Chapter

Biogas for Clean Energy

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Abstract

This chapter demonstrates a biogas renewable energy resource potential study for electric power generation from easily available biogas feedstock materials in four selected case study sites. Under this study, the site used in the model is a rural Kebele in Jama Woreda at 10.548° N, 39.33° E. The common biogas feedstocks considered under this study are animal slurry, human feces and jatropha byproducts whereas the biodiesel is considered from jatropha seed.

Keywords: anaerobic digestion, bioenergy, *biogas digester*, feedstock, Jatropha

1. Introduction

Biogas is a byproduct of biomass which contains methane (CH_4) and carbon dioxide (CO_2) as a main gas component in a 3:2 ratio and it is produced through micro bacterial digestion processes under anaerobic conditions from a variety of organic material from animal, agricultural, industrial and domestic wastes [1]. The biogas production level is depending on the ingredient level in the feedstock. For example; if the material consists of mainly carbohydrates, like glucose and other simple sugars and high-molecular polymers such as cellulose and hemicelluloses, the methane production is low. However, if the fat content is high, the methane production is likewise high (**Table 1**) [2].

Methane and other additional hydrogen compounds make up the combustible part of biogas. Methane is a colorless and odorless gas with a boiling point of −162°C and it burns with a blue flame. At normal temperature and pressure, methane has a density of approximately 0.75 kg/m^3. Due to carbon dioxide being somewhat heavier, biogas has a slightly higher density of 1.15–1.25 kg/m^3. Pure methane has an upper calorific value of 39.8 MJ/m^3 (11.06 kWh/m^3) (**Table 2**) [2].

Gas	%
Methane (CH_4)	55 – 70
Carbon dioxide (CO_2)	30 – 45
Hydrogen sulphide (H_2S)	1 – 2
Hydrogen (H_2)	
Ammonia (NH_3)	
Carbon monoxide (CO)	trace
Nitrogen (N_2)	trace
Oxygen (O_2)	trace

Table 1.
Biogas composition.

Substrate	HRT (days)	Solid concentration (%)	Temperature (°C)	Biogas yield (m^3/kg VS)	Methane (%)
Sewage sludge	25	6	35	0.52	68
Domestic garbage	30	5	35	0.47	—
Piggery waste	20	6.5	35	0.43	69
Poultry waste	15	6	35	0.5	69
Cattle waste	30	10	35	0.3	58
Canteen waste	20	10	30	0.6	50
Food-market waste	20	4	35	0.75	62
Mango processing waste	20	10	35	0.45	52
Tomato-processing waste	24	4.5	35	0.63	65
Lemon waste	30	4	37	0.72	53
Citrus waste	32	4	37	0.63	62
Banana peel	25	10	37	0.60	55
Pineapple waste	30	4	37	0.37	60
Mixed feed of fruit waste	20	4	37	0.62	50

Table 2.
Potential biogas production from various biomass feedstocks on VS based.

2. The biogas production process

Anaerobic digestion (AD) is a biochemical process during which complex organic matter is decomposed in absence of oxygen, by various types of anaerobic microorganisms. The result of the AD process is the biogas and the digestate. Biogas is a combustible gas, consisting primarily of methane and carbon dioxide. Digestate is the decomposed substrate, resulted from the production of biogas. If the substrate for AD is a homogenous mixture of two or more feedstock types (e.g., animal slurries and organic wastes from food industries), the process is called “co-digestion” and is common to most biogas applications today.

The process of biogas formation is a result of linked process steps, in which the initial material is continuously broken down into smaller units. Specific groups of micro-organisms are involved in each individual step. The simplified diagram of the AD process, shown in **Figure 1**, highlights the four main process steps: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The process steps quoted in **Figure 1** run parallel in time and space, in the digester tank. During hydrolysis, relatively small amounts of biogas are produced. Biogas production reaches its peak during methanogenesis [3].

Methanogenesis is a critical step in the entire anaerobic digestion process, as it is the slowest biochemical reaction of the process. Methanogenesis is severely influenced by operation conditions. Composition of feedstock, feeding rate,

