ASSESSING THE COST-EFFICIENCY AND WILLINGNESS TO ADOPT BIOGAS AS A SUSTAINABLE SOURCE OF RENEWABLE ENERGY: THE CASE OF SENIOR HIGH SCHOOLS IN THE GREATER ACCRA REGION

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THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF PHILOSOPHY DEGREE IN CLIMATE CHANGE AND SUSTAINABLE DEVELOPMENT

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DECLARATION

I John Leonard Doghle, author of this thesis, do hereby declared that the work presented in this thesis titled "Assessing the Cost-Efficiency and Willingness to Adopt Biogas as a Sustainable Source of Renewable Energy: The Case of Senior High Schools in the Greater Accra Region" was done entirely by me in the University of Ghana, Legon, except where references of other work was duly acknowledged. This work has never been presented in part or whole for any degree in this University or elsewhere

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JOHN LEONARD DOGHLE **Date**

CERTIFICATION

We hereby certify that the preparation and presentation of the thesis was supervised in accordance with the guidelines for supervision laid down by the University of Ghana, Legon. This thesis has been submitted for examination with our approval as supervisors

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ABSTRACT

Energy is an indispensable component of human living. Renewable energy (RE) is regarded as a strategic approach to the reduction of Greenhouse Gas (GHG) emissions. Biogas is regarded as one of the most reliable forms of renewable energy capable of addressing the energy needs of many institutions. Research indicates that Ghana has enough potential in terms of feedstock for the generation of biogas at both institutional and household level. The aim of this study was therefore to assess the cost efficiency and willingness to adopt biogas technology as a sustainable source of renewable energy for boarding Senior High Schools in the Greater Accra Region of Ghana. The study was guided by a theoretical framework that focused on the technology adoption process, diffusion of innovations and a technology acceptance model. In all, forty-four schools were sampled for quantitative and qualitative research. Forty schools did not have biogas plants and were studied using the probability approach while four schools which had biogas plants were purposively selected and qualitatively analysed. Six biogas installers, commercial biogas to electricity operator, two regulatory agencies and a research institution also participated in the study. The findings of the study indicated that there is a high potential for Senior High Schools to generate enough biogas for cooking and heating based on the mean population of 1,054 students from the 40 schools sampled, with more than 80% of the students being boarders. The main sources of cooking/heating energy at the school level were LPG at 25.9%, firewood at 10.3% and charcoal at 10.3%. Eighty-eight (88) percent of institutions without biogas expressed their willingness to adopt biogas technology but are constrained by access to finance and institutional bottlenecks. Cost efficiency variables indicate that initial cost of adopting biogas as a supplementary energy for cooking, averages GHS 8,000. Biogas has the potential to reduce waste and supplement energy for cooking purposes. These two elements constitute major budget allocations of Senior High Schools. The main constraints in adopting biogas technology as observed by user institutions were the high initial installation and maintenance cost, low gas production and accessing technical experts for routine maintenance. The study recommends government financial support in the form of subsidies to help provide biogas systems at minimum cost. This will facilitate more schools to adopt biogas technology and reduce the financial burden they incur in waste management and energy consumption.

DEDICATION

This work is dedicated first to God for showering His merciful love, guidance, protection and above all for providing for me knowledge and wisdom throughout my course. Finally, to my parents Mr Thomas Doghle and Mrs Benedicta Kutir Doghle for their profound support, endurance and encouragement, commitment and devotion throughout my education. Daddy, though not physically present to see the joy of your toils, I hope your soul is beaming with smiles. May God richly bless you in all your endeavours. Amen.

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List of Abbreviations

ABR …………………Anaerobic Baffled Reactor

BAG…………………Biogas Association of Ghana

CAMARTEC ……….Centre for Agricultural Mechanization and Rural Technology

COD…………………Chemical Oxygen Demand

CSIR…………………Centre for Scientific and Industrial Research

CT……………………Compensating Tank

EPA………………….Environmental Protection Agency

GHG…………………Greenhouse Gas

GTZ………………….German Agency for Technical Assistance

HRT………………….Hydraulic Retention Time

IAP……………….….Indoor Air Pollution

IPCC…………………Intergovernmental Panel on Climate Change

KVIP…………………Kumasi Ventilated Improved Pit

LPG………………….Liquefied Petroleum Gas

MMDA………………Metropolitan, Municipal and District Assemblies

MSW…………………Municipal solid waste

OLR………………….Organic Loading Rate

RE……………………Renewable Energy

SDGs…………………Sustainable Development Goals

SIDO…………………Small Industries Development Organization

SRREN………………Special Report on Renewable Energy

UNEP………………...United Nation Environmental Programme

WBA…………………World Biogas Association

CHAPTER ONE

INTRODUCTION

1.1 Background

Energy has for a long time been a channel through which almost everything throughout the world is accomplished (International Energy Agency (IEA), 2014). Globally, energy influences and limits our stage of development and standards of living. The consumption of energy has dramatically risen, especially in the twentieth century with projections indicating a continuous rise within the next 50 years (Kreith & Goswami, 2007). The high consumption of energy is attributed to increases in population with a corresponding increase in industrialisation. A great part of the energy consumed for industrialisation and economic growth is from fossil fuel-natural gas, crude oil, uranium and coal-which accounts for a total of 85% of primary energy produced globally (Minde, *et al.*, 2013; Ruppert, *et al.*, 2013). Twidell and Weir (2006), posited that the rising world's energy demand is due to industrialization and rapid population growth in this twenty first century. The IEA, (2016) added that the world's population was about 7.3 billion in 2015 and is expected to further rise to 9.2 billion by 2040. This will imply high energy demand and consumption.

The implication of high energy consumption from fossil fuel is that it will generate significant global environmental problems (Panwar, *et al.*, 2011). This they believed, will lead to global climate change and global warming as more Greenhouse Gases (GHGs) such as Methane (CH_4), Carbon dioxide (CO_2), Chlorofluorocarbons (CFCs), Nitrous Oxide (N_2O), Halons and other gases will be released into the atmosphere. The Intergovernmental Panel on Climate Change Synthesis Report (IPCC, 2014) indicates that "Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years". The high content of CO_2 in the atmosphere is attributed to the high amount of fossil fuel that is being utilized. The IPCC (2014), confirmed that CO_2 emissions constitute about 78% of the total GHG mainly from fossil fuel as a result of combustion and industrialisation processes. The effect is that global average temperatures have significantly risen from 0.65 to 1.06^0C over the period 1880 to 2012 (Shrestha, 2014). The effects of high CO_2 and other GHGs are manifested in increased temperatures, erratic rainfall patterns, wildfires, frequent and destructive floods, and prolonged droughts. The increasing global temperatures have also resulted in a rise in global sea levels which is estimated to be rising between 1mm to 2mm per annum over the last century (Shrestha, 2014; Panwar, *et al.,* 2011).

According to IPCC (2014), limiting the emission levels of CO_2 and other long-lived GHGs as well as reducing the warming of global earth temperatures to below 2°C requires adopting an integrated approach that centres on reducing energy use, decarbonizing energy supply, and improving carbon sinks in land-based sectors. This means reducing high dependence on energy sources which are emitting large quantities of GHGs into the atmosphere and switching to renewable energies. The Paris Agreement (COP21), signed in December 2015, gave a roadmap on measures to reduce GHG emissions and limit temperature rise (Kinley, 2017; Savaresi, 2016). The agreement allowed countries to submit their Nationally Determined Contributions-(NDCs) which outlined the strategies and means each country will take to decarbonize and reduce GHG emissions (Kinley, 2017; IEA, 2015). Globally, many of the NDCs countries including those in Africa, focused much on renewable energy (RE) use (ClimDev-Africa, 2016; Cabré & Sokona, 2016). According to the

Environmental Protection Agency (EPA)-Ghana (2015), Ghana's NDCs on energy centred on; scaling up RE to 10% of energy mix, promoting clean energy for rural areas, and doubling energy efficiency from existing power plants to 20% by the years 2020 and increasing this to 45% by 2030.

RE is thus regarded as a strategic approach to the reduction of GHG emissions. This explains why the IEA (2014), indicated that, the share of RE will increase from 29% to 42% between 2020 to 2030. The IPCC (2012) Special Report on Renewable Energy (SRREN) also added that there is a substantial increase in RE consumption, especially biomass in developing countries which account for about 60% of the total energy. The Report also identified RE's as; Biomass, Solar Energy, Geothermal Energy, Hydropower, Ocean Energy and Wind Energy.

Biomass energy[1] is approximately 10% of global RE, making it by far the major source of RE for many countries, especially developing countries (Janssen & Rutz, 2012; IEA, 2009; IEA, 2008; IPCC, 2007). About 70–80% of biomass is made up of wood, crop residues, and animal waste. These sources are used primarily in rural domestic cooking appliances in many countries in transition (Janssen & Rutz, 2012; IPCC, 2007). About 80% of the total population in developing countries in the view of Cameron *et al.*, (2014) and IEA, (2017) depend on traditional biomass as their main form of energy. However, the unsustainable use of biomass and the problem of indoor air pollution (IAP) from biomass consumption in developing countries are of great concern.

The main sources of energy for Ghana are currently four: biomass, petroleum, solar energy and hydro power. The bulk of energy needs in Ghana is met from wood fuels,

[1] refers to energy derived from organic waste or waste materials from recent living organisms

i.e., firewood and charcoal (Armah, *et al.*, 2015). The Energy Commission (EC) of Ghana (2015), confirmed that about 70% of Ghana's primary energy needs is met by wood fuel. The high consumption of wood fuel has serious implication for deforestation, climate change and depletion of carbon sinks (Energy Commission of Ghana, 2015). And if the high consumption of wood fuel continues unabated, Ghana stands the risk of consuming more than 25 million tons of wood by the year 2020 (Energy Commission, 2012).

This means that a relatively cost-efficient and sustainable source of RE must be pursued to reduce overreliance on the wood-fuel and fossil fuel base. This requires a technology that has the capacity to deal with energy shortages, to supply a clean form of energy and reduce environmental pollution in order to promote and attain the sustainable development goals (SDGs). A technology that can respond to these unique characteristics is biogas technology. Chen *et al*., (2017); Akinbomi *et al*., (2014) and Abbasi, *et al.*, (2012) posited that biogas technology has an urgent answer to providing adequate, clean and affordable energy (renewable energy) for all geographical locations. In other words, biogas technology can be deployed at any location, uses local materials for its construction and utilises waste materials (biodegradable) which would have constituted an environmental nuisance.

More so, the pursuance of biogas technology will lead to the attainment of many of our SDGs, especially Goals 3, 6, 7, 13, 14, 15 and 17 (Good Health & Well-Being, Clean Water & Sanitation, Affordable & Clean Energy, Climate Action, Life Below Water, Life Above Water and Partnership for the Goals respectively). The World Biogas Association (WBA) Factsheet 3 (2016) indicated that biogas technology "contributes to at least nine of the 17 SDGs agreed by the countries of the United Nations to be achieved by 2030". It can be inferred that biogas technology addresses directly three key fundamental issues of human activities-waste management, energy consumption, and agriculture which creates environmental challenges and high GHG emissions. The total emissions from these three activities constitute the highest of all GHGs in the atmosphere (IPCC, 2007).

In spite of the numerous benefits offered by biogas, there are equally challenging issues confronting the adoption of this technology. Biogas has been in use for a long time in Ghana but there has not been any comprehensive programme to promote its deployment and dissemination in the country. The first biogas plant in Ghana was built in the 1980s (Bensah, *et al.*, 2010). There is enough evidence from the literature that Ghana indeed has enough potential in terms of feedstock for the generation of biogas either from the institutional level or at the household level (Mohammed, *et al.*, 2017*;* Kemausuor, *et al.*, 2015*;* Ahiekpor, 2014; Daniel, *et al*., 2014; Auther, *et al.*, .2010; *&* Dafrallah, *et al.*, 2010). Also, within the context of Senior High Schools in Ghana, the Free Senior High School policy directive with an expected increase in student population pose an impending threat to the management of large volumes of waste that will be generated. A technology that can help schools deal with their energy, sanitation, and water supply needs is urgently required. However, the adoption of an appropriate technology such as biogas requires an assessment of the relative cost efficiency as well as the extent to which major stakeholders within these schools are willing to adopt the technology.

1.2 Problem statement

Green and cost-efficient forms of energy such as biogas are necessary for meeting the energy needs of an energy deficient country like Ghana. There is a heavy reliance on energy sources like fuel wood and charcoal by many households and institutions in Ghana. Institutions such as Senior High Schools (SHSs) in the Greater Accra Region are no exception to the overreliance on traditional sources of energy for cooking. The reliance on wood fuel and charcoal has far-reaching environmental, health and financial implications for the country (Nelleman, *et al.*, 2014; United Nation Environmental Programme ((UNEP), 2012). This has greatly contributed to the loss of carbon sinks and other valuable ecosystem services that emanate from shrub ecosystems. The combustion of wood fuel has been identified as a cause of IAP and respiratory ailments among users. This is due to the excessive inhalation of smoke from products of incomplete combustion (PICs) and poorly installed cooking technologies being used (Armah, *et al.,* 2015).

Energy is critical to the attainment of many of the goals outlined in the SDGs. Biogas use will facilitate the provision of an affordable, clean and sustainable source of energy as stipulated in SDG 7. However, the source of energy (fuelwood and charcoal) used by many SHSs, especially for cooking, in the Greater Accra Region is not clean due to inefficient technology for combustion which emits a lot of smoke. Meals are not prepared on time especially on rainy days as wood becomes too wet for combustion and produces the huge amounts of smoke. This affects learning as the meals are served late. Consequently, this affect performance in the long run as teachers have less time to complete their syllabuses. Equally, students are not able to prepare adequately for the West Africa Senior School Certificate Examination (WASSCE), thereby affecting their quality of grades. Although Liquefied Petroleum Gas (LPG[2]) is arguably a clean form of energy for cooking, it is expensive and its usage adds to the financial burdens of managing schools. From a preliminary survey, majority of SHSs that use LPG to prepare meals have to supplement it with fuelwood

[2] A flammable gas derived from a mixture of hydrocarbons which can be used for heating, fuelling of vehicles and cooking

and charcoal in order to cut down cost and manage the financial resources for the term.

The use of biogas[3] in Senior High Schools (SHS) as an alternative source of sustainable energy is fairly new per the preliminary survey that was conducted. The use of biogas became common in Ghana a decade ago when the energy crisis and increasing cost of LPG hit the country. This made it difficult for some schools to manage their finances sustainably in a term.

In addition to the high cost of LPG and to some extent fuelwood, managing sanitation is a big challenge to the managers of SHSs. There are no designated disposal sites for these schools and their only option is to contract waste management companies for the disposal of their waste. These schools pay significant sums of money for the disposal of biodegradable waste (food waste from the kitchen and leftover foods, and faecal matter). Even when these wastes are taken from the school compound, their improper disposal leads to unsanitary conditions at the disposal sites (Agyepong, 2018). Schools with Kumasi Ventilated Improved Pit (KVIP) toilets have foul smell and flies from these toilets, creating a nuisance to nearby communities and students as well. Until recently, faecal waste in the Greater Accra Region was either discharged into the sea or into water bodies. According to Ghanaweb (www.ghanaweb.com, 2019) the "liquid waste from some parts of Accra was damped untreated in the sea, causing sea pollution which in turn affected fishing and tourism, among others". From the preliminary survey, majority of SHSs in Greater Accra Region pay between GhȻ 350-400.00 per truck for dislodging human excreta, with some schools requiring as many as seven or eight trucks per term as at March 2018. The cost for dislodging is

[3] Gas produced and captured for use from the decomposition of biodegradable waste in an anaerobic digester

even higher if the school is far from Tema and Accra Metropolis, and worse if it is a KVIP toilet. This constitutes a health hazard since even when the toilet is full students would have to "manage it" till the end of term. The unsanitary conditions forces students to practise open defecation especially in the night at the blind side of school authorities. This has been confirmed by ghanaweb.com (2019) when it stated that students in Opoku Ware SHSs have resorted to open defaecation due to; lack of and inaccessibility toilet facility, fear of contracting diseases in a locally constructed toilet and the dilapidated toilet structure in the school. This is a common state of most toilets in SHSs in Ghana.

Biogas plants if explored fully will help schools deal with their large volume of biodegradable waste streams from the kitchen, dining halls and toilets which will serve as feedstock. A feasibility study conducted by Hanekamp and Ahiekpor, (2014) affirmed this SHSs has the potential to generate biogas for use. Prakasam *et al.,* (1986) pointed out that biogas plants utilising organic waste would generate a clean source of energy for cooking, serves as soil conditioner and fertilizer for farming and minimized the spread of some diseases. Also, the use of biogas as an energy source for SHSs has the potential to reduce the overall cost of waste management and fuel consumption. It is in the light of the foregoing background that this research seeks to assess the cost efficiency and willingness of SHSs to adopt biogas system as a sustainable form of RE for schools and a strategic solution biodegradable waste in the Greater Accra Region of Ghana.

1.3 Aim and Objectives of the study

The aim of the research was to assess the cost efficiency and willingness to adopt biogas technology as a sustainable source of renewable energy for SHSs in the Greater Accra Region.

The research was guided by four key objectives. These are:

1. to determine the extent to which biogas usage was convenient,
2. to assess the cost efficiency of biogas plants,
3. to determine the factors that influences the willingness to adopt biogas technology, and
4. to determine the challenges confronting the adoption of biogas technology.

1.4 Main Research Questions

To attain the above objectives, the research was guided by the question; to what extent do cost efficiency and willingness affect the adoption of biogas technology as a sustainable form of renewable energy for SHSs in Greater Accra Region? The key research questions include;

1. To what extent was biogas usage convenient for SHS in the Greater Accra Region?
2. How costs efficient are biogas plants as sustainable sources of renewable energy for SHSs in Greater Accra?
3. What factors influence the willingness to adopt biogas technology among SHSs in the Greater Accra Region?
4. What are the challenges confronting biogas adoption and utilization in SHSs within the Greater Accra Region?

1.5 Justification of the Study

Africa is well endowed with a lot of RE resources but their full exploitation and utilization still remains a challenge. Ghana is said to be well endowed with RE resources such as solar, biomass, wind energy, and mini-hydro power. If pragmatic measures are taken to promote RE development in Africa and particularly Ghana, it will significantly increase energy access, reduce energy crises and insecurity, and limit GHG emissions (International Renewable Energy Agency (IRENA), 2015).

This study will be of immense significance in the wake of pressing need for alternative RE mix which has great social, economic, and environmental benefit for Ghana and the world as a whole. It would first of all contribute to the academic literature by filling a knowledge gap on how the multiple uses of biogas plants can contribute to the financial gains of public institutions as well as highlight how cost efficient the technology is to a developing country like Ghana. By exploring this gap, it will create the avenue for public institutions to experience their own financial freedom while lessening their over-dependence on the government for subventions. This aspect of literature appears as one with a narrow focus which is not widely explored.

Also, the results of the study will be beneficial to policy directives on climate change, RE adoption strategies and biodegradable waste management in Ghana. In the midst of striving efforts to address the energy concerns of Ghana, there is the need to assess the cost relativity and potential of biogas plants in generating gas for institutions while at the same time-saving revenue used in disposing biodegradable waste. This study could also be a means of helping the country to address SDG 6 on Water and Sanitation, SDG 7 on Clean and affordable energy and SDG 13 on Climate Action; by contributing towards mitigation and adaptation concerns within the energy sector.

Also, faced with the challenges of inadequate waste treatment facilities, and diminishing landfill sites, especially in the Greater Accra Region, this study, will be of enormous benefit to the various Metropolitan, Municipal and District Assemblies (MMDAs) to consider anaerobic digesters for community toilet and treatment of other streams of biodegradable waste and wastewater. Pursuance of this will limit the pollution of air, water bodies and the environment from the improper disposal of these wastes streams in the various MMDAs. It may also help to lessen the health risk burden from unsanitary conditions in the country.

The recommendations of this study are targeted at stakeholders such as the Government of Ghana, public institutions, private institutions, Biogas Association of Ghana (BAG), Energy Commission, and the Climate Change and Cleaner Production Units of the Environmental Protection Agency on measures that can be taken so that institutions that install biogas technology can receive the multiple benefits of the plants.

This research will also expose the core challenges that beset biogas plants in the few institutions that have adopted it. It will also reveal the anticipated challenges that potential adopters are likely to face. This will help the BAG and regulatory agencies to devise and adopt locally friendly measures or strategies that are compatible with the operating systems of biogas plant designs for Ghana.

1.6 The scope of the Study

The study was carried out in the Greater Accra Region of Ghana. Specifically, it targeted second cycle institutions that have boarding or hostel facilities. The research assessed individual biogas plants in user and non-user institutions within the context of cost efficiency and willingness to adopt biogas as a sustainable source of RE option.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter examines existing literature that borders on the cost efficiency and willingness to adopt biogas technology. It is organised into various sections that include: the definition of basic concepts, historical antecedents of biogas plants, sources of energy and usage in Ghana, renewable energy demands, types of biogas plants, processing channels for biogas, uses and potentials of biogas plants, theoretical framework and conceptual framework.

2.2 Conceptual Definition of Terminologies

In order to enhance the understanding of key concepts and their usage in the study, there is the need to review previous understandings that relate to the research. Aside from enhancing understanding, this section will as well give a basis for certain parameters that will be employed to measure some variables that pertain to the study. Particularly, this aspect of the review considers terminologies that include: renewable energy, biogas plants, cost efficiency, and potentials.

2.2.1 Renewable Energy

In a generic sense, renewability implies the ability to regenerate after use. Thus, RE according to Panwar, *et al.*, (2011) is any form of energy that is produced again and again without exhausting the source of generation. Such energies include geothermal energy, wind energy, biomass energy, solar energy, etc. These forms of energy are also often referred to as alternative sources of energy (Panwar, *et al.*, 2011). Kaygusuz, (2001), defined renewable to broadly include "the usage of any energy storage reservoir which is being refilled at rates comparable to that of extraction". He argues that RE sources can either be directly from the sun (solar energy) used for electricity generation and heating or indirectly from the use of water, wind, waves/running water and plant/animal waste. Synthesising the variety of meanings, the source of RE in the context of this study refers to that which is produced from plant and animal waste within institutions.

2.2.2 Biomass:

This refers to all biological materials obtained from living entities such as plants, trees and other waste materials from the forest, agricultural residue, and waste from cities and towns.

2.2.3 Biogas

Biogas is one of the renewable forms of gas energies that is produced by the breakdown of organic waste through anaerobic (in the absence of oxygen) processes. According to Fachagentur Nachwachsende Rohstoffe e. V., (FNR) (2012), the name biogas suggests gas production through a biological process. Igoni, *et al.*, (2008), posits that the production of biogas as an end product of anaerobic decay can either be as a result of the natural process of decay in the guts of animals, underwater or artificially from sealed biogas plants or landfill.

Thus, within the context of this study, biogas is viewed from an artificial perspective where organic materials pass through anaerobic processes in a biologically engineered system known as a digester (Fischer, *et al.*, 2002) to produce energy (gas). In line with this concept, Wellinger, *et al.*, (2013), opine that, “biogas is produced in biogas plants by the bacterial degradation of biomass under anaerobic conditions”. Biogas is an end product of the conversion of various organic matters with the aid of microorganisms which go through a number of metabolic stages in a digester (Surendra, *et al.*, 2012).

