

Biogas for Clean Energy Consumption and GHG Emission Reduction

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Abstract

This study analyses the biogas for clean energy consumption and GHG emission reduction in two ecological regions - Hill and Terai – of Nepal. Biogas is methane-rich gas mostly used for cooking in rural households in Nepal. Biogas is interrelated with energy consumption and associated greenhouse gas emissions. The unsustainable use of emission-intensive biomass cooking fuel and other commercial fuels are the major sources of GHG emissions. If biogas is produced and used to its full capacity, it can replace other cooking fuels in the household. The main objective of this study was to observe the existing production and use status of biogas to explore the new pattern of energy consumption and associated GHG emission reduction. This research was carried out in Chitwan and Lamjung districts, representing both Terai and Hill regions of Nepal. Biogas household survey, key informant interview, and direct field observations were used for data collection, while Statistical Package for Social Sciences (SPSS), Volumetric Methane Prediction (VMP), and Long-Range Energy Alternative Planning System (LEAP) Energy Environment Modal were used for data analysis. The result showed that if the biogas completely replaces other cooking fuels, it reduces energy consumption by 40% and GHG emission up to 19 tCO₂e per year. It is mostly from saving on fuelwood burning, by 31.8 GJ/household in the Chitwan/Terai and 19.3 GJ/household in Lamjung/Hill from 2012-2040 compared with a non-biogas household.

Keywords

Biogas, energy consumption, SPSS, VMP, LEAP, GHG emission reduction

1. INTRODUCTION

1.1 Biogas

Biogas basics

Biogas is methane-rich gas produced through the anaerobic decomposition of organic matter. Cattle dung is the most used feedstock at GGC 2047 domestic type biogas digester in Nepal. Biogas is a renewable clean energy source that is mostly used for cooking in rural households in Nepal. Domestic biogas plants seem highly potential to reduce the unsustainable use of biomass cooking fuel, however, the production and use of biogas should be enough to fulfill the daily cooking energy needs of the biogas household. The production capacity of a biogas

plant depends on the quality and quantity of feedstock used.

The capacity of a biogas plant in terms of theoretical biogas production efficiency depends on (i) plant size (feeding of the prescribed quantity of feedstock); and (ii) actual daily feeding. Mostly used domestic plants in Nepal are the size of 4 m³, 6 m³, 8m³, and 10m³. The size of a 1 m³ capacity plant requires 6 kg of cattle dung per day and each kg of dung produce up to 40-liter biogas. One adult cow gives an average of 8 kg dung per day, So, at least 3 cows need to rear to feed into a 4 m³ size biogas digester daily, and on the same basis for other sizes plants. The actual biogas output can be assessed based on the

gas being used per day, considering that a biogas stove burning at full capacity consumes 400 liters (0.4 m^3) of gas per hour [1] [2]. Hence, a family of 5 members uses biogas daily for two meals, breakfast and afternoon tea/snacks. The methane and energy content in biogas are determined by the biochemical composition of the feedstock. High protein content feedstock produces higher methane content biogas while rich organic fat content feedstock produces biogas with higher energy content [3].

Besides type and quantity of feedstock, several factors affect the rate of digestion and biogas production capacity, including temperature, carbon-nitrogen (C/N) ratio, hydraulic retention time (HRT), organic loading rate (OLR), dilution and consistency of inputs, pH value of the input mixture, toxicity, altitude and precipitation [4], [5], [6].

Production and use of biogas in the world

There is a strong potential role for biogas in the transformation of the global energy system. In 2019, global biogas production had an equivalent energy content of 1.43 exajoules whereas the production was only 0.29 exajoules in 2000 [7]. Production and use of biogas have also been increasing as a source of bioenergy to achieve Sustainable Development Goals (SDG) in many ways. [8]. It is forecasted that biogas production will nearly be doubled by 2030 [9].

Production and use of biogas in Nepal

Biogas is one of the promising renewable energy sources in Nepal. Total biogas potential households in Nepal are estimated to be 1.93 million, out of which 57% are expected in the Terai, 37% in the Hill, and the remaining 6% in

the Mountain (Table 2) [10]. Although almost all the districts in Nepal now have access to biogas systems, less than 30% of the total potential has been covered yet.

Table 1: Geographical region-wise biogas potentiality and % of biogas plants constructed by 2014 (Source: [10])

Region	Potential biogas households	Number of biogas plants constructed	% of total potential covered
Mountain	123900	2050	1.6
Hill	7,23,600	1,65,698	22.9
Terai	1,089,000	162,839	14.9

Production and use of biogas in Chitwan and Lamjung districts

Installation of biogas plants in both districts was started in 1992/93. The total number of biogas plants installed in Lamjung and Chitwan was 9,623 and 17,798, respectively (Table 2).

Table 2: Total number of biogas plants installed in Chitwan and Lamjung districts (Source: [10],[11])

District	Total number of households	Potential number of households suitable for biogas	Total number of biogas plants installed by 2014
Lamjung	42,048	14,246	9,623
Chitwan	132,345	57,115	17,798

The number of annual biogas plant installations in the districts has been relatively steady over the past decade after increasing in the 1990s (Figure 1). The demand for biogas plant construction remains encouraging, with more than 400 biogas plants installed in Lamjung, while more than 800 biogas plants were constructed in Chitwan in 2014 [10]. However, both districts showed a

general decline in biogas plant installation from 2011.

