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BIOGAS PRODUCTION FROM VARIOUS RESOURCES AND SUSTAINABILITY IN BRONG AHAFO REGION OF GHANA.

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ABSTRACT

The energy consumption in Ghana is deteriorating due to the increase of its population, which has enormous impact on national economy. To remedy some of these issues biogas technology appears favorable to reach sustainable energy yields without damaging the environment. Biogas production project are judged by their contribution to sustainable development, long-term viability to integrate sustainable goal. The aim of this study is To identify and characterize the various biomass resources sufficiently available for biogas generation in the Brong Ahafo region of Ghana. The first objective is to analyze the sustainability of biogas production in Brong Ahafo region in Ghana using sustainability indices. The second objective is to estimate the emission reduction from biogas production. The analysis tool, RETScreen software is used to determine the potential emission reduction from kitchen, abattoir, and market waste. The assessment is empirically illustrated with a qualitative and quantitative analysis. The administering of questionnaires randomly to the people in the region and the survey of biogas was used through the qualitative analysis. The quantitative analysis was carried out at laboratory scales through anaerobic fermentation using the fresh cow dung for each substrate in three separate bio-digesters comprising of ingester, kitchen waste and market waste under the temperature between 27 – 35 ^{o}C. The average methane value for the ingester was 54 % with 7.24 pH content, followed by the market waste 42 % average methane with 5.74 pH content and then

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kitchen waste 40 % average methane with 4.55 pH content. The survey of biogas found that of the seven (7) biogas plants covered in this study, 29.0 % have been operational since their construction and 71.0 % were non-operational. Comparative analysis for the seven biogas plant project shows 83.3 %, 16.7 %, 26.7 % and 40.0 % priority for economic, technical, and environmental criteria, respectively during its implementation stages. In the study areas the use of biogas for energy production in place of wood saves 72,897 tCO_2 per year from being released into the atmosphere.

Keywords: biogas, sustainability, greenhouse emission, waste, Brong Ahafo, Ghana

1. INTRODUCTION

Energy is essential to life. Without it, billions of people would be left cold and hungry. Sustainable Energy has become an important development factor in the world. In developing country assess to the energy present challenges to the environment and economic development[1]. In recent year due to the increase of population, the energy demand is exponentially increasing while the fossil fuel resources are considerably decreasing. The historically fossil fuel is now confronting a major challenge derived principally from economic growth, scarcity of non-renewable resources and steady demand of raw materials, all which are concomitantly linked to problems such as greenhouse gases (GHGs) emission, global warming, climate change uncertainty of fuel supply and the massive generation of waste products and pollutants associated with industrial activity[2]. In order to overcome this ongoing threat of air pollution and to promote GHGs emission mitigation and sustainable energy production many sources of energy has been exploited and used in order to ensure development. Some of the major sources include the use of renewable energy sources such as biogas, solar, hydroelectric power supply and geothermal.

Biogas energy is among the renewable energy sources which promises an environmentally less damaging way by reducing CO_2 emissions into the environment and reduces energy dependence on imported energy sources [3]. It is essential to develop sustainable energy supply system aimed at covering the energy demand from renewable sources [4] [5]. Biogas production can contribute to both climate change mitigation through energy or nutrient recovery and to climate change adaptation through innovative sanitation systems and waste management.

Biogas energy is a renewable energy that can be used for cooking, lighting, heating purposes, and for generating electrical power [6]. It is produced by bacteria that decomposes organic matter under anaerobic condition (i.e. in the absence of oxygen). For it production various substrates can be used such as mixture of excreta, organic waste from households or agricultural farm, animal manure etc.[7]. When that organic matter is stored without the approach, a biological process starts, resulting in biogas. Biogas from sewage digesters usually contains 55

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% to 65 % methane, 35 % to 45 % carbon dioxide and <1 % nitrogen biogas from organic waste digesters usually contains 60 % to 70 % methane, 30 % to 40 % carbon dioxide and <1 % nitrogen while in landfills the methane content is usually 45 % to 55 %, 30 % to 40 % carbon dioxide and 5 % to 15 % nitrogen [8] [9]. Typically the biogas also contains hydrogen sulphide and other sulphur compounds, compounds such as siloxanes and aromatic and halogenated compounds [10] [11].