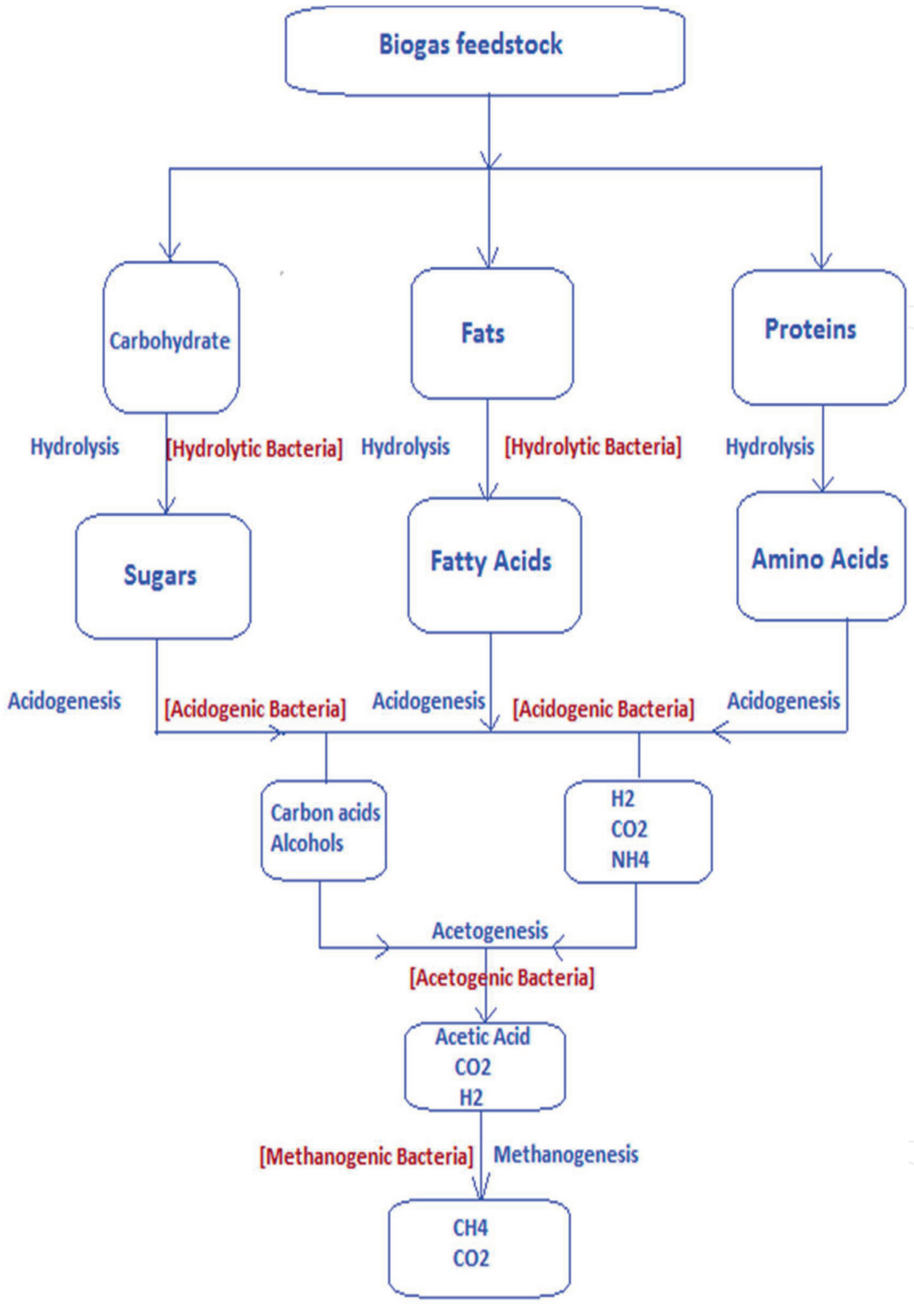

Figure 1.
Biogas production process by anaerobic digestion.

temperature, water content, NH_3 concentration and pH are examples of factors influencing the methanogenesis process.

Temperature for fermentation will greatly affect biogas production. The AD process can take place at different temperatures, divided into three temperature ranges: psychrophilic (below 20°C), mesophilic (30–42°C), and thermophilic (43–55°C). There is a direct relation between the process temperature and the HRT. The biogas production rate increases with increase the process temperature (**Table 3**).

Thermal stage	Process Temperature	Minimum HRT
Psychrophilic	< 20° C	70–80 days
Mesophilic	30–42° C	30–40 days
Thermophilic	43–55° C	15–20 days

Table 3.
Biogas production thermal stage and their corresponding retention time [4].

In practice most modern biogas plants operate at thermophilic process temperatures because this process provides many advantages, compared to mesophilic and psychrophilic processes:

- Effective destruction of pathogens
- Fast grow rate of methanogenic bacteria at higher temperature
- Minimization of biogas production period, making the process faster and more efficient
- Improve digestibility and availability of substrates
- better decomposition and utilization of solid substrates
- Increase the chance to separate liquid and solid fractions

The metabolic processes in the production of biogas from different biomass feedstocks are hydrolysis, acidogenesis, acetogenesis and methanogenesis and their byproducts in the process is represented in the figure below.

In this study thermophilic biogas temperature process is chosen in order to get higher biogas output and to achieve this target flat plate collector can be used to maintain digester process temperature at 55°c.

3. Biogas plant

A biogas plant is a complex installation, consisting of a variety of elements. The layout of such a plant depends to a large extent on the types and amounts of feedstock supplied. Now there are several main types of biogas plants all over the world. Each time it is necessary to find the most suitable type in different case. Public acceptance, cost and energy efficiency are the main criteria to install biogas plant and efficiently utilize the biogas production. In smaller areas with scarcity of biogas feedstock or slurry to use low cost clay, concert or stone masonry made biogas digester.

Installation and operation of a biogas plant is a combination of environmental, safety, economic and technical considerations. Acquiring maximum methane output, by complete digestion of feedstock substrate, would require a long fermentation or digestion time of the material inside the biogas digester and a correspondingly large digester size. The ultimate goal of biogas production is getting the highest possible methane output and having justifiable plant economy. Biogas plants have the following main components and operate with four different process stages [3].

Process stages of biogas production:

- Transport, delivery, storage and pre-treatment of feedstocks
- Biogas production
- Storage of digestate, conditioning and utilization
- Storage of biogas, conditioning and utilization.

Main components of biogas plant:

- Feedstock pre-storage tank
- Substrate mixing Tank
- Biogas digester
- Post storage tank
- Gas holder tank and
- CHP system

The amount and type of available feedstock can determine the size, type and design structure of the biogas plant. The amount of biogas feedstock could determine the dimensioning of the digester size, storage capacities and CHP unit (**Figure 2**).