According to Akinbomi, *et al*., (2014) and Ignoni, *et al*., (2008), "biogas is made up of various chemicals including: 50-75% Methane (CH_4), 30-45% Carbon dioxide (CO_2), 1-2% Hydrogen sulphide (H_2S), 0-1% Nitrogen (N), 0-1% Hydrogen (H_2), drops of Carbon monoxide (CO) and traces of Oxygen (O_2)". The Rohstoffe e. V., (FNR, 2012), however point out that the composition of the gas usually depends on "the substrates, the fermentation (digestion) process and the various technical designs of the plant. This implies that the percentage constituents of biogas as posited by Ignoni, *et al*., (2008), is not fixed but depends on some factors. Irrespective of these factors, biogas has methane and carbon dioxide as the main gases that are produced. El-Halwagi (1986) opined that biogas technology is a system that needs to be integrated with other systems and the environments to be addressed socio-cultural and environmental problems.

2.2.4 Cost Efficiency

The concept of "efficiency" is generically used to imply the level of competence associated with a particular unit of interest. Das, *et al*., (2017), averred that biogas is efficient in the sense that biogas burns at an efficiency level of 60 percent when compared to five to eight (5–8) percent efficiency of firewood. Stuckey, (1985) added that biogas technology has the lowest financial inputs per kWh of output in all RE sources and it is one of the most 'mature' in terms of years of use and number of units installed world, especially developing countries.

2.2.5 Renewable Energy Demands

Renewable energy (RE) options are critical for providing energy delivery in a sustainable manner, especially with regard to mitigating climate change. RE can serve the energy needs of the current high demand of energy for the population and industrialisation requirements. RE as defined by IPCC (2011), in the SRREN; is any source of energy from geothermal or biological or solar sources that replenishes itself naturally at the rate equivalent to or exceeds its rate of use. Globally, RE contributes about 12.9% (2.3% for hydro and 0.4% for other sources) of 492 exajoules (EJ) (an equivalent of 4.92^{+20} joules) of principal energy supply as at 2008 with the largest being biomass (10.2%). Traditional usage of biomass for cooking and heating stands at 60% in third world countries. The implementation of RE technologies has substantially increased in recent years due to government policy, declining cost of many RE technologies, changes in prices of fossil fuels and other supporting factors (IPCC, 2011). The preference of RE to fossil fuels is because REs have low specific emissions of CO_2 into the atmosphere. According to IRENA (2015), it is estimated that at least about 1.3 terawatts (TW) of renewable energy would be installed worldwide within 2015 and 2030, as a result of the implementation of NDC's submitted by various countries to the UNFCCC. This will happen if all the countries are really committed to the targets set for themselves and will thus account for about 76% increase in total global installed capacity of biogas as compared to 2014.

2.2.6 Energy Usage and the Potentials of Biogas to Addressing Sustainable Development Goals in Ghana

The type of energy and the kind of technology that is employed for its utilisation has a direct impact on a sustainable source of energy for livelihood improvement, the health of the people, protection of the environment and poverty reduction. This is because accessing clean and affordable energy within Africa, especially Ghana, is a critical aspect for the attainment of the developmental goals of the country (Eshun & Amoako-Tuffour 2016; Mohammed, *et al.*, 2013; Brew-Hammond & Kemausuor, 2009). This explains why energy crises in Ghana are linked to constant development challenge since the severity of the crises affects all fundamentals of the country's economic growth and transformation agenda. Access to energy has a direct bearing on the country's developmental agenda and the attainment of the SDGs (Kemausuor, *et al.*, 2012; Brew-Hammond & Kemausuor, 2009). In the view of Kemausuor, *et al.*, (2012) and; Brew-Hammond and Kemausuor (2009), energy access should be looked at with the services it provides such as heating, cooking, and lighting. In the case of Sub-Sahara Africa (SSA), energy access has a close linkage with food security and good health. This is due to the fact that the high dependence on traditional biomass for cooking contributes negatively to ill health, poor land use management, malnutrition, and low productivity. It is estimated that about 2.74 billion people rely on traditional biomass, with some having 90% of cooking energy mix from biomass and 1.2 billion lack access to electricity in SSA. Bruce *et al.*, (2014) indicated that about 2.8 billion people uses solid fuels as their primary source energy for cooking leading household air pollution (HAP) and this has resulted in about 4 million premature deaths as at 2012. (Ouedraogo, 2017; Brew-Hammond & Kemausuor, 2009). This figure is estimated to increase over the next 25 years (Ouedraogo, 2017).

In Ghana, about 60% of the population depends on traditional biomass for energy utilisation (Asumadu-Sarkodie, *et al.*, 2016; Energy Commission, 2012). On the contrary Armah, *et al.*, (2015), found that about 92% of the population depends on traditional biomass-36% for charcoal and 56% for wood. They added that, about 84% of household income on energy is spent on fuelwood. The high dependence on traditional biomass is linked to low per capita income which does not allow switching to the use of modern fuels (Armah, *et al.*, 2015; Brew-Hammond, 2009). Apart from the negative impact of land degradation associated with biomass energy use, there is also the issue of high death rate of about 16,600 per year from indoor air pollution (IAP) as postulated by Armah, *et al.*, (2015). The high cost and irregular supply of

LPG and other modern fuel sources makes it a challenge for people with low income in Ghana to switch from fuelwood use.

Lack of access to energy leaves many people more impoverished and vulnerable with little capacity to adapt to the current climate change challenges. There is also a wide gap on access to energy between rural and urban areas in Ghana and this is further deepened by the challenge to achieve nationwide electrification which is heavily dependent on hydropower (Mensah, *et al.*, 2014). Energy access in the view of Brew-Hammmod (2009) means the ability to utilise energy from either electricity, LPG, charcoal or other forms of energy. Energy access can either be the utilisation of electricity in the home or the grid penetration rate in a particular geographical area. If this trend of inadequate access to energy continues, the attainment of the SDGs will be elusive to many SSA countries, especially Ghana.

The options for cleaner and efficient forms of energy require technologies that will lead to the attainment of many of the SDGs for Ghana, especially goal 7. This explains why biogas technology as an option of RE is so critical for Ghana. The technology will not only provide low energy but will enhance environmental protection, good health, clean water and attainment of many of the SDGs. Fortunately, there is vast potential of feedstock for biogas systems in Ghana, mainly agriculture-manure from animals, waste from farms, agricultural by products and other organic waste-food and food processing industries. Another source is municipal waste (the organic fraction including faecal matter). These three sources-agriculture, food and municipal-constitute a waste management challenges to many MMDAs in Ghana. However, biogas technology can solve these waste management challenges and contribute significantly to the attainment of many of SDGs as outlined in Table 2.1

Table 2.1: Contribution of Biogas Technology to SDGs Attainment

SDGS	Contribution of biogas technology to goal attainment
GOAL 2 No Hunger	• Nutrient recycling by restoring soil nutrient through the use of digestate as organic fertilizer or the effluent serves as soil ameliorator. This will give good crop yields. Savings made from the non-purchase of inorganic fertilizers can be used to soar the family income for other business ventures. • The use of biofertilizer (dry or wet) will enhance humus retention and improves plants resilience to diseases. This will improve food production, reduce hunger and malnutrition, and enhance sustainable agricultural practices. • Recirculation of essential nutrients for plant growth like phosphorus into the soil through the slurry can facility the growth fruit trees or tree plantation. This will provide food and extra income as well as carbon sinks for climate change mitigations. • Bio-slurry can be used as a form of insecticide and pesticide, a common practice Tanzania. This can be used to fight against the army worms and other insects that attack crops, thus ensuring food security. Owners of biodigesters can also sell bio-slurry (organic chemicals) to make direct extra income for their families**. • The slurry from the digester can be used for fish farming. This is because it is rich in nitrogen and phosphorus contents and high in organic nutrient. These (nitrogen and phosphorus) facilitate zooplankton and phytoplankton growth that the fish feed. This is done by allowing the slurry to flow into the fish pond in

SDGS	Contribution of biogas technology to goal attainment
	moderation. Fish and cropping farming are double insurance against any adverse impact of climate change, since nutritional meals, non-malnutrition in children and regular income are assured* and**. • The slurry can be used in the production of organic mushrooms for consumption. Other avenue for extra income generation and food sufficiency* and **.
GOAL 3 Good Health and Well Being	• The substitution of biogas with fuelwood reduces IAP and improves health, especially women and children. • Anaerobic Digesters (AD) treats and recycles organic sewage, reducing toxic pollutants released from landfills or poor waste disposal which would pollute surface and ground water. This reduce disease burden of drinking contaminated water. • Anaerobic Digester takes away bad odours emanating from faecal waste (human and animals) as well as landfills which attract flies and other pathogens that spread diseases. This prevents the spread of diseases-ensuring good health and well-being. • Availability gas (biogas) for domestic cooking, reducing the burden on women and children in gathering firewood and carrying heavy loads on their heads for long distances. This will invariably reduce neck and spinal injuries in the long run on women. Wasted time in wood gathering offers opportunity for girls to remain and stay in schools, and women to improving their social and economic well-being.

SDGS	Contribution of biogas technology to goal attainment
GOAL 6 Clean water and sanitation	• Anaerobic Digester can be located anywhere, serving as a decentralised tool for municipal waste treatment facility. This removes waste from being washed into drains and surface water-minimising the spread of illnesses due to drinking unclean water. • Also, Anaerobic Digester recycled wastewater for reuse. This reduces the pollution burden of raw wastewater discharged into water bodies and ensures water availability for other uses. AD removes about ninety to ninety-five (90 to 95) percent of pathogen waste*. Water discharged from AD if not treated is better off than untreated sewage.
GOAL 7 Affordable and Clean Energy	• Biogas help reduce heavy dependence on fossil-fuel based energy sources by providing readily available gas which can be used for cooking, lighting and powering of other electric gargets with minimal emissions. • Utilising locally produced waste and crops to generate energy for rural and remote communities will eliminate death due IAP because biogas smokeless.
GOAL 9 Industry, Innovation and Infrastructure	• Biogas programme allows collaboration between industries, installers and farmers in order to design innovative digesters for mutual benefit. • Generating long chain of employment during construction to operation of digesters-welders, masons, carpentry, and engineers-through the manufacturing of biogas systems accessories and installation. This is an innovative way of reducing unemployment.

SDGS	**Contribution of biogas technology to goal attainment**
	• Biogas encouraging growth of micro-enterprises by providing reliable energy, waste treatment facility, inorganic fertilizer for farming and developing innovative strategies for environmental challenges.
GOAL 13 Climate Action	• Anaerobic Digester facilitates the reduction of CO_2 and CH_4 emissions through the use of biogas to replace/reduce the consumption of fossil and wood fuel-based. This is done by capturing methane from decaying organic waste and using the methane gas instead of fossil or wood fuel. This is a smart way to combat global warming and a great path for climate change action. • Anaerobic Digester minimises the release of nitrous oxide and methane emissions from livestock manures and inorganic fertilizers by utilising it to produce biogas for use and replacing it with digestate for farming respectively. • Anaerobic Digester helps in the reduction of deforestation by replacing fuel wood with biogas for domestic use. This allows CO_2 sequestration from the trees, creating carbon sinks.
GOAL 15 Life on Land	• Treatment of biodegradable waste reduces the amount of nutrients that would have caused environmental challenges to water bodies like eutrophication and algal blooms. • It also prevent environmental pollution.

Source: WBA Factsheet 3 (2016); * Marchaim, (1992) and **www.africabiogas.org

2.3 Historical Background of Biogas Plants Development

Biogas an age-old form of energy dates back to the tenth century BC when it was first used by the Assyrians for heating bath water in 900 BC (Bond, & Templeton, 2011). The Chinese are reported to have used bamboo as pipes to transfer biogas for lighting (Harris, 2014). Modern biogas is attributed to Van Helmont who in 1630 made an observation of flammable gases coming from decaying vegetable. In 1776 Volta was able to determine the direct correlation between decayed matter and gas produced from the decayed matter. In 1786 Berthollet, conducted a study on the chemistry of methane. His findings were further enhanced by Davey in 1808 when he made an observation that methane gas was being emitted from decomposing cattle manure (Bond, & Templeton, 2011; Harris, 2014).

In 1859, the first biogas digester was installed in Mumbai, India, at a leper's colony and the gas was used to power a gas engine by 1897. Also, in 1896, a sewage treatment plant was built in Exeter, England, to treat the entire municipality's wastewater and the biogas recovered was used for street lamps lighting (Abbasi *et al.*, 2012; Marchaim, 1992). From these humble beginnings, more research, design, adoption and usage of biogas began to grow and by 1925 Essen municipality in England saw inhabitants' homes being piped through with biogas. And in the 1930s, biogas was bottled in Germany and used to fuel cars (Deublein & Steinhauser, 2008; del Real Olvera & Lopez-Lopez, 2012). As the knowledge of biogas grew, Barker and Buswell in the 1930s, identified methanogenic bacteria and the necessary environments conditions for methane production; this led to some more rigour in the design of digesters and their operations (Abbasi *et al.*, 2012; Marchaim, 1992). Still, in the same 1930s, the Chinese and Indians implemented a series of biogas programmes which saw a considerable number of anaerobic digesters installed for households in these countries with the main aim of producing gas for cooking and lighting (Fischer & King, 2001). In the 1970s, the oil crisis led to the high demand for biogas plants. This coincided with the period where many developing countries in Asian, Latin America and Africa saw their faster growth in biogas technology.

According to Wellinger, *et al.*, (2013), over the last 40 years what has changed with regard to biogas technology is that it has seen a move to generate biogas on an industrial scale with a high degree of efficiency, complexity and specification, especially in Europe and North America. And that policy and decision makers in the 21st century have affirmed the fact that biogas technology provides a solution to many challenges such as its ability to; reduce the emission of GHGs e.g. methane; provide a sustainable source of renewable energy for cooking, lighting, electricity, heat and transportation; be upgraded to provide organic fertilizer where the fertilizer-soil-crops- produce-waste- back to digester is closed and reduce pollution from waste disposal

In spite of the numerous purposes/benefits of biogas, there are a number of challenges confronting biogas with the major one relating to the cost of installation. This cost is a great impediment to biogas technology adoption in many countries, especially developing countries where the cost may amount to a substantial fraction of a family's annual income. In addition, there are technical problems in terms of maintenance cost and after installation follow-ups which are usually not factored into the cost. Finally, the issue of low gas production demoralised users and potential adopters.

2.3.1 Biogas Plant Development in Africa

African countries are experiencing excess demand for energy over the supply of energy leading crisis, both from the commercial and traditional sources of energy

(Parawira, 2009). Parawira, (2009), indicated that energy utilisation and demand in Africa will continue to increase at a rapid rate than developed countries as a result of high growth rates in their populations. Due to commercial fuel shortages, biomass has become a substitute to fill the vacuum in most African countries. Traditional biomass has been less expensive and an abundant resource which is over utilized in a manner that limits the regenerative ability, this can cause significant environmental consequences (Janssen & Rutz, 2012). It is therefore necessary to develop renewable energy technologies, particularly biogas technology to augment this. Biogas technology will help to reduce their dependence on non-sustainable resources and reduce the environmental pollution caused by fossil fuel and fuelwood. African countries are encouraged to turn to renewable energy systems that are more sustainable, resilient to the effects of climate change and environmentally friendly-biodiesel, bio-ethanol, biogas systems and solar power plants. These energy systems are less complicated and can be installed and operated at both small and large scales in almost all geographical locations. Biogas technology is a simple technology which requires local materials for construction and local expertise for management. It is therefore considered as an appropriate, adaptable and generally acceptable technology for Africa because of the availability of feedstock for its operation and it's resilient to the impacts of climate change (Parawira, 2009).

In 2007 at the Biogas Africa Initiative, it was envisioned "better the lives of two million Africans through biogas". However, in the words of Van Nes and Nhete, (2007), the initial biogas plants witnessed about 60% failure, leading to less interest in the technology. Currently, Africa is witnessing an increasing number of biogas installations across the continent. This is particularly common in the domestic energy area, which has currently seen a number of national supports for domestic biogas programmes, with each nation targeting about 10,000 domestic biogas plants to be operationalised in the next 5 years (Austin & Morris, 2012). Countries like Rwanda, Kenya, Tanzania, Ethiopia, Uganda, Cameroon, Benin and Burkina Faso have initiated their national support for domestic biogas programmes. This has led to about 1,665 biogas plants being installed between the period of 2007 and 2010, aside other digesters that have been built before and outside the programmed (Austin & Morris, 2012). These programmes adopted multilateral and coordinated financing schemes with the view of leveraging national investments, marketing and financial elements for the uptake market. Subsidies on accessories are also provided as option for supplementary funding.

2.3.1.1 Kenya

The first attempt to adopt biogas technology was to access it as an alternative energy from coffee pulp in the middle of the 1950s. This was followed by 25 years' period by Hutchinson, a private company that sold over 100 biogas plants of varying models to commercial farmers. Within 1983/1984, the German government sponsored the training of technicians for the installation of biodigesters and this saw 40 anaerobic digesters installed in the Meru province (Strauß *et al.,* 2012). In 1988, efforts were made in the deployment of biogas plants to other provinces. This saw about 250 floating-drum biodigesters being installed across other provinces to enhance the supply of energy. Private companies were also by the government to be involved in providing biogas accessories. Subsidies were offered for demonstration anaerobic digesters that were installed in new areas; else the biogas customer paid the full cost of installation for his/her biogas plant. From 2006 to 2011, the European Union provided funds as part of measures to disseminate sustainable energy resource technologies and over 200 biogas plants were installed. Also, Germany and the

Netherlands co-adapted an integrated biogas up-scaling project in Kenya's agricultural sector since 2003. Commitment to sustain the biogas industry has thus been demonstrated through a national biogas technology standard which was prepared in 2011 and strongly supported by donor agencies.

2.3.1.2 Tanzania

Dating back to 1975, the development of biogas in Tanzania is credited to Small Industries Development Organisation (SIDO), which installed about 120 anaerobic digesters of the floating drums types, mostly for schools (Mshandete & Parawira, 2009). The success of the SIDO biogas programme, paved way for the Centre for Agricultural Mechanization and Rural Technology (CAMARTEC) in 1982 to pioneer the promotion of the Chinese fixed dome biogas plants in Arusha. In 1983, a biogas extension service was launched by the German Development Cooperation (GIZ) and biogas technology spread in the region quickly. The project adopted a standardised biogas plant design with clear administrative processes operation, two years' warranty and a technical assistance to the beneficiaries in rural communities (Strauß *et al.*, 2012). Biogas plants with digester volumes ranging from 8, 12 to 16m^3 were deployed. However, after 5 years of the programme, new standardised plants sizes were added: 12, 16, 30 and 50m^3 for institutions, households and special "toilet biogas plant" (Mshandete & Parawira, 2009).

The Tanzania biogas programme started with a unit concept which has the following elements; (1) a pressure testing for the piping system, (2) a suitable stable solid floor, (3) gas use accessories, and (4) finally the use of bio-slurry by the individuals for farming (Strauß *et al.*, 2012). There was an augmentation in the unit cost for installing a anaerobic digester ranging from TSh 300,000 as at 1989 to between TSh 4,000,000 to 7,000,000 in 1990s. Cheng, *et al.*, (2014) stated that to reduce initial cost of biogas plants, a low-cost polythene biodigester was introduced for Africa countries in 1993 and these digester used with animal manure as their feedstock, Tanzania is currently using some. Also, four international training courses were organized between 1990 and 1993 by CAMARTEC with both local and international participants as well as other trainers. This led to the promotion of the CAMARTEC design in four countries, namely Thailand, Ethiopia, Uganda, and Kenya (Strauß *et al.,* 2012). The CAMARTEC project was transfered to a counterpart organization and this led to changes in the programme around 1990.

German experts who were trained in the installation of large-scale biogas plants and they built very big ones for sisal industry. The first large-scale biogas plant was built through a co-operation between the Chinese-Germans with support from the United Nation Industrial Development Organization in 2007. However, in 2009 Tanzania Domestic Biogas Programme has developed a new nationwide biogas dissemination programme with support from SNV. Tanzania has a successfully biogas programme and about 8,796 biogas plants has been deployed from 2009 to 2013 (Rupf *et al.,* 2015; Strauß *et al.,* 2012; Mshandete & Parawira, 2009)

2.3.1.3 Rwanda

German technicians from Kigali Institute of Science, Technology and Management (KIST) played a major role in the support of fast-growing biogas technology in Rwanda. German experts have designed and installed 150m^3 fixed-dome biodigester at the Cyangugu prison. The biogas plant obtained its feedstock from waste generated by 1,500 inmates and gas produced from the digester was able to carter for 50% of the cooking needs for six thousand inmates (Strauß *et al.,* 2012). Again, the sewerage and hygiene problem that was faced at a school named “Lysee de Kigali” got solved by KIST when a 25m^3 fixed-dome biogas plant was installed and connected to the six bio-latrines of the school. The biogas from the digester was used as a fuel for cooking to a student population of 400 and part of the gas supplied to the laboratories of the school. Chinese technicians supported the KIST to introduce biogas digester known as Decentralised Wastewater Treatment Systems (DEWATS). As at 2007, the National Domestic Biogas Programme of Rwanda with funding from SNV proposed with an aim of installing 15,000 biogas systems in a 5 years period. However, only 5,000 digesters were installed by 2011 (Roopnarain & Adeleke, 2017). China has also contributed independently to the Rwandan biogas programmes since 2009 and through these 100 prefabricated biogas plants have been installed (Roopnarain & Adeleke, 2017; Strauß *et al.*, 2012).

2.3.1.4 Evolution of Biogas Technology in Ghana

Evolution of Ghana's biogas can be viewed from three stages; the experimental stage, adoption stage and maturity, and current stage.

The Trial or Experimental stage

Historically, the interest and awareness of biogas systems in Ghana dates back to 1960s, but it was in the middle of 1980s that this interest was materialized (Arthur *et al.*, 2011). Bensah *et al.*, (2010), indicated that before the 1980s, biogas plants that were installed were for the provision of domestic energy for cooking. However, many of these biogas systems collapsed shortly after installation due to immature technology. According to Bensah, and Brew-Hammond (2010); and Arthur, *et al.*, (2011), the first biogas plants were constructed at Appolonia in 1986. The plants were 10 m^3 Chinese fixed dome digester and were installed by the Government of Ghana through the Energy Ministry with support from the Chinese government (Arthur *et al.*, 2011). These biogas plants were constructed at a cattle ranch so that the cow dung can be used as feedstock for the plants. The biogas technology was selected as an alternative to cooking fuels sources and a means of halting the incidence of deforestation with its attendant environmental challenges (Arthur *et al.,* 2011).

However, the biogas technology took a nose dive from government involvement possibly because the government did not understand or appreciate the demand of the technology or a deeper and collaborative stakeholder engagement was not properly done leading to feedstock challenges for the digesters. Arthur *et al.,* (2011) argued that "the plant is not functioning at full capacity due to lack of feedstock materials". Regarding the high failure of biogas plants in developing countries, Smil (1986) averred that the operation of a bio-digester may look simply but the daily care for optimum benefits may be far from achievement. This is because the digester requires constant and continuous feeding as well as ensuring that optimum parameters for acidity, alkalinity, C/N ratios, temperature and uniform mixing of feedstock for best performance is attained. This creates theoretical and practical gaps leading to the low support and deployment of the technology, especially Ghana.

Non-Supportive Stage

Government has detached itself from any active involvement in biogas technology in the 1990s-2012 (Arthur *et al.,* 2011). The deployment of biogas systems was left in the hands of donor agencies; especially German Agency for Technical Assistance (GTZ) and the Catholic Secretariat aided in the installation of some biogas plants in some hospitals; notably Battor, Akwatia, and Nkawkaw hospitals; these are currently still functioning mainly as sewage treatment facilities. GTZ also offered training to some technicians in the form of local capacity building and helped to install other biogas plants at Ejura slaughterhouses and the Animal Science Department of the

Kwame Nkrumah University of Science and Technology (KNUST), Accra Psychiatric Hospital etc. (Bensah *et al.*, 2010). From 2000 - 2012, the promotion, design and installation of biogas plants were left to private companies such as Biogas Engineering Ltd (BEL); Biogas Technology Africa Limited (BTAL); Beta Civil Engineering Limited (BCEL); Impact Environmental (IE) and others. Their passion and zeal for the biogas technology despite the many challenges made them to hold the fort for the technology up to date in Ghana (Bensah *et al.*, 2010).