This work concerned the pure biogas energy. Nowadays, biogas technologies are widely used around the world in various forms of application such as generate electricity for houses in rural areas. It provides electricity for cooking, fuel for lighting, cooling, it is often the most appropriate technology to meet the energy demand of the rural communities especially the farmers at large or small scale. Biogas has an average methane content of 55 – 75 %, which provide an energy of 6 – 6.5 kWh/m^3 [12]. A 100 goats and 15 people's waste can be used to produce 10 m^3 of biogas [13]. A 1000 liter capacity digestion tank using 750 liter gas holder capacity have 700 liter available gas with a duration of burning 2 hours which will be sufficient for a small household for daily cooking purpose. A 2500 liters capacity digestion tank with 2000 liters capacity gas holder produce 1750 liter of available gas for 5 hours of duration of burning. A 1 kg of green biomass is equivalent to 100 g methane which is also equal to 100g LPG or 0.5 kWh energy. Hence, the first objective of this study is to identify and characterize the various biomass resources sufficiently available for biogas generation in the Brong Ahafo region of Ghana (as shown in figure 1). The second objective is to analyze the sustainability of biogas production. And the third objective is to estimate the emission reduction from biogas production. This work is divided in five sections. In the first one, the energetic and renewable biogas energy situation in Brong Ahafo region were presented. The second section entails of relevant literature review focusing on biogas, anaerobic digestion and greenhouse emission. The third section, examine the data and methodology of the experimental design used to conduct this study. Results are presented on section fourth. A general conclusion on the sustainability of biogas production is given on section five.

2. STUDY AREA

The study area was selected because, it is the second biggest region and has acres of land for cultivation and its population are the major producers of most of the littered agricultural products. When the waste are not managed well it will contribute to the increase of greenhouse gases emission into the atmosphere, also it contribute to air and water pollution which lead to diseases. To protect the environment and reduce the emissions, the focus is need to collect and recycle waste. Over this region this kind of the research has never been carried out.

2.1 Renewable biogas energy Situation of Brong Ahafo

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Brong-Ahafo region is located between 7º 45N latitude and 1º 30 W longitude in the southern part of Ghana and is the second largest region with a land areas of 39,558 km^2 with an estimate population of 2,282,128 [14]. It covers 16.6 % of the country's total land area. Its capital is Sunyani with an average elevation of about 384.8. It has a bi-modal rainfall with an average annual rainfall between 1,088 – 1,197 mm. Brong Ahafo is renowned for its large cocoa production and agriculture agribusiness industries. The region has different types of maize residues which generate a total amount of 4,936 TJ of energy content. The total amount of electrical energy that could be produced from residues in the region annually was around 494,127 MWh, equivalent to 494 GWh. In the Atebubu-Amantin the dry maize residue will be able to supply a 40 kW plant on a sustainable basis to produce electrical energy[15]