The CHP system utilizes the biogas either in heat or electrical energy. The properties of the combustible methane gas (like as shown in **Table 4**) will affect the operation of the CHP equipment. The combustion nature of the gas must be

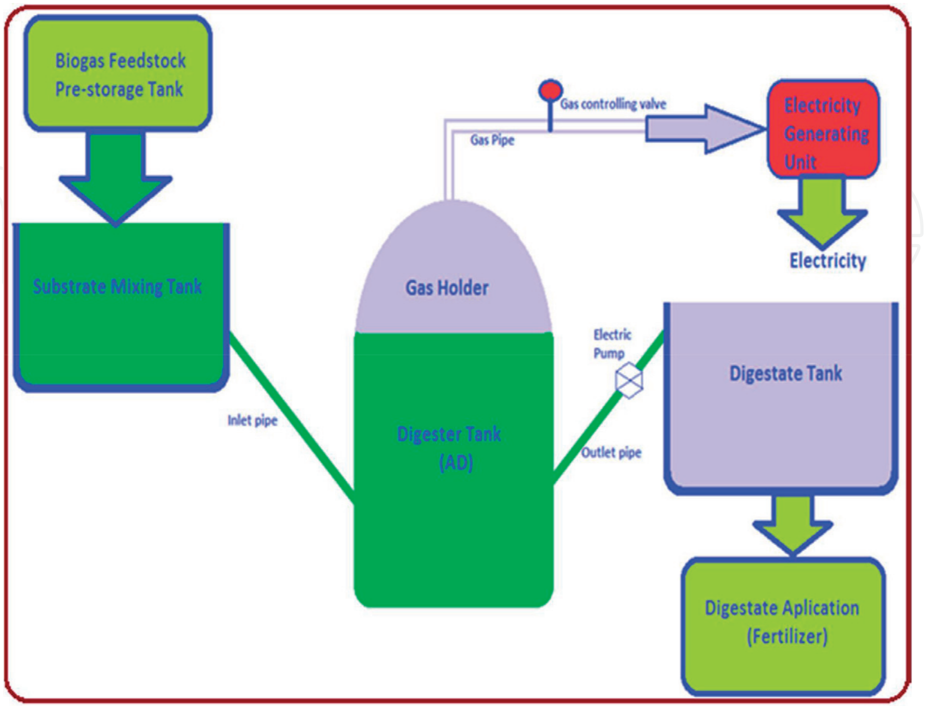

Figure 2.
Main components and general process flow of biogas production.

No.	Parameter	Symbol	Value
1.	Lower heat value	LHV	$\geq$4 kWh/m^3
2.	Sulfur content	S	$\leq$2.2 g/m^3 CH_4
3.	Hydrogen sulfide	H_2S	$\leq$0.15 Vol. %
4.	Chlorine content	Cl	$\leq$100 mg/m^3 CH_4
5.	Fluoride content	F	$\leq$50 mg/m^3 CH_4
6.	Dust (3–10 μm)	—	$\leq$10 mg/m^3 CH_4
7.	Relative humidity	ϕ	<90%
8.	Flow pressure	P_{gas}	20–100 mbar
9.	Gas pressure fluctuation	—	<±10% of set value
10.	Gas temperature	T	10–50°c
11.	Hydro carbon	HC	<0.4 mg/m^3 CH_4
12.	Silicon	Si	<10 mg/CH_4

Table 4.
Biogas minimum requirement used in an electric engine [3].

guaranteed, to prevent damage to the engines. Further treatment and enhancing chemical and physical properties of biogas even possible to use it for other utilizations like as vehicle fuel or in fuel cells application.

4. Design of the biogas plant

The design of the biogas plant includes the design of:

- The digester
- The gas Holder
- Digester heat maintaining system
- Siting of biogas plant

To calculate the scale of a biogas plant, certain characteristic parameters are used. These are:

- **Daily fermentation slurry feeding (Sd)**, which is an equal mixture of biogas feedstock (animal dung, human feces, poultry waste and jatropha byproduct) with water feed in to the biogas digester.
- **Retention time (RT),** the time by which the fermentation slurry stays in the digester. It is about 2–5 weeks.
- **Digester loading (R).** This parameter indicates the amount of biogas feedstock material per day is fed to the digester or to be digested. It can be measured in kg/m^3/day.

- **Specific gas production per day (Gd),** which depends on the retention time, the digestion temperature and the feed material.

4.1 Sizing of biogas digester and gasholder

The size of the digester—the digester volume (V_D)—is determined by the length of the retention time (RT) and by the amount of fermentation slurry supplied daily (S_D). The amount of fermentation slurry consists of the feed material considered in this study (e.g., cattle dung) and the mixing water.

4.1.1 Sizing of site-A biogas digester and gasholder

Daily average collectable biogas feedstock potential from cow dung, oxen dung, donkey, mule, and horse waste, chicken waste, human feces and jatropha byproduct in this study in tons/day is 10.867 = 10,867 kg/day = 15.53 m^3/day. Since the average density of animal slurry mix is 700 kg/m^3.

Additional 15.53 m^3/day water is required for proper digestion of biogas feedstock material to enhance biogas production.

HRT = 20 day, under thermophilic digestion temperature (55°C) the hydraulic retention time of the digestion process becomes short.

The volume of digester should be, $V_D = HRT \times S_D$.

$= 20$ day $\times$ (15.53 $\times$ 2 m^3/day) = 621 m^3.

Therefore the size of the digester for site A could be 621 m^3.