Current State

The promotion of biogas technology has seen renewed interest by the government as stated in the SE4ALL 2012 document that highlighted government intension to establish about 200 biogas plants in institutions throughout the country. In line with this vision, government initiated and constructed ten (10) biogas plants in some selected schools in the Greater Accra Region. With the exception of one school (St John's Grammar) in which the accessories were installed and completed for electricity; the rest are left uncompleted. Three others private SHS have also installed biogas plants on their own because of the enormous benefits of the technology, especially as an answer to their sanitation and energy needs. Also, the Ghana EC and EPA collaborated with installers of biogas to form BAG which was launched at the EC in 2018. There are plans to organize training and bring sanity into the biogas technology sector in Ghana. This will definitely bring some change.

2.4 Biogas Plants and Processing Channels

There are various categories of biogas plants that have been implemented throughout the world. However, each biogas plants must be designed to suit the local conditions of the area since the conditions differ significantly between different areas (Edelman, 1986). In terms of feedstock method, three different forms of plants have been identified by Talia (2018); and Sasse (1988). These are;

- *The Batch Plants*; in which the feedstock (input) and output (digestate) is done periodically when the cycle ends. This process is appropriate for dry fermentation, leading to a lower operational cost. However, this is labour intensive as there are feeding and emptying of substrates work to be done.
- *The Continuous Plants*; where feeding and emptying (feedstock and digestate) are done simultaneously. It requires fluid and homogeneous substrates. These types are the commonest of all biogas plants implemented since they fit well into the daily routine of many institutions and geographical locations. It also produces stable biogas.
- *Semi-Batch Plants*; these types use heterogeneous substrates with different rates of biodegradability. Slow digesting feedstock like straw is fed twice in a year while the fast digesting material (e.g. cow dung, food residues) is fed and removed regularly like the batch plants.

Biogas plants can also be categorized into various segment based on certain parameters- organic loading rate, (OLR), hydraulic retention time (HRT) and the carbon-nitrogen ratio (C/N). These parameters are critical for the plan design for the biogas plant (Strauß *et al.*, 2012).

Hydraulic Retention/Residence Time (HRT in days) refers to the time period a substrate stays in the digester. HRT hinges on the process temperature and the sort of concentration the substrates have in the digester. HRT is needed in order to determine the capacity of the biodigester to be designed as digesters are built to balance the optimum biogas yield and capacity of the digester. A high yielding biogas plant would usually have at least 20 days of HRT while low yielding biogas (sanitation) system should have a minimum HRT of 60 days; this adequately treats substrates (Talia, 2018; Djatkov *et al.*, 2014; Mang *et al.*, 2013). Mahanta *et al.*, (2005) argued that HRT should range from 20 to 120 days depending on the design and interior temperature of the digester in order to destroy pathogens. The maximum limits of psychrophilic and the minimum limits of mesophilic should have their temperature ranging from 17–33^{0}C. According to Mang *et al.*, (2013); and Strauß *et al.*, (2012) the minimum HRT values should be applied to the following feedstock in order to kill pathogens:

- 30 days minimum for a cow or cattle manure
- 25 days minimum for pig manure
- 40 days minimum for poultry manure
- 80 days minimum for animal manure mixed with easy biodegradable plant material
- 60 days minimum for faecal matter

If the HRT of sludge within the digester is longer, then the degradation and the stabilization of the sludge from the biogas plant is better, removing most of the pathogens within sludge (Mang *et al.*, 2013). This is very crucial for installers to consider in determining the type of biogas-sanitation (biogas plants) envisioned for SHS in Ghana.

Organic Loading Rate (OLR) is the number of volatile solids (VS) fed into the digester and it is measured in kgVS/m^3/d (where kg = kilogram; m = metres and d =day). The OLR depends on Chemical Oxygen demand (COD/m^3) or Organic Dry Matter (ODM/m^3) and active fermenter volume. Mahanta *et al.*, (2005) indicated that if the biogas plant is overfed, it will lead to the acids accumulation and this will inhibit biogas production since micro-bacteria cannot survive in acidic situation. But if the biogas plant is underfed, it will result alkaline conditions leading to low gas been produced since the alkaline will not be favourable for anaerobic bacteria. In a start-up of a biogas plant, the OLR should gradually be increased so that microorganisms in the AD can efficiently adapt to the digestion process.

For efficient performance of biogas plants, there is the need to monitor the following parameters: the pH value, the organic dry matter, the volatile fatty acids, the carbon-nitrogen ratio (C/N ratio), the moisture content of the biogas, the stability of temperature, the composition of substrate and the content of total solids in the digester effluent and influent (Strauß *et al.*, 2012).

Also, the weight of carbon-to-nitrogen (C/N) ratio should be in a range ratio of 8 and 30:1 in order to obtain optimal digestion rate of the substrate. This is because if the ratio of C/N levels are elevated, the nitrogen constraint will lead to low biogas generation since the nutrients for anaerobic bacteria growth will be lacking. On the other hand, if the ratio C/N is very low, the pH value may rise and this will cause toxicity effect on the methanogen’s bacteria, leading to low biogas generation (Talia, 2018; Mang *et al.*, 2013; Strauß *et al.*, 2012).

In terms of construction and design of biogas plants, Sasse (1988) has identified six (6) types of biogas digesters. They are; Fixed-dome plants, Floating-drum plants, Balloon plants, Horizontal plants, Earth-pit plants, and Ferrocement plants. However, the popular types that are commonly used in countries that are developing are the fixed dome, the floating drum plants, and the balloon plants. The choice of each type of plant is determined mostly by the prevailing design in the region and other considerations such as; the space, existing structures, cost minimisation and the availability of substrate/feedstock.

2.4.1 The Biogas Plant Components

A typically simple biogas plant consists of a slurry mixing tank, a digester, a gasholder, a compensating tank; a slurry storage tank, a slurry distribution canal, a gas piping system, and a biogas appliance (see Figure 2.1). Additional components such as stables, latrines, rainwater tanks, fish ponds, compost pits, and demonstration fields could as well be part of the biogas unit but not very necessary. The various parts of the biogas plant are discussed below (Bensah *et al*., 2010).

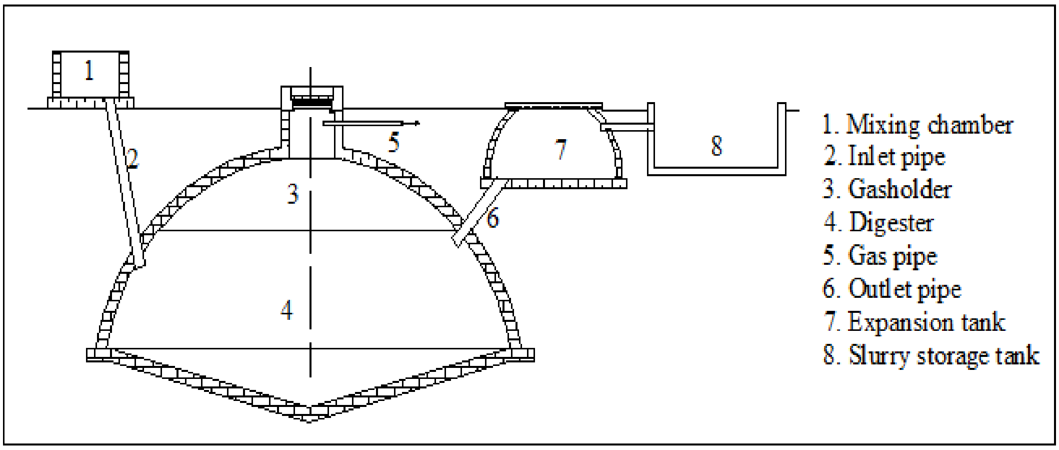


Figure 2.1: Typical Biogas Plant and its components

Source: Bensah *et al.* (2010)

The Mixing Tank

The feedstock material is mixed with water in the mixing tank. Some designs make it possible to poke the digester directly from the mixing tank. An inlet pipe links the mixing tank to the digester. The inlet pipe should be connected a few centimetres above the bottom of the mixing tank to prevent grit and sand (which have settled on the bottom), from entering the digester. A circular shape is ideal in terms of cost and operation (Fulford, 1988; Sasse, 1988).

The Compensating (Expansion) Tank (CT/ET)

The design and construction of the compensating tank (CT) should be well done. The bottom tip of the expansion tank must correspond to the zero or filling line. If the bottom of the CT is too low, some portion of the slurry will be exposed to air and if it is too high the gas pressure rapidly becomes very high. This may affect the volume of biogas or the structural integrity of the digester respectively (Fulford, 1988). The shape of the CT is very critical as it determines the height of the slurry surface and therefore the gas pressure. A low CT leads to low but stable gas pressures.

Inlet and Outlet Pipes

The inlet pipe should be straight and its axis should be directed towards the centre of the digester in order to make stirring easier. Furthermore, the inlet pipe should be fixed as high as possible, but must not pass through the gas space for fixed-dome digesters. The outlet pipe should be placed below the middle of the digester. This eliminates the discharge of too much fresh material from the digester. The height of the outlet pipe determines the surface level of the fermentation slurry. Diameters between 200 – 400 mm are good for feed materials that are fibrous while 100 mm diameters are good for non-fibrous feed materials (Abbasi *et al.,* 2012; Fulford, 1988; Sasse, 1998). PVC pipes are ideal for use as inlet and outlet pipes

The Entry Hatch

The construction of a fixed-dome entry hatch is important to prevent gas leakages. The gas pipe should penetrate the shaft a few centimetres below the cover, with the cover sealed with screened and well-run clay. However, the bottom of the cover should be wrapped with paraffin. Weights are placed on top to keep it firmed and a pool of water on the shaft to keep the clay gastight.

The Bottom Slab

The bottom slab receives the weight of the digester wall at its edge and distributes the weight over the ground. There is a risk of slab breakage if it is too weak and if the ground is uneven. A rigid shell distributes loads and this is better than a soft slab. However, a vaulted shell is the best foundation even though a conical shell is easier to excavate.

The Biogas Digester

The digester is the actual structure in which anaerobic conditions (air tight environment) for the generation of biogas is provided. It must be both water- and air-tight in order to prevent seepage of water into soil and leakage of biogas into the air respectively. It must also have good insulation properties in order to ensure a stable temperature for the digestion process. Furthermore, it must be able to withstand all static and dynamic loads as well as a minimum surface area in order to bring down the cost of construction (Abbasi *et al.*, 2012; Fulford 1988; Sasse, 1998).

The most common types of biogas digesters include; floating-drum digesters, fixed-dome digesters, bag digesters, plug flow digesters, anaerobic filter digesters, UASB (Upflow Anaerobic Sludge Blanket), earth pit digesters, lagoons, and complete mix digesters. With the exception of the fixed-dome and the floating-drum types, the rest are rarely used in Ghana.

2.4.2 Functional Processing of Biogas

According to Monson *et al.*, (2007), biogas is developed from different microbes with differing environmental requirements for four active phases and these are summarized in Figure 2.2.

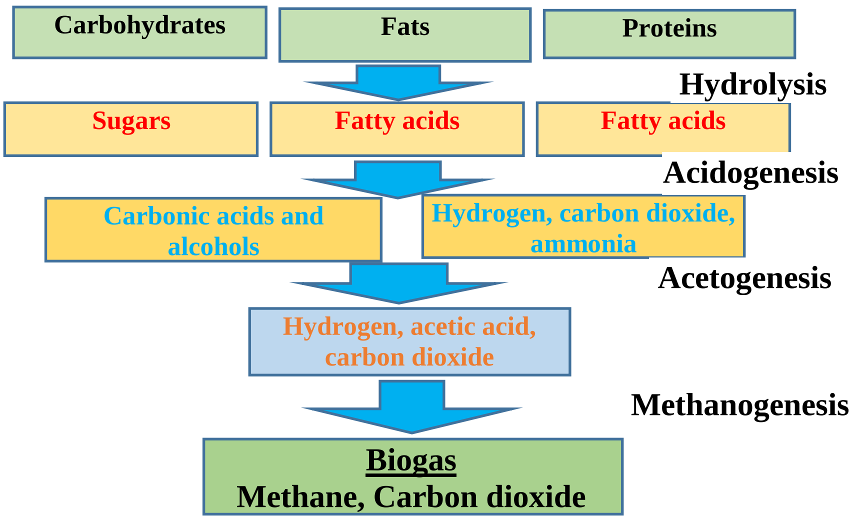


Figure 2.2: Chemical Processes of Biogas Formation

Source: Monson *et al.*, (2007)

- *Hydrolysis*: Microorganisms excrete enzymes that break down the organic matter such as carbohydrates, lipids, and nucleic acids into smaller units like glucose, glycerol, purines and pyridines. Hydrolysis connotes degradation of the particulate or macromolecular substrate to soluble monomers and this process is catalyzed by enzymes which are produced by organism feeding on the soluble products. The main mechanism utilized by hydrolytic bacteria is the attachment of the organism to a particle to produce enzymes and utilize the secretion from the enzymes in order to break the organic matter into smaller units (Deublein & Steinhauser, 2011; Monson *et al.*, 2007).
- *Acidogenesis*: Fermentative bacteria process is a product of hydrolysis into acetate, carbon dioxide, hydrogen, and volatile fatty acids. Acidogenesis is generally seen as an anaerobic acid producing microbial process and this is an example of fermentation. The process involves the breaking down of soluble sugars and amino acids into a number of simpler products like acetate, propionate, butyrate, lactate, and ethanol. The proportion of the organic products of the acidogenic bacteria is

determined by the H_2 concentration and pH levels. When the hydrogen levels are elevated, production of propionic acid predominates and this generates neutral pH values. Conversely, if the pH levels become acidic, the production of butyric acid will begin to predominate. In a stable digester, the low H_2 pressure will normally be maintained by the hydrogen utilising methanogens (Deublein & Steinhauser, 2011).

$C_6H_{12}O_6$ (aq) + 2 H_2O (g) → 2 CH_3COOH (aq) + 2 CO_2 (g) + 4 H_2 (g)
(Acetic acid)

$C_6H_{12}O_6$ (aq) → $CH_3CH_2CH_2COOH$ (aq) + 2 CO_2 (g) + 2 H_2 (g)
(butanoic acid)

$C_6H_{12}O_6$ (aq) + 2H_2 (g) → 2 CH_3CH_2COOH (aq) + 2 H_2O (l)
(propanoic acid)

- *Acetogenesis*: Volatile fatty acids and alcohols are oxidised into acetate, hydrogen and carbon dioxide before conversion into methane. This process is closely interlinked with methanogenesis. The organisms oxidising the organic acid utilizes additional hydrogen ions to produce H_2 gas or CO_2 or both.

- *Methanogenesis*: Specialised single-celled microorganisms (archaea) produce methane from acetate, hydrogen and carbon dioxide. The survival of the methanogenic bacteria depends on their ability to reduce carbon dioxide to methane. About 70% of the methane produced comes from acetate while the remaining 30% originate from hydrogen and carbon dioxide conversion. Methanogenesis is a vital step in the entire biogas process as it is the slowest biochemical reaction stage for methane production. When the methanogenesis process is disturbed, acidification set in, leading to low biogas yield. This step is influenced by operational conditions like feedstock, feeding rate, temperature, and pH (Deublein & Steinhauser, 2011).

2.4.3 Type of Digesters in Ghana

According to Bensah *et al*., (2010) the most successfully promoted biogas plants in Ghana that witnessed many installers deploying them are the fixed-dome and the floating-drum. These digesters have led to four most common models such as fixed dome, CAMARTEC, Puxin and Deenbanhu being evolved and implemented in the country. However, the Anaerobic Baffled Reactor has also been in use since the 1990s and it is currently being promoted by CSIR for SHSs in Ghana.

2.4.3.1 The Fixed-dome Digester

This digester is made up of a closed, dome-shaped digester with the following components; fixed gasholder and a displacement pit, called the compensating or expansion tank. It is usually an underground digester pit lined up with bricks or concretes or both in a dome-shaped cover, of bricks placed over it. The cover is fixed and held in place with earth piled over the top to resist the pressure of the gas inside. Just about mid of the digester are two rectangular openings facing each other and serving as the inlet and outlet with the outlet serving as the slurry reservoir (expansion tank). Some of the fixed domes do have a central man-hole in the dome; this allows easy emptying of the digester. The dome-shaped roof is fitted with a pipe at its top which acts as the gas outlet of the plant. There is also a concrete pad on the dome shape, which at times is sealed with thick clay. There is a pool of water on the clay pad to allow detection of gas leakages. A bubbling of the water on the clay pad is a sign that the digester is leaking. Biogas is stored in the upper part of the dome as it is given off by the slurry. The collected gas in the dome pushes some of the digestate into the reservoir tank at the side of the digester and the digestate flows into the digester when the gas is used. The expansion tank volume should be proportional to the stored gas volume. Figure 2.3 shows the various parts of the fixed-dome digester.

The benefits of this type of digesters are; low constructional cost, no moving parts, no steel parts to rust, long lifespan of over 20 years, provides employment opportunities for local skilled craft men and a relatively stable digestion temperature for maximum performance. However, the drawbacks of this digester include; fluctuating gas pressure i.e. either high or low gas pressures, a small crack in the upper brickwork can cause heavy losses of biogas and low digester temperatures (Abbasi *et al.*, 2012; Fulford 1988; Sasse, 1998)

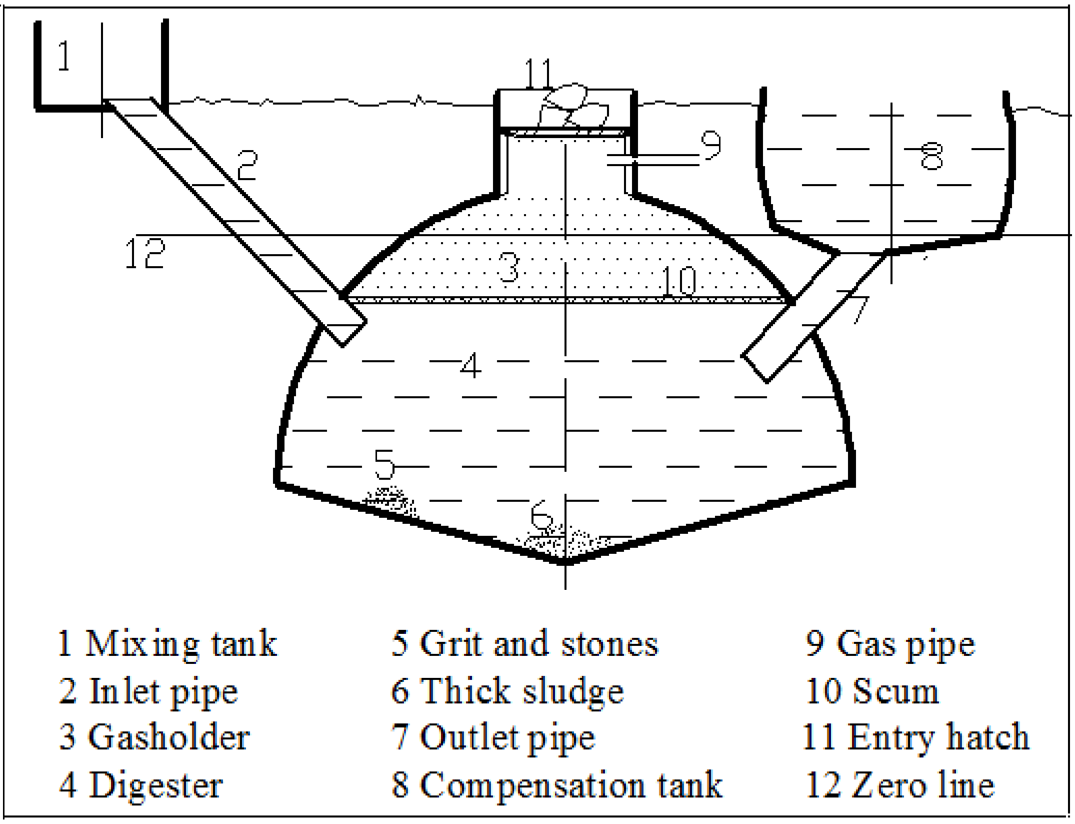


Figure 2.3: Model of Fixed-Dome Digester

Source: Bensah *et al*. (2010)

Several variations of the fixed-dome plant have been developed from the Chinese design based on; cost reduction as local materials are used, less time for construction, improved performance, and increased durability. Some of the most notable models of the fixed dome plants are briefly described below:

The Chinese Dome

This model of fixed dome consists of a digester which is cylindrical with a round top and a round bottom underground bricks masonry compartment. The fermentation chamber and the gas holder are combined as a unit. The most frequently used type of this digester has a roof and a floor in the shape of a sphere, joined together by a conical or cylindrical section. The inlet and outlet channels are made from PVC pipes. A modified version developed at Chengdu, has its inlet and outlet pipes made from concrete. To gain access to the biogas plant pit during construction or cleaning of the pit, it is usually through the outlet or reservoir of the slurry (Bensah *et al.*, 2010).

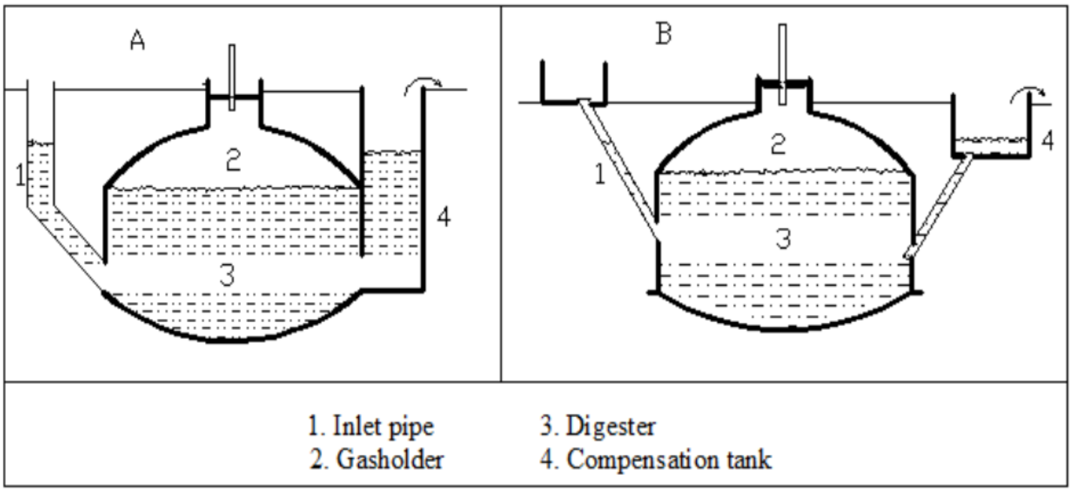


Figure 2.4 Chinese fixed-dome and the Chengdu design

Source: Bensah *et al.*, (2010).

2.4.3.2 Deenbandhu model

In an effort to bring down the cost of digesters (fixed dome and floating drum), this model was developed from the Action for Food Production in New Delhi (India) in 1984. This model is a resilient type as cracks hardly occurs and it utilises less building material, making it less costly (GTZ, 1999). It has a spherical shape gasholder and a round bottom. The digester is constructed from ferrocement. A modified form of this model, known as Deenbandhu 2000 and it has a dome-shaped expansion tank as opposed to the square-like shape of the earlier model. The Deebandhu model proved to be thirty (30) percent cheaper than the Janata Model and about forty-five (45) percent cheaper than the Khadi and Village Industries Commission (KVIC) plant of comparable size in India (FAO-Nepal, 1996). Deenbandhu plants with spherical expansion tanks were built at Appolonia in Ghana as part of the Appolonia Household Programme in 1987 (Bensah *et al.*, 2010).