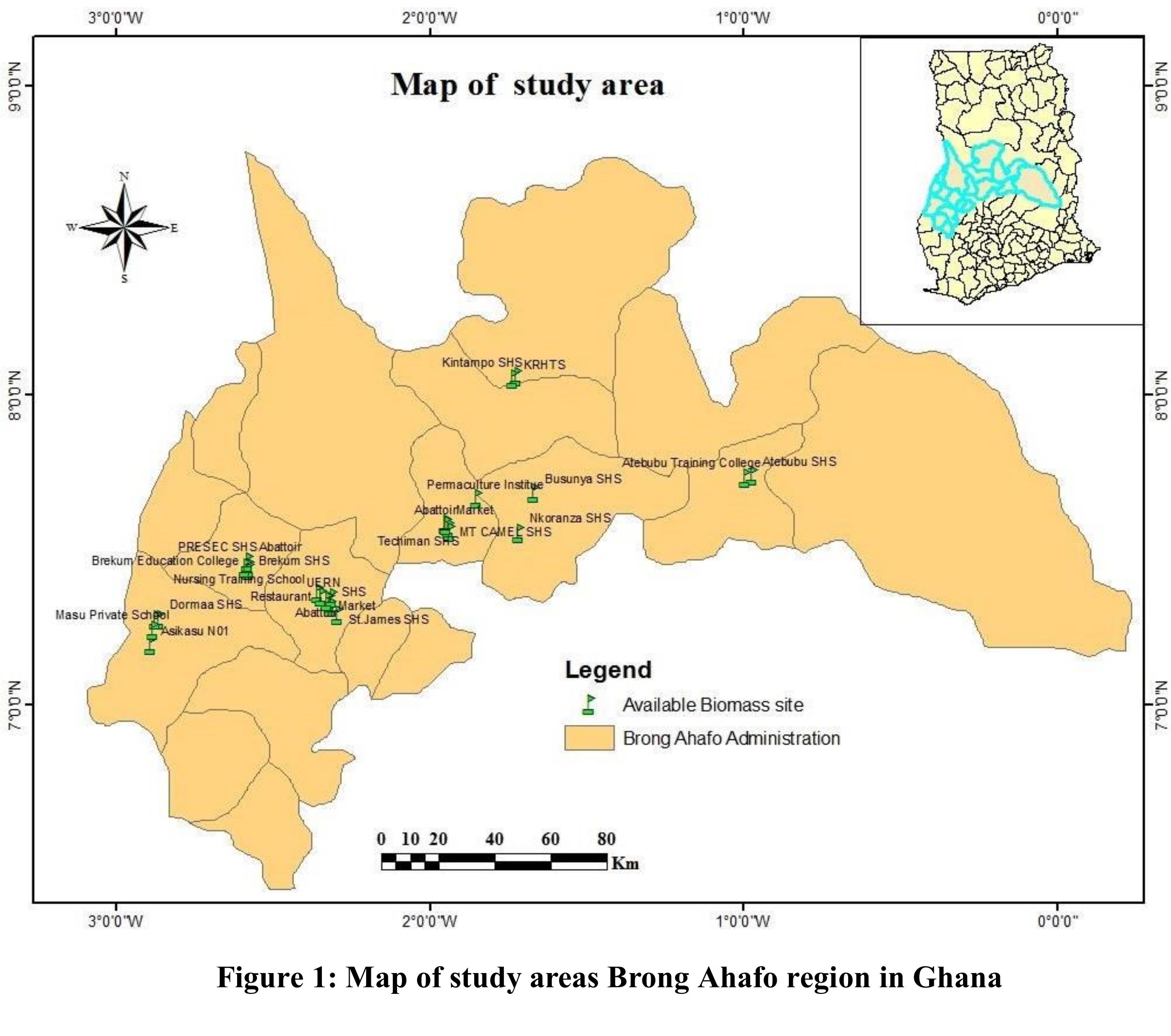

Figure 1: Map of study areas Brong Ahafo region in Ghana

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2.2 Income pattern

Majority of people in Brong Ahafo earn their income from agriculture activities 56 %, industrial activities 19 %, commercial activities 7.4 % and the service sector 23.6 %. A large proportion of the low income group is found in the agricultural sector. Apart from improving income levels and the majority of this low income earners rely solely on fire wood and charcoal both for their heating and electricity.

3. MATERIALS AND METHODS

This work was carried out in three steps: a) survey on biogas plant technology to check out works done in the field, b) experimental biogas plant and c) potential biogas production and emission reduction in the study areas.

3.1 Survey:

The field survey was conducted to investigate a right information on the methods, the techno-economic feasibility and the sustainability of biogas production in the region. The survey were carried out in some major towns such as: Sunyani, Techiman, Berekum, Atebubu, Dormaa, Nkoranza and Kintampo. In all, 47 people from school, Hotel, Restaurant, Market and Abattoir were interviewed.

3.2 Questionnaire Design

A set of interview questionnaire was designed for the Market, the Senior High Schools, Hotels, Restaurants and Abattoirs to obtain information about biomass resources and, technology use and their preferences. A total of 30 questions were prepared considering various aspects of the study goal. Some of the parameters considered in questionnaire design included the types of waste they generate daily, in the abattoirs how many animals they slaughter daily, the disposition of their waste, their sources of cooking fuels with their amount and their knowledge of biogas technology. Interview session was placed during end of April and early June, 2015. The average time spent in waste collection data and one biogas household to collect data and information was 20 minutes maximum and 10 minutes minimum.

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Table 1: Sampling Distribution

Region	District	Number of Sampled					
		School	Hotel	Restaurant	Market	Abatoir	**Total**
Brong Ahafo	Sunyani	5	5	4	1	1	16
	Brekum	4			1	1	6
	Nkoranza	1	1		1		3
	Kintampo	3	1	1			5
	Techiman	3	2		2	1	8
	Dormaa	4			1	1	6
	Atebubu	2			1		3
	Total	**22**	**9**	**5**	**7**	**4**	**47**

Sources field work

3.3 Experimental Design

3.3.1 Material for construction

Three polytanks of 300 liters capacity was used as the digester and three polytanks of 150 liters was used as gas holder, 6cm diameter PVC pipes was used for feeding the waste and outlet for the slurry, PVC glues, Silicon sealant, Epoxy steel, valves socket, flexible tubes.

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Figure 2: Some materials used for construction for three 300 liters polytanks as digester and 150 liters tank as a gas holder

3.3.2 Fabrication of small scale Biodigestors

Figure 3: Polytanks used as a bio-digester

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Figure 4: A 150 liters of gas holder tank

- In digester tank two holes were created for the inlet and outlet respectively; one on top and the other at the bottom. The connector's tank were fitted into the hole and sealed with the silicon to prevent leakages. A 6 cm of PVC pipes were connected into the tank connectors for the inlet and outlet.
- One hole was created on the top of the 150 liters gas holder which serve as the outlet of the gas. Also a stirrer was used for mixing the waste. The hole for the gas outlet was fitted with a pipe valve. The silicon sealant and the PVC glue were used to the lid to make the gas holder air tight.
- Two days were allowed for all joints to get cured and become leak-proof before feeding the system.