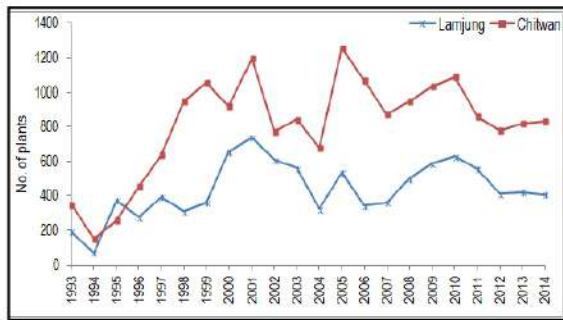


Figure 1: Trend of Biogas Development in Chitwan and Lamjung (Source: [1])

1.2 Energy consumption

Global energy consumption patterns

IEA [12] declared that clean energy transition can reduce consumers' energy bills through managing energy-efficient improvements like the use of biogas biofuels [9]. Global energy consumption rebounded with a 5% growth in 2021, after a 4.5% decline in 2020, in the context of the global pandemic. However, it is estimated that global energy consumption in 2040 will be 56% higher than in 2010. Moreover, a study revealed that energy demand may double in the first half of this century mostly because of use in developing countries, as they use low-quality fuels as GDP and energy consumption trend (Figures 2 & 3). The amount of energy consumed per unit of GDP in Nepal is 1.8 times higher than India, 4.5 times in Bangladesh, and 4.5 times the world average [13]. This figure suggests that it has significant potential to increase both- its use for energy production and energy efficiency [14].

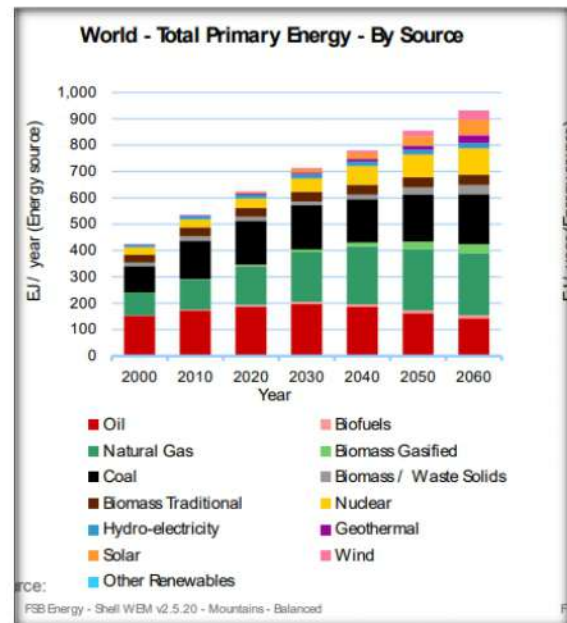


Figure 2: World energy status (Source: [12])

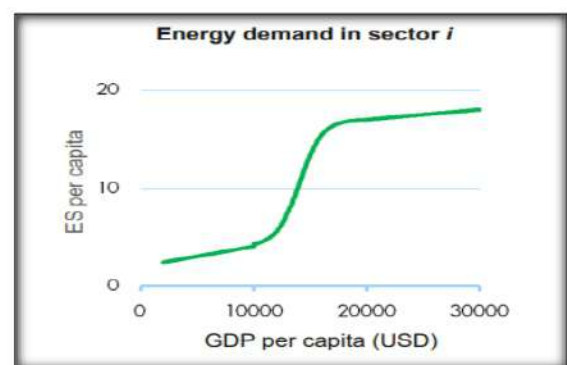


Figure 3: Energy Service (ES) /demand per capita versus GDP per capita (Source: [13])

IEA also reported that bioenergy accounts for roughly one-tenth of the world's total primary energy supply today. According to Net Zero Emissions (NZE) by 2050, biogas provides clean cooking access for 400 million people in 2030, and total biogases demand rises to 5.5 EJ [12].

Nepal's energy consumption patterns/ trends

"From 2000 to 2013, Nepal's energy consumption grew 27%, from 8.04 to 10.17 million tonnes of oil equivalent (mtonne), and consumption is projected to continue to increase, driven by a growing population and increased

economic production” [15] [13]. Seventy percent of the total primary energy supply in Nepal in 2017 was biomass [16]. More than 80% of total final energy consumption was used in the residential sector (Figure 4).

Table 3: Energy Consumption Trend in Nepal
(Source: [16])

Fuel type	2014/15	2015/16	2016/17	2017/18
Firewood	71.2	65.8	67.6	62.5
Agriculture residue	3.5	3.2	3.3	3.1
Cow dung	3.7	3.4	3.5	3.3
Biomass Total	78.4	72.4	74.5	68.9
Coal	4.6	5.2	4	2.79
Petroleum Products	10.8	16.2	13.8	18.7
Electricity	3.7	3.9	4.1	4.0
Renewable	2.5	2.3	3.5	3.2
Total Energy in Mtoe	11,768	12,866	8,257	9,019

Around 70% of biogas developed today is used for power and heat, 20% is for cooking purposes and the other 10% is upgraded to biomethane. More than half of biogas production today takes place in Asia, which also has the largest growth potential given the availability of significant volumes of organic feedstocks such as crop residues and rising levels of municipal solid waste.