2.4.3.3 Anaerobic Baffled Reactor (ABR

This is an elongated vessel that has been divided by a series (number) of baffles into five (5) or six (6) equal compartments in order to produce fully or incomplete separated unit of reactors arranged in series (Valijanian *et al.*, 2018; Mao *et al.*, 2015). The baffles usually control the flow in order to generate a plug system of flow. Each baffle of an ABR may entirely use different principles of waste treatment in order to improve the biogas production (Valijanian *et al.*, 2018). Ran *et al.*, (2014) examined four compartments of an ABR with an overall volume of 3.46L and made the observations that the fermentative hydrogen was produced in the first compartment and that methane production occurred in the last three compartments. The outcome showed that the first compartment produced 20.7% of hydrogen whilst the other three compartments produced 98.0%, 93.6%, and 70.1%, respectively of methane. COD removal rate was 98.0% achieved. The ABR system operates on 24hrs hydraulic retention time (HRT) with influent of chemical oxygen demand (COD) concentration ranging between 3500 mg/l to 4000 mg/l. The advantages of ABR are; the production of hydrogen, cleaner effluent and methane generation for use (Valijanian *et al.*, 2018). The ABR system was proposed by CSIR as the best option to be deployed in SHSs and ten (10) ABR plants that were installed; nine of which are still at various stages to be completed in schools in the Greater Accra Region.

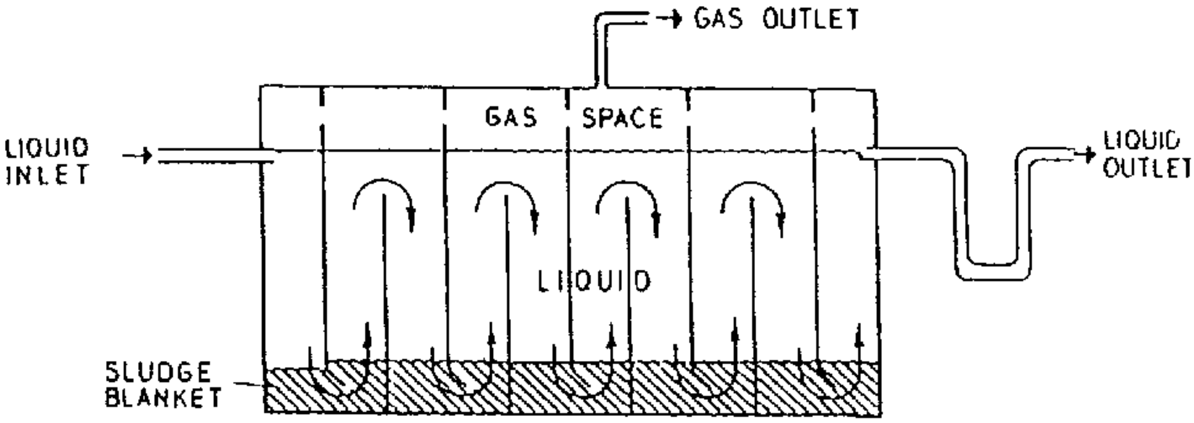


Figure 2.5: Anaerobic baffled reactor

Source: Valijanian *et al.*, 2018

2.5 Factors that influence Biogas Adoption

2.5.1 Uses/Benefits of Biogas

In Ghana, about 70% of the population relies on biomass in the form of fuel wood, charcoal, crop residues, and animal dung in order to meet their energy needs for cooking. About 90% of domestic energy consumption is catered for by biomass at the household level in Ghana. The direct burning of biomass in traditional cook stoves releases a lot of gases such as carbon monoxide, hydrocarbons, and particulate matter. This is confirmed by Armah *et al.*, (2015) when they posit that cooking in Ghana is done in poorly ventilated areas which cause a lot of severe health-related illness from indoor air pollution (IAP). Lambe *et al.*, (2015); and Surrendra, *et al.*, (2011) corroborated this statement and indicated that there is enough evidence linking solid fuels and the occurrence of sicknesses like child pneumonia, chronic obstructive pulmonary diseases and lung cancer in developing countries like Ghana due to IAP. The World Health Organization (WHO, 2007)) stated that about 1.5million premature deaths per year are attributable to IAP from solid fuel use. Out of the 1.5 million, 85% (1.3 million people) is directly related to biomass use and the remaining deaths due to the use of coal. Women and children suffer more from IAP since they are directly involved in cooking with traditional biomass, inhaling the smoke constantly (Lambe *et al.*, 2015). Possibly the high rates of health-related problem such as asthma and cataracts, low birth weight and stillbirth, tuberculosis and high blood pressure in Ghana could be attributed to IAP exposures.

Biogas provides clean and smokeless environment unlike firewood, dried cow dung, and crop residue (Surrendra *et al.*, 2011). The biogas system has been in use for long at slow paced in Ghana but the technology progression is necessary in order to improve energy outputs especially for institution. The use of biogas in Ghana can significantly contribute to reducing IAP and eliminate IAP related sicknesses. Also, because biogas technology requires individuals and institutions to construct toilets, this will eradicate the issues of open defecation which is a common phenomenon in Ghana. The adverse effects of open defaecation are cholera, typhoid, dysentery and other water born related disease. This is confirmed when UNICEF on 19 November 2015, indicated that open defaecation is high in Ghana and it contributes to the high incidence of diarrhoea, spread of intestinal parasites and malnutrition (www.unicef.org)

Environmental benefits

Municipal solid waste (MSW) disposal especially the organic fraction is a challenge to most African countries because of unavailability of landfills or landfills that are not engineered, affecting environmental good practices. The widespread use of wood fuel for cooking and heating in Ghana has severely affected forest and wood resources. This requires a technology like biogas system that can supplement wood fuel in order to safeguard forest resources and restore the environment (Surrendra *et al.*, 2011). Brown, (2006) added that a well designed and installed biogas digester has several benefits; "it improves sanitation; it reduces greenhouse gas emissions; it reduces demand for wood and charcoal for cooking, and therefore helps preserve forested areas and natural vegetation, and it provides a high-quality organic fertilizer". Ilyas, (2006) posit that biogas technology has reduced the rate of environmental deterioration and deforestation in Pakistan by providing biogas as an alternative to fuel wood in order to meet their energy demand especially domestic energy for cooking and heating.

Berhe *et al.*, (2017) viewed biogas systems as a sustainable source of energy that has the potential of providing low-cost energy without gathering wood as fuel, lessens the degradation of indigenous forests, reduces GHG emissions into the air and improves carbon sequestration of indigenous forest tress. Kelebe, and Olorunnisol (2016) confirmed this when they said that 12 rural households that substituted biogas with firewood resulted in a decrease of 50-60% of firewood consumption. They also stated that a total of 9,577 domestic biogas installed in Ethiopia as at 2014 save approximately 2,873 ha of forest land. Minde *et al.*, (2013) pointed out that if 1kg of wood was burned in the traditional cookstoves, it generates about 318grams of Carbon. However, if biogas is used, each household annually save the consumption of 3 metric tons (6600 pounds lbs) of firewood and 576 kg (1,270) of cow dung. This means that biogas technology adoption will bring about 70% to 85% reduction of the global warming potential (GWP) of GHGs if biogas is used (Berhe *et al.*, 2017; Battini *et al.*, 2014; Minde *et al.*, 2013). Biogas technology can combat environmental challenges such as eutrophication, acidification, air pollution, spread of diseases and climate change issues.

Social benefits

The major responsibility of energy needs in terms of access to wood fuel requirements lies largely with women and children who have to trek long distances in order to harvest them for domestic use. This is not only time consuming but tiring as well since the loads are usually very heavy. This practice denied women and children, especially the girl child the opportunity to education since they are usually sacrificed on the altar of tradition and customs in many parts of Sub-Sahara African countries for this task. Lambe *et al.,* (2015); Minde *et al.,* (2013); and Fullerton *et al.,* (2008) pointed out that biomass burning releases pollutants like carbon monoxide, methane, nitrogen oxides, benzene, formaldehyde, benzopyrene, aromatics and particulate matter which causes considerable damage to women and children, since they are more at risk for a long time of exposure. Smokeless biogas would offer an excellent substitute for use in developing countries, especially Ghana, improve well-being of women and children. The time saved from gathering fuelwood can be used for productive ventures and offer chance for girls to be in school.

Economic benefits

The bio-slurry from biogas plants is estimated to yield about 0.5kg of Nitrogen compared to fresh manure which is lower than this value. When bio-slurry is considered as manure, the return on investment in the process can be realised within 3 to 4 years' time. This is because the use of bio slurry saves about 39kg of Potassium, 39 kg of Nitrogen and 19 kg of Phosphorus and this can solve the problem of soil degradation and reduce the dependence on artificial fertilizer as highlighted by Minde *et al.,* (2013). A nationwide deployment of biogas technology for institutions will generate a lot of jobs in the form of carpentry, masonry, and plumbing. Also, there will cost savings on fossil fuel importation since pressure on its demand will reduce. The economic benefit of biogas has both national and international levels.

2.5.2 Cost of Waste Management

Waste can be anything which is not of value or of use anymore. It can come from control (household/institutional/commercial) or uncontrolled (natural like mining, agricultural, and quarries) sources. The organic (biodegradable) fraction of waste is of concern because of its potential to release methane when it decomposed and also because it forms about 60-70% of all solid waste generated (Asomani-Boateng & Haigt, 1998). Also, the management of municipal waste both institutional and household levels constitute a drain to the state and household financial resources. According to myjoyonline news (www.myjoyonline.com, 2016), “Accra Metropolitan Assembly spends about US$ 3.45 million each year (GH¢ 6.7 million) on collection and transport of waste for disposal”. Fortunately, the larger segment of this waste can be utilised as feedstock for anaerobic digestion (AD). As such, addressing waste management through AD technology, waste challenges would be solved in the country. Equally, this will directly address SDGs 3, 6, 7 and 13 (Good Health and Well-being; Clean Water and Sanitation; Affordable and Clean Energy; and Climate Action respectively). Specific targets of SDG 3 which is about ensuring good health and well-being are appropriate in this respect: targeting the elimination of epidemics like malaria, cholera, dysentery, and unrestrained tropical illnesses like hepatitis, water-borne diseases and other infectious illnesses; and 3.9 which is targeting a substantial reduction of deaths and diseases from dangerous chemicals, water, soil, and air pollution and/or contamination.

AD will ensure that organic waste does not pollute sources of good and portable water for drinking; reduced the likelihood of deaths by unsafe drinking water and ensures good health and well-being. AD technology will enhance good sanitation and hygiene leading to reduction in diseases from cholera, malaria, pathogens, and insects causing ill health which are all critical targets of meeting SDGs 3 and 6. Poor waste management (collection and disposal) and open burning will generate environmental pollution, and create health hazards to public health and increase the risks from air pollution respectively (Agyepong, 2018). Choke drains due to blockages from waste usually creates flooding during rains and stagnation of water leading to breading of mosquitoes can be tackled by AD if effluents are channelled into a digester. AD provide gas which is a clean and affordable, which directly addresses SDG 7 (WBA Factsheet 3, 2016; Armah, *et al.*, 2015; Janssen & Rutz, 2012). Methane and CO_2 which will otherwise be emitted into the atmosphere from the decay of organic waste is eliminated since the methane is captured is used. This contributes to the attainment of SDGs 7 and 13 if biogas technology is deployed (WBA Factsheet 3, 2016; Kasap, *et al.*, 2012; Engler *et al.*, 1999). Weitz *et al.*, (2015) argued that energy is linked to the attainment of good health and education SDG targets-provide electricity for schools and clinics, and light at home for homework. While clean water and sanitation are linked to achieving health SDG targets and through biogas this can be attained by ensuring that sewage are treated reduce pathogens.

2.5.3 Student Population

In order to understand how viable a biogas plant will be, there is the need for prediction of the feedstock inflow, which influences the potential yield of biogas. Efforts should be made to ensure better predictability (via total population) of feedstock before installation of the plant. This will help the implementing institution to project the quantity of biogas yield they will obtain.

Bond and Templeton (2011) indicated that the number of cattle that a household owned is critical to the excreta that will be available as feedstock for the biogas digester, giving credence to total number of students as key to feedstock availability. Bedi *et al*., (2015) amplified this when they said that for a family size biogas digester to produce gas for cooking, at least two cows are needed, but adding an electrical connection would require more cows in order to increase possibility of producing enough biogas. This would serve as basis to motivate an individual institution to adopt a biogas plant. Similarly having enough human population (students) will in-like manner increase the chances of having enough biogas yield as each student excreta is a valuable input for biogas production. This will equally motivate a school to adopt the technology, since there is enough feedstock.

2.5.4 Sustainable Biogas Production

The term sustainability has become a global concern in all spheres of life. Biogas system is a model for sustainable energy because it safeguards the stability of environmental, economic and social elements (Poudel, 2018). Its sustainability stems from the fact that this energy source utilises a simple technology that relies on locally but regularly available raw materials (feedstock)-agriculture, municipal, industrial waste and animal wastes-to produce and supply a clean form of efficient renewable energy (Boulamanti, *et al.*, 2013; Budzianowski, 2012). Also, biogas systems are able to address major environmental challenges ranging from IAP from fuel wood, degradation of soil, global warming, deforestation; which mainly result from unsustainable exploitation of wood fuels. Finally, it contributes to mitigating public health challenges like infections respiratory diseases and, water and air-borne diseases.

However, the sustainable deployment of biogas technology in Africa, especially Ghana is very slow, because the deployment of the technology has been restricted to household use for energy. This has made the deployment of the technology dependent on the decision of the family and their total wealth. Individuals and institutions are unable to afford the high upfront cost for biogas system. Bensah, *et al.*, (2010) confirmed that the obstacles to sustainable biogas promotion, deployment and production are hampered by economical, technical, and social problems. Other underlying factors for the slow deployment of biogas technology are;

- The difficulty for most users to obtain technical services during operation for regular maintenance to enable proper functioning of their biogas plants.
- The difficulty to persuade an uneducated person if learnt experiences on one sided benefit, especially energy to the neglect of the overall benefits of biogas technology (sanitation, energy and agriculture) are bad; so that they are not well motivated to adopt the technology and discourages potential adopters, and.
- The available biogas technologies are not appropriate for consistent and high yielding biogas generation.

Biogas yields are mostly influence by the climatic conditions of the area and poor structure of the digesters. To overcome these, there is the need to incorporate designs that can maintain uniform temperature within the biogas plant and be installed by trained and certified personnel. To achieve sustainably biogas generation, environmental, social and economic aspect should be incorporated into both national and local policies as well as organizational capacity building. Nzila *et al.*, (2012) argued that sustainability assessment of biogas should focus on three main sustainability dimensions of technical, economic and environmental. It is also important to appraise the cost-benefits of biogas generation from sanitation and hygiene, health benefits and reduction of GHG emissions but not just only financial gains with other energy sources (Surrendra *et al.*, 2011).

2.6 Willingness to adopt Biogas Plants

2.6.1 Feedstock Availability

Feedstocks for biogas plants are all biodegradable materials that are suitable, available, and easily digestible in the AD. Feedstock for biogas can be grouped according to their sectors of origin namely; agricultural, industrial, municipal and aquatic materials (Wellinger *et al.,* 2013). Ghimire, (2007) stated that the type of feedstock available, determines the kind of biogas digester that can be built and the amount of gas that can be generated. Langeveld and Peterson (2018) postulated that there is a wide difference in terms of quality and composition of the feedstock obtainable for biogas plants. Within a particular waste streams it can vary widely from dry matter to proteins and/or fats contents. Knowledge of feedstock types and quantity enables one to predict gas yields from a biogas plant (Ghimire, 2007). In order to understand the relationship between a given feedstock and its biogas potential, you need to evaluate the physicochemical properties of the feedstock, its moisture content and the organic matter.

Also, the percentage of total solids (%TS), the percentage of volatile solids (%VS*)* and the fresh matter (FM) fed into digesters are crucial determinant of the gas volume per inflow of feedstock (Langeveld & Peterson, 2018). If the feedstock has a very high-water content or a lot of fresh water is added, then the nutrient concentration will be low and this will produce low biogas output. This is especially so with liquid manure like cow dung, pig dung and faecal matter from flushing toilets. This has been given credence by Langeveld and Peterson (2018); and Wellinger *et al.*, (2013) when they indicated that low TS values in a substrate means that the substrates are highly diluted and will results in reduced biogas per unit of the fresh matter, whether solids or liquids. A high yielding substrate for methane (biogas) should contain cellulose, crude protein, hemicellulose, crude fat and nitrogen contents (Amon *et al*., 2007). This explains why co-digestion of feedstock is important for maximum gas output from an AD. Pöschl, *et al.,* (2010) determined the energy efficiency on biogas plants based on feedstock resources (i.e single feedstock versus co-digestion). They found out that primary energy input to output (PEIO) ratio ranges between 10.5% and 64.0%, for single feedstock while co-digestion of feedstocks PEIO ranged between 45.6–55.0%. This suggests that more biogas is generated from multiple feedstock than from a single feedstock.

> *"Toilet wastewater alone could not produce enough biogas to cover completely the energy demand for cooking or lighting of a household. Feeding easy biodegradable organic kitchen waste or animal dung into the biogas-sanitation digester could increase the biogas yield"* (Mang *et al.*, 2012 :225).

Another critical aspect of feedstock is the carbon-to-nitrogen ratio (C/N). If the C/N fluctuates significantly, either too high or too low, it will affect the digestion process by slowing it or even stopping it. The microorganisms need a 20-30:1 ratio of carbon to nitrogen in order to act on the substrate efficiently, with a large percentage of the carbon being readily digestible. Generally, if the substrate is from human (like. faecal matter or wastewater from municipality) or animal sources (e.g. manure, slaughterhouse waste), the use of thermophilic digestion is preferable as this is an effective method in destroying the pathogens within the substrates. Various feedstocks per methane yield potential can be seen in Table 2.2

Table 2.2: General Feedstocks Characteristics

Type of feedstock	C:N ratio	DM[a] (%)	VS[b] % of DM	VS (%)	Methane yield (m^3 CH_4/ kg VS)
Pig slurry	7	5	80.0	4.0	0.30
Cattle slurry	13	8	80.0	6.4	0.20
Poultry droppings	7	5	80.0	4.0	0.30
Food remains		10	80		0.5–0.60

Source: Wellinger *et al.*, (2013).

From the table food remains, pig and poultry droppings have the highest methane yields with the least being that of cow dung. This implies that biogas systems that will utilise faecal matter and food residue will give the maximum gas yield need for their cooking and heating needs if the digesters are well constructed.

2.6.2 Availability of subsidy

The high upfront cost on biogas plants makes subsidy an indispensable strategy that will entice many potential adopters to the technology. In countries like China, India, and Nepal that have the highest household/domestic biogas plants, subsidy has been the driving force. Biogas plants may be subsidised from grants, low or no interest loans and/or free supply of biogas accessories. The rate at which potential adopters will respond to a subsidy will invariably depends on the types of subsidies, the amounts available and the bureaucratic procedures in accessing the funds (Energypedia, 2015). Aside this, how popular and reliable the subsidy programmes are in a particular area, will determined the number of adopters that will access it.

Agostini *et al.*, (2015) indicated that when tariffs and subsidies for renewable electricity were provided in Italy, its increased electricity generation from Anaerobic Digestion (AD). This resulted in about 994 biogas plants being installed with power generation capacity of 756 MW as at 2012 to supply power to some Italians. Sun, *et al.*, (2010) added that subsidies should be given to people with low income and who are more willing to utilise biogas energy. And that the subsidy should cover the entire value chain of installing biogas plants-utilisation of the gas, provision of cooking appliances and maintenance services.

Berhe *et al.*, (2017) highlighted that biogas plants are heavily subsidised by the Ethiopian government with the hope of ensuring that more people adopt the technology so that they can enjoy the social and environmental benefits of the technology.

The absence of subsidy for biogas technology and the fact that it is not given priority by the government as compared to other RE resources made people feel that the technology might not be that much important, hence potential adopter's reluctance to adopt the technology (Wawa & Mwakaila, 2017). They also pointed out that the absence of biogas in Tanzania national energy policy plans shows that its importance is being underestimated by the government and hence discourages it adoption.

In order to ensure support for the adoption of biogas systems, there is the need for proper channelling of subsidies and loan by government and other multi-lateral Biogas Support Programmes (BSP) to identify companies and national banks so that users and potential users can access the funds for the installation, use and maintenance. Ilyas (2006) confirmed this as a similar thing that has been done in Pakistan.

2.6.3 Source of finance

According to research findings, the construction, operation and maintenance of biogas plants require a substantial financial resource which can be conveniently covered by borrowed capital or supplemented by the Government or Non-Governmental Organisations (NGOs). Findings from literature indicates that the cost of installing biogas is high and that providing a financing source and accessories for biogas technology is key for its successful deployment and adoption. Countries like China and India that has the highest domestic household biogas plants is as a result of a series of funding sources provided by their governments and the continuous research and development (R & D) leading to new designs of biogas plants with associated production of biogas accessories. In Ghana, the situation is different, because each adopter or potential adopter would have to pay for the full cost of installation, acquisition of appliances (stoves and utensils) and maintenance. Also, there is low research and development on designs of biogas plants and its accessories. This makes the adoption of biogas technology in Ghana very expensive.

Three private schools that had installed biogas plants in Ghana as at 2008, had their average cost of installation as GH₵5,050.00. However, the Centre for Scientific and Industrial Research (CSIR) is rolling out their biogas plants (ABR) at the cost of GH₵8,000.00. Some of the institutions are of the belief that the cost of biogas systems is too high but worth installing it because of multiple benefits. Kossmann, *et al.,* (1999) confirmed that the cost component for the installation of biogas plants most often exceeds the means of the investor either from his regular income or savings. According to Kossmann *et al.,* (1999) and www.energypedia.info, the following sources of funding the cost of biogas plants should be made available such that potential users can tap into it in order to ameliorate the high upfront initial cost and maintenance fees. They identified these sources of funding:

- Grants and credits from institutes from international donors
- Budgetary allocation/support from f the country (public support)

- Credits/loans from financial institutions (Banks)
- Funding from international carbon trading schemes
- Resources of the biogas installer
- Fees/contributions from users who have been supported

These sources must be individually examined in order to determine which one brings the best returns and more convenient to clients.

2.6.4 Cost of Alternative fuel

Bedi *et al.,* (2015) highlighting the effect of Rwanda Biogas Programme, explained that though users of biogas continue to use other sources of fuel, their annual total expenditure was far less than 31–32% of non-users of biogas with a corresponding reduction of annual fuel wood consumption of about 1,825 kilograms. They attributed the reduction of expenditure to a reduced spending on fuel wood and charcoal as their heavy usage has been supplemented with the biogas. By inference biogas serves as an alternative source of fuel to pre-dominant fuel types to countries in transition, especially Africa countries.

According to Wawa and Mwakaila (2017), the motivating factor for biogas system adoption is shortage of wood fuel and other alternative fuels like LPG. This can be aggravated if there is energy crisis, making people to look for cheap alternative supplement of fuel like biogas. Das *et al*., (2017) pointed out that household with high income has a greater probability to adopt biogas digesters compared to the poorer counterpart because of the high initial cost.

2.6.5 Multiple Uses of Fuel

Many SHS use multiple sources of fuels to supplement the main sources of fuel (either LPG or wood fuel or both) with other forms of fuels like charcoal or biogas. Senior High Schools using biogas also used LPG when cooking meals for a large number of students. A study conducted by Ahiekpor *et al*., (2015) indicated that households in Ghana use multiple sources of fuel for their energy needs. The study identified that the choice of cooking fuel was based on four factors: availability, cost, cleanliness in terms of usage, and time (hours) for cooking. The study indicated that about 89% of LPG users also use charcoal as a backup fuel since they are not able to determine the quantity of LPG in the tanks/cylinders and are also not sure of LPG availability if it runs out.