Where, V_D = the size of the digester, HRT = hydraulic retention time, and S_D is the amount of fermentation slurry (water + feedstock) feed in to the digester per day. Biogas yield in m^3/kg of fresh biogas feedstock mix is 1736.4 m^3/31850 kg = 0.054 m^3/kg; the biogas production rate is 10,867 kg/day $\times$ 0.054 m^3/kg = 588 m^3/day. Therefore the size of gasholder should account this daily biogas production.

4.1.2 Sizing of site-B biogas digester and gasholder

Daily average collectable biogas feedstock potential from cow dung, oxen dung, donkey, mule, and horse waste, chicken waste, human feces and jatropha byproduct of Site-B in tons/day is 9.253 = 9253 kg/day = 13.22 m^3/day. Since the average density of animal slurry mix is 700 kg/m^3.

Additional 13.22 m^3/day water is required for proper digestion process of biogas feedstock material to enhance biogas production.

HRT = 20 day, under thermophilic digestion temperature the hydraulic retention time of the digestion process becomes short.

The volume of digester should be, $V_D = HRT \times S_D$.

$= 20$ day $\times$ (13.22 $\times$ 2 m^3/day) = 529 m^3. Therefore the size of the digester for **site-B** is 529 m^3. The biogas gas production rate is 9253 kg/day $\times$ 0.054 m^3/kg = 501 m^3/day. Therefore the size of gasholder should account this daily biogas production.

4.1.3 Sizing of site-C biogas digester and gasholder

Daily average collectable biogas feedstock potential from cattle dung, donkey, mule, and horse waste, chicken waste, human feces and jatropha byproduct of site-C in tons/day is 8.82 = 8820 kg/day = 12.6 m^3/day, Since the average density of animal slurry mix is 700 kg/m^3.

Additional 12.6 m^3/day water is required for proper digestion of biogas feedstock material to enhance biogas production.

The volume of digester should be, $V_D = HRT \times S_D$, HRT = 20 day.

= 20 day × (12.6 × 2 m^3/day) = 504 m^3.

Therefore the size of the digester for **site-C** is 504 m^3.

The gas production rate is 8820 kg/day × 0.054 m^3/kg = 477 m^3/day. Therefore the size of gasholder should account this daily biogas production also.

4.1.4 Sizing of site-D biogas digester and gasholder

Daily average collectable biogas feedstock potential of Site-D in tons/day is 3.091 = 3091 kg/day = 4.42 m^3/day, since the average density of animal slurry mix is taken as 700 kg/m^3. Additional 4.42 m^3/day water is required.

The volume of digester should be, $V_D = HRT \times S_D$, HRT = 20 day.

= 20 day × (4.42 × 2 m^3/day) = 179 m^3.

Therefore the size of the digester for **site-D** is 179 m^3.

The gas production rate is 3091 kg/day × 0.054 m^3/kg = 168 m^3/day. Therefore the size of gasholder should account this daily biogas production.

4.2 Location of biogas plant

The next planning step in a biogas plant project idea is to find a suitable site for the establishment of the plant. The list below shows some important considerations to be made, before choosing the location of the plant: [3].

- The site should be located at suitable distance from residential areas in order to avoid inconveniences, nuisance and thereby conflicts related to odors and increased traffic to and from the biogas plant.

- The direction of the dominating winds must be considered in order to avoid wind born odors reaching residential areas.

- The site should have easy access to infrastructure such as to the electricity grid, in order to facilitate the sale of electricity and to the transport roads in order to facilitate transport of feedstock and digestate.

- The soil of the site should be investigated before starting the construction.

- The chosen site should not be located in a potential flood affected area.

- The size of the site must be suitable for the activities performed and for the amount of biomass supplied.

- The site should be located relatively close (central) to the agricultural feedstock production (manure, slurry, energy crops) aiming to minimize distances, time and costs of feedstock transportation.

- For cost efficiency reasons, the biogas plant should be located as close as possible to potential users of the produced heat and electricity.

The required site space for a biogas plant cannot be estimated in a simple way. Experience shows that for example a biogas plant of 500 kW_{el} needs an area of approximate 8000 m^2. This figure can be used as a guiding value only, as the actual area also depends on the chosen technology [3]. Based on the above criteria of site selection of biogas plant, the location of the biogas plant for each site of the study area is chosen and the detail of it is found in the economic analysis section of the biogas plant in this paper.

5. Biogas potential

5.1 Biogas potential from jatropha

Various literatures show that methane yield of jatropha fruit hull is 0.438 m^3/kg VS, and the VS is 76% of the TS of the jatropha fruit hull. Methane is 50% of the total biogas yield (1.153 m^3/kg). The biogas yield of Jatropha seed presscake is approximately 1 m^3/kg of presscake. The biogas yield of jatropha fruit hull is better than the seedcake [5]. Based on the jatropha fact sheet given in **Table 5**, the

Parameter	Unit	Minimum	Average	Maximum	Source
Seed yield	dry ton/ hectare/year	0.3	3.15	6	Position Paper on Jatropha Large Scale Project Development, FACT 2007
Fruit hull yield	dry ton/ hectare/year	0.2	2.1	4	
Rainfall requirements for seed production	mm/year	600	1000	1500	Position Paper on Jatropha Large Scale Project Development, FACT 2007
Oil content of seeds	% of mass	_	34%	40%	Jatropha bio-diesel production and use, W. Achten et al., 2008
Oil yield after pressing	% of mass of seed input	20%	25%	30%	Jatropha handbook, 2010
Presscake yield after pressing	% of mass of seed input	70	75	80	
Energy content of Seed	MJ/kg	—	37	—	

Table 5.
Jatropha fact sheet.