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Figure 5: Three experimental set up for biogas production

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- The main components of this system are:

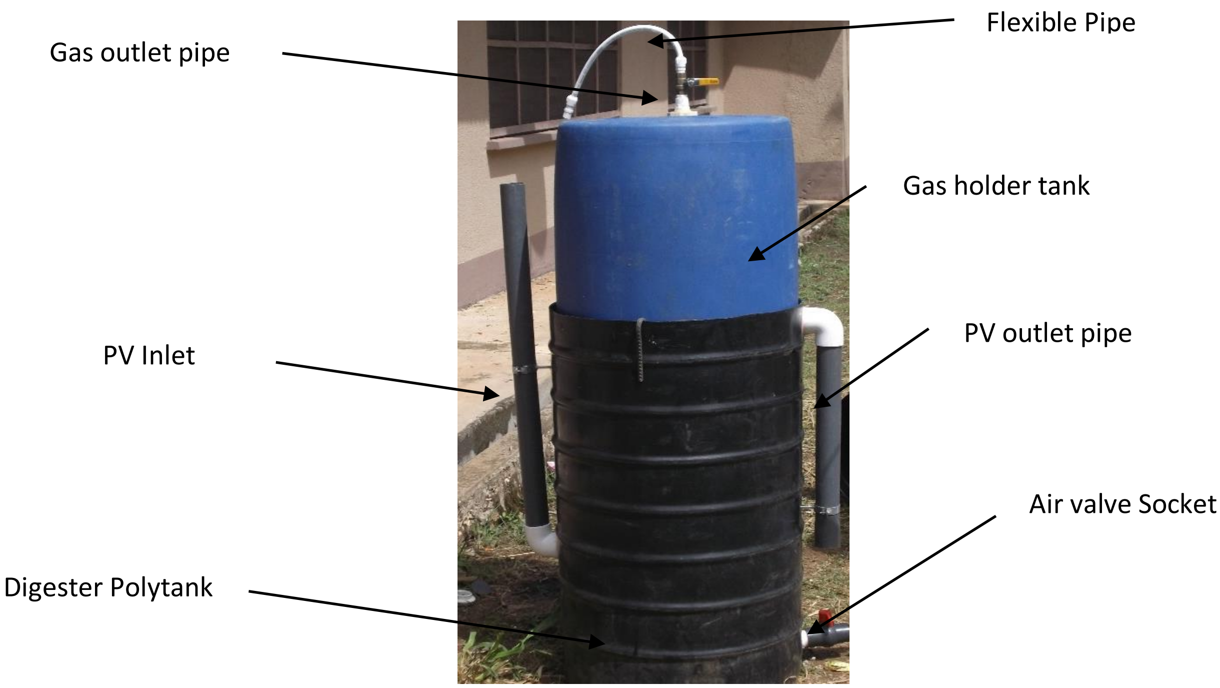

Figure 6: Complete unit digester tank

3.3.3 Fermentation and Data collection

Firstly for each three tank 20 kgs of cow dung were mixed with twenty liters of water thoroughly by hand and poured into the 300 liters digester and feed it with water until the top. And closed with the 150 liter thank. The gas outlet valve was open to allow all the air to be removed and closed it. Secondly when the gas started to form. Subsequently, food waste, ingester and market waste (orange, avocado, vegetable, tomato etc.), were diluted with water and used to feed the system. The market waste like orange, avocado, pineapple, papaya, water melon, vegetable and leaves) was blended using blender and mashing, into small particles to facilitate digestion of biomass resources under anaerobic conditions. The purpose of cow dung is to make a culture of the microorganisms, so that when fresh food waste, market waste and ingester was added it, biogas production is enhanced. For the gas to ferment more easily, the digester was stirred for a least 1 – 2 times daily for about 30 seconds. The pH of the digester was measured weekly by collecting some slurry into a container and then read with the pH meter. For each feedstock (Ingester, food waste and market waste), measurement of methane, flow rate, temperature were

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taken daily during three months using the flow meter (see figure 7). And also the quantity of gas for each thank was measured using the meter. The biogas production potential of the area under study was assessed by estimating the available biomass resources and using the RETScreen software. The potential emission reduction was also assessed using the RETScreen. The annual biomass feedstock yield from each locality was calculated by multiplying the daily feedstock weight by 300. (300 is the number of days).

The annual biogas production (ABP) was calculated from the equation:

$$ABP = w * q * DM * VS * BF$$

Where, w = average weight per unit

q = quantity of unit. DM = % dry matter. VS = % dry matter volatile solids

BF = biogas production factor

Figure 7: Flow rate measurement

4. RESULTS AND DISCUSSION

4.1 Experimental biogas production

The anaerobic digestion process takes place in an airtight container, known as a digester. The amount of gas production in a digester is influenced by the characteristics of the waste applied to the digester. It is also influenced by the temperature, the hydraulic retention time, and the loading rate and by how readily wastes are biodegraded. The hydraulic retention time (HRT) 5 days (for 10kg waste + 10l water per day for one digester). The daily feed from the three digester generate

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about 20.411 of biogas per day which correspond to 4 min burning period. In digestion, different bacteria dominate at different temperatures which develop and cause the methane production to be reduced. The bacteria give up heat from respiration as they work. The heat is generally not suitable to keep the liquid warm. In digester the temperature need to be uniform to prevent undesired bacterial activity. In the digester the temperature fluctuation will affect the activity of methane forming bacteria. In this work, the optimum temperature recorded was between 27 ºC – 36ºC. The average methane value for the ingester was 54%, followed by the market waste 42%, then by food waste 40%. For the food waste, after 48 days the methane start decreasing as acid concentration increases (Figure 8) and pH decreases to 4.47 (Table 2).