Also, a similar study conducted in Ethiopia by Berhe, *et al.,* (2017) showed that households do not necessarily switch to cleaner or more efficient forms of energy when their income level increased in developing countries. Rather they depend on one or more energy sources as far as they obtain their maximum threshold level of satisfaction. This assertion finds confirmation in the study conducted by Mensah and Adu (2015) who postulated that an increase in income level in Ghana does not correlate to switching fuel source to a cleaner one like LPG, biogas or electricity in the country. But rather the restraining variable is availability for the utilisation and adoption of a particular fuel type. Berhe *et al.,* (2017) argued that, though users know the benefits of biogas as a clean form of fuel for cooking and lighting, they will still use other fuel sources because biogas stoves are not compatible and the abundant availability of cheaper and readily available sources of fuels like cow dung, fuel wood and agriculture residue. However, in a research carried out by Mensah and Adu (2015) availability seems to be the restraining factor to adoption of particular source of energy and its utilization for cooking in Ghana.

2.6.6 Knowledge and Use

Knowledge and perception are key factors that influence an individual or an institution's behaviour in the adoption of a technology. Increased knowledge on cost efficiency and potential benefits of biogas would greatly determine the deployment, adoption rate and sustainable use of the technology in SHS in Greater Accra Region and the country at large. Knowledge and perception are affected by the educational level, publicity and demonstration results.

Knowledge and awareness of biogas as well as the potential benefits of using the technology, will influence the adoption behaviours of potential users. However, the lack of awareness is one important challenge militating against the biogas adoption and its sustainable use. In many localities, the awareness of biogas is just limited to the use of the gas for cooking or heating, to the neglect of other uses of biogas system for sanitation, rich bio-slurry for farming, and protection of human health against IAP and GHG reduction. (Kabir *et al.,* 2013). Luthra *et al.,* (2015) postulated that awareness level increases if an individual is exposed to media networks like newspaper, radio, magazine, television, facebook; this will lead to high rate adoption of biogas technology. The knowledge of women about the harmfulness of smoke in their cooking and processing of food in rural areas will influence their likelihood to recommend the adoption of cleaner form of energy like biogas technology (Luthra *et al.*, 2015). Poeschl, *et al.*, (2010) argued that biogas plants have the capacity to contribute towards the attainments of renewable energy for national targets if existing technology, policy drivers and incentives are provided to enhance upgrading biogas to natural gas quality. If this is done, it can expand the use of the biogas to fueling of vehicle and powering thermal plants through natural gas pipelines for electricity generation.

The knowledge and awareness of biogas positively correlate with the level of education one attains. People with adequate knowledge and a higher level of education are easier to adopt new things than people with deficient knowledge and low level of education. Walekhwa *et al.*, (2009) reported that the willingness to adopt to newer and cleaner forms of fuel is higher among residents with the higher pedigree of educational levels than those with low education level. This is contrary to the view by Jiang *et al*., (2011) when they posit that knowledge and use is crucial to influence the adoption of biogas systems as in rural China. They asserted that in areas where users knew how to operate and maintain their biogas stove and plants despite their low level of education of education, adoption rate was higher than areas where educated people couldn't operate and maintain their biogas plants and stoves.

In the view of Wawa and Mwakalila (2017) people are motivated to adopt biogas plant by installers. However, most biogas installers give reasons for adoption as the promise of biogas for cooking instead extra energy for cooking, power for lighting, ironing and refrigeration as well as other benefit for agriculture cost saving from waste disposals.

2.7 Environmental Protection

The extensive use of woodfuel and fossil fuel has a significant impact on the, environment and the economy as well. Also, management of Municipal solid waste (MSW) disposal, especially the organic faction is a big due to the big due to the challenged it posed to most African countries. Such waste ends up in the sea or in landfills that are not engineered, thus affecting environmental health and sustainability (Agyepong, 2018). The widespread use of firewood and charcoal for cooking in Ghana has severely impacted local forest and wood resources in the country as there is high diminishing rate of forest cover. This calls for a renewable technology like biogas technology that can safeguard the forests.

According to Akinbomi *et al.,* (2014), "Biogas can be used to augment conventional energy sources for various purposes including cooking, heating, vehicle fuel, and electricity generation while the sludge from the anaerobic process can be used as organic fertilizer”. Many of the waste sewage treatment facility built, occupying large tracks of land by donor agencies in Sub-Saharan Africa, especially Ghana are broken down. The famous Lavender Hill is a classic example where trucks continuously dump more than 250,000 gallons/day of human faeces directly onto the beach and into the ocean (www.myjoyonline.com, 2019). Auther *et al.*, (2010) added MMDAs and institutions can rely on biogas technology to overcome the waste disposal and wastewater treatment problems that has bedevilled the country. Replacing septic tanks with biogas plants is the most sustainable and cost-efficient way of treating sewage and biodegradable municipal waste. This is confirmed by Mattocks (1984) when he stated that “tests have shown that biogas systems can kill as much as 90 to 100 percent of hookworm eggs, 35 to 90 percent of ascarid (i.e., roundworms and pinworms), and 90 to 100 percent of blood flukes (i.e., schistosome flukes, which are found in water snails that commonly live in paddy fields and ponds)”.This will consequently protect the environment from flooding and indiscriminate dumping of waste, disease pathogens leading epidemic diseases and bad odour (Akinbomi *et al.*, 2014; Bensah, 2010)

Global issues on increasing GHG emissions largely from woodfuel, fossil fuel, unsatisfactory waste management are of great concern. Biogas technology, aside providing clean fuel for cooking and lighting, and an excellent manure for farming from the slurry, it also provides a chance for mitigation global warming and reducing GHG emissions. This is attained by substituting firewood for cooking, kerosene for lighting and cooking and inorganic chemical fertilizers for farming (Pathak, *et al.*, 2009). Alayi, *et al.*, 2016; and Vorbrodt-Strzałka and Pikoń, 2013 indicate that biogas if purified can be used in all equipment that natural gas uses, making it comparable to natural gas in terms of cleanness and usage. Pondel *et al.*, (2016), confirmed that a household in India consumed 71.29 GJ, emitting 646.1 tCO2e per year per. However, when biogas plant was used, GHG emissions reduction was found 7.62 tCO2e per biogas plant. They concluded that 84 biogas plants with sizes $6m^3$, can reduce a total of 638.82 tCO2e GHGs emission per year and saved 217.32 tons of fuelwood per year per household. This an indication that biogas technology aside mitigating climate change and global warming, it will also help minimize deforestation in Ghana.

In fact, a sustainable way in tackling organic waste management or municipal sewage in our environment which is a major source of pollution and safeguarding our forest resources through biogas technology. Biogas technology is necessary in maintaining environmental sustainability for good human and animal health, food security through the use of the bio-slurry for farming (Vorbrodt-Strzałka & Pikoń, 2013; Mattocks, 1984).

2.8 Constraints/Challenges confronting Biogas technology

The deployment of biogas plants suffers from many challenges as it is a very complex technology. Aside the complexity, the technology requires the combination of a variety of classified fields of engineering. This constitutes a big challenge to the constraint against a fast diffusion of biogas plants. Some challenges indicated by literature are examined in the ensuing paragraphs.

2.8.1 High Initial Cost

One of the biggest constraints to large-scale deployment of biogas technology is the fact that the high upfront cost of investment for the technology is beyond the reach of the majority of the rural population and institutions in adopting the technology. In Ghana, per field interview, the price of a digester varies from GH₵5,000.00 to

10,000.00 depending on size, nature of land (waterlog or rocky) etc. High initial cost, has been affirmed by Kambele (2003); Ng'wandu *et al.*, (2009); and, Wawa and Mwakalila (2017) saw that the high installation cost of biogas is a big hindrance to wide scale adoption of the technology. The cost seemed to be unaffordable to the majority of the rural population; a large proportion of potential adopters of the technology.

According to Ilyas (2006), the high initial cost has been overcome in Pakistan by ensuring that biogas companies use a single price quotation in order to eliminate competitiveness in the cost of the biogas plant and makes the price stable across for all installers. Standardisation also ensure that the quality of construction is more or less the same. Added to this, manufacturers of biogas appliances are required to submit the appliances for inspection and quality control test before they are sent back to the biogas company for usage. This is to ensure that substandard equipment or appliances are not used for any biogas plant by any installer.

2.8.2 High cost of maintenance

In building a biogas plant, there is the need to pay special attention to how the running, maintenance and repair costs can be financed. The funds for servicing and repairing of the biogas plant are as essential as installing the plant. Regular maintenance will ensure that the lifespan of the biogas plant is realised and the confidence level of the user in terms of the reliability of the plant is attained (Kossmann *et al.,* 1999). The issue of poor maintenance is one of the most important causes of biogas plant failure in many countries. Evidence suggests that access to technical services is a major determinant to plant performance (Merchaim, 1992).

According to Wawa and Mwakalila (2017), biogas adopters mentioned the high cost of maintenance services as a major factor. The high cost of maintenance services has led to poor performance of biogas plants since many users are not able to afford the cost. This has in turned discourages both biogas users of the technology and also potential adopters to adopt the technology. This is because users expressed their frustration about the poor performance of their biogas plants which have made them being laughed at by non-users and labelled the users as losers, a stigma that haunts them. Furthermore, accessing technical services is a big challenge since there is little or no support from either government or installers; installers do not respond promptly to complaints. According to Taşdemiroğlu (1988), many biogas plants are abandoned mainly due to inability of get in touch with installers for regular maintenance services. The poor performance of biogas could be due to inadequate training or no training at all of technicians. Wawa and Mwakalila (2017); and Ng'wandu *et al.* (2009) argue that a minimum supervision of biogas plants construction improves the quality of the yields, resulting in users being satisfied with the performance of their biogas plants. And that prompt response to maintenance with reduced charged fees extends the biogas plant lifespan and improved the confidence level of users.

2.8.3 Low level of knowledge or awareness and Promotion

According to Surendra *et al*., (2011) many individuals or institutions are unaware of both the full benefits and the adverse effects of biogas systems in relation to health, economy and the environment, even though they may be using the technology. Taşdemiroğlu, (1988) added that as a result of lack of knowledge or awareness, many people are not sufficiently informed of the ecological benefits of biogas as one of the most vital renewable energies that can solve their energy problems.

To increase the number of biogas system users, promotional strategies and materials (radio, biogas posters, publication of calendar leaflet on biogas, and TV advertisement and programme) should be designed to capture the total benefit (sanitation, energy and nutrient rich effluent for farming) of the technology. Also, user's friendly guides or manuals on repair, maintenance and servicing should be made available to users. This will improve their knowledge level on measures to adopt for the well-functioning of their biogas plant. The challenge of not getting prompt service on maintenance work from installers will be minimised since users can perform minor servicing while major maintenance will be reserve for installers

2.8.4 Inadequate technicians

Nguyen (2011) postulated that the inadequate number of technicians and skilled labourers for biogas construction, operation and maintenance works is a crucial constraint of wide scale adoption of biogas technology. Most biogas technicians are masons who have minimal education but have the benefit of either being an apprentice or got some short training from a biogas plant construction projects or just learned by imitation (Tran *et al.*, 2009). This makes them lack the necessary engineering techniques, skills and science on how to plan, design, construct and install a biogas system to function properly (Nguyen, 2011). Also, there is very little after-construction service on biogas plants by installers because of the low numbers and busy schedule of the few experts in the system, leaving users frustrated and non-users unwilling to adopt (Tran *et al.*, 2009). This gap can be bridged if there are training centres for biogas installers with regulators monitoring standards and installation so that improperly trained people do not install biogas plants.

2.9 Theoretical Framework

2.9.1 Technology Adoption Theories and Models

The terms adoption and diffusion have been used interchangeably though they are different from each other (Sharma & Mishra, 2014). According to Carr (1999) adoption is defined as "the stage in which a technology is selected for use by an individual or an organization" while for Rogers, (2003) diffusion refers to "the stage in which the technology spreads to general use and application". Thus, adoption is used at the level of the individual and diffusion is seen as adoption by the society. According to Sharma and Mishra (2014) adoption usually leads to diffusion. Therefore, any studies into technology adoption must consider diffusion as well.

With rapid technological innovations, diffusion is crucial to justify the huge investment in the technology. If these innovations are not adopted by the intended users, the investments may not yield the anticipated results (Sharma & Mishra, 2014). Venkatesh *et al*., (2012); and Sharma and Mishra (2014) indicated that technology adoption does not only relate to the aspects of the technology but also cover much more complex issues of the user's attitude and personality, social influence, trust (Gefen *et al.*, 2003) and other enabling conditions.

Theories of the Adoption Process

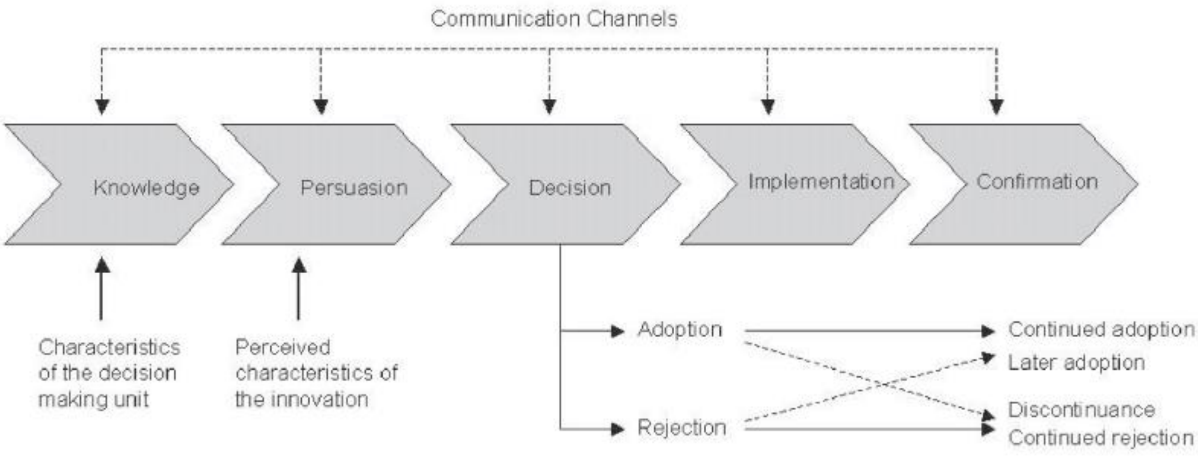
Adoption Process

Technology adoption refers to the process through which an individual or organization decides to fully use an innovation in their daily business (Rogers, 2003). In other words, adoption refers to the decision to use a new improved technology. The adoption process in biogas technology can be explained as a series of stages that an individual/institution passes through; i.e first from hearing about biogas technology (the stage of awareness), to information gathering about biogas technology's on expected usefulness in terms of its profitability and ease of operation (the stage of evaluation). If the information is adequate and the evaluation is positive, the potential user will first experiment with the technology by installing it. Every potential adopter evaluates an innovation on its merit and the compatibility with pre-existing system.

Rogers (2003) identified five stages involved in innovation-decision process which the individual must go through as depicted in Figure 3.1 and explained in the ensuing paragraphs.

- First, they must learn about the innovation (knowledge stage) i.e. "what the innovation is, how it works and why it works". This calls for education, knowledge sharing and promotional messages on the multiple benefits of biogas technology in Ghana. These multiple benefits should highlight on sanitation and hygiene, lower cost of energy (LPG, Fuelwood, and Charcoal), environmental protection, soil nutrient improvement from bio-slurry, poverty reduction and employment creation.
- Second, they must be persuaded or convinced about the value of the innovation (persuasion stage), normally through social networks like colleagues and peers. This is where government, through its regulatory agencies, must encourage institutions, especially SHS with boarding facilities, to adopt biogas technology using the existing users of biogas for instance the four schools already using biogas as a guide.
- Third, they must decide to adopt it (decision stage). The adoption of an innovation increases when there is opportunity for partial trial. Biogas installers must showcase biogas plants that are well-functioning so that others can also be convinced and adopt.
- Fourth, the innovation must then be implemented (implementation stage). There is the need to provide technical assistance at this stage in order to reduce the degree of uncertainty. This requires constant follow-ups with technical assistance in order to resolve minor and major challenges on biogas plants. These can be effective if there are installation guides and maintenance manuals on biogas technology or there are follow up calls to users by installers.

- Fifth, the decision must be confirmed or rejected (confirmation stage). A positive message about the innovation confirms an individual's decision on the adoption of an innovation/technology. However, an individual may reject or discontinue with an innovation adoption when negative messages are given or when the individual



is not satisfied with the performance of the innovation.

Figure 3.1: Rogers Innovation-Decision Process

Source: Sharma & Mishra (2014)

These five steps follow each other in a sequentially or time-ordered manner (Sahin, 2006). The individual may at any particular stage decide not to adopt an innovation in this process, including rejecting the innovation after initially accepting it (Cowan & Daim, 2011).

Lai, (2017) posits that there are a number of theories put forward to explain consumers' acceptance of new technologies and their intention to adopt such a technology. These theories in the view of Lai (2017) includes; Theory of Diffusion of Innovations (DIT) by Rogers in 1955[4]; Theory of Task-technology Fit (TTF) by

[4] The theory of DIT by Rogers was propounded in 1955 but commenced implementation in 1960

Goodhue, and Thompson, (1995); Theory of Reasonable Action (TRA) by Fishbein and Ajzen, (1975); Theory of Planned Behaviour (TPB) by Ajzen, 1985 and revised in (1991); Decomposed Theory of Planned Behaviour by Taylor and Todd, (1995); Technology Acceptance Model (TAM) by Davis, Bogozzi and Warshaw, (1989) with the final version of Technology Acceptance Model (TAM) and later reviewed and updated by Venkatesh and Davis in 1996; Technology Acceptance Model 2 (TAM2) Venkatesh and Davis in 2000; Unified Theory of Acceptance and Use of Technology (UTAUT) by Venkatesh, Morris, Davis and Davis in 2003; and Technology Acceptance Model 3 (TAM3) by Venkatesh and Bala in 2008.

This research will focus on some of these theories that have potential implications for biogas technology adoption, especially the willingness to adopt biogas systems.

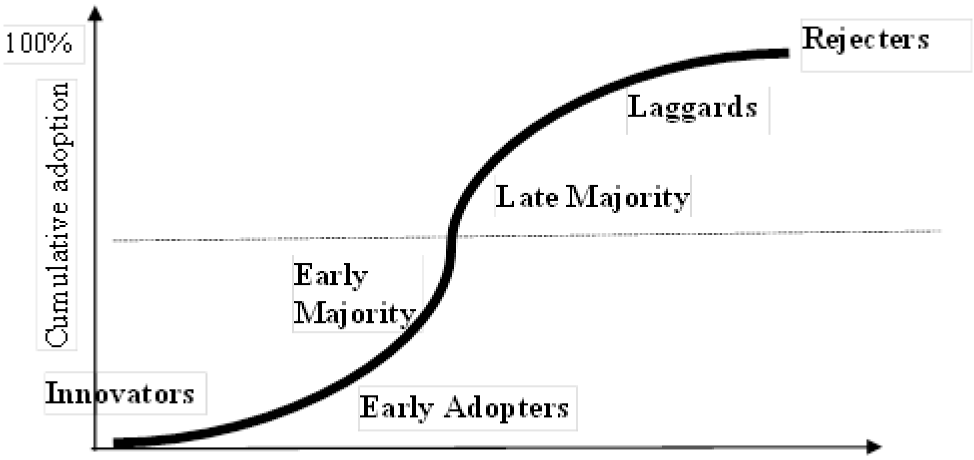
2.9.2 Diffusion of Innovation Theory

This is one of the most popular and widely used in the series of consumers' acceptance of new technology theories. Research on this theory can be traced to Everett Rogers' work in 1960 coined as the DIT Theory (Sharma & Mishra, 2014; Lai, 2017). Lai (2017) citing from Rogers (1995) indicated that the theory explains "the process by which an innovation is communicated through certain channels over time among the members of a social system". According to Rogers (1995), an innovation can be an idea, a practice, or an object, like a technological innovation.

Sharma and Mishra (2014) posit that the theory has four main elements that influence the spread of a new idea: the innovation, the channels communication, time and social system in an area. Basically, the theory of DIT states that an innovation and adoption happen after going through a series of stages including understanding, persuasion, decision, implementation, and confirmation that leads to the development and adoption of technology (Rogers 1995; Lai, 2017).

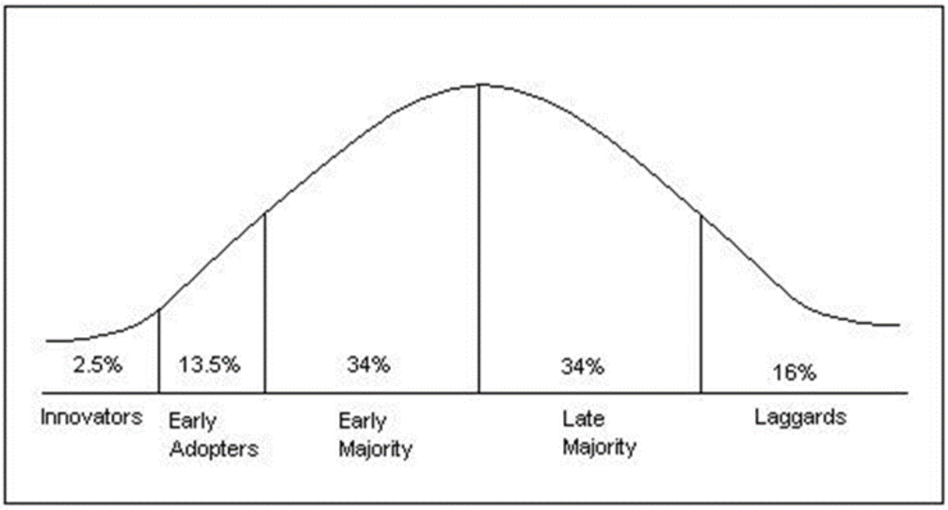
The underlining principle of the theory is that technology innovations are diffused over a time period in a pattern that has an S-shaped curve (see Fig 3.2). The S-shaped curve signifies the spread of biogas technology among the population and this can be likened to the pattern of spread of a new technique or idea or technology. Usually, at the initial stage, the technology starts to spread at a slow rate but with a gradual progression. In the mid-range of the S-shape, shows a period of a relatively rapid rate of growth. Thereafter, it stabilizes and then begins to decline as depicted in Figure 3.3 (Hillmer, 2009). Innovativeness is seen as an open behavioural change to which an individual or organization adopts new ideas earlier than other members of a system.

Figure 3.2: S-Curve of Innovation over Series



Source: Sharma & Mishra (2014)

Figure 3.3: Individual Adopter Categorisation on Basis of Innovation



Source: Hillmer (2009)

Individuals or organizations do not adopt an innovation at the same time in a system but they tend to adopt in a sequence of time (see Fig 3.2). This is because of the learning effect as a result of interpersonal influence on non-users or adopter. In the views of Sharma and Mishra (2014); and Lai (2017), the networks and the opinion leaders play a crucial role in the possibility of an innovation being adopted. According to the theory, the innovativeness of individuals and organizations are distributed along a normal distribution curve or bell-shaped curve over time (Fig 3.3). Rogers (1995) posits that adopters can be categorized into five, based on innovativeness. The earliest adopters on the curve referred to as innovators (earliest to jump on a new technology), followed by early adopters, followed by an early majority, followed by late majority and finally the laggards (Rogers, 1995). The above can be summarised into innovators 2.5%, early adopters 13.5%; early majority 34%; late majority 34% and the laggards 16% to Fig 3.3 (Rogers 1995 & Hillmer, 2009).