Biogas feedstock	Jatropha biomass, tons/year	Average jatropha biomass, tons/year	Biogas yield, m^3/kg	Methane yield, m^3/kg	Total biogas yield, m^3	Average biogas yield, m^3/year	Average methane yield, m^3/year
Presscake	4.2–96	50.1	1	0.5–0.6	4200–96,000	50,100	25,050-30,060
Fruit hull	4–80	42	1.153	0.576–0.69	4612–92,240	48,426	27,894–33,414
Total	8.2–176	92.1	1.07	0.575–0.689	8812–188,240	98,526	52,944–63,474

*Jatropha biomass (from presscake) = seed yield (ton/hectare) × % of presscake yield during oil production * total land for Jatropha farming (hectare)*
Jatropha biomass (from fruit hull) = hull yield (ton/hectare) × total land for Jatropha farming (hectare).

Table 6.
Jatropha byproduct biomass potential in the study area.

Profile	Jatropha biomass, tons	Biogas yield, m^3/kg	Biogas yield, m^3	Methane yield, m^3/kg	Methane yield, m^3
Yearly average	92.1	1.07	98,526	0.575–0.689	52,944–63,474
Daily average	0.253	1.07	270	0.575–0.689	145–174

Table 7.
Jatropha biogas potential of the study area.

Jatropha product	Jatropha oil (liter/year)	Jatropha biogas (m^3/year)	Jatropha fertilizer (kg/year)	Jatropha biomass (ton/year)
Product yield	16,090–18,774	98,526	18,420	92.1

Table 8.
Summary of Jatropha potential of the study area.

biomass, biogas and methane yield potential of the jatropha byproduct is estimated in **Tables 6, 7** and **8**.

5.2 Biogas energy potential of the study area from animal dung

A wide range of biomass types can be used as substrates (feedstock) for the production of biogas from AD. The most common biomass categories used in biogas production are listed in **Table 9** for this thesis work. To produce biogas from animal manure first we have to check whether we have animal livestock potential sufficient for biogas feedstock production or not. The following Table demonstrates the animal livestock potential for each sites of the study area.

The average fresh manure obtained from, cattle is 4.5 kg/day/head [1, 6, 7], donkey, horse and mule is 10 kg/day/head [6, 7], sheep and goat 1 kg/day/head [6, 7], and chicken is 0.08 kg/day/head [6, 7]. The average biogas yield of cattle, horse, mule, and donkey manure is 0.24 m^3/kg DM [2, 3, 8] and pigs, sheep and goat is 0.37 m^3/kg DM whereas chicken is 0.4 m^3/kg of DM [2, 3, 8]. The dry matter

Animal livestock	Site-A	Site-B	Site-C	Site-D	Ave. no. of animal/HH	Total livestock in the study area
Cows	666	566	535	172	1.7	1935
Oxen	719	612	577	184	1.85	2092
Goats	163	139	131	43	0.42	476
Sheep	1841	1567	1477	472	4.72	5350
Mule	12	10	9	3	0.03	29
Chickens	2340	1992	1878	600	6	6810
Pigs	0	0	0	0	0	0
Horse	48	40	37	12	0.12	133
Donkey	345	295	278	89	0.89	1007

Source: Jama Woreda rural development and Kebele-8 administration office, Nov 2012.

Table 9.
Jama Woreda, Kebele-8 districts animal livestock potential.

Biomass source	Average fresh manure, kg/day/head	m^3 biogas/kg DM	DM % fresh manure	Methane % biogas
Cattle	4.5	0.24	16.7	65
Pigs	2	0.37	4.4	65
Sheep, goats	1	0.37	30.7	65
Chickens	0.08	0.40	30.7	65
Horse, mule	10	0.24	7	65
Donkey	10	0.24	15	65

Total fresh manure potential of the study area (tons/day) = Average fresh manure (kg/day/head) × Total no. of livestock in study area.
Total dry mater (DM) from fresh manure = DM % of fresh manure × Total fresh manure potential of the study area (tons/day).
Total biogas production, m^3/day = Biogas m^3/kg of DM × Total dry mater (DM) from fresh manure in kg/day.
Total electricity production in kWh/day = electricity production by biogas generator from 1 m^3 biogas in kWh × total biogas production in m^3/day.
By using biogas generator it is possible to generate 1kWh electricity from 0.7 m^3 biogas [42].

Table 10.
Summary of fresh manure, biogas and methane yield of animal livestock.

Animal livestock	Ave. fresh manure, kg/day/head	Total no. of livestock in study area	Total fresh manure (ton/day)	Total DM (kg/day)	Biogas, m^3/kg of DM	Total biogas, m^3/day	Electricity production, kWh/day
Cows	4.5	1935	8.708	1455	0.24	350	500
Oxen	4.5	2092	9.414	1573	0.24	378	540
Goats	1	476	0.476	147	0.37	55	79
Sheep	1	5350	5.350	1643	0.37	608	869
Mule	10	29	0.290	24	0.24	6	9
Chicken	0.08	6810	0.545	168	0.40	68	98
Pigs	2	0	0.000	0.00	0.37	0.0	0.0
Horse	10	133	1.330	92	0.24	22	32
Donkey	10	1007	10.070	1511	0.24	363	519
Total animal manure biomass			**36.183**	**6613**	**0.28**	**1850**	**2646**

Table 11.
Summary of expected animal manure potential of the study area.

content from the total mass of fresh animal manure and the proportion of methane from the total biogas production is summarized in **Table 10** [2, 3, 9] (**Table 11**).