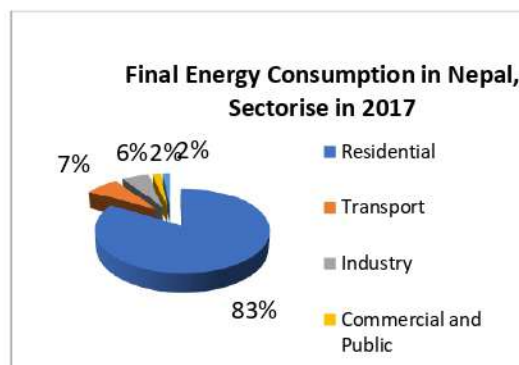


Figure 4: Energy consumption pattern in Nepal
(Source: [16])

In 2019, the primary energy consumption of Nepal increased from 0.05 quadrillion btu in 2000 to 0.15 quadrillion billion tonnes unit (btu) in 2019 growing at an average annual rate of 6.49%. Most of the population in Nepal lacks access to clean and safe methods of cooking [16], [17]. The residential sector consumed almost 84% of the total energy consumption in Nepal 2017/18), where about 85% of the residential energy is consumed by the rural population who represent about 80% of the country's population [18]. Thus, the rural population still depends on biomass resources to meet their energy demand.

Energy use pattern in Chitwan and Lamjung

Following the trend of the national energy consumption pattern, fuelwood is the major source of energy used for cooking and heating in both districts (Table 4). About half (49.1%) of the total households in Chitwan district use fuelwood as the major source of cooking fuel. followed by LPG (39%) and biogas about 9.2%. though kerosene, cow dung, and electricity are used for cooking by only 0.75%, 0.16%, and 0.18% of the total households, respectively [11]. Similarly, about 70% of the total households in Lamjung use fuelwood as their major source of energy for cooking which is followed by LPG (19%). Biogas is the third major source with about 10% of the total households in Lamjung using biogas for cooking. Kerosene, cow dung, and electricity are used for cooking by only 0.4%, 0.14%, and 0.13% of the total households, respectively [11].

Table 4: Energy Consumption in Chitwan and Lamjung District, Nepal (Source: [11])

	Chitwan		Lamjung	
	Cooking		Cooking	
Fuelwood	49.1		70	
LPG	39		19	
Biogas	9.2		10	
Electricity	0.18		0.13	
Kerosene	0.75		0.4	
Cow dung	0.16		0.14	

1.3 GHG emissions

Global GHG emission status

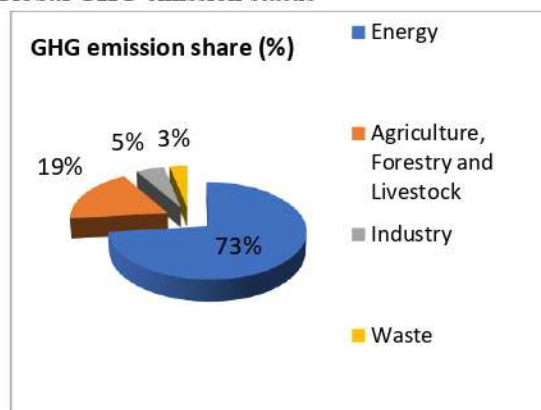


Figure 5: Global GHG emission by sector (Source: [12])

Globally, around 50 billion tonnes of greenhouse gases are emitted each year. Global energy-related carbon dioxide emissions rose by 6% in 2021 (36.3 billion tonnes), their highest ever level, as the world economy rebounded strongly from the Covid-19 crisis and relied heavily on coal to power that growth [12]. But, most of the emission sources are fossil fuel combustion and industrial processes.

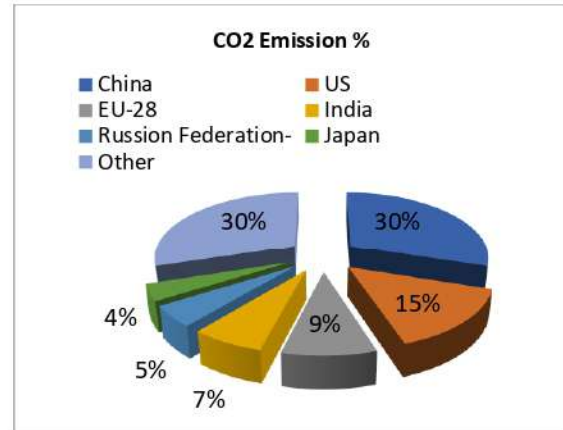


Figure 6: Global CO₂ emission in 2014 (Source:[19])

It has been reported that: "Biogas has the potential to reduce global GHG emissions by 3,290 to 4,360 Mt CO₂ eq., which is equivalent to 10-13% of the world's current greenhouse gas emissions. Generally, biogas is a clean gas that comparatively does not produce GHG emissions except for some methane gases released from the biogas plant. Methane gas is 25 times more dangerous than CO₂ emission [20], [21]. Hence GHG emission from biogas plant is also counted.

Nepal's GHG emission status

Nepal has ratified the Kyoto Protocol from the UNFCCC, which considers the justifiable use of resources to limit or reduce the emission of gases that contribute to global warming (MoPE, 2004). A study by [22] revealed that about 4.17 million tCO₂e can be mitigated by deploying RETs in Nepal, and biogas has the potential to mitigate about half of it by replacing traditional woody fuels which have the highest emission factor. Per capita, the GHG emission rate in Nepal is decreasing from 2005 to 2020, though it is predicted to be increased after 2025.