Even though this theory was developed years ago, it is still relevant and it works perfectly as a tool to explain many different phenomena pertaining to the adoption of technology, especially biogas technology. This means that technology is continually upgraded for more efficient technology to be deployed. For this reason, biogas installers must develop new digesters that accommodate cost efficiency and maximization of benefits from the digesters. If biogas digesters and installers fail to innovate, eventually diffusion will remain elusive.

2.9.3 Technology Acceptance Model (TAM).

Some studies focusing on biogas technology have their roots in the TAM by Daves (1998). This was introduced to predict user's acceptance of information technology (IT) and usage on the job. According to Venkatesh and Daves (2002), TAM has become, a powerful and robust model that is used to predict user's acceptance.

The basis of TAM lies on the type's assumptions that the intention to use is dependent on two variables; perceived usefulness and perceived ease of use. In the view of Daves (1998), perceived usefulness is the degree to which an individual think that using a particular system will be effortless. Also, TAM theory believes that perceived usefulness and ease of use are influenced by external factors such as intention to use the system, training, system characteristics and development process (Venkatesh & Daves, 2000). Thus, perceived usefulness and ease of use make users to form an attitude towards technology.

The rationale behind TAM is that technology is easy to use and will have a profound positive influence on the intended user's attitude and the intention towards using the technology. This will consequently increase the overall acceptance of that particular technology. If potential users of biogas technology find it easy to use, then there will be an increase in the adoption of the technology and vice versa.

2.10 Conceptual Framework

The production, use, and disposal of by-products from biogas plants work in a spiral manner. Within the context of this study as shown in Figure 3.4, the organic waste generated from the consumption of food plants by human beings serves as the raw materials for the production of institutional biogas. The organic waste is fed into an anaerobic digester which is expected to produce usable biogas composed of methane (CH4), carbon dioxide (CO2).and other gases. The review of literature on the functioning of biogas plants indicates that the technology has the ability to generate methane for energy uses such as heating, cooking, incineration, and/or electricity.

After the extraction of biogas from the digester, the remaining organic waste and water need to be evacuated. This study focuses on the use of such by-products as organic fertilizer and water for growing plants. The combination of all by-products resulting from biogas production (water, solid waste and carbon dioxide) together with sunlight help in plant photosynthesis. The growth of plants contributes to human survival. The photosynthesis process releases oxygen (O2) and sequestrate CO2. Hence, the conceptualization of this study on the adoption of biogas is from the viewpoint where every stage of the cycle has a contribution to environmental sustainability. It is viewed as a source of energy that goes beyond its energy use purpose to generate other benefits for the growth and use of plants as food.

The Diffusion of Innovations theory posits that, the adoption of technologies/innovations such as biogas by institutions largely depends on awareness, the decision to either adopt or reject, initial use potentials of the technology, and the track records associated with continuous use of the technology. Thus, the conceptualization of this study draws on the summation of these critical elements required for a successful adoption of technologies to focus on the willingness of schools to adopt the technology, and the cost efficiency associated with the use or non-use of biogas plants among second cycle schools. Willingness as a major influencing factor among institutions is centred on decisions by school authorities to either adopt or reject the use of biogas technologies based on initial stage, implementation stage and post-adoption stage considerations by stakeholders of such institutions. Cost efficiency, on the other hand, is situated within the context of the proven results of biogas plants within user institutions, cost of faecal waste management and supplementing the cost of fuel compared to the cost of installation from both private and public installers. The determination of the cost efficiency of the decision not to adopt the technology among non-user schools is conceptualized as a factor of the amount spent on installing the plant, energy and dislodging organic waste.

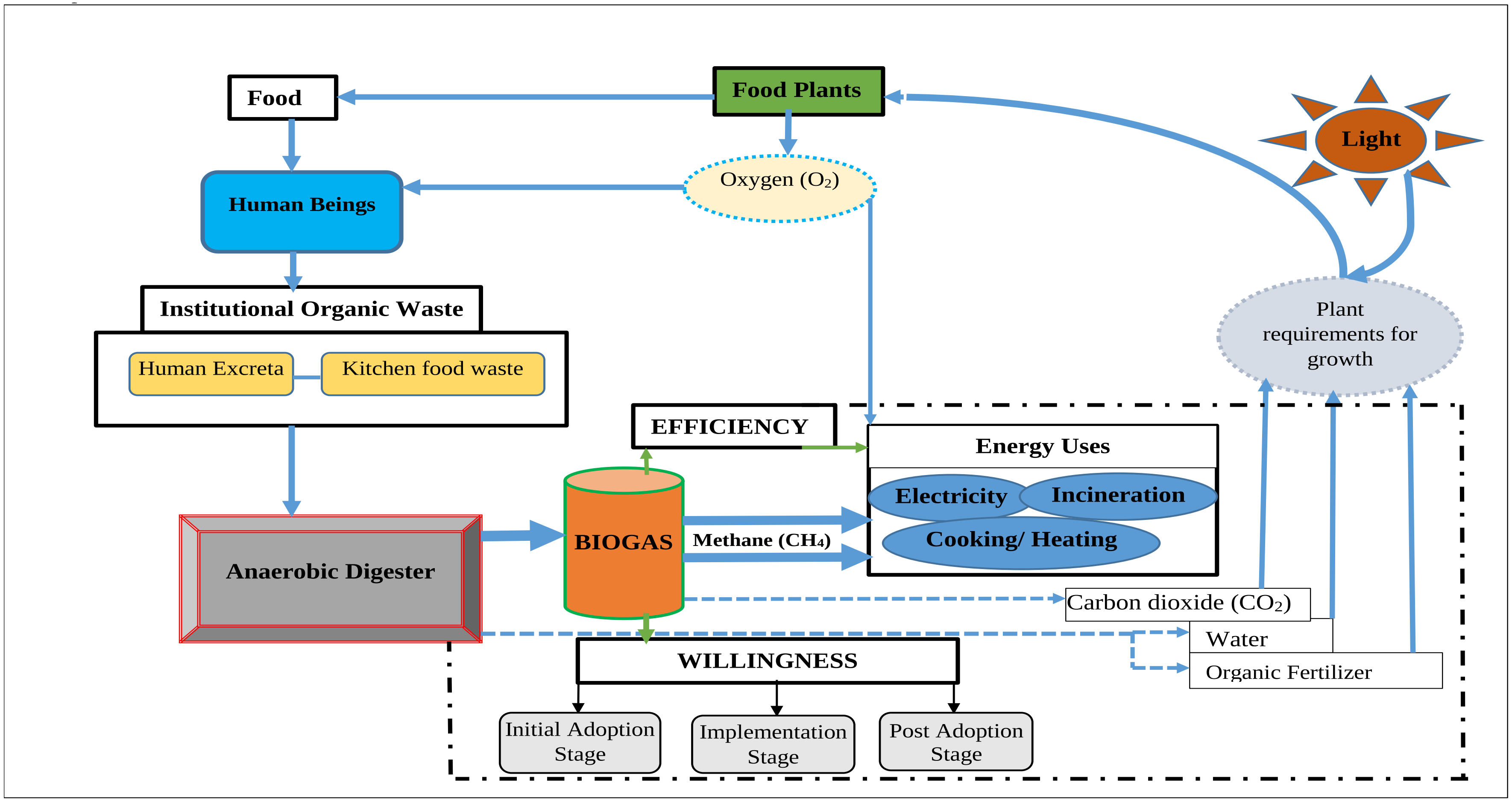


Figure 3.4: Conceptual Framework
Source: Author's Construct (2018)

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter contains two major aspects. Specifically, it comprises information about the study area and the methodology that was used to achieve the purpose of the study. In order to ensure that the research was carried out successfully, an outline of the essential information pertaining to the area of study and specify a well-defined route to identifying, collecting, analyzing and presenting information on various research variables were put in place.

In the subsequent paragraphs, the two major sections are outlined in greater depth. The first section contains well-outlined profile of Greater Accra with emphasis on second cycle educational facilities provided the basis for the selection of various institutions that were used for the study characteristics. The second section looks at methods of data collection and analysis of the data.

3.2 Profile of the Greater Accra Region of Ghana

3.2.1 The Study Area

The Greater Accra Region was established by Law as a separate region to include the local council of the Ada traditional area (PNDCL 26). The region was one of the sixteen (16) administrative regions of Ghana (www.ghana.gov.gh, 2019). It is bordered to the east, west, north and south by Volta, Central and Eastern Regions and the Gulf of Guinea respectively. It has land size of approximately 3,245 km^2 (1.4%) of the total land mass of Ghana. It’s the second most populous region of the country after the Ashanti Region, accounting for 4,010,054 (16.3%) of the total population. Also, it is the most urbanized region of the country, with 87.4% of the population living in urban centres (Ghana Statistical Service (GSS) (2013) and www.ghana.gov.gh)

3.2.2 Relief and Drainage

The Greater Accra Region stretches over 8 to 16 kilometres inland, broad at the east-west but narrows towards Weija and beyond. The Region has three unique physical features. The south-eastern side is generally flat with few isolated hills like Osudoku, Krobo, and Ningo hills. The general elevation of this part of the region is usually not more than 75 metres above sea level with exception the isolated hills. The second feature is the coastline which stretches approximately 225 kilometres and can be subdivided into eastern and western sections. The eastern section extends from west of Kokrobite all through to the east of Ada (Kwamena & Benneh, 1988). The western side which is the last feature is usually undulating, with some areas having steep hills rising from the plain.

The Region can be said to be well drained with series of both large rivers and streams with some of the streams drying up within the shortest period of dryness. Some large rivers worth mentioning are the Volta, Densu and Odaw Rivers (with the Odaw river currently turned into the largest drain in Accra). All the rivers empty into the Gulf of Guinea (Kwamena & Benneh, 1988). Also, there are other small but seasonal rivers that takes their source from the Akwapim Ridge and enter into the sea through several lagoons dotted along the Gulf of Guinea. Notable lagoons and wetlands in the Region are; Korle–Lagoon in the Accra Metropolis, Chemu, Gao and Gyankai lagoons in the Tema Metropolis (these legoons in the metropolis are heavily polluted with sewage) and Songor lagoon-which is relatively not polluted-in Ada in the Dangbe East. Subsistence farming is predominant in the Dangme and Ga Districts. In terms of mineral deposits, the region can boast of salt, clay, and granite

3.2.3 Climate and Vegetation

The climate of Greater Accra Region is the dry equatorial type. The Region has an interesting rainfall characteristic which is quite unique and different from other Regions. The Region lies within the equatorial rainfall regime but receives a mean annual rainfall of about 720mm around the coast to about 1,140mm in the northern section of the region. The region experiences two rainfall maxima with the first peak coinciding with the month of June and the second peak with the month of October (Kwamena & Benneh, 1988). April to July marks the major raining season for farming. The mean monthly temperature of the region is 26.7^{0}C and temperature ranges between 20 – 35^{0}C. The relative humidity ranges between 50-80% (Kwamena & Benneh, 1988). The winds blow predominantly in a south-westerly direction with an average speed of $3ms^{-1}$ throughout the year (GSS, 2010).

There are three broad vegetation zones in the Accra area, which comprise shrub, grassland, and coastal savannah.

3.2.4 Political and Administrative Structure

The region's administrative structure can be grouped into two diverse but complementary in terms of her political and traditional structures. Traditional administration is done through local governance (chiefs) network. Their administrative role is limited to traditional matters like customs and stool land administration. The political administration is through the local government system. Its power is derived from the 1992 Constitution of Ghana and the Local Government Act of 1993 (Act 462) (GSS, 2010). The region has 16 districts as shown in Figure 3.4 and each is headed by a Chief Executive. The Chief Executive is assisted in running the district by presiding member who is elected from among the assemblies' members from the various communities (GSS, 2010). However, the coordination and monitoring of the Assemblies activities is carried out by the Regional Coordinating Council (RCC).

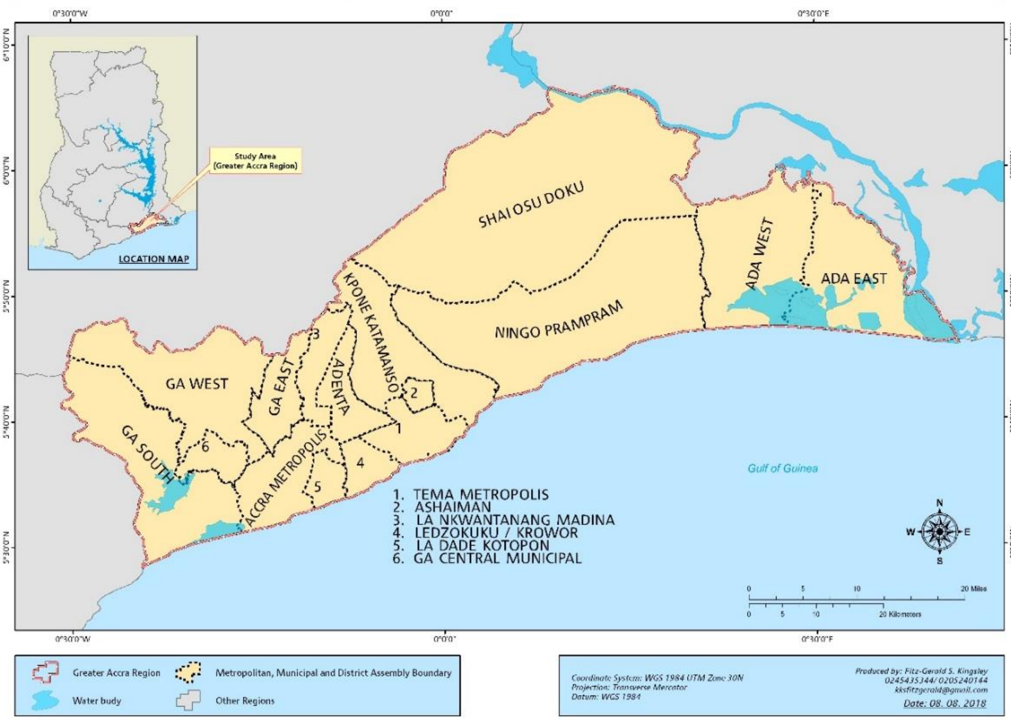


Figure 3.4: Administrative Districts within Greater Accra

Source: www.ghanadistricts.com and Credited to Kingsle

3.2.5 Economy and Living Conditions

There are two occupational patterns common in this area: sales and general work who are generally self-employed. In some of the Districts peri-urban agriculture, mainly animal husbandry, fishing hunting are engaged by the population. The next most important category of economic activities is that of sales workers.

3.2.6 Population and Settlement

The Region is one of the most populous after the Ashanti region with a total population of 4,010,054 (1,938,225 males and 2,071,829 females) as indicated by the 2010 Population and Housing Census. The highest population here is due high population influx from rural areas of Ghana to the urban centre couple with high fertility rate (GSS, 2013).

3.3 Methods of Data Collection

3.3.1 Research Design

A research design conceptualized the structure for operationalization of a study (Kothari, 2004). The choice of a particular research design depends on the philosophical assumptions and the type of information required for achieving the objectives of the study (Bhattacherjee, 2012). Also, in the view of Yin (1984), one of the major determinants that give direction on the type of research design to adopt depended on the questions of the study. Schell (1992) added that, questions of who, what, where, how many and how much relate to surveys (quantitative) whiles questions of why and how relates to case studies (qualitative). The combination of such questions (as in the case of this study) suggest a design that blends both qualitative and quantitative approaches. This influenced the choice of a mixed method.

A mixed method design, as noted by Creswell (2009); Creswell *et al.*, (2011); and Fetters *et al.*, (2013) provides an approach to addressing contemporary issues since it maximizes the strengths of both qualitative and quantitative designs in a single study. In the context of the above, the researcher adopted a mixed design in order to provide a strong basis for triangulation and careful generalization of findings for cost efficiency and the willingness to adopt biogas by various institutions in Ghana. Notwithstanding, the strength of the design, its adoption presents challenges relating to its complex design, time consumption and the potential of generating large volumes of data sets.

3.3.2 Data and Source

Various forms of qualitative and quantitative primary data methods were used to gather from the units of enquiry identified. Primary data obtained from the various units of enquiry were complemented with secondary data that was obtained from various institutions, journals and desk stop studies.

3.3.3 Sample and Sampling Procedure

Onwuegbuzie and Collins (2007), and Collins *et al.*, (2006) argue that the sampling procedure adopted in a mixed research design informs the quality of inferences or generalizations that can be valid. As such, they suggest that to arrive at a midpoint between the qualitative-quantitative paradigms of sampling, there was the need to consider the timing of the study (concurrent or sequential) and the relationship among samples (parallel, multilevel, identical or nested) in choosing a particular procedure.

The use of probability and non-probability sampling techniques at different points within the study, the *concurrent sampling procedure* as proposed by Teddlie and Yu (2007) appears an appropriate strategy to arrive at midway between the dominant qualitative (QUAL.) and supportive quantitative (QUANT.) study and therefore the choice of concurrent sampling procedure. The adoption of this sampling procedure also made it possible for the researcher to adopt both open and close-ended questions among either probability or non-probability sampling units (Teddlie & Yu, 2007).

The research also adopted a two-stage multisampling technique by employing convenience sampling and probabilistic sampling. The convenience sampling was used to segregate boarding schools from non-boarding schools. This also afforded the study the opportunity to cluster the schools into four main districts: Accra Metropolitan Assembly, Ga District, Dangbe District and Tema Metropolitan

Assembly of the Greater Accra Region. A sample fraction was then determined from each District to know the number of boarding schools that qualified for the simple random sampling. Names of schools were written on pieces of paper, folded and put in a bowl. Four people were asked to pick the schools until the total numbers of schools per cluster were selected. Each picking was accompanied with shaking of the bowl before another picking was done.

Inclusive and exclusive Criteria

Inclusive and exclusive criteria were used in order to have a defining criterion of the population under study. For an SHS to qualify to be sampled, the school must have boarding or hostel facilities. This was to ensure feedstock availability (one of key ingredient) for the anaerobic digester and usability of the gas generated if the biogas plant were to be built.

Inclusive criteria were used to select those SHSs that met the defining criterion for the sampling procedure. The essence of this was to ensure constant and regular feedstock as input for the biogas plant. The probability of each student in the boarding school or hostel facility using the washroom at least once to defecate and urinate within a day was higher than a student in the non-boarding school. Also, food waste from the kitchen, dining hall and other food residues was an additional feedstock for the biogas plant.

Exclusive criteria were used to delineate schools that did not meet the defining criterion for the sampling procedures. Schools without boarding or hostel facilities were excluded. This was due to the unlikelihood to produce constant and regular feedstock for the biogas plant. The possibility of some students not using the washroom on the school compound was high especially if the washrooms are not hygienic, could affect feedstock availability. Supplementary feedstock from kitchen waste and food residues will be minimal as input for the biogas plants.

Per the list of SHSs in the Greater Accra Region from the Regional Director Office's of the Ghana Education Service, the Region had eighty-four (84) schools. Based on inclusion and exclusion criteria, forty-nine (49) schools met the defining criteria. Out of the 49 schools, four (4) has biogas plants while forty-five (45) of them are non-users of biogas plants. Probability sampling was done on the 45 schools while non-probability sampling was done on four schools as described in the ensuing paragraphs.

The probability sampling procedure was used to select a representative number of schools without biogas plants within the region. The willingness to adopt biogas was assessed among this category of institutions. The selection of schools to participate in the study was based on clusters as per the boundaries of Metropolitan, Municipal and District Assemblies (MMDA's). After clustering all schools without biogas, a proportional number was selected from each district cluster using a simple random sampling technique.

From the preliminary survey, it was revealed that Greater Accra in 2016 had 45 boarding Senior High Schools without biogas plants. Thus, all such schools were considered eligible for the study since they were boarding in nature. In calculating a representative number of schools that could participate in the study, a statistical Slovin's formula was adopted. The Slovin's formula is used when the researcher does not know the population. This is confirmed by Ryan (2013) when he pointed out that "when there is ignorance of population, use the Slovin's formula". More so, the Slovin's formula is good for non-parametric test or distribution free test and the data is not a normal distribution one. Also, it used to undertake a specific study. Like any other statistical formula, Ryan (2013) identified the weaknesses of this formula to include; no variability of the population being measured and no indication of the margin of error. However, considering the fact the research uses non-parametric statistical test (1 Sample T-test, Kendall Coefficiency), the number of schools without boarding/hostel facilities were unknown, the small sample size, and the fact that the study was specifically on cost efficiency and willingness to adopt biogas technology, the Slovin's formula was the best choice for this work. The calculations and proportional distributions of the sample according to district cluster of schools are shown below:

$$n = \frac{N}{1 + N(e)^2} \quad (1)$$

Where 'n' is sample size

N is total target population

e is the margin of error

N=45, e=0.05

$$n = \frac{45}{1 + 45(0.05)^2} \quad (2)$$

n=40

$$SF = \frac{n}{N} \quad (3)$$

Where SF is sample fraction

n is sample size

N is the target population

n= 40

N=45

$$SF = \frac{40}{45} \quad (4)$$

SF=0.889

The result of a sample size of 40 schools was obtained. From the sample frame, a sample fraction (40/45) of 0.889 was determined and used to calculate (sample fraction*sample frame in district) the proportion of the sample that could be picked from each district. The distributions of the sample size per the cluster of districts are shown in Table 3.1. Finally, the qualified schools for the study were selected through simple random sampling. This allowed each school within a cluster in a district an equal chance of being selected in the sample.

Table 3.1: Sample Distribution

Cluster of Districts in Greater Accra	Number of SHS boarding schools per each cluster	Sample size per each cluster
Accra Metropolitan	15	(13.335) ≈13
Dangme East and West	8	(7.112) ≈7
Tema Metropolitan	2	(1.778) ≈2
Ga East and West	20	(17.78) ≈18
Total	**45**	**40**

Source: Author’s construct (2018).

The **non-probability sampling**, on the other hand, was mainly based on purpose. Prior to the commencement of data collection, a chain approach to sampling revealed that four schools in Greater Accra (as shown in Figure 3.5) have biogas plants installed. The interest of the study in acquiring in-depth information about the functionality of these biogas plants, therefore, served as the basic criteria for the purposive sampling of these schools.

Also, the purposive approach was used to choose qualified participants in the study and this was applied to decide on the inclusion of various stakeholders considered key to biogas plant installations. These key stakeholders identified were; the Biogas Installers, Ghana Energy Commission, Ministry of Energy, Industrial Research Unit of the Centre for Scientific and Industrial Research (CSIR) and the Environmental Protection Agency. These stakeholders were purposively selected to be included because they are regarded as experts and key informants. Thus, they are knowledgeable on issues relating to biogas installation, plant design, usage, renewable energy, maintenance and environmental impacts. Table 3.4 summarizes the various institutions that were purposively selected in the study.

