lying in the bin for both Landless and land owning families.

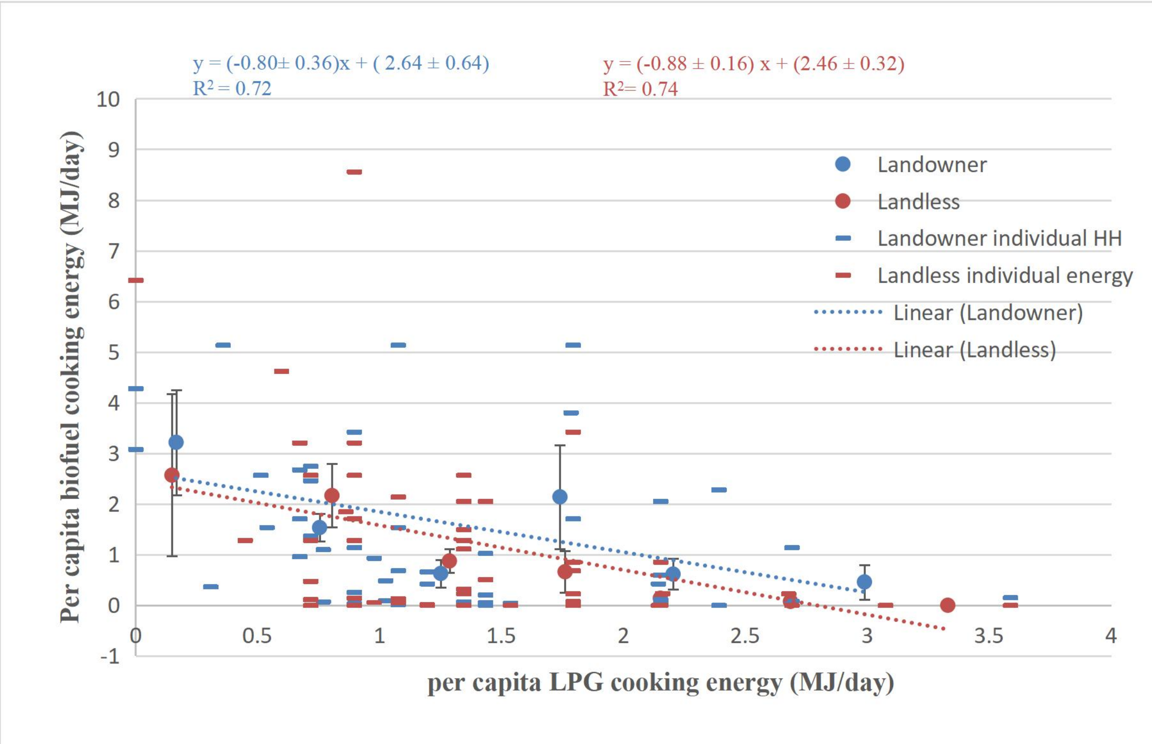

Figure 7: Per capita biofuel cooking energy vs Per capita LPG cooking energy consumption

The graph shows that in both landowning and landless families, consumption of biofuel cooking energy and LPG cooking energy are inversely related. This indicates that in both cases LPG and biofuel substitute each other. In the case of landowning families, the substitution seems to be driven by income, however, in the case of landless families, the parameters that drive the household to choose biofuel or LPG as preferred fuel were not captured by our questionnaire.

3.3.5. Establishing relationship between total energy consumption and family size

To look at total energy consumed by family as function of size of household, Total cooking energy is plotted against number of family members.

Total cooking energy is sum of energy consumption by individual through LPG and biofuels as calculated in equation 3 and 6.

Equation 7: Total Energy Consumption in MJ/kg

$$\textit{Total energy consumption} = \textit{Energy consumed through LPG} + \textit{Energy consumed through biofuels}$$

