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Effect of cooking fuel transition on energy demand and GHG emissions in rural households of Nepal by 2050

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ABSTRACT

Nepal —a least developed country from South Asia— is targeting towards graduating to become a developing country by 2021. In Nepal, approximately 80% of the population lives in rural areas. The energy demand in rural households is dominated (~97%) by the use of emission-intensive cooking fuels such as firewood, kerosene, and cow dung, which is responsible for the significantly high (~25 $MtCO_2e$ in 2010) GHG emissions in rural households in Nepal. Therefore, the rural household sector in Nepal must transition to a sustainable form of cooking fuel to reduce its GHG emissions in the future. The objective of the study was to develop an energy-emissions model to estimate and forecast the effect of cooking fuel on energy demand and GHG emissions in the rural household sector in Nepal up to 2050. We showed that Nepal's energy demand would be ~95 TWh by 2050 (1.3 times) than that of 2010 under Business-as-usual scenario. Furthermore, Nepal's rural household sector may reduce 92% of GHG emissions and 84% total energy demand by 2050 as compared to 2010 by transitioning to electricity and LPG based cooking fuel.

Keywords: Cooking fuel transition, energy demand, GHG emissions, rural household sector.

NOMENCLATURE

Abbreviations	
GHG	Greenhouse Gas
$MtCO_2e$	Million tons CO_2 equivalent
km	Kilometre
GDP	Gross domestic product
kWh	Kilowatt-hours
MWh	Megawatt-hours
TWh	Terawatt hours
LPG	Liquefied petroleum gas
EPSRC	Engineering and Physical Sciences Research Council
Symbols	
n	Year
i	Appliance
g	GHG gases (CO_2, CH_4, N_2O)
E_{elec}	Electricity demand
E_{lf}	Liquid fuel demand
E_{bio}	Biomass demand
A_{grid}	Access to grid electricity
H	Number of rural households
$F_{GDP-elec}$	GDP electrification index
EF_{lf_g}	Liquid fuel emissions factor
EF_{bio_g}	Biomass emissions factor
Em_{lf_g}	Liquid fuel emissions
Em_{bio_g}	Biomass emissions
O_i	Operation hours of an appliance
N_i	Number of the appliance (ownership)
P_i	Rated power consumption of an appliance

1. INTRODUCTION

Nepal —a least developed landlocked country from South Asia surrounded by India and China— is targeting towards graduating to become a developing country by 2021 [1]. Nepal had a population of 28.6 million in 147,516 km² area in 2019 [2]. In 2019, 79.85% of the population in Nepal lived in rural areas, which was 82.89% in 2011 [2]: a slight but rather gradual decrease. Nepal's average rural household size was 4.32, and the number of rural households was 4.38 million in 2011 [3].

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Nepal had an annual 6.99% GDP growth in 2019 [2] and categorised as a least developed country with US$ 1072 GDP per capita in 2019, which was US$478 per capita in 2009 [2]; a 2.24 times rise in the past ten years. Nepal's GDP per capita and electricity use showed a positive linear relationship (Fig 1), similar to other rapidly growing economies such as Bangladesh, Kenya, Philippines [4, 5]. The growth trend in Nepal's economy suggested that Nepal might have a significant electricity demand by 2050.

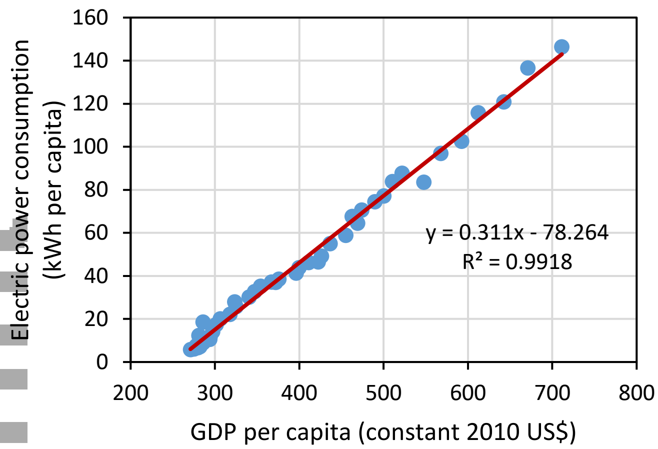

Fig 1: Relationship between GDP per capita and Electric power consumption per capita in Nepal (1971-2014); data source

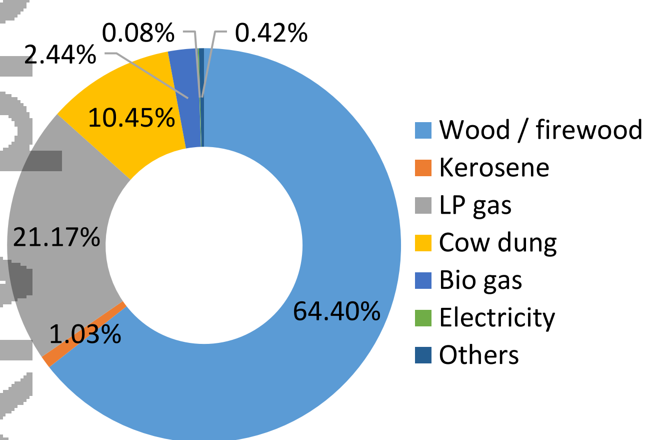

Fig 2: Cooking fuel used in Nepal's domestic sector in 2011-12; data source [6]

In 2011/12, the total energy consumption in the household sector (rural and urban) was 84 TWh in Nepal [6]. However, electricity consumption in Nepal was very low, 115.82 kWh/capita in 2011 [2]. Furthermore, in 2011, only 61.72% of the rural population in Nepal had access to electricity, which increased to 93.47% by 2018 [2]. Despite the access to electricity, the cooking fuel use in 72% Nepal's households depended on firewood in 2011-12 [7] (Fig 2), which was highly emissions-intensive. In terms of cooking fuel, rural households mainly use firewood, agricultural residue, animal waste (e.g. cow dung), biogas, LPG, kerosene and electricity [6].

Therefore, the rural household sector in Nepal must transition to a sustainable form of cooking fuel to reduce its GHG emissions from the rural household sector in the future. The objective of the study was to develop an energy-emissions model to estimate and forecast the effect of cooking fuel on energy demand and GHG emissions in the rural household sector in Nepal up to 2050.

2. METHODOLOGY

The total energy demand was calculated from the summation of electricity, liquid fuel and biomass demand. These demands and associated GHG emissions were calculated with the following equations:

$$E_{elec_n} = A_{grid} H F_{GDP-elec} \sum_{i}^{n} O_i N_i P_i \quad (1)$$

$$E_{lf_n} = H \sum_{i}^{n} O_i N_i P_i \quad (2)$$

$$E_{bio_n} = H \sum_{i}^{n} O_i N_i P_i \quad (3)$$

$$Em_{lf_n} = \sum_{g}^{n} EF_{lf_g} E_{lf_n} \quad (4)$$

$$Em_{bio_n} = \sum_{g}^{n} E_{bio_g} E_{bio_n} \quad (5)$$

Two types of assumptions were used in the model to forecast the energy demand-

Scenario assumptions: Population, access to grid electricity (A_{grid}), GDP electrification index ($F_{GDP-elec}$), and cooking technology choice was driven by scenario assumptions.

Fixed assumptions: These assumptions were based on historical data. The rural household size which determines the number of rural households (H), appliance ownership (N_i), Operation hours of an appliance (O_i), Rated power consumption of an appliance (P_i) were driven by fixed assumptions.

The conclusive pathways were derived from the calculation stage with the aid of the trajectory and fixed and compared, to suggest future energy demand and emissions pathways.

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2.1 Scenario assumptions

There were four scenario assumptions in the model: population, access to grid electricity, GDP-electrification index, and cooking technology choice. Each scenario assumptions had four levels, and 2010 was the base year. Nepal's population was ~27 million in 2010 [2], which would reach ~48.5 million by 2050 under current fertility rate Level 1 (Fig 3). Furthermore, under the level 2 (upper 95% Probabilistic Population Projections based on the World Population Prospects 2019), level 3 (Maiden), level 4 (lower 95%) the population might reach to approximately 39.5, 35.3 and 31 million, respectively.

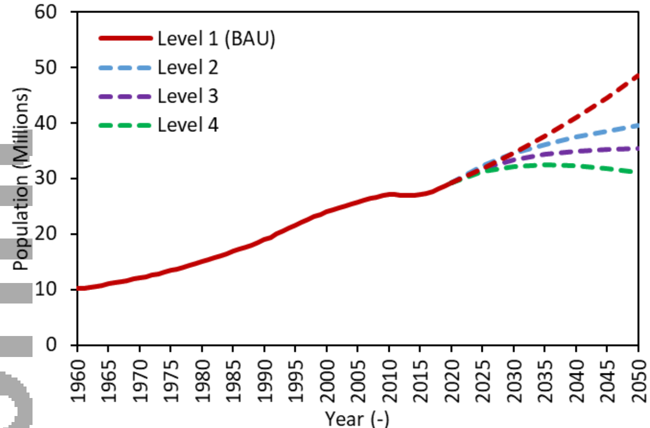

Fig 3: Historical and projected population in Nepal; data source [2, 8]

In the case of access to grid electricity, only 59.21% of people in the rural population had access. However, the access reached to 94.74% by 2017 [2]. In the study, we conducted a logit forecasting analysis to derive the scenario assumptions. Under the level 1 assumption, we assumed that ~99% of the rural population would have access to electricity by 2035. The access would be rapid under Level 2, in which case ~99% of the rural population would get it by 2030, which would be possible by 2025 and 2020 under Level 3 and 4, respectively.

GDP and electricity consumption per capita in Nepal showed a positive relationship in Fig 1, which was represented as GDP-electrification index in the model. In the model under Level 1 scenario, the index would double by 2050, which would reach 3, 5, 7-time higher than that of the base year (2010) under Level 2,3 and 4, respectively.

Cooking technology was another important scenario variable for this study. In the model, we assumed minimal change in cooking technology distribution in 2050 as compared to 2011/12 under level 1 (Fig 2, Fig 4). The dominating cooking fuel would be biomass and solids followed by LPG. Under level 2 scenario assumption, the dominating cooking fuel would be LPG (66%) followed by 22% biomass and 10% electric in 2050. The cooking fuel mix would be dominated by LPG (44%) and electric (46%) in 2050 under Level 2 assumption. The most optimistic scenario assumption would be level 4, where 80% of the rural households in Nepal might use electric cooking in 2050.

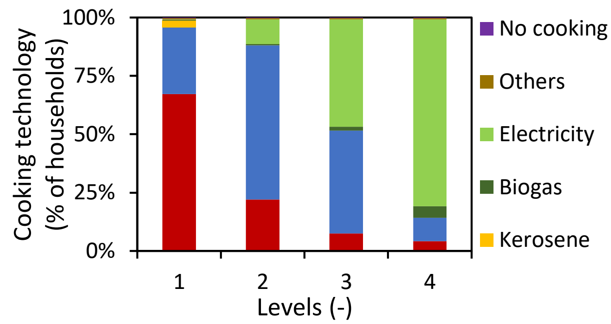

Fig 4: Cooking technology choice in 2050

2.2 Fixed assumptions

There were four fixed assumptions such as rural household size, appliance ownership, rated power consumption and operation hour of those appliances. The average rural household size was calculated to be 5.12 in 2011 from a total rural population [2] and rural household numbers [9]. In the model, we estimated from World Urbanization projection 2020-2050 [10] that the size of the rural household might reduce gradually to 4.8 in Nepal by 2050.

The appliance ownership was projected (Table 1) with the utilisation of logit forecasting methodology adopted from [11]. Also, the rated power consumption and operation times in a day were showed in Table 2.

Table 1: Appliance ownership projection 2010-2050

Appliances	Ownership* in 5-year timescale (%)								
	2010	2015	2020	2025	2030	2035	2040	2045	2050
Lighting	61	70	80	92	105	121	138	159	182
Radio	51	31	25	24	23	22	21	20	19
TV	29	33	36	39	43	47	51	56	61
Computers	3	4	4	4	4	4	4	4	4
Mobile Phone	54	84	110	143	186	242	242	242	242
Refrigerator	3	5	5	5	5	5	5	5	5
Fan and Air-conditioning	61	70	80	92	105	121	138	159	182

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Cooking (Biomass)	75	72	69	66	63	61	58	56	53
Kerosene	2	2	2	2	2	2	1	1	1
LPG	19	21	23	25	27	29	32	34	37
Biogas	3	3	3	3	3	3	3	2	2
Electrical	0	2	3	4	5	6	6	6	6
Others	2	2	2	2	2	2	2	2	2

Table 2: Rated power consumption and operation time of appliances

Appliances	Rated consumption (W)†	Operation (hrs/day)
Lighting (Incandescent)	40#	2#
Lighting (CFL)	10#	4#
Lighting (Florescent)	20#	4#
Lighting (LED)	5#	4#
Radio	1#	2#
TV	20#	3#
Computers	60#	0.5#
Mobile Phone	1#	2#
Refrigerator	300#	8#
Fan	15#	4#
Air conditioning	1100#	2#
Cooking (Biomass)	59##	-
Cooking (Kerosene)	79##	-
Cooking (LPG)	2##	-
Cooking (Electric)	2000	3

Adopted from [12]
Unit was kWh. Calculated from [13]

3. SCENARIO DEVEOPLMENT

For the study, four scenarios were modelled with constant population growth (Level 1) and present GDP growth (Level 1) for Nepal up to 2050. The scenarios were:

a) Business as usual (BAU): The cooking fuel mix would be dominated by biomass and solid fuel (67.2%).
b) High emissions scenario (HES): The cooking fuel mix would be dominated by LPG (66%).
c) Moderate emissions scenario (MES): The cooking fuel mix would be dominated by LPG (44%) and electric (46%).
d) Low emissions scenario (LES): The cooking fuel mix would be dominated by electric (80%).

4. RESULT AND DISCUSSION

Under the BAU scenario, the aggregated energy demand in the rural domestic sector of Nepal would reach ~95 TWh in 2050 (Fig 5) which would be 1.3 times than that of 2010. The aggregated energy demand would reduce to 36 TWh by 2050 by shifting the majority of cooking fuel choice to LPG under HES. The demand could be reduced further to 16 TWh by 2050 under MES. Under LES, rural households in Nepal might reduce total energy demand to 11.6 TWh by shifting 80% of the household cooking to electric.

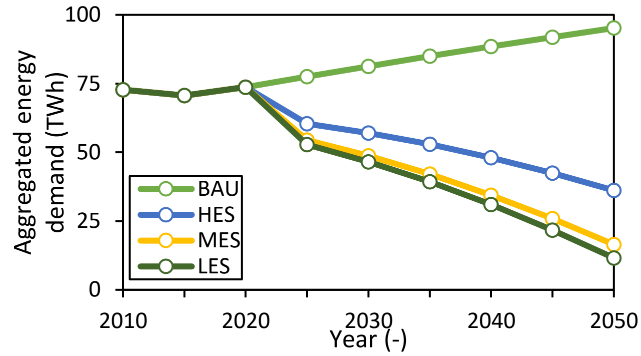

Fig 5: Total aggregated energy demand 2010-2050

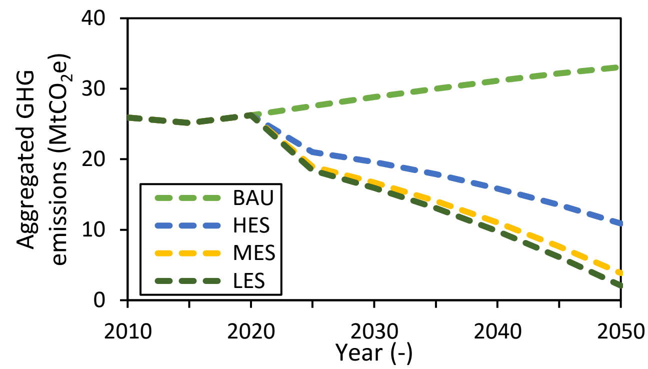

Fig 6: Aggregated GHG emissions 2010-2050

Under the BAU scenario, the aggregated GHG emissions would be 33 $MtCO_2e$ by 2050 (Fig 6), which would be 1.28 times higher than that of 2010. Nepal's domestic sector would reduce the emissions to 11 $MtCO_2e$ under HES scenario. Under MES scenario, the rural domestic sector would reduce the emissions to 4 $MtCO_2e$ by shifting to a dominating mix of electricity and LPG and substantially reducing biomass energy use for cooking (Fig 7). Nepal could reduce 92% of the aggregated GHG emissions from rural households by 2050 under LES as compared to 2010 by shifting 80% of the households towards electric cooking. Furthermore, shifting towards electricity as cooking fuel choice under LES scenario would reduce the aggregated energy demand 84% by 2050 as compared to 2010 (Fig 5), which would be predominantly due to reduction in the use of biomass-based cooking fuel.

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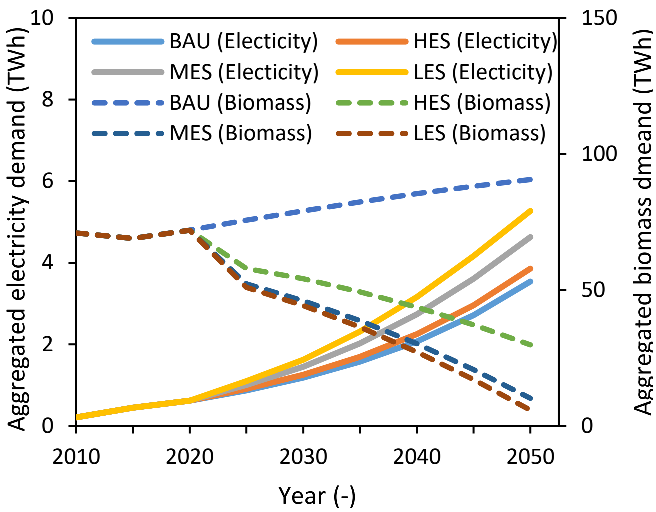

Fig 7: Electricity and biomass energy demand 2010-2050

5. CONCLUSION

The energy demand model demonstrated a significant rise in energy demand by 2050 in Nepal's rural household sector. Under the BAU scenario, the energy demand would increase 1.3 times by 2050 than that of 2010. Although, the significant number of households had access to grid electricity, most of them used biomass-based cooking fuel, which was responsible for the majority of 33 $MtCO_2e$ aggregated GHG emissions. A shift towards electricity and LPG based cooking would significantly reduce the aggregated energy demand and associated GHG emissions in the rural domestic sector of Nepal. The results showed 92% GHG emissions and 84% energy demand reduction potential (by 2050) by shifting the cooking fuel from biomass to electricity. The model rendered an opportunity to focus on the detail energy use in rural households of Nepal and suggested a shift towards efficient, sustainable and convenient form of energy/technology for cooking may substantially reduce the energy demand and GHG emissions by 2050.

The presented research outputs will also further be used to inform the work of the 'Decarbonisation of energy systems of South Asian developing economies through regional collaborations' project (funded by the EPSRC Supergen Energy Networks Hub) where the objective is to combine energy-emissions models for Nepal, Bhutan, Bangladesh and India to examine the decarbonisation feasibility for Bangladesh through regional energy collaboration.

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