Table 3.2: Institutions for Purposive Data Collection

1. Biogas Plant Users			
Name of Institution	**Position of Key Informant**	**Year of Biogas Installation**	**Role of Key Informant to Biogas Plant**
Biogas User SHS			
Ghana Christian High International School (GCHIS)	General Administrator	2007	• In charge of all administrative work of the school • A pioneer and instrumental in the installation of the Biogas plants • Take charge of minor repairs on the biogas plant and liaised with the installers for major repairs
SOS Gmeiner Herman International College (SOS)	Domestic Bursar	2008	• Supervisor over the kitchen staff and students in their dormitories • Conducts daily check-ups on the biogas plant • Liaises with maintenance officer to work on minor repairs and major repair works with the biogas plant installer
Tema International	Administrator	2008	• In charge of all

School (TIS)			administrative work of the school • Liaises with maintenance officer to work on minor repairs and major repair works with the biogas plant installer
St. John Grammar School (JOHN)	Senior House Master	2014	• Liaises with housemasters and mistresses to ensure disciplined among student during classes and after classes • Contact person when the biogas plant was under construction • The school nominee for the biogas project
	2. Biogas Plant Installers		
Name of Institution	Year of Company Establishment	Position of Key Informant	Roles Key Informant
Biogas Engineering Ltd**	2002 and Registered in 2005		• Consultant to the Energy Sector at Kwame Nkrumah University of Science & Technology (KNUST) • Retired Lecturer at Engineering Department at KNUST • Over 20 years' experienced in installing biogas (Anaerobic Baffled Reactor for Wastewater treatment and Anaerobic Digesters) • Trainer in biogas plant installation at KNUST Engineering Department • Founder of the Company
Beta Construction Engineering (BCE)**	2006	CEO	• Currently the only installer of Puxin digester types in Ghana • Over 15 years' experience

			of installing Puxin digesters in Ghana and Nigeria
Biogas Technology Africa Ltd (BTAL)**	2000	Chief Executive Officer (CEO)	• Installs fixed dome digester throughout Africa. Installed more than 200 plants • Founder and Engineer in charge of designing and executing contracts on biogas • Manufactures accessories of biogas plants
SPB Biogas Company Ltd (SPB)**	2012	SBP Biogas Company Ghana	• Civil engineered who installs Fixed Dome and Flexible Biogas Plants • Installs biogas plants throughout Africa • Designs and manufacture biogas accessories for his clients and plants • Produces bio-charcoal and bio-fertilizer in small-scale basis • Organises and train people on biogas installation • Installed over hundred (100) biogas plants
Impact Environmental SCS Ghana Ltd (SCS)	2008 2009	Managing Partner CEO	• The only female biogas installer. The CEO of SCS Ghana Ltd and Managing Partner of Impact Environmental Company based in Kumasi and Accra • Specializes in the installation of Fixed Dome • Installed over 500 biogas plants for institutions, communities and private homes
3. Regulatory Institutions			
Energy Commission of Ghana (EC)	• Principal Programme Officer (PPO) in Charge of Renewables in the area of Biomass Energy		

Environmental Protection Agency (EPA)*	• Director of Compliance & Enforcement, and Cleaner Production Unit at EPA • Senior Programme Officer (SPO) at the Ghana National Cleaner Programme in charge of promoting Biogas Technology in Ghana
Centre for Scientific and Industrial Research (CSIR)**-Institutes of Industrial Research	• Senior Research Scientist and Head of Metrology and Calibration • Senior Research Scientist in Charge of Design and Deployment of Biogas Technology • The Institute research into cost efficient biogas technology, install biogas plants and train installers as well
Ministry of Energy (MoE)	• Director Renewables at the Ministry of Energy
Safi Sana Ghana Ltd (SAFISANA)	• Country Director of a Commercial Biogas Plant that is generating 2MW electricity that is fed into the National Grid • Have been in charge of the plant for more than five (5) years

NB: **Install and train installers of biogas *Train installers

Figure 3.5 depicts the number of actual schools that were sampled and studied for this work and their geographical location in the Greater Accra Region. Those highlighted "red" are biogas user schools for which non-probability purposive sampling was conducted. The remaining schools are non-users of biogas that were simply randomly sampled.

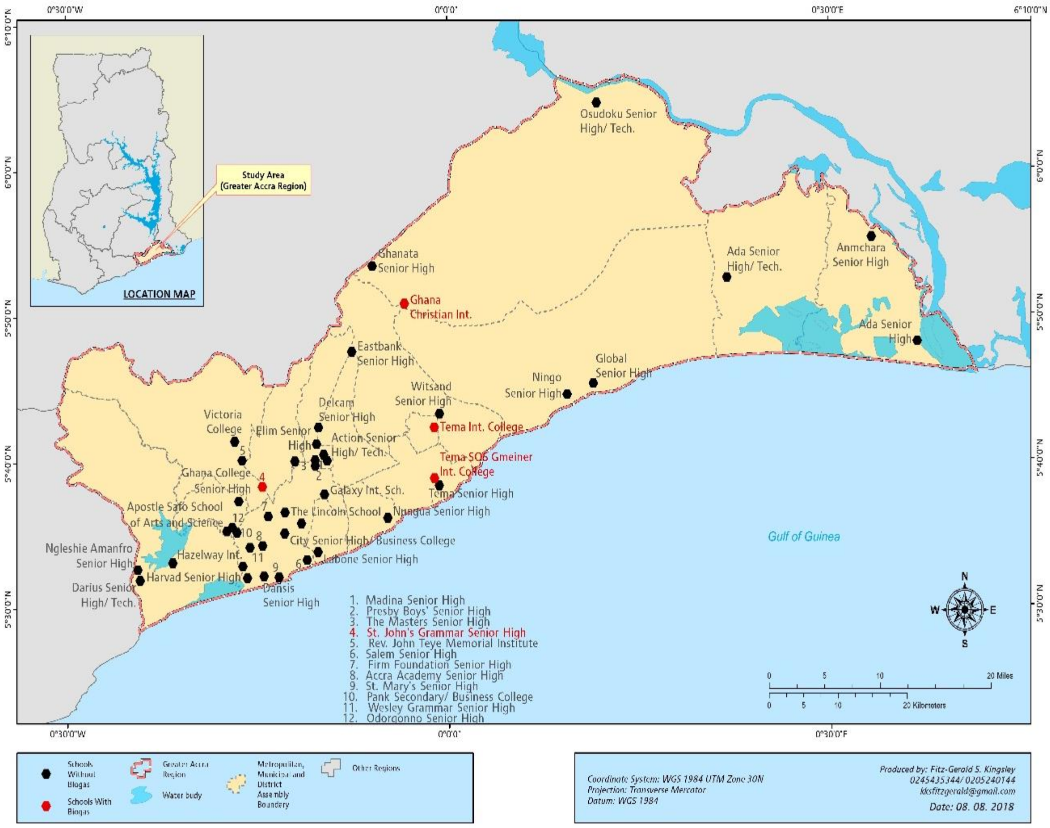


Figure 3.5: Spatial Distribution of Sampled Schools   Credited to Kingsle

3.3.4 Target Population

In order to effectively apply the concurrent mixed method for the achievement of the study objectives, there was the need to identify and define the target population. According to Bhattacherjee (2012), the target population in research referred to a person, a group, or object targeted for an investigation. They could be individuals, groups, organisations or objects about which information is needed to achieve or address the research objectives.

The main targeted set of the population for the study was all SHS in Greater Accra that have boarding or hostel facilities. Within each boarding school, an individual (s) with in-depth knowledge was targeted for the needed data. Thus, within each institution that has adopted biogas technology as a source of sustainable energy, specific individuals that deal with the usage and routine maintenance of the biogas plant or the individual-in-charge of operating the biogas plant were considered for data collection. On the other hand, within schools that have not adopted biogas technology; the Headmasters/Headmistresses or the Assistant Headmasters/Headmistresses or Senior Housemasters/Housemistresses of the school were required as a target for the collected data. These targeted group were selected based on the fact that they have the final authorisation in the daily running of schools.

The second targeted group of the population were installers of biogas. The targeted individual should be the head of the company/institution's or his immediate sub-ordinate as a target for data. They are required to provide technical information regarding the installation of biogas plants within the various schools.

Apart from the installers, the Regulatory and Research Institutions like Environmental Protection Agency, Energy Commission, Centre for Scientific and Industrial Research were also targeted. These are legally mandated with the right to assess all such projects that have likely environmental effects, install of new energy technologies, designing and disseminating scientific research on technology respectively. The respondents were required to provide data that border on the specific regulatory framework and research in relation to biogas in the specific mandates.

3.3.5 Research Instrument

In order to gather information required from the various sample units, there was the need for strategies that outline the specific tools for eliciting data. Due to the concurrent mixed nature of the research and its attendant adoption of both probability and non-probability approaches to sampling, various methods for data collection were required to adequately serve the needs of both qualitative and quantitative research.

In gathering data from various schools that participated in the probability sampling technique, the questionnaires were used to elicit responses. Closed and open-ended questionnaires were used to gather data. Basically, the questionnaires addressed issues relating to willingness of SHS to adopt biogas plant and the source of funding for the installation of the technology in their respective schools. It also identified the various energy sources and expenditure patterns on energy and waste streams management in the various schools that participated in the study. The questionnaires were hand-delivered to the schools and picked up after one week. In order to minimize non-response rate-a common weakness of this technique-a constant follow-up with phone calls and text messages was done. Coordinates of the schools were picked using Garmin GPS for a map to be constructed (see fig 3.5)

Also, the study used interviews as a method of eliciting information from respondents that were purposively selected for data. The interviews involved basically key informants within SHS who used biogas or have installed biogas plants, installers of biogas and regulatory/research institution. A face-to-face interview approached was used. The interviews were conducted and audio recorded with the permission of the respondent through the use of an interview guide which contained a list of questions on various themes of interest to the study. The recorded responses were transcribed and coded into various themes for analysis. Much of the data that was gathered via this instrument (interview guide) was qualitative in nature. However, some aspects involved numeric data since they form part of the process of assessing cost efficiency and willingness to adopt biogas.

Another method of gathering data was the use of observation. This method involved data gathering through a visual approach. Thus, it involved a non-participant observation where the researcher participated in the process and described what was observed. The observation used all aspects of data collection especially among participating Senior High Schools. Data from observation was recorded as field notes for analysis.

The use of observation was advantageous because it allowed the researcher to visually assess the state of biogas plants which otherwise could not be adequately described by respondents.

3.4 Methods of Data Analysis

Data analysis implies adopting a technique appropriate to interpret facts gathered in order to meet research objectives. The dualistic nature of data that was gathered from the use of both qualitative and quantitative data collection techniques required a well-defined plan of analysing, presenting and interpreting the data to meet the objectives of the research. Data analysis primarily sought to make meaning out of the information gathered from the field. According to Fetters *et al.*, (2013); and Creswell *et al.*, (2011) the adoption of the mixed method requires understanding the basic aim of the study which suggests integration either through merging, connecting or embedding data sets. Within this study, the various approaches that were adopted to analyse data in each case are as follows:

3.4.1 Objective One: To determine the extent to which biogas usage is convenient as a sustainable source of renewable energy for SHSs in the Greater Accra Region

This was analysed qualitatively by looking at the key variables below. Information from literature, users, installers, regulatory institutions and commercial biogas operator in Ghana was used to analyse.

- Benefits
- Risks

- Initial Investment Cost
- Maintenance Cost of Operation

3.4.2 Objective Two: To assess the cost efficiency of biogas as a sustainable source of renewable energy for SHSs in the Greater Accra Region

The one sample t-test was used in assessing the cost efficiency of biogas technology as a sustainable form of renewable energy. The one-sample t-test compares the mean score of a sampled to a known value, usually, the population mean (the average for the outcome of some population of interest). The basic idea of the test is a comparison of the average of the sampled (observed average) and the population (expected average), with an adjustment for the number of cases in the sample and the standard deviation of the average. The cost of installing biogas plant by CSIR (Industrial Research Unit) was compared with the cost of biogas plant installation by other private installers in order to determine the cost efficiency. CSIR was chosen because it is the state institution charged with responsibilities for developing technologies that are cost efficient and adaptable to the Ghanaian environment. Also, they are mandated in collaboration with the Ghana Standard Authority to have a standardised design for technologies that are deployed in Ghana.

The statistical model for one-sample t-test is:

$$X_i = \mu + \varepsilon_i \qquad with\ \varepsilon_i \sim \mathrm{N}\,(0, \sigma^2) \qquad (1)$$

The statistical model is equivalent to assume that $X_1, \ldots, X_n$ is a random sample from N (μ, σ^2).

The sample mean is denoted by $\bar{X}$.

The sample variance is denoted by

$$S^2 = \sum_{i=1}^{n}(X_i - \bar{X})^2/(n-1) \quad (2)$$

Under the normality assumption,

$$\frac{(n-1)S^2}{\sigma^2} \sim X_{n-1}^2 \quad (3)$$

Then under H_o,

$$\frac{\bar{X}-\mu_0}{\sqrt{\sigma^2/n}} \sim \text{N}\,(0,1) \quad (4)$$

Since $\bar{X}$ and S^2 are independent the H_0 becomes

$$\frac{\bar{X}-\mu_0}{\sqrt{S^2/n}} \sim t_{n-1} \quad (5)$$

In this study, the population mean was the cost of installing the biogas plant given by the CSIR. The CSIR gave the cost of installing a biogas plant to be GHS 8,000 as per interview. The sample mean is the mean cost of installing the biogas plants from the four schools sampled who have already installed the biogas plant.

Hypothesis

H_o: the costs of installation of biogas by the schools is equal to the cost of installation by CSIR

H_a: the costs of installation of biogas by the schools is not equal to the cost of installation by CSIR

Where:

H_o is the null hypothesis and

H_a is the alternate hypothesis.

Decision rule: The null hypothesis is rejected if the calculated *t* – value is greater than the tabulated *t* – value. Rejection of the null hypothesis implies that the costs of installation of biogas by the schools are not equal to the cost of installation by CSIR

3.4.3 Objective Three: 3. To determine the factors that influence willingness to adopt biogas technology as a sustainable source of renewable energy for SHS in the Greater Accra Region

The logistic regression model was used to analyse objective three because the dependent variable was dichotomous. Logistic regression is used when the dependent variable is a dichotomy and the independent variables are of any type of variable. It applies maximum likelihood estimation after transforming the dependent into a logit variable and estimates the odds of a certain event occurring (Garson, 2008). The dependent variable is a logit, which is the natural log of the odds, that is:

$$ln\left(\frac{P}{1-P}\right) = a + bx \qquad (6)$$

$$P = \frac{e^{a}+bx}{1+e^{a}+bx} \qquad (7)$$

Where *P* is the probability of the event occurring, *X* are the independent variables, *e* is the base of the natural logarithm and, *a* and *b* are the parameters to be estimated by the model.

The empirical form of the model:

$$PrY = \frac{1}{1+ e^{-(a+bx)}} \qquad (8)$$

Where Y is the logit of the dependent variable

The logistic prediction equation:

Y= In (odds (event)) = In (prob (events)/prob (non-event))

=In (prob (event)/1-prob (event)

$$=b_a + b_1x_1 + b_2x_2 + \cdots + b_nx_n \quad (9)$$

Where *b* a is constant term, X_1, X_2...........X_n are independent variables likely to affect the probability of adopting biogas technology and b_1, b_2......b_n are the coefficient to be estimated. The dependent variable Y= adoption of biogas technology =P(Y) = (1 if the school choose to adopt and 0 if the school choose not to adopt)

Following Ngo *et al.*, (2008) the logit model is specified as:

$$(P) = [Pi/1-Pi] \quad (10)$$

$$Let\ Pi = Pr\ (Y=1/X=xi) \quad (11)$$

$$[Pi/-Pi] = logit\ (Pi=\beta o+ \beta_1X_1+\beta_2X_2+ \beta_3X_3+ \beta_4X_4+ \beta_5X_5+ \beta_6X_6+ \beta_7X_7+\mu) \quad (12)$$

Where:

βo is the intercept and

μ is the error term.

Pi = probability of willingness to pay, that socio-economic background of the respondents can influence the willingness to adopt biogas technology. *(1-Pi)* = probability that socio-economic factors will not influence willingness to pay.

The seven independent variables used for the model include student population, source of finance, lack of subsidy, knowledge of biogas technology, cost of dislodgement, cost of other energy sources and environmental concerns.

X_1= Student population: schools with more student are inclined more to adopt biogas technology than schools with low student population.

X_2= Source of finance: schools with the ability to finance themselves are more willing to adopt biogas technology than schools who do not have the ability to finance themselves.

X_3=Lack of subsidy: the lack of subsidy will prevent schools from adopting the biogas technology.

X_4= Knowledge of biogas technology: schools which have knowledge of the biogas technology are more likely to adopt than schools which do not have any knowledge

X_5= Cost of dislodgement: the higher the cost of dislodgement, the more likely a school will be willing to adopt biogas technology

X_6= Cost of other energy source: the higher the cost of other sources of energy, the more likely a school will be willing to adopt biogas technology

X_7= Environmental concerns: a school which is more environmentally conscious will be more likely to adopt biogas technology than a school which is not.

3.4.4 Objective Four: To identify and rank the constraints militating against the adoption of biogas utilization

The Kendall's Coefficient of Concordance test was used to rank the constraints facing the various institutions. The Kendall's Coefficient of Concordance is a non-parametric statistical procedure which was used to categorise a set of constraints or challenges, usually from the most to the least influential and also measured the degree of agreement or concordance between respondents. The identified challenges were then ranked from the most to the least influential using numbers, 1, 2, 3 ... n, in that order where n was a positive integer. The overall rank score for each challenge was computed and the challenge with the lowest score was ranked as the most pressing one. On the hand, the constraint with the highest score was ranked as less pressing one. The total rank of scores were computed using the Kendall's Coefficient of Concordance (W) to determine the degree of agreement among respondents in the ranking. The formula for the Kendall's coefficient of concordance was given as:

$$W=\frac{12[\sum T^2-\frac{(\sum T^2)}{n}]}{nm^2(n^2-1)} \qquad (13)$$

Where;

W = Kendall's Coefficient of Concordance

T = Sum of ranks for constraints being ranked

m = Total number of respondents

n = Total number of constraints being ranked.

W ranges from 0 to 1, where 0 implies perfect disagreement and 1 implies perfect agreement. The Coefficient of Concordance (*W*) was to test for significance in terms of the *F* – distribution factor was done. The ratio *F* –was given as $F = [(m - 1) * W/(1 - W)]$, with the numerator and the denominator degrees of freedom of $(n – 1) - (2/m)$ and $m – 1[(n - 1) - 2/m]$ respectively (Edwards, 1964).

Test of hypothesis

The hypothesis tested was:

H_o: Respondents disagree on the ranking of constraints faced in the biogas utilization sector

H_a: Respondents agree on the ranking on the constraints faced in biogas utilization sector

Decision rule: Rejected the null hypothesis if the calculated *F* – value is more (greater) than the tabulated *F* – value. The null hypothesis rejection implies that respondents agree with each other on the ranking of the challenges faced in biogas utilization sector.

3.5 Limitation of the Study

Resources constraint, access and locating some schools with boarding facilities in the Greater Accra Region was a big challenge to the researcher. This limitation was however addressed with the aid of Google Locational Maps to identify the geographical locations of some schools. Some schools have also relocated from where they were occupying and nobody seems to know their new location. In this, the researcher adopted a search and find approach.

The sampling technique and the method of data collection under this research ensured the correct data and information on SHS energy sources and their willingness to adopt biogas plants were taken. However, the researcher's inability to measure and ascertained the calorific value of biogas in order to determine the expected efficiency of installed biogas plants posed a limitation to the research.

3.6 Ethical Issues

An introductory letter was obtained from the Centre for Climate Change and Sustainable Development, which was presented to the institutions participated in the study. This served as the first point of clearance for approval. After acceptance, concerned stakeholders were sufficiently briefed on the purpose of the research and the time needed to complete the interview guide/questionnaire. Based on the preference of the institution, a time was scheduled for data collection. Assurance of confidentiality was given to respondents with regards to the use of data collected from their institutions. As part of highly upheld ethics, authors of scholarly works which are used in this study are duly referenced.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents the empirical findings of the study and discusses these results in line with existing literature on the subject matter. In the first section, the characteristics of the sampled institutions selected for the study are discussed in view of their influence on biogas adoption. The next section presents and discusses results on the extent to which biogas usage is convenient for sampled institutions. Results and discussions in the third section focused on cost efficiency in the installation of biogas by private companies as compared to the cost of installation as public institutions. The last section presents result and discussions on the constraints that are encountered in the use of biogas by SHS.

4.2 Characteristics of sampled institutions

The characteristics of these institutions in terms of ownership and size are presented in Table 4.1 and discussed.

Table 4.1: Characteristics of the institutions

Characteristic/Grouping	**Frequency**	**Percentage (%)**
Ownership of School		
Public	17	39
Private	27	61
Number of students		
1-200	5	14.7
201-400	9	26.5
401-600	3	8.8
601-800	1	2.9
801-1000	3	8.8
1001-1200	2	5.9
1201-1400	0	0
1400+	11	32.4

Source: Survey Data, 2018

Population is a key determinant of the requirements for the production of biogas since it positively correlates with the potential input into the digesters (Bond & Templeton, 2011). The study revealed that the mean student population for all the schools that participated in the study was 1,045 people. Also, more than 80% of the entire student population sampled were boarders. An average of 128g/day of wet faecal matter is generated by each student (Rose *et al.*, 2015). This presents a high potential for the generation of biogas by all SHSs that were studied because Oranusi and Dahunsi (2013) found that only 3kg of excreta from 15 male students, mixed with 12kg of food waste and water to make could generate 30 litres of slurry and consequently 84,750cm^3 of gas with methane constituting 58% of the gas.

It was also realised that all schools that were involved in the study had central points for collection of both human and food waste. The nature of toilet facilities used in schools however differed. Majority of the public schools (about 70%) used KVIP's while majority of the private senior high schools visited (85%) used water closet system. On the other hand, two public schools were found with the two major systems water closets and KVIP. This implies that, every senior high school, especially within the cities of Ghana, has a collection point for students' faecal matter which can be used to generate biogas energy. The difference however between these two systems for the generation of biogas is the suitability of the excreta for direct use in biogas digesters. While all faecal matter is approximated to be composed of 75% water (see Rose *et al*., 2015), the open pit system (due to evaporation) will require extra water to mix faecal content for use in the bio-digesters (Oranusi & Dahunsi, 2013).

The foregoing discussion of characteristics on the schools that were selected for the study indicates that, all schools have the required raw materials for the generation of biogas energy.

4.3 Energy Consumption and Knowledge of Biogas Usage

4.3.1 Energy types used in schools

Table 4.2 shows the different types of energy identified in the schools sampled for the study. All the schools sampled had at least more than one source of energy for use which could be attributed to the non-reliability associated with the use of only one energy source (Arthur *et al.*, 2011). Electricity was found to be the dominant source of energy constituting 35.2% while solar and biogas contributed the least to the energy-mix, (each contributing 3.5%). The low use of biogas and solar by SHSs confirms the finding of Asumadu-Sarkodie, *et al.*, (2016) and Brew-Hammond, (2009), that the bulk of Ghana's renewable energy potential remains undeveloped. The extensive dependence on electricity could be attributed to government policy on subsidising electricity and the opportunity to defer payment particularly for those that are not prepaid. All the schools that consumed electricity indicated that it was primarily utilised for lighting.

Table 4.2: Energy type used in schools

Energy type	**Frequency**	**Percentage**
Firewood	11	9.6
Charcoal	11	9.6
Solar energy	4	3.5
Electricity	40	35.2
LPG	30	26.3
Biogas	4	3.5
Diesel/Petrol for Gen. Set	14	12.3
Total	**114***	**100**

Source: Survey Data, 2018.

[1]* Frequency is more than sample size due to multiple responses.

None of the biogas user institutions indicated their use of biogas for lighting. As to why the biogas was not utilised for lighting, they indicated the high cost of infrastructure and the low amount of gas that is generated as the main reasons. The low gas output was so because the feedstock was mainly from faecal matter. This was confirmed by installers who lamented that though the schools had chances to increase gas yields through food waste, they are not doing that. The schools indicated using the food waste to feed pigs owned by the schools. This is however contrary to research findings that shows that more biogas is generated from multiple feedstock than from single feedstock (Pöschl, *et al.*, 2010).