Feedstock	pH	Flow rate (m^3/s)	Temperature (ºC)	Quantity of gas (cm^3)	Methane content (%)
Ingester	**6.50 – 7.25**	**0.758977**	**27 - 36**	**6593.62**	**45 - 64**
Food waste	**4.47 – 7.15**	**0.817742**	**27 - 35**	**5947.187**	**43 - 55**
Market waste	**6.10 – 7.00**	**1.048452**	**27 - 34**	**7864.324**	**44 - 71**

Table 2: Characteristics of the different feedstock in the experimental digestion

The pH level of the anaerobic digestion should be kept from 5.5-8.5 with an optimum interval of 7.0 to 8.0 for most methanogens and the temperature between 30-60°C, in order to maximize digestion rates. This is to ensure a balance between the acetogens which are responsible for acid production and the methanogens that consumes acid thereby increasing the alkalinity to be able to produce the methane gas. The pH value of the anaerobic substrate impacts the progression of methanogenic microorganisms and affects the separation of some compounds of importance for the process (ammonia, sulphide, organic acids) [16]. A properly operating digester will convert most of the volatile solids into biogas. From the substrates that were used, it can be observed that (see figure 8), quantity of gas production per day from the three digesters were not stable. Consequently, the difference in the production of biogas depends on the characteristics of the type of substrate applied to the digester, digester temperature, and organic loading rate to the digester. The highest average flow was recorded for the market waste 1.048452 m 3 /s higher followed by the food waste 0.817742 m 3 /s and the ingester which had 0.758977 m 3 /s. The flow rate of gas depend on the quantity of gas produced.

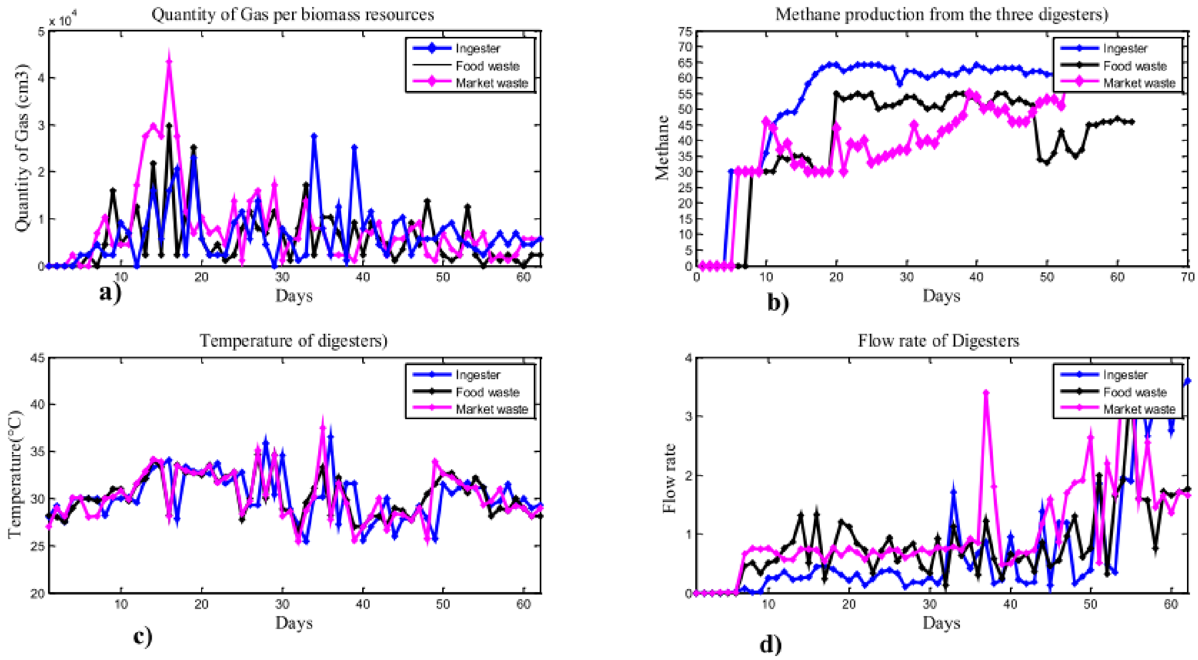

Figure 8: Biogas production. a) amount of biogas per feedstock through production period; b) methane content per feedstock; c) temperature variation through production period per feedstock; d) flow rate variation through production period per feedstock