For a given size of plant (rated gas production capacity per day) the amount of feedstock required can be estimated using the biogas yield data provided. The specific biogas consumption in biogas engines is 0.6–0.8 m^3/kWh [1]. This specific fuel consumption value can be used to calculate the requirement for biogas for power generation purposes. The expected biomass potential from animal manure of the case study area is 36.2 tons/day and its biogas production capacity is 1850 m^3/day. Various literatures show that the collection efficiency of animal manure varies from country to country and region to region.

Most significantly the collection efficiency varies from 50 to 100% [10]. Let as consider collection efficiency of 90% for cattle, donkey, mule, horse, pig and chicken manure, 50% for goat and sheep manure and 100% for human feces based

Animal livestock	Ave. fresh manure, kg/day/head	Total no. of livestock in study area	Total collectable fresh manure, tons/day	Total collectable DM, kg/day	Biogas, m^3/kg of DM	Total biogas, m^3/day	Electricity production, kWh/day
Cows	4.5	1935	7.837	1309.5	0.24	315	450
Oxen	4.5	2092	8.473	1415.7	0.24	340	486
Goats	1	476	0.238	73.5	0.37	27.3	39
Sheep	1	5350	2.675	821.5	0.37	304	434.3
Mule	10	29	0.261	21.6	0.24	5.2	7.43
Chicken	0.08	6810	0.491	151.2	0.40	60.5	86.43
Pigs	2	0	0.000	0.00	0.37	0.0	0.0
Horse	10	133	1.197	82.8	0.24	19.9	28.43
Donkey	10	1007	9.063	1360	0.24	326.4	466.3
Total animal manure Biomass			30.235	5235.8	0.27	1398.3	1998

Table 12.
Summary of collectable animal manure potential of the study area.

on their difficulty of collecting it. Therefore the biomass potential available for biogas generation is estimated as follows.

The total collectable fresh animal manure biomass potential of the study area is estimated to be 30.235 tons/day and its biogas production capacity is 1398.3 m^3/day (**Table 12**).

5.3 Biogas potential of the study area from human feces

Human feces are another feedstock for biogas production in the study area and the potential biogas production from human feces is discussed in this section. Feces are mostly made of water (about 75%). The rest is made of dead bacteria that helped us digest our food, living bacteria, protein, undigested food residue (known as fiber), waste material from food, cellular linings, fats, salts, and substances released from the intestines (such as mucus) and the liver (**Table 13**).

One person produces on average 100–140 g of feces per day, the dry matter content of which is about 25% and its biogas yield of about 0.2 m^3/kg DM [11]. The total collectable fresh manure biomass potential of the case study area from humans is estimated to be 0.681 tons/day and its biogas production capacity is 34.05 m^3/day. This figure accounts the collection efficiency of human excreta. **Table 14** demonstrates the biogas potential of the study area from human feces.

Population	Site-A	Site-B	Site-C	Site-D	Total
Number of household	390	332	313	100	1135
Average Family per household	4.39 (5)	4.39 (5)	4.39 (5)	4.39 (5)	4.39 (5)
Total population	1950	1660	1565	500	5675

Table 13.
Jama Woreda, Kebele-8 districts population data.

Live stock	Ave. fresh manure, kg/day/head	Total no. of population	Total fresh manure potential (ton/day)	Total DM (kg/day)	Biogas, m^3/kg DM	Total biogas, m^3/day	Electricity production, kWh/day
Human	0.12	5675	0.681	170.25	0.2	34.05	48.7

Table 14.
Biogas potential of study area from human feces.

5.4 Total biogas potential of the study area

The total biogas potential from Jatropha byproduct, Animal waste and human feces discussed above can be summarized in this section.

> **Taking** *the density of biogas 1.15 kg/m^3 and calculating the gasification ratio (the mass of biogas produced per unit mass of feed stock consumed) of the biogas system. From* ***Table 15*** *the mass of biogas feedstock consumed is 31,850 kg/day and the gas produced is 1736.4 m^3/day. Therefore the gasification ratio of biogas feedstock mix is 1736.4 m^3/31850 kg = 0.0545 m^3/kg =* **0.0626 kg/kg**.

As we have seen from **Table 15**, animal manure is the major biogas feedstock constitutes which accounts 97% from the total biogas feedstock potential whereas jatropha byproducts and human excreta constitute 1 and 2% of the total biogas feedstock potential of the study area respectively. However, the share of biogas production from, animal manure is 82%, and human excreta is 2% but biogas production from jatropha byproduct is increase to 16% regardless of its low contribution to the biomass potential since the biogas yield of jatropha byproduct is high as compared to both animal and human manure and this can be summarized in **Figure 3** given below.

Animal Livestock	Ave. fresh manure, kg/day/head	Total no. of live stock	Total collectable fresh manure (ton/day)	Total collectable DM (kg/day)	Biogas, m^3/kg DM	Total biogas production, m^3/day	Electricity yield, kWh/day
Cows	4.5	1935	7.837	1309.5	0.24	315	450
Oxen	4.5	2092	8.473	1415.7	0.24	340	486
Goats	1	476	0.238	73.5	0.37	27.3	39
Sheep	1	5350	2.675	821.5	0.37	304	434.3
Mule	10	29	0.261	21.6	0.24	5.2	7.43
Chicken	0.08	6810	0.491	151.2	0.40	60.5	86.43
Pigs	2	0	0.000	0.00	0.37	0.0	0.0
Horse	10	133	1.197	82.8	0.24	19.9	28.43
Donkey	10	1007	9.063	1360	0.24	326.4	466.3
Human	0.12	5675	0.681	170.25	0.2	34.05	48.7
Jatropha byproduct biomass			0.253	253	1.07	270	386
Total			31.85	5829.3	0.3	1736.4	2481.4

Table 15.
The total biogas and collectable feedstock potential of the study area.