4.3.2 Management of institutional waste

Table 4.3 shows the cost of disposal of the different types of waste generated by the SHSs sampled for the study per annum. Between GH₵ 400 and GH₵ 4,800 is spent on the disposal of kitchen waste. The wide variance between the cost of manging kitchen waste was attributed to the use of the kitchen waste as livestock feed by some of the schools. The cost of managing solid waste range from as low as GH₵ 480 to as high as GH₵ 21,520. The large variation between the minimum and maximum figures on solid waste disposal was due to incineration of the combustible fraction of the solid waste, leaving only the non-combustible component for disposal at a fee. The highest amount of money was spent on emptying septic tanks which ranges from GH₵ 600 as the lowest to GH₵ 52,000 as the highest. Interestingly, half of the highest amount could construct a large biodigester which could utilise both the “night soil” and kitchen waste as feedstock leaving only solid waste to be disposed off at a relatively smaller cost. Conservatively, using the average cost of managing both kitchen waste and night soil, a school could be making savings of about GH₵ 9,515, leaving the biogas, the slurry, etc as surplus. The biogas can be a source of energy for cooking, lighting and vehicles fuel. The slurry can be used for fish farming, crop production and as feed for livestock/pigs rearing. Beside improving sanitation in the schools, the digester also reduces foul odour, pathogens and flies; and deforestation (Berhe *et al.*, 2017; IRENA, 2017; Lam, 2010). In the words of Dr Aklaku "fire wood consuming institutions can be turned into tree growing institutions" if the slurry are allowed to around where trees are planted.

Table 4.3: Amount spent on management of institutional waste annually

	Average (GHS)	Minimum (GHS)	Maximum (GHS)
Kitchen waste	2185.71	400	4800
Solid waste	5065.83	480	21,520
Night soil (Septic tank)	7329.41	600	52,000

Source: Survey Data, 2018

4.3.3 Level of Awareness and Source of information on biogas technology

Table 4.4 shows the source of information on biogas technology by the SHSs sampled for the study. All the respondents indicated that they have heard of the biogas technology. Almost half of them (48.9%) heard of biogas technology from the media (TV/Radio/News Paper/Web Advert). However, less than 10% of respondent heard of biogas technology from an installer, indicating that installers are not promoting the technology adequately to potential users. Also, less than 20% (15.6%) of respondents heard of the technology from government/NGOs, which indicates that even government is not promoting and supporting the technology enough for adoption and perhaps should be engaged more by researchers like the CSIR to promote the merits of the technology. Surprisingly, just over ten percent (13.3%) heard of the technology from researchers/academia which corroborate the earlier remarked that researchers are not adequately engaging the critical stakeholders to promote the technology for adoption. Since the technology is not widely adopted among institutions, it is only normal that just over ten percent respondents (13.3) heard of the technology from their neighbours. Policy makers can therefore leverage on the high level of awareness and promote the benefits of the technology.

If promoting the use of biogas among public institutions would be improved, it is important that government and NGO's play a central role as in the case of some African countries like Kenya, Tanzania, Burkina Faso and Rwanda where biogas is being promoted nationally with donor support (Roopnarain & Adeleke, 2015; Abbasi *et al.*, 2012; Barry *et al.*, 2011)

Table 4.4: Level of Awareness and Source of information on biogas technology

Information source	**Frequency**	**Percentage (%)**
Government/NGO	7	15.6
TVs/Radio/Newspapers/Web Advert	22	48.9
Friend/neighbour	6	13.3
Researcher/Academia	6	13.3
An installer	4	8.9
Total	**45***	**100**

Source: Survey Data, 2018

*Frequency of responses is more than sample size due to multiple responses

4.3.4 Possible reasons for the adoption of biogas technology

Respondents were asked to comment on the possible reasons which could influence their decisions to install a biodigester. Table 4.5 summaries the possible reasons why they might adopt biogas technology. Cooking was found to be the foremost reason (21.8%) why most non-users would adopt biogas technology. Followed by lightening with 18.4%. Organic fertilizer for farming was found to be the most unpopular reason why non-users would adopt biogas system. Even though sanitation appears to be a major problem nationwide in most institution (Agyepong, 2018), it did not appear that important on the list of reasons why non-users would install a biogas technology. This is contrary to the testimonies of biogas using institutions who indicated improved sanitation and hygiene as the primary reason why they have installed biogas technology. This was confirmed by the installers when they said many people demand for biogas plants but when the cost of dislodging burden is removed, they forget the energy part of biogas. The study revealed that even among the users the initial reason for installing biogas plants was usually not sanitation but with time sanitation becomes the main reason for maintaining the technology, especially due to cost savings from dislodging septic tanks. LPG and Fuel wood ranked third among the reasons why non-user would like to adopt the biogas technology.

Table 4.5: Possible reasons for adoption of biogas technology

Reasons	**Frequency**	**Percentage**
Cooking	26	21.8
Lighting	22	18.4
Improved hygiene and sanitation	17	14.3
Environmental Protection	12	10.1
Organic fertilizer for farming	9	7.5
Save cost on LPG/Wood fuel	19	16.2
Recycle water for watering/flashing of toilets	14	11.7
Total	**119***	**100**

Source: Survey Data, 2018
*Frequency of responses is greater than sample size due to multiple responses.

4.4 Cost-Efficiency in Biogas Plants of public compared to private installers

The cost-efficiency in the adoption of biogas should be based on a profitability criterion. Thus, the economic, environmental and social gains that individual households/institutions stand to gain in converting waste to biogas instead of treatment/dislodgement of waste (Feiz & Ammenberg, 2017). Data from biogas user institutions indicate that the average amount that was spent on installing the plant is GHS 5,050.00. This served as the standard average cost of installing biogas plant among sampled institutions.

The installers of biogas plants that were interviewed indicated that, installing the plant was dependent on many factors and as such difficult to indicate an average price. However, the CSIR provided an average price for the installation of institutional biogas plant as GHS 8,000.

Table 4.6: Cost efficiency Analysis of Public Compared to Private Biogas Installers

One-Sample Statistics				
	n	**Mean**	**Std. Deviation**	**Std. Error Mean**
Cost	4	5050.0000	404.14519	202.07259

One-Sample Test						
	Test Value = 8000					
	t	**df**	**Sig. (2-tailed)**	**Mean Difference**	**95% Confidence Interval of the Difference**	
					Lower	Upper
Cost	-14.599	3	.001	-2950.00000	-3593.0852	-2306.9148

Source: Survey Data, 2018

4.5 Factors Influencing the Adoption of Biogas among Secondary Schools

4.5.1 Willingness to adopt biogas technology

Table 4.7 shows the willingness to adopt and pay for biogas plants installation in SHSs sampled for the study. Almost 90% (88.2%) of the SHSs are willing to adopt biogas technology as alternative source of energy. This shows that biogas is regarded as an alternative source of energy. Achinas *et al.,* (2017) confirmed that anaerobic digestion (AD) as an efficient alternative technology for adoption is growing in the European energy market and it continues to grow rapidly, especially in the rural communities in Germany. Nonetheless, only about 60% (56.7%) are willing to pay for the installation, implying that baring availability of funds, most schools would like to adopt biogas technology. This suggests that these schools are open to and interested in alternative sources of energy. However, none of the schools indicated the amount they were willing to pay to install a biogas plant. Those that were willing to adopt but were not willing to pay for biogas plants installation gave various reasons for their response. These reasons included the initial high cost of installation and lack of funds due to low enrolment of students. The high initial cost has been confirmed from many research findings in literature. Others also indicated that the school is publicly owned and hence such projects are initiated by the Ministry of Education. Some also cited that with the Free SHS Policy being implemented, school authorities are prohibited from requesting for any form of payment from students or their parents, which leaves government as the ultimate bearer of the cost of biogas plant installation. This also indicate that mangers of SHSs are not freely allowed to adopt innovative ways of dealing with their sanitation challenges. This requires proactive government role in stimulating the adoption of biogas technology through interventions like tax holidays and subsidy provisions to installers. This will lead to a reduction in the initial cost of investing in biogas technology and enable many more schools to totally adopt the technology. It is clear that the adoption of biogas technology in SHSs and government support are inseparable (Akinbomi et al., 2014).

Table 4.7: Schools willing to adopt and pay for biogas

	Frequency	Percentage
Willingness to adopt biogas		
Yes	30	88.2
No	4	11.8
Willingness to pay for biogas		
Yes	17	56.7
No	13	43.3
Possible time frame for adoption		
1-3 years	10	29.4
4-6 years	9	26.5
7-9 years	7	20.6
10-12 years	5	14.7
13-15 years	3	8.8
Source of funding		
Government	4	23.5
Internally Generated Fund	7	41.3
Non-Governmental Fund	6	35.2

Source: Survey Data, 2018

Over 40% (41.3%) suggested internally generated funds to finance the cost of installation of biogas plants. Incidentally financing by government was the most unpopular suggestion among respondents, only 23.5%. This could be attributable to the visible low government interest in biogas technology since government through the Ministry of Energy has indicated its reluctance to provide guarantees in support of renewable power projects, especially biogas technology (Kemausuor *et al.*, 2018). Also, there is currently no government programme to motivate potential users for the technology, thus low desire of respondents to see government as a source of funding. Wawa and Mwakaila, (2017) confirmed that when government does not give priority to biogas technology as compared to other RE resources means that the technology is not very much important and this will make potential adopter's reluctance to adopt the technology.

The other 35.2% suggested non-government fund including Parent Teachers Association (PTA), Old Students Association, NGOs and Other Charitable

Organisations. An indication that some schools know where can get funds but only wants government directives, especially public SHSs.

On the possible time frame for the adoption of the technology, the responses are mixed. However, most institutions preferred early installation-29.4% the first three years, 26.5% between four to six years and 20.6% between seven to nine years. Only 8.8% suggested installation after thirteen years.

4.5.2 Logistic regression of factors that influence adoption of biogas

Direct logistic regression was performed to assess the impact of a number of factors on the likelihood that respondents would report that they were willing to adopt biogas technology. The dependent variable was therefore willingness to adopt to biogas use. The logit model was estimated to determine the probabilities associated with the willingness to adopt. The results from the model are presented in Table 4.8.

The full model containing all predictors was statistically significant, $\chi 2 = 63.12$, $p < 0.000$, indicating that the model was able to distinguish between respondents who were willing to adopt and those who were not willing to adopt biogas technology. The model as a whole explained 73.2 % (R^2=0.732) of the variance in willingness to adopt responses.

Table 4.8: Logit regression results

Variable	Coefficient	Std. error	z-stat.	Prob.
Student population	6.0338	2.9703	2.0314	0.0854*
Source of finance	4.6071	1.6975	2.7141	0.0081***
Lack of subsidy	0.1270	0.0438	2.8971	0.045**
Knowledge of biogas technology	0.5663	0.0770	7.3533	0.001***
Cost of dislodgement	-0.0450	0.0622	-0.7230	0.1202
Cost of other energy source	3.2720	2.0135	1.6250	0.1010*
Environmental concerns	-0.0462	0.0706	-0.6542	0.1769

Pearson goodness-of-fit X^2=63.1232

Prob. = 0.000

Pseudo R^2 = 0.732

*, **, ***, coefficient is significant at 10%, 5%, 1% probability levels, respectively.

As shown in Table 4.8, five of the independent variables made a unique statistically significant contribution to the model (student population, source of finance, knowledge of biogas technology, cost of fuel and lack of subsidy) at 10%, 5% and 1% probability levels respectively. This suggests that a school's willingness to adopt biogas use depends very much on these variables. However, the cost of septic tank dislodgement and environmental concerns were not statistically significant.

In line with priori expectations, the first two variables of student population and source of finance are found to influence the biogas investment positively. Student population is the overall number of students in the school both-day and boarding students-and the source of finance included the schools' own contribution as against others (credit/loan, sponsorship from old students, subsidy from government, levies and contribution from parents). Higher number of student population and source of finance are significant at 10% and 1% respectively. The high number of student population with high statistical significance is confirmed when Walekhwa *et al.*, (2009) indicated that house-hold size (student population) and biogas adoption have significantly positive inter-relationship, influencing potential adopters to adopt the technology. When there are not enough students in the school, it will negatively affect the decision to install biogas, which is quite logical as feedstock for the biogas plant would be a challenged. Also, the schools' ability to finance the biogas themselves increases the odds of adoption by 4.6 times as against if the funding is coming from other sources.

The variable on binary "Lack of subsidy" has a value of 1(yes) which means that in case there is no subsidy, with the understanding that when a school is not getting a subsidy for the installation of biogas plant, it would influence negatively on the willingness to invest in biogas plant. The positive insignia for the variable was an indication that the respondents are willing to invest and adopt biogas technology– but missing the option of a subsidy – and would answer yes to "lack of subsidy". Hence, subsidizing biogas would increase the likelihood of investment. This assertion has been confirmed by Osei-Marfo *et al.*, (2018); Mukumba *et al.*, (2016) and Rupf *et al.*, (2015) when they indicated that subsidies and tax holidays will serve as catalyst to wide adoption of biogas technology. The installers confirmed this when they said all the materials for biogas installation are sourced at a high cost and this has to be passed on to the final consumer (user). This is because these variables have the potential to reduce the initial cost of installation. Without incentives biogas technology, its deployment will continue to remain low, especially among SHS in the country.

The knowledge of biogas technology increases the probability of a school adopting biogas use. Njoroge *et al.*, (2013) indicated that access to information about biogas technologies is a key factor in explaining the differences in the technology adoption.

This is because a greater understanding of a new technology as a result knowledge gained facilitate its easy adoption. The cost of septic tank dislodgement did not meet its prior expectation. This is because, it was hypothesized that the higher the cost of dislodgement, the more likely the school was expected to adopt biogas technology. However, the negative influence of the cost of dislodgement pre-supposes that the higher the of cost dislodgement, the more likely the school would fail to adopt biogas technology. Simply because competing financial resources would not permit a school to make savings so that they can adopt the technology. Also, the upfront many payment for the cost biogas systems installation is higher in terms of budgetary allocation per term than that of dislodgement.

When using other sources of energy in the school and the cost is high, this variable will have a value of 1 for yes (otherwise 0) and a positive answer is thereby related to a higher likelihood of investing in biogas technology. This means saving money as other sources of energy is an expensive source for the school. The last factor that relates to the school being environmentally concerned was the least factor that would make a school want to adopt biogas technology and this did not meet prior expectation. Thus, is an indication of the fact that the environmental benefits of biogas technology are not very much appreciated by managers of SHSs. Installers together with regulators should place more emphasises on this aspect of biogas technology.

4.6 Constraints Analysis of Biogas Use

Table 4.9 shows the constraint that were identified by the SHSs and the analysis of these constraints using the Kendall’s Coefficient of Concordance. In the ranking, a lower value was assigned to the most important factor, hence the constraint with the least Total Weight Score (TWS) is the most important.

The high initial cost of installation of the biogas plant was identified by the majority of SHSs surveyed as the most pressing constraint. This is conformity with many findings from researcher that indicated the high initial cost of installing digesters as the major constraint to the adoption of biogas in Africa, especially Ghana (Osei-Marfo *et al.*, 2018; Mukumba *et al.*, 2016; Rupf *et al.*, 2015; Smith 2011; Bensah & Brew-Hamond 2010). For instance, the investment cost of biogas ranges from 5,000 to 10,000 Ghana cedis in the country and the upfront payment of this amount makes it high SHSs that receives terminal fees from students or government subvention. This will require a subsidy, grants, or long-term repayment loans to motivate SHSs to adopt biogas technology.

This was followed by the high cost of maintenance of the biogas plant after its installation. Longevity of biogas plants requires that regular maintenance and servicing is carried, especially when the plant breaks down. The general maintenance cost according to users, may cost between GH₵ 200 to 500. for minor works while major maintenance that may require changes for the digester accessories may cost GH₵ 1,000 to 2,000 (all in Ghana cedis). These combined with the investment costs, seem to deter potential adopters from embracing the technology. However, user institution sees this as a minimal cost they would have been incurring for dislodging their faecal waste every term. The third constraint identified by the schools as a hinderance to the adoption of biogas technology was the low level of knowledge or awareness of such energy source. Inadequate number of technicians who could do the installation as well as maintenance of the plant was ranked as the fourth factor. The factor that was ranked fifth was the lack of promotion of biogas technology.

Since Fcal (306) is greater than Ftab (5.9) at the 5% significance level, we accept the alternative hypothesis (Ha) that there was a degree of agreement between the constraints ranked by the respondents. The value of the coefficient W (0.643) implies that 64% of the schools sampled agreed to the ranking of the constraints.

Table 4.9: Identification and ranking of constraints associated with biogas technology

Constraints	**Overall Rank**	**TWS (T)**	**Rank score of factors**				
			1	**2**	**3**	**4**	**5**
High initial cost	1st	**51**	24	7	1	0	2
High cost of maintenance	2nd	**82**	5	16	7	6	0
Low level of knowledge/awareness	3rd	**117**	2	5	13	4	10
Inadequate technicians	4th	**128**	2	2	10	8	12
Poor promotion	5th	**138**	1	3	3	17	10

F*cal* =306, F*tab*= 5.9 at 5% significance level, TWS = total weight score

Test Statistics

N	34
Kendall's W[a]	.643
Chi-Square	57.561
df	4
Asymp.	Sig.
.000	

The constraints of biogas technology among user institution are low gas yield, problems of getting immediate response on maintenance calls and the high cost of major maintenance. As to whether the cost of installation was not high to them, they had this to say "If you discount the amount we would have been spending on the termly dislodgement from the septic tanks and the number of years we have installed the technology, high cost does not come at all". They added that the cost difference between the installation of septic tank and that of a biogas plant is very insignificant. This was confirmed by the installers when they said not much difference exist in terms of installation cost between a septic tank and biogas plant. However, the installation of a septic tank after five (5) years period will constant have to dislodge the tanks every term the schools is in session. This will definitely increase the cost of septic tanks. They added that many researchers are just writing "cost of biogas plants are high" without taking time do comparative cost analysis with septic tanks against the wide range of benefits derived from a biogas plant. When user institutions were asked why their kitchen waste and food residue was not used as feedstock, they indicated that it was been used to feed their pigs outside the school. However, the pigs' dung was not considered as a feedstock to their digesters as the schools regarded carry back the pigs' dung to feed the digesters as extra cost and unhygienic. An installer indicated that the low gas yield schools were due to poor feedstock as faecal matter alone would not produce enough gas but a mixture of food waste, cow dung and human excreta could produce enough gas for use. This is given credence by Amon *et al*., 2007 and Mang *et al.*, 2012 when they highlighted that a high yielding biogas plant aside containing cellulose, crude protein, hemicellulose, crude fat and nitrogen contents should also co-digestion various feedstock for maximum gas output. Langeveld and Peterson, (2018) posits that a very high-water content feedstock like faecal matter from flushing toilets cannot generate much gas. Orcullo (1986) in his finding from biogas plant attached to an apartment concluded that it is technically possible to produce biogas from faecal matter but the economics of operation would not permit its proliferation due to low gas output because of low organic matter. Many adopters of biogas may continue to remain dissatisfied with their gas yield if their feedstock used remains on faecal matter without consideration of co-digesting with mixed feedstock

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Findings

The aim of this study was to assess the cost efficiency and willingness to adopt biogas technology as a sustainable source of renewable energy for boarding SHSs in the Greater Accra Region of Ghana. The findings indicate that, there is a high potential for SHS's to generate enough biogas for cooking and heating based on the mean population of 1054 student with more than 80% of them being boarders. This gives credence by Oranusi and Dahunsi (2013) study which states that only 3kg of excreta from 15 students, mixed with 12kg of food waste and water to make 30liters of slurry generated 84,750cm^3 of gas with methane constituting 58% of the gas. The main sources of cooking/heating energy at the institutional level were LPG at 25.9%, firewood at 10.3% and charcoal at 10.3 %. The adoption of biogas at SHS would not only improve the health conditions by eliminating IAP and improving sanitation of the cooks but would also contribute directly to the attainment of SDGs 6, 7 and 13. The main constraints to adopting biogas technology was the perceived high upfront installation and maintenance cost. This could be surmounted with government support in the form of subsidies and tax waivers on biogas plants accessories. This would encourage more schools to adopt the biogas technology to reduce the financial burden they go through to their waste management and pay for energy consumption.

The study also showed that biogas technology users faced a number of challenges ranging from low gas production-after the re-opening of schools- and accessing technical expertise for routine maintenance. The low gas yield was attributed to the principle retention time, temperature, pH, and feedstock of digesters. Installers and promoters must emphasis more on sanitation and the biogas as a supplementary energy source. However, if user wants to optimised the performance if the digester, co-digestion of feedstock in constant proportion is encouraged (Chen et al and survey interviewed).

In terms of the initial cost of installation of biogas digesters, the new Anaerobic Baffled Reactor (ABR) developed by CSIR was more expensive to install than the average cost of the fixed dome biogas plants. However, the Anaerobic Baffle Reactor is simpler and easier to construct as the design and form is identical to a septic tank.

5.2 Conclusion

Public educational institutions in Ghana, especially those with boarding facilities, have great potential of producing biogas as a sustainable energy source while at the same time generating quality manure for soil amelioration. Promotion of sanitation through sustainable waste management is an added benefit. The merits of biogas technology as a supplementary energy source is common knowledge among institutions. Nonetheless, the willingness to adopt the technology is confronted with a number of drawbacks including high initial cost, low level of awareness, weak national policy to promote biogas technology and inadequate number of skilled personnel to deploying biogas plants.

The adoption of biogas technology holds high potential in assisting Ghana to meet a number of the SDGs. It is therefore important to take deliberate and pragmatic steps including raising awareness on the merits of the technology, provide subsidies and tax waivers on biogas plant accessories and enhance capacity to both deploy the technology and man the digesters in the various institutions among others, to ensure that the full merits of the technology is realised in Ghana

5.3 Recommendations

To unlock the potential of Biogas Technology in SHSs in the Greater Accra Region of Ghana, there is the need for policy and institutional framework reforms on biogas promotions in the public and private sectors. In order to develop sustainable strategies to improve the adoption and use of biogas among potential adopters, the following recommendations are made as a way forward in enhancing the adoption of biogas technology:

- There is the need to develop a national policy aimed at promoting biogas plants installation for institutions that have boarding facilities. The policy should stipulate the development of guidelines to guide the installation and operations of the plant as well as highlighting government's role in the biogas industry. Currently, the industry is unregulated and some substandard installers build digesters that are poorly constructed with associated environmental and health hazards.
- The provision of of subsidies and tax waivers on biogas plant accessories will reduce the cost of installation and also create an enabling environment to promote the technology in Ghana
- There is also the need to direct attention on raising awareness on the multiple benefits of biogas technology. There is currently limited awareness on the economic, social and environmental benefits of biogas technology among SHSs in Ghana. The awareness raising campaign should target three major benefits of biogas plants with the overarching benefit as environmental protection;

    1. The sanitation and hygiene improvement potential
    2. The alternative and supplementary energy potential

3. The advantage of generating manure, nutrient-rich effluent and slurry as soil ameliorant for crop production and tree plantation.

- There is the need to educate users and potential users that co-digestion is key to optimising the productivity of biogas plants. Adopters should ensure that they add other feedstock to their digester as the faecal matter.

- There should be routine training on biogas technology on the various biogas digesters designs, maintenance and repair work on biogas plants. This will ensure that there is enough pool of trained technicians who understand the science behind biogas technology and are able to offer maintenance and repair works at reduced prices. Also, the availability of trained biogas technicians would go a long way to reduce the costs of installation, rectify the challenges poorly constructed digesters post and the proper information on the actual benefits of biogas plants but not only energy.

- There should be public and private sector involvement in the biogas technology promotion by encouraging investments in the sector. This can be done through BAG members, ABP and others regulatory institutions (EPA, CSIR, Energy Commission and Ghana Standard Authority) creating enabling environment for development of the sector.

- Further research is needed in the biogas technology sector to identify locally available and appropriate materials that can