4.2 Biomass resources sufficiently available for biogas generation

The study found that several resources exist or are available as biomass resources for biogas production in the Brong Ahafo region of Ghana. Biogas can be produced from variety of substrates, such as animal manure, energy crops, industrial wastes etc. Biogas production is a sustainable solution to treat waste and the cost of the waste treatment is low[17]. The study found that of all biomass resources 30.0% are animal manure. This type of biomass resource are mostly solid waste generated by animals. They include cow dung, goat and sheep droppings among other animal droppings mixed with other materials such as straw, hay and fodder. Further, the next most common type of biomass resource available for biogas production in Brong Ahafo region is household waste. This also forms 30.0% of all biomass resources available. This type of biomass resources include all waste generated by individual households. It comprises of plastic and papers from packaging; cans; peels of vegetables, fruits and root crops such cassava, yam, cocoyam and water yam among others. Household wastes also comprised of left over foods; among others. The study found that about households in the region 40.0% generates 90 liters of waste daily, 40.0 % generates 180 liters of waste daily, whilst 17.0 percent and 3.0% respectively generates 270 liters and 360 liters and above daily (see figure 9 for details).

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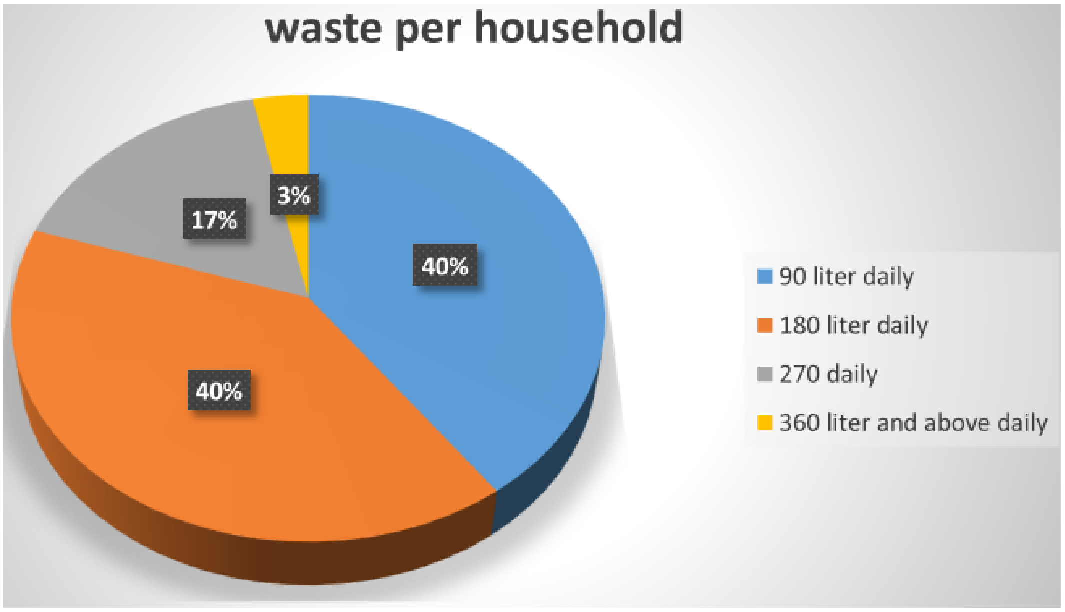

Figure 9: showing volume of waste generated per day per household in the region (Source: Field Survey, 2015)

The second largest biomass resources found in the study area is the agriculture residue. Agriculture residue as a biomass resource account for 20.0% of all biomass resources available in the region. Agriculture residue comprises of matter that remains in the farm after crops have been harvested. They include stalks, stubble, leaves, seeds, husks, bagasse, and roots of plants. The third largest biomass resources available in the region as found by the study is the abattoir waste. This represents 13.3% of all biomass resources in the region. Abattoir waste as a biomass resource comprise of leftover meats, intestines of animals; particles of bones; fur of animals and undigested ingester found in animals that have been slaughtered for meet found in abattoirs, meat houses and butcher joints in the region. It is found that each abattoir in the region slaughters an average of 75 animals per day. The last type of biomass resources as identified by the study in this category is the municipal waste. This is the least type of waste identified as biomass resource. It represents 6.7% of all biomass resources found in the metropolis (see table 3 for details). Municipal wastes also comprised of human and domestic waste matter both solid and liquid carried away through sewers. These wastes come from our homes, schools, hospitals, and businesses within the region.

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Table 3: Biomass resources from Biogas Production Units

Biomass resources	Frequency	Percent
Animal manure	9	30.0
Household waste	9	30.0
Agriculture residue	6	20.0
Municipal waste	2	6.7
Abattoir waste (ingesta)	4	13.3
Total	30	100.0

Source: Field Survey, 2015

Other types of biomass resources as identified by the study include food waste and Toilet or human excreta. The study identified toilets or human excreta as one of the most important resources for biogas generation. This comprises of urine and feces from the human body (Table 4).