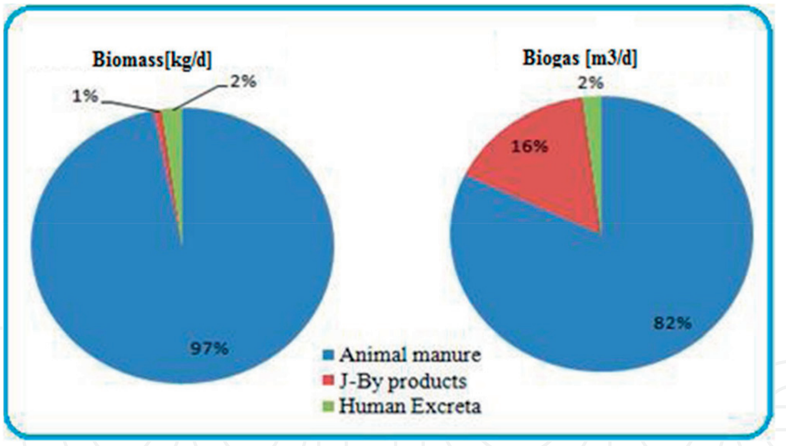

Figure 3.
Biogas feedstock contributions for biogas production in the study area.

5.5 Monthly variation of the biogas feed stock potential

The variation of jatropha byproduct feedstocks is assumed to be constant throughout the year and the potential biomass obtained from it was divided to each site regardless of the total house hold in each of the study area.

However, the biomass obtained from animal is highly depending on the availability and type of the animal feeding material. The animal feeding materials are varying in type and amount from month to month in the study area. In June and July there is enough root grass in addition to the usual animal food, let as consider this value as the annual average in ton/day (the data obtained by multiplying the biomass obtained per animal live stock in ton/day with the total number of animal live stock for each animal group in the district), as a reference frame. In January, February, and December there is excess dry agricultural farm grass for the animal food in the study area and assuming a 5% biomass resource increment is expected from the reference. March and April is a dry season and there is no enough food for the animal so considering a 5% biomass resource decrement from the reference. May, extremely drought month and August, animal grazing area are not permitted for animal food assuming a 10% animal based biomass resource drop is expected. From September to November there is excess animal food and a 10% biomass growth is assumed. Also assuming chicken manure and human feces are constant throughout the year. Taking in to account the assumption listed above the biogas feedstock potential month to month variation is presented in **Tables 16–19**.

6. Conclusion

The renewable energy potential of the site is estimated based on the primary data collected directly from the study area and secondary data obtained from various sources. The biogas feedstock mix potential of the study area is found to be 10.9 tons/day, 9.25 tons/day, 8.81 tons/day and 3.09 tons/day for Site-A, Site-B, Site-C and Site-D respectively with a gasification ratio of 0.0626 kg/kg. The study result shows that there is a sufficient biogas feedstock potential for all districts of the study area and the feasibility simulation result demonstrates there is an excess biogas after running a biogas generator in a hybrid system. The excess biogas left unused from a hybrid electric generating unit would go to biogas cooking application for the community cooking loads. Also, the biodiesel potential of the study area from Jatropha is estimated to be 18.5 m^3/year.

Month	Biomass, tons/day										
	Cow	Oxen	Mule	Horse	Donkey	Sheep	Goats	Chicken	Jatroph	Human	Total
Jan	2.82	3.069	0.114	0.4536	3.28	0.967	0.086	0.17	0.0633	0.234	11.257
Feb	2.82	3.069	0.114	0.4536	3.28	0.967	0.086	0.17	0.0633	0.234	11.257
Mar	2.552	2.775	0.1031	0.4104	2.97	0.875	0.08	0.17	0.0633	0.234	10.233
Apr	2.552	2.775	0.1031	0.4104	2.97	0.875	0.08	0.17	0.0633	0.234	10.233
May	2.417	2.63	0.0972	0.3654	2.811	0.83	0.074	0.17	0.0633	0.234	9.693
Jun	2.686	2.921	0.108	0.432	3.123	0.921	0.082	0.17	0.0633	0.234	10.740
Jul	2.686	2.921	0.108	0.432	3.123	0.921	0.082	0.17	0.0633	0.234	10.740
Aug	2.417	2.63	0.0972	0.3654	2.811	0.83	0.074	0.17	0.0633	0.234	9.6912
Sep	2.954	3.213	0.119	0.475	3.4353	1.013	0.09	0.17	0.0633	0.234	11.767
Oct	2.954	3.213	0.119	0.475	3.4353	1.013	0.09	0.17	0.0633	0.234	11.767
Nov	2.954	3.213	0.119	0.475	3.4353	1.013	0.09	0.17	0.0633	0.234	11.767
Dec	2.82	3.069	0.114	0.4536	3.28	0.967	0.086	0.17	0.0633	0.234	11.257
Average	2.693	2.958	0.1096	0.4335	3.1628	0.9327	0.083	0.17	0.0633	0.234	10.867

Table 16.
Biomass resource of site-A—390 families.