Table 5: Energy consumption and GHG emission status of Nepal (Source: [22])

Index	2005	2010	2015	2020	2025	2030
Per capita energy (GJ)	15	16	16	17	19	23
Energy per household (GJ)	76	79	78	78	13	17
Share of Renewable (%)	11.7	11.9	11.2	12.3	15.4	22.1
Per Capita GHG production (kg)	474	459	420	392	508	672

The CES (2013) predicted that the per capita GHG emissions increase from 200 kgCO₂e in 2005 to 240 kgCO₂e in 2030. Nepal emitted 51.2 million tonnes of GHGs in 2018. The total GHG emission contribution of Nepal is very modest (0.025%) compared to the global annual emissions [23]. Nepal's contribution to global CO₂ emissions from fuel combustion in 2013 was only 0.01%, which was just 0.21% and 0.11% of India and Asia's emissions [24].

Although Nepal is one of the lowest GHG emitters in the world, the country is highly vulnerable to climate change impacts [25]. It ranks fourth on the climate change vulnerability index as being at extreme risk from climate change effects due to a high level of climate change risk exposure and low adaptive capacity. The key determining factors in the ranking are poverty, population pattern, development, natural resource management, agriculture dependency and conflicts, and adaptive capacity [26]. The majority of GHG emissions in Nepal are derived from the unsustainable use of firewood for household energy applications and petroleum fuels for the transport and industrial sectors [27].

1.4 Research problem, objectives, and rationale of the study

More than 70% of the total primary energy consumption in Nepal is biomass. Unsustainable use of fuelwood and other cooking fuel are the main causes of GHG emissions. Biogas is a clean renewable source of energy which can be produced at the household level by using simple technology and at low cost. Total potential biogas households in Nepal are 1.3 million but less than 30% of total potentiality has been covered yet. Moreover, it is reported that biogas households are using other cooking fuels as alternative energy sources as biogas is not produced enough to fulfill their daily cooking energy needs. It is obvious that once the use of biogas production is enough to replace emission-intensive other cooking fuels it directly impacts on entire energy consumption pattern. However, the study of the existing status of domestic biogas production; the pattern of biogas consumption; the way of biogas production increment, and its impact on clean energy consumption; and associated GHG emission reduction in the present context and even up to far future has not been done yet. Hence, the main objective of this study was to assess the existing condition of biogas production & use in that particular biogas household to analyze the impact of biogas on clean energy consumption and associated GHG emission reduction. The findings of this study would be useful beyond the country where similar conditions exist.

2. RESEARCH METHODOLOGY

This research included quantitative and qualitative data gathered from both primary and secondary sources. Two districts of Nepal, namely, Lamjung from the Hill region which extends up to the High Himalayas, and Chitwan from the Terai region were selected for this study (Figure 7). The selected districts represent the two distinct regions in terms of biogas production which depend upon temperature, energy use practices, fuel costs, availability of feedstock, subsidy policy, and remoteness. Both districts have more than 20-year history of biogas installation [28].

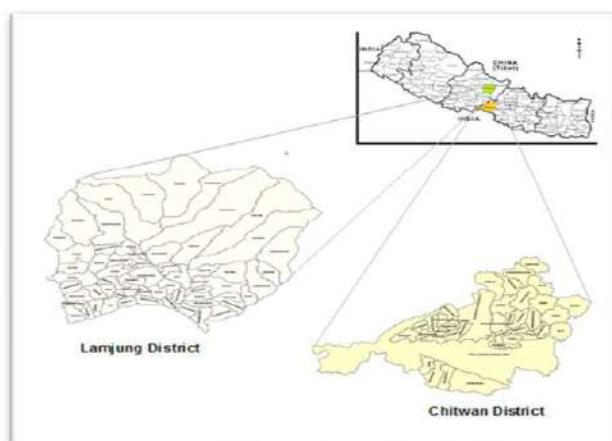


Figure 7: Map of Nepal showing the two study districts

2.1 Sampling

A circular systematic sampling method was used to select the survey households. For each district, the total number of biogas households (N) was then divided by the sample size (n) to obtain the interval (i).

$$n = \frac{Nz^2p(1p)}{Nd^2 + z^2p(1-p)} \dots \dots \dots \text{(Equation 1)}$$

where,

n = Sample size

N = Total population size

z = Confidence level (at 96% level, $z = 1.96$)

p = Proportion of samples on population estimate (95%)

d = margin of error ($\pm 3.4\%$, expressed as a proportion, i.e., 0.034)

The original sample size given by the above equation was 157 for both districts.

2.2 Data collection methods



Figure 8: A household survey in Lamjung district



Figure 9: Biogas Plant Observation in Chitwan District

Biogas household surveys with formal and informal discussion, interview, and site observation methods were adopted for primary

data collection. A thorough literature review was applied for secondary information and model application.

2.3 Data analysis methods

A comprehensive analysis of household energy consumption patterns for cooking before the use of biogas, and changes in the consumption and quantity of fuels after the use of biogas, were analyzed to examine the role of biogas in replacing conventional fuel sources. Analyzing the changes in energy use patterns after the use of biogas is important for measuring the potential and real benefits of biogas systems. The data were analyzed using Microsoft Excel and Statistical Package for Social Sciences (SPSS) for statistical data analysis of surveyed households, Volumetric Methane Prediction (VMP) model for biogas plant efficiency increment analysis, and Long-Range Energy Alternative Planning System (LEAP) model for assessing the impact of biogas systems on energy consumption and GHG emissions reduction.