Table 4: other biomass resources as Identified by household heads

Biomass resources	Frequency	Percent
food waste	18	60.0
Toilet (Human Excreta)	12	40.0
Total	30	100.0

Source: Field Survey, 2015

4.3 Sustainability of biogas production in Brong Ahafo

The study found that 29.0% of the 7 biogas plants covered in this study, have been operational since their construction. The institutions with operational biogas plants reported that the biogas plants remain operational because they provided the needed methane yield to satisfy their energy needs. Nevertheless, 71.0% of biogas plants covered by the study were non-operational (see figure 10 for details). Many of them collapse whilst others were abandoned for poor quality yield, poor quality of construction materials, high cost of maintenance, lack of expertise to ensure frequent maintenance and operationalization of the plant, lack of technology transfer and high initial construction costs. Therefore they stressed that due to the aforementioned factors

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biogas production in the region can be classified as unsustainable. Furthermore, in analyzing the sustainability of biogas production in the region, the study focused on the availability and cost of biomass resources. The study identified popular biomass resources to include agricultural residue, animal manure, food waste, household waste, and human excreta among others (refer to table 3 and 4 for details). The use of these resources as alternative energy or fuel source will help for reducing deforestation thereby promoting environmental conservation and ecological sustainability. Preserving forest cover and increases the periodicity of photosynthesis of plants and abundant supply of oxygen for human survival and well-being thereby promoting social sustainability in the region. The study found that a total of 83.3% of heads or supervisors (owners) of biogas plants reported that biogas production is sustainable in the context of the cost of installation and maintenance of the plants. They reported that the cost of plant installation are cheap (16.7%), reasonable (26.7%) and sustainable (40.0%) in the long term. However, 16.7% of owners of biogas plants reported that the installation and maintenance costs associated with biogas production are very expensive (see figure 10). The expertise to set up the plants are not readily available in Ghana, those around charges exorbitant fees whilst cost construction materials particularly cement rises with the inflation of the country.

In the Brong Ahafo region in Ghana, the penetration of the biogas technology will contribute immensely to the technical, economic, social, and cultural activities of this region. Its benefits are: It will provide economic and environmental sustainability, providing additional income by increasing agricultural yields and farm output, It reduces the work load mainly on women towards the firewood collection and smoke, It reduces fuel wood use (through deforestation), indoor pollution and chemical fertilizer use, the implementation of biogas technology will help in the global climate change mitigation through capturing of methane.

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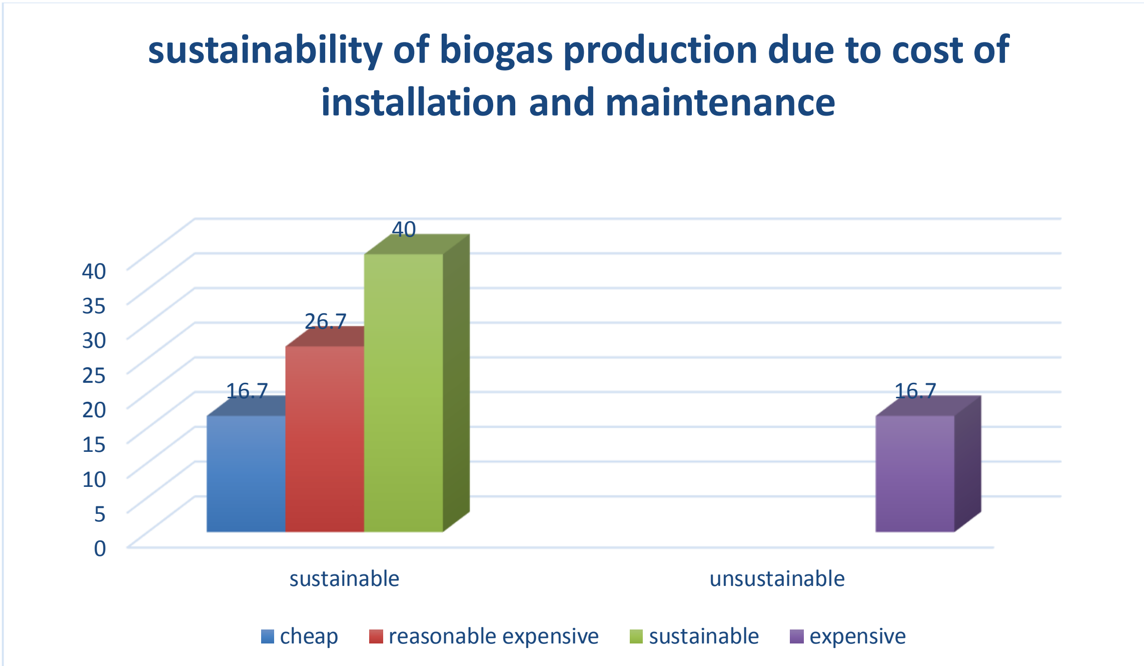