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Month	Biomass, tons/day										
	Cow	**Oxen**	**Mule**	**Horse**	**Donkey**	**Sheep**	**Goats**	**Chicken**	**Jatropha**	**Human**	**Total**
Jan	2.40	2.614	0.095	0.378	2.788	0.823	0.073	0.144	0.0633	0.183	9.56
Feb	2.40	2.614	0.095	0.378	2.788	0.823	0.073	0.144	0.0633	0.183	9.56
Mar	2.17	2.364	0.086	0.342	2.523	0.744	0.066	0.144	0.0633	0.183	8.69
Apr	2.17	2.364	0.086	0.342	2.523	0.744	0.066	0.144	0.0633	0.183	8.69
May	2.056	2.240	0.081	0.324	2.390	0.706	0.062	0.144	0.0633	0.183	8.25
Jun	2.284	2.489	0.09	0.36	2.655	0.784	0.070	0.144	0.0633	0.183	9.12
Jul	2.284	2.489	0.09	0.36	2.655	0.784	0.070	0.144	0.0633	0.183	9.12
Aug	2.056	2.240	0.081	0.324	2.38	0.706	0.062	0.144	0.0633	0.183	8.24
Sep	2.513	2.737	0.099	0.469	2.921	0.862	0.077	0.144	0.0633	0.183	10.07
Oct	2.513	2.737	0.099	0.469	2.921	0.862	0.077	0.144	0.0633	0.183	10.07
Nov	2.513	2.737	0.099	0.469	2.921	0.862	0.077	0.144	0.0633	0.183	10.07
Dec	2.40	2.614	0.095	0.378	2.788	0.823	0.073	0.144	0.0633	0.183	9.56
Average	2.313	2.52	0.09	0.383	2.69	0.794	0.071	0.144	0.0633	0.183	9.25

Table 17.
Biomass resource of site-B—332 families.

Month	Biomass, tons/day										
	Cow	**Oxen**	**Mule**	**Horse**	**Donkey**	**Sheep**	**Goats**	**Chicken**	**Jatropha**	**Human**	**Total**
Jan	2.263	2.46	0.085	0.755	2.637	0.776	0.069	0.136	0.0633	0.188	9.434
Feb	2.263	2.46	0.085	0.755	2.637	0.776	0.069	0.136	0.0633	0.188	9.431
Mar	2.048	2.23	0.077	0.316	2.385	0.702	0.062	0.136	0.0633	0.188	8.206
Apr	2.048	2.23	0.077	0.316	2.385	0.702	0.062	0.136	0.0633	0.188	8.206
May	1.94	2.13	0.073	0.30	2.26	0.665	0.059	0.136	0.0633	0.188	7.812
Jun	2.156	2.35	0.081	0.333	2.511	0.739	0.066	0.136	0.0633	0.188	8.618
Jul	2.156	2.35	0.081	0.333	2.511	0.739	0.066	0.136	0.0633	0.188	8.618
Aug	1.94	2.123	0.073	0.30	2.26	0.665	0.059	0.136	0.0633	0.188	7.812
Sep	2.37	2.556	0.089	0.41	2.76	0.813	0.072	0.136	0.0633	0.188	9.457
Oct	2.37	2.556	0.089	0.41	2.76	0.813	0.072	0.136	0.0633	0.188	9.457
Nov	2.37	2.556	0.089	0.418	2.76	0.813	0.072	0.136	0.0633	0.188	9.457
Dec	2.263	2.463	0.085	0.755	2.637	0.669	0.069	0.136	0.0633	0.188	9.328
Average	2.183	2.372	0.082	0.449	2.542	0.739	0.067	0.136	0.0633	0.188	8.820

Table 18.
Biomass resource of site-C—313 families.

Month	Biomass, tons/day										
	Cow	**Oxen**	**Mule**	**Horse**	**Donkey**	**Sheep**	**Goats**	**Chicken**	**Jatropha**	**Human**	**Total**
Jan	0.723	0.787	0.029	0.1134	0.841	0.496	0.044	0.0432	0.0633	0.06	3.199
Feb	0.723	0.787	0.029	0.1134	0.841	0.496	0.044	0.0432	0.0633	0.06	3.199
Mar	0.654	0.712	0.026	0.1026	0.761	0.448	0.04	0.0432	0.0633	0.06	2.910
Apr	0.654	0.712	0.026	0.1026	0.761	0.448	0.04	0.0432	0.0633	0.06	2.910
May	0.620	0.674	0.024	0.0972	0.721	0.425	0.038	0.0432	0.0633	0.06	2.766
Jun	0.689	0.750	0.027	0.108	0.801	0.472	0.043	0.0432	0.0633	0.06	3.056
Jul	0.689	0.750	0.027	0.108	0.801	0.472	0.043	0.0432	0.0633	0.06	3.056
Aug	0.620	0.675	0.024	0.0972	0.721	0.425	0.038	0.0432	0.0633	0.06	2.766
Sep	0.757	0.825	0.03	0.1188	0.881	0.519	0.046	0.0432	0.0633	0.06	3.344
Oct	0.757	0.825	0.03	0.1188	0.881	0.519	0.046	0.0432	0.0633	0.06	3.344
Nov	0.757	0.825	0.03	0.1188	0.881	0.519	0.046	0.0432	0.0633	0.06	3.344
Dec	0.723	0.787	0.028	0.1134	0.841	0.496	0.044	0.0432	0.0633	0.06	3.199
Average	0.697	0.759	0.027	0.1094	0.811	0.478	0.043	0.0432	0.0633	0.06	3.091

Table 19.
Biomass resource of site-D—100 families.

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