In VMP Model the effect of co-digestion of dung with agricultural residues to increase a plant's production capacity was analyzed and calculated to identify how much methane (CH₄) could be produced per kg Volatile Substate (VS) % in any feedstock (both in mono and co-digestion condition) with different (a,b,c,n) biochemical composition per unit size of biogas digester per day by using Bushwel's equation :

$$\text{BMP (m}^3 \text{ CH}_4\text{/kg VS)} = 22.4 * \frac{\frac{n}{2} + \frac{a}{8} + \frac{b}{4} + \frac{3c}{8}}{12n + a + 16b + 14c}$$

..... (Equation 2)

LEAP is a bottom-up energy environment model which is a widely used modeling tool for the study

of integrated energy policy analysis and climate change mitigation assessment [29].

The four different scenarios were generated in LEAP based on energy use information and related policy conditions such as biogas and subsidy policy: 1) reference or business-as-usual; 2) improved production efficiency; 3) increased subsidy; and 4) integrated scenario (with the cumulative effect of improved biogas production and increased subsidy scenarios (Figure 10).

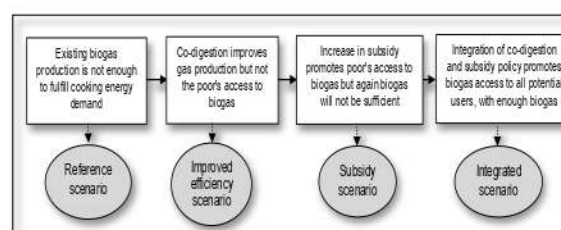


Figure 10: The logic connecting the alternative scenarios to the reference scenario

Key assumptions in LEAP model

The *Key assumptions* for the scenario analyze and comprise demographic variables (population, population growth rate, households, and household size), microeconomic data (GDP, GDP growth rate, per capita income/growth), existing and potential biogas households and feedstock potential (dung and crop residues) for the studied districts and the representative regions. The demographic details were taken from the National Population and Housing Census 2011 [11]. It is assumed that the population growth rate, household growth rate and household size remain the same over the study period for all the scenarios.

The demand analysis consists of final energy demand in which energy consumption is calculated as the product of total activity level and

final energy intensity at each given technology branch (Equation 2) [29].

$$(\text{Energy demand})_{b,s,t} = (\text{Total activity})_{b,s,t} \times (\text{Energy intensity})_{b,s,t} \dots\dots\dots (\text{Equation 3})$$

Where b is the branch, s is the scenario and t is the year (from base year [0] to the end year).

The environmental emissions are calculated as the product of energy consumption and emission factor for each technology, year, and pollutant (Equation 3) [30], [31].

$$(\text{Emission})_{t,y,p} = (\text{Energy consumption})_{t,y} \times (\text{emission factor})_{t,y,p} \dots\dots\dots (\text{Equation 4})$$

Where t is technology, y is year and p is a pollutant.

The IPCC Tier 1 default emission factors contained in LEAP were used for the emission analysis. The environmental emissions or effects were expressed in terms of GHG emissions using the default global warming.

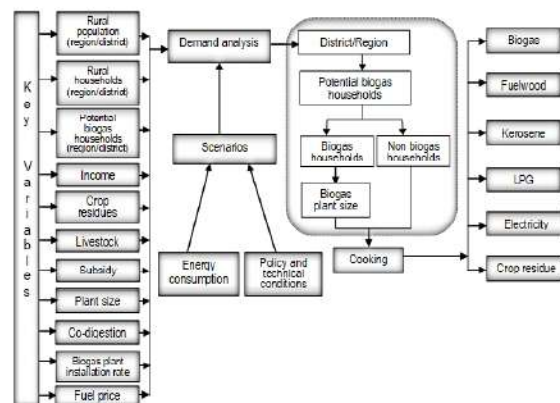


Figure 11: Conceptual framework for analysing energy consumption and GHG emission in LEAP

3. RESULTS

3.1 Existing status of energy consumption in Chitwan and Lamjung before and after biogas

The study showed that although fuelwood was the most prevalent energy source before the installation of biogas plants, biogas changed the energy use pattern, successfully substituting the fuelwood and other biomass sources in both districts.

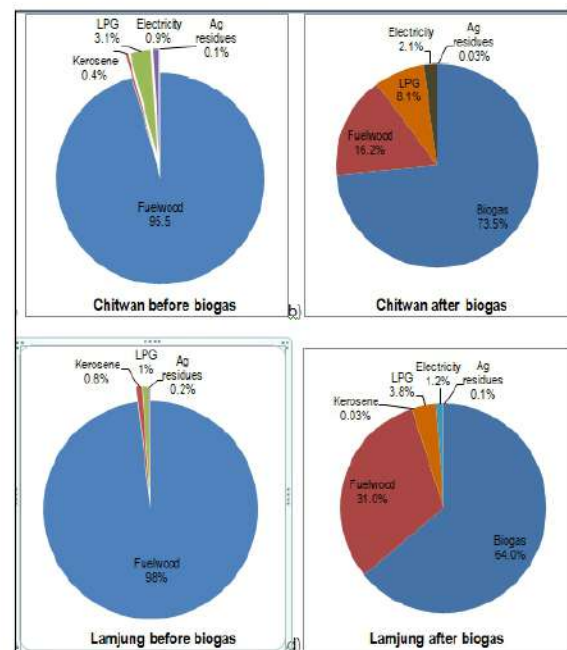


Figure 12: Biogas demand and consumption pattern in Chitwan and Lamjung

The demand and consumption of biogas in the surveyed households were analyzed to identify the daily biogas deficit. Households reported a peak energy demand for cooking between 7:00 am and 8:00 am and 7:30 pm and 8:30 pm (Figure 12). The existing biogas production was usually not enough to fulfill the cooking energy needs of a household all year round. Biogas deficit was higher during winter due to lesser gas production in colder temperatures. On average, biogas

fulfilled 87% and 79% of the cooking energy needs of a household in summer and 60% and 49% of the demand in winter in Chitwan and Lamjung, respectively. Users were using multiple sources of energy for a meal.