Figure 10: sustainability of biogas production in the context of cost of installation and maintenance (Source: field survey, 2015)

4.4 Estimation of emission reduction from biogas production

Biogas production through anaerobic digestion (AD) is a renewable source of energy with potential of reducing carbon emission[18]. The annual biomass feedstock yield from the various localities visited are shown in Table 5. The largest amount of waste generated was from the market, whilst restaurants had the least waste generated. The abattoir waste was smaller than that of kitchen waste due to the smaller number of abattoirs in the region, although the daily feedstock average for abattoir is much higher than any of the kitchen waste. Consequently, the annual biogas production potential was least for abattoir waste and highest for kitchen waste (Table 6). The potential emission reduction derived from RETScreen is shown in Tables 7 and 8.

Table 5: Annual feedstock yield from field survey

Biomass feedstock	Location	No. visited	Daily feedstock average weight (kg)	Total feedstock average weight (kg)	Annual feedstock yield (kg)
Kitchen waste	School	22	400	13010	3903000
	Hotel	9	340		
	Restaurant	5	230		
Abattoir waste	Abattoir	4	999	3996	1198800
Market waste	Market	7	2000	14000	4200000

Table 6: Annual biogas production potential from field survey

Biomass Feedstock	Average weight per unit (kg)	Quantity (kg)	Dry matter (%)	Dry matter - volatile solids (%)	Biogas production factor (m^3/kg)	Biogas production - annual (m^3)
Kitchen waste	1	3,903,000	23.0%	89.0%	0.35	279,630
Abattoir waste	27	44,400	12.0%	95.0%	0.30	40,999
Market waste	1	4,200,000	15.0%	83.0%	0.45	235,305
					TOTAL	**555,934**

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Table 7: Emission Analysis (RETScreen)

	Base case	Proposed case
Fuel type	Wood (t)	Biogas (m^3)
Fuel consumption	2,084,753	333,560

Table 8: Emission Analysis (RETScreen)

GHG emission		
Base case	tCO_2	73,519
Proposed case	tCO_2	622
Gross annual GHG emission reduction	tCO_2	72,897
Net annual GHG emission reduction	tCO_2	72,897

From Tables 7 and 8, the use of biogas in the studied areas, in place of wood for energy potentially saves seventy two thousand, eight hundred and ninety seven (72,897) tonnes of CO_2 from being released into the atmosphere. This 72,897 tCO_2 emission reduction is equivalent to 14,820 cars and light trucks not used.

5. CONCLUSION AND RECOMMENDATIONS

Biogas technologies are among the most promised renewable energy technologies and research is still ongoing to improve the efficiency in the World. There is abundance of waste in Brong Ahafo and the largest amount of this waste comes from Abattoirs, Markets, saw mills and the separation and collection are easy. In the Brong Ahafo region in Ghana, the penetration of the biogas technology will contribute immensely to the technical, economic, social, and cultural activities of this region. It is found that on the basis of durability of plants and continuity of biogas production, biogas production is 60.0% sustainable and 40.0 % unsustainable. Furthermore, the study found that on the basis of availability of biomass resources as input in the biogas production process, biogas production in Brong Ahafo is highly sustainable due to the greater availability of biomass resources such as household waste, food waste, agriculture residue, animal manure and human excreta among others. Finally, the study found that on the basis of cost of installation and maintenance of biogas plants, biogas production in Brong Ahafo is 83.3% sustainable and 16.7% unsustainable. The production of biogas makes a significant contribution to climate protection, because methane is used in the biogas plant to ferment slurry (liquid manure) and manure, which otherwise escapes into the atmosphere from the liquid manure tank. Biogas technology is the one of the best energy sources that provide energy in one hand and reduce the emission of the GHGs on the other hand. It is the effective and appropriate mitigation effort in Ghana. Biogas technology is increasing in Ghana particularly in Brong Ahafo region. It also protect the forest area by reducing the fuel wood consumption and has positive socio-economic impacts that improve the adaptive capacity of the people that help to minimize the vulnerability of the community, people to changing climate. A biogas plant with an installed electricity capacity of about 500 kilowatts (kW) produces about four million kilowatt hours (kWh) of electricity and 4.4 million kWh of heat in one year from about two million cubic meters (m^3) of biogas. Therefore it replaces the equivalent of 440,000 liters of fuel oil. Thus, a farmer can produce enough electricity for more than 1,000 average four-person households in one year at his power station [19]. Therefore, there is a need for government to make a decision about the way to provide support to Non-Governmental Organizations (NGOs) on energy, centers for Energy and Environment to help assist in providing the technical, economic and financial support to this biogas users.

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CONFLICT OF INTEREST

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

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