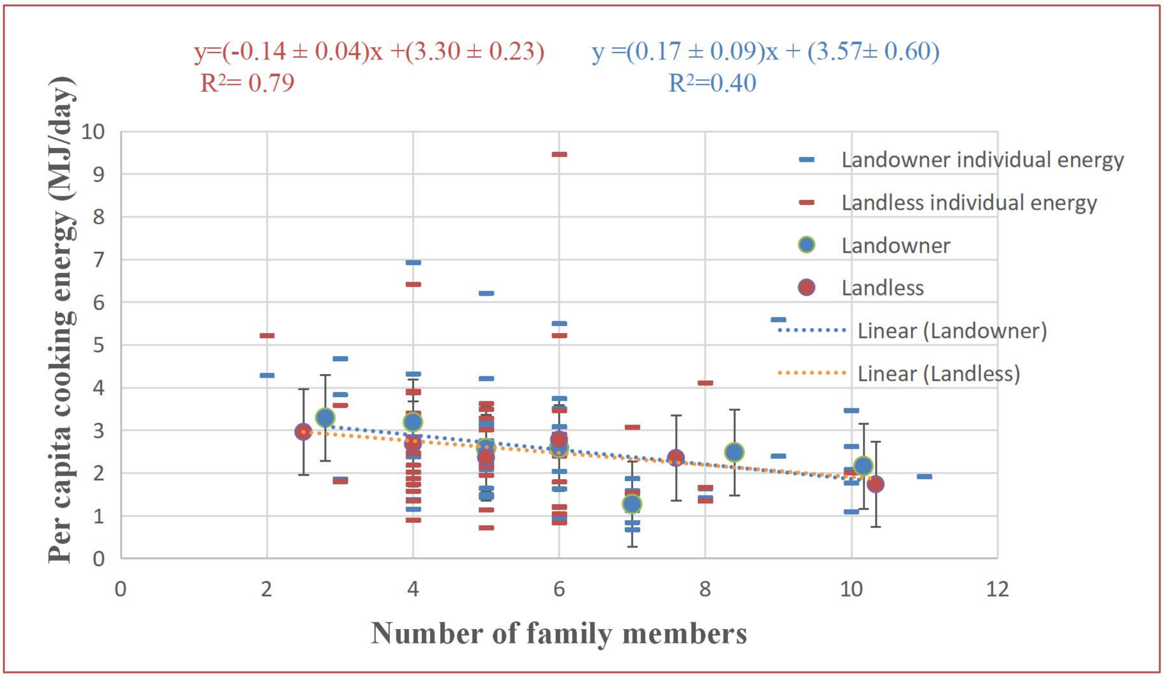

Figure 8 : Total per capita cooking energy VS size of family

The graph shows that there is no significant difference between per capita cooking energy for land owning families and landless families. The energy requirements of both categories are nearly same. This plot also clearly shows that the overall per capita cooking energy use depends on family size. It appears that cooking for a larger number of people in one go is more energy efficient than cooking for less people. An alternative explanation could be that food wastage in larger families is less.

Chapter 4

Conclusions

From the results obtained in previous chapter, following conclusions are drawn.

Domestic LPG sales are increasing every year, There is an increase in populations and consumers as well. The average per capita per day consumption calculated in study for rural Punjab is 0.055Kg / person /day, whereas, calculating it from most recent reports of Domestic LPG sales for year 2018, it comes out as 0.0437Kg/per person /day. Overall the two numbers appear to be consistent.

Family size is an important determinant of per capita cooking fuel consumption. Larger families consume less cooking energy than smaller families. Smaller families generally tend to have average sized pots whereas bigger families need bigger pots and utensils, which consume less energy when consumption is normalized to the amount cooked. Hence more energy is needed to cook the food for a person living in a small family and more wastage tends to occur with individuals and small families. The drop in the per capita cooking energy consumption with increasing family size is called the economy of scale.

Pressure cookers require less MJ of energy to cook the same food as compared to ordinary pots. The use of such energy efficient appliances as opposed to traditional earthen pots can be a confounder adding statistical noise to the per capita energy consumption recorded for families of the same size. Another confounder would be dietary preferences and income.

Landownership is a significant parameter that impacts fuel choices. Among landowning families, those with lower disposable income use more biofuel and less LPG whereas those with more disposable income use less biofuel and more LPG. For landless families both biofuel and lpg consumption appear to be independent of the disposable income.

This interesting phenomenon deserves further study. It is possible that parameters not recorded such as cattle ownership impact the cooking fuel choices of landless families.

The increase of LPG energy usage for landowning families with larger cooling bills somehow satisfies the concept of 'energy ladder theory'. This theory proposes that increase in income leads to people leaving traditional fuels and moving to modern clean fuels, however independence of biofuel energy from cooling bill for landless families indicate that there is no exhaustive use of clean fuels, even when income is increased. At the same time the data also shows that households with little disposable income can be LPG users. Stove stacking is common practice in majorly rural India as well as urban parts where accessibility is not a problem. Landless families that owns cattle have easy access to dungcake, hence easy accessibility makes less sense to them to switch exhaustively to LPG. The landless families without cattle, have to pay for the fuel in any case even if they buy firewood or dungcakes. Similar is the case with daily wagers. So if the prices of LPG are cheap, people with no cattle and daily wagers who anyways buy their fuel, might chose to switch to the more convenient LPG fuel. Also those who are landless but have secured jobs with fixed incomes may be in a position to plan better for buying LPG cylinders every month, than those that depend on variable incomes.

The calculations, show an inverse relationship between biofuel and LPG average cooking energy consumption for both Landless and land owning families. The families with higher biofuel consumption show a general trend of lesser LPG consumption and vice-versa. This indicates that even for landless families the two substitute each other. We just do not understand the factors that drive the substitution in this case.

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