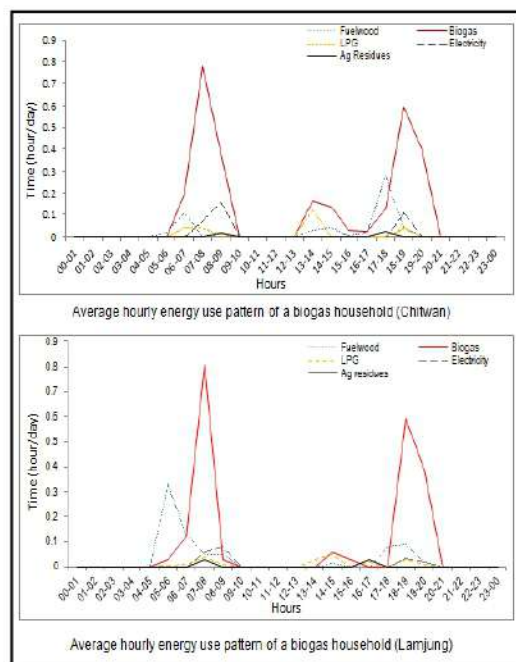


Figure 13: Average daily biogas demand and consumption per household in Chitwan and Lamjung

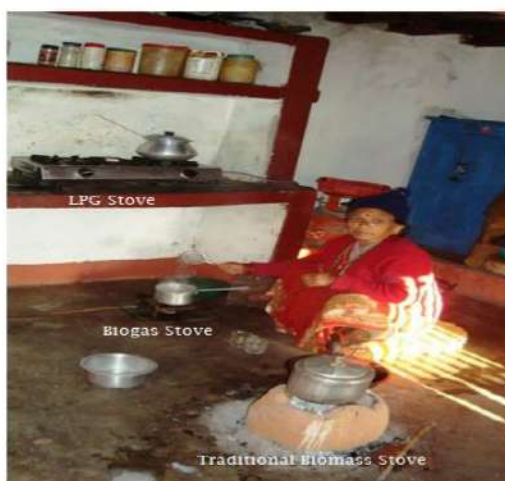


Figure 14: Using three energy sources for cooking a meal in Lamjung

Reasons for lower biogas production

Respondents mentioned more than one reason for lower gas production. The lower temperature was felt as the main reason for less gas production during winter in 76% and 87% of households in Chitwan and Lamjung, respectively (Table). Similarly, insufficient feedstock, lower than the prescribed amount, fed into the digester was considered another major reason in 49% of households in Chitwan and 46% of households in Lamjung.

3.2 Biogas production increment due to co-digestion

This study suggests that co-digestion of mixed feedstock could be the best solution for underfed domestic biogas plants to increase biogas production. Co-digestion of crop residues with dung and human excreta could increase biogas yield by approximately 50-150% depending on the proportion of the co-substrates and temperature. It is assumed that this amount of biogas increment will be enough to replace other emission cooking fuels of the biogas household every day.

3.3 Impact of biogas on energy consumption pattern in both districts

The energy consumption after the installation of biogas is mainly driven by the activity level and impacts of various scenarios. In the reference scenario, the total final energy consumption in the potential biogas households for cooking from all fuels is projected to decrease by 506 TJ from 2012-2040 in Chitwan with an average annual reduction of 0.8%, and 72 TJ in Lamjung with an average annual reduction of 0.4% in the same period (Table 8.10). The reduction in total energy

consumption is due to the reduction in inefficient fuelwood consumption replaced by biogas.

Table 6: Final energy demand projection of biogas households in Chitwan and Lamjung under different scenarios in LEAP for selected years by plant size (TJ).

Fuels	2012	Reference		Improved efficiency		Subsidy		Integrated	
		2020	2040	2020	2040	2020	2040	2020	2040
Chitwan									
Electricity	2.7	3.8	6.5	6.5	17.0	4.0	8.4	7.3	26
LPG	8.4	12.1	24.5	2.2	2.3	13.2	35.9	2.0	-
Fuelwood	2485	2310	1840	2096	1295	2207	1004	1930	-
Biogas	106	137	225	213	401	154	359	246	668
Crop residue	0.05	0.03	-	0.03	-	0.04	-	0.03	-
Total	2602	2463	2096	2318	1715	2378	1407	2184	694
Lamjung									
Electricity	0.3	0.5	1.0	4.1	9.9	0.5	1.1	4.6	15
LPG	1.0	1.4	2.6	0.01	0.02	1.4	3.3	0.03	-
Fuelwood	642	618	550	427	271	603	431	337	-
Biogas	47	52	64	79	109	54	82	82	137
Crop residue	0.12	0.08	-	0.06	-	0.08	-	0.06	-
Total	690	672	618	510	390	659	518	424	152

Total fuelwood energy consumption is estimated to decrease by 645 TJ with an average annual reduction rate of 1.1% in Chitwan and by 92 TJ with an average annual reduction rate of 0.6% in Lamjung in the reference scenario from 2012-2040. The total consumption of biogas is predicted to increase by 2.7% per annum from 106 TJ in 2012 to 225 TJ in 2040 in Chitwan and 1.1% per annum from 47 TJ to 64 TJ in Lamjung in the same period.

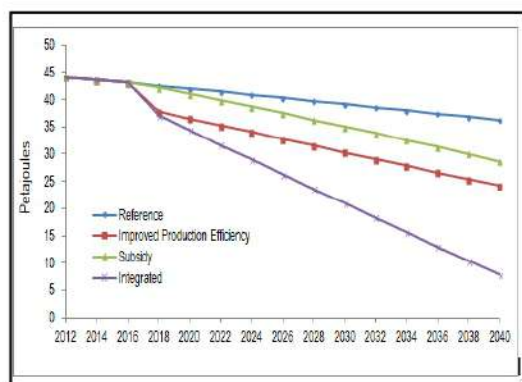


Figure 15: Final energy demand projection of potential biogas households from all fuels in the Lamjung district for the four scenarios respectively in LEAP

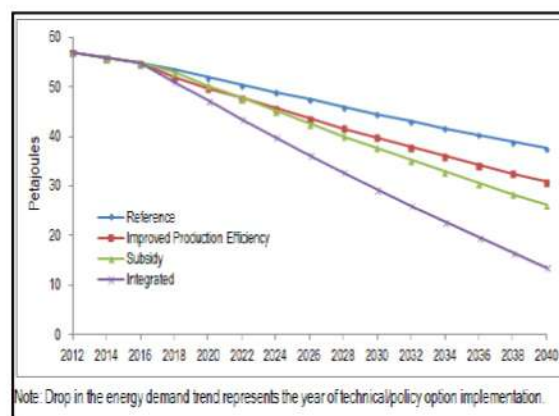


Figure 16: Final energy demand projection of potential biogas households from all fuels in the Chitwan district for the four scenarios respectively in LEAP

As in the case of the surveyed districts, the most striking feature in the final energy demand prediction for the Lamjung (Figure 14) and Chitwan (Figure 15) is the significant decrease in demand in the improved biogas production efficiency and integrated scenarios as a result of increased availability of biogas after co-digestion of crop residues with dung.

Saving energy after the use of biogas

Comparison of total predicted energy consumption of potential biogas households in the studied districts and both regions with and total energy consumption after the installation of biogas plants across all scenarios. This saving is mainly due to the reduction in the burning of inefficient fuelwood and the use of efficient cooking fuel such as biogas and electricity, which illustrates the impact of biogas technology in reducing the energy demand of user households. If the biogas completely replaces other cooking fuels, it reduces energy consumption by 40%.

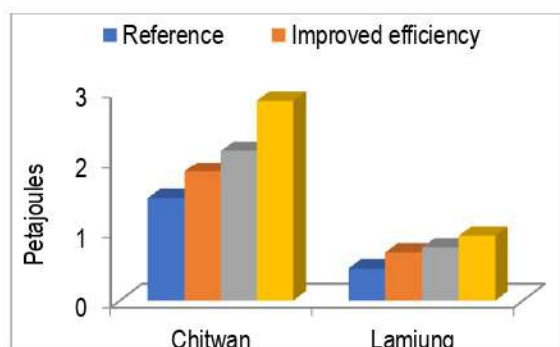


Figure 17: Saving on total energy consumption (GJ) Projection after the installation of biogas plants compared with no biogas household

3.4 Impact of biogas on the GHG emissions reduction

Biogas is a lower carbon fuel and it can reduce GHG emissions from the domestic sector by replacing the burning of emissions-intensive fuels with efficient fuels/stoves. The replacement of traditional biomass and petroleum fuels has a significant impact on environmental emissions reduction. If the current trend of fuelwood consumption continues, the total GHG emissions in the reference scenario are predicted to decrease by 0.72%/year from about 22,500 tCO₂e in 2012 to 18,300 tCO₂e in 2040 in Chitwan, and by 0.42%/year from 5,800 tCO₂e in 2012 to 5,100 tCO₂e in Lamjung (Table 11).

Table 7: GHG emissions projection of potential biogas households in Chitwan and Lamjung by fuel-type under different scenarios for selected years (tCO₂e)

Fuels	2012	Reference		Improved efficiency		Increased subsidy		Integrated	
		2020	2040	2020	2040	2020	2040	2020	2040
Chitwan									
LPG	575	831	1670	146	154	899	2454	135	0
Fuelwood	21,598	20,084	16,005	18,220	11,250	18,186	8,723	16,772	0
Biogas	319	399	677	643	1210	463	1082	740	2,013
Crop residue	0.4	0.3	0	0.2	0	0.4	0	0.2	0
Total	22,492	21,314	18,352	19,010	12,614	20,548	12,259	17,648	2,013
Lamjung									
LPG	65	92	179	1.8	1.5	96	228	1.0	0
Fuelwood	5,578	5,369	4,777	3,708	2,349	5,244	3,750	2,930	0
Biogas	141	155	193	237	329	162	248	247	412
Crop residue	1	0.7	0	0.5	0	0.7	0	0.5	0
Total	5,785	5,617	5,149	3,948	2,680	5,502	4,226	3,179	412

The emissions are predicted to reduce further in the integrated scenario to about 2,000 tCO₂e (8.3%/year) in Chitwan and 400 tCO₂e (9%/year) in Lamjung in the same period. The total emissions from the burning of fuelwood are projected to decrease by about 21,600 tCO₂e in Chitwan and about 5,600 tCO₂e in Lamjung in the integrated scenario from 2012-2040. The total emission from biogas is predicted to increase by about 1,700 tCO₂e (2.7%/year) in Chitwan and 270 tCO₂e (1.1%/year) in Lamjung in the same period when all potential households have access to biogas. The predicted emissions from fuelwood in the integrated scenario are virtually zero in 2040 in both districts and regions, as none of the biogas households are expected to use fuelwood for cooking.

3.5 Total global warming mitigation potential (GMP)

Total Global Warming Mitigation Potential was calculated by considering emission from both energy and non-energy sector by using the following equation.

GMP = GHG emissions from burning of conventional fuels + reduction in GHG emissions from forest cleared for fuelwood + reduction in GHG emissions from the decomposition of unfed dung + reduction in GHG emissions from replacing chemical fertilizers - GHG emissions from methane leakage from biogas plants.....(Equation 5)

The GMP of biogas plants from all sources increases significantly with the increase in the

number of biogas plants. Total GMP in a 100-year time horizon (including both energy and non-energy related emissions) of all the biogas plants installed in the reference scenario is estimated at 410,000 tCO₂e in Chitwan and 143,000 tCO₂e in Lamjung in 2040 (Table 10). This is projected to further increase to 1.04 million tCO₂e and 309,000 tCO₂e, respectively, in the integrated scenario when all the potential biogas plants are installed and biogas (and electricity to supplement biogas deficit replaces all conventional fuels.

Table 9: Total global warming mitigation potential of biogas plants in different scenarios including energy as well as non-energy emissions (1,000 tCO₂e)

District/ Region	2012	Reference		Improved production		Increased subsidy		Integrated	
		2020	2040	2020	2040	2020	2040	2020	2040
Chitwan	194	248	410	326	621	278	660	377	1039
Lamjung	91	102	143	178	248	104	160	185	309

The total GHG emission mitigation potential of a co-digested biogas plant from both energy and non-energy sector sources, such as replacing emission-intensive fuels; avoiding deforestation for fuelwood; decomposition of dung for biogas production; and bio-slurry to replace chemical fertilizers in 2040 are projected to be about 16.7 tCO₂e in Chitwan and 19.3 tCO₂e in Lamjung.

4. DISCUSSION

This study assumed that co-digestion of dung with crop residue at different mixing proportion increase biogas production up to 150%. This finding is consistent with [34], [35] [36] [37] that reported an increase in biogas yield of 50-200% more than single feedstock digestion, depending on plant operating condition and co-substrates used. [38] Moreover, if the biogas completely replaces other cooking fuels, it reduces energy

consumption by 40%. Although specific studies on the impact of biogas on reducing energy consumption could not be found, this study's finding is consistent with the finding of other studies on renewable energy technologies, that use of efficient energy sources reduces the consumption of inefficient traditional fuels and hence on total energy consumption [39] [32] [33] [40]. Similarly, the average annual rate of GHG emissions reduction after improving plant efficiency through co-digestion of mixed feedstocks in Lamjung is higher than in Chitwan because increased biogas production is projected to replace more fuelwood in Lamjung. These findings are comparable with the findings of [41], (Shakya & Shrestha, 2006), [43], [44] because they did not take into account the improved production efficiency of the plants and non-energy sector emissions.

5. CONCLUSION

The use of biogas is directly proportional to high clean energy consumption and GHG emission reduction, hence has strong nexus between them. Insufficient biogas production has been identified as one of the major constraints for the wider replication of domestic biogas technology. The increased biogas production efficiency through co-digestion of cattle dung with crop residues is enough to replace the existing use of other cooking fuels. Hence, this increment in all the potential households can increase the saving on total annual energy consumption up to 46.2 GJ in Chitwan district and 57.1 GJ in Lamjung district by substituting all of the traditional fuels. Regarding GHG emission, the mitigation potential per plant is lower in Lamjung compared

with Chitwan in the reference and increased subsidy scenario but higher in the improved production and integrated scenarios. Moreover, the GHG emission mitigation potential of a co-digested biogas plant from both energy and non-energy sector sources, such as avoiding deforestation for fuelwood, decomposition of dung and bio-slurry replacing fertilisers by 2040 is projected to be about 16.7 tCO₂e in Chitwan/Terai and 19.3 tCO₂e in Lamjung/Hill. However, only about 5% of households reported using slurry to replace fertilisers and hence the reduction in emissions would be less than the projection. The GHG emissions due to the methane leakage from biogas plants are significant at about 1.02 tCO₂e/year/plant. This is higher than the GHG avoidance from burning of traditional fuels substituted by biogas though it is much lower compared to the GHG avoidance from both energy and non-energy sector sources.

6. RECOMMENDATIONS

Digestion of dung with human excreta only as currently practiced in Nepal, however, has no significance in improving biogas production. Feedstock insufficiency has been identified as one of the major reasons for lower biogas production. Relevant biogas companies should therefore carefully assess the feedstock availability beforehand to ensure that a newly constructed plant will not be under-fed. Similarly, extending awareness and training on co-digestion to potential users should be seriously considered for the option and smooth operation of co-digested plants. Lastly, the GHG emissions due to the methane leakage from the biogas plant should

also be taken as a precautionary measure as it is about 1.02 tCO₂e/year/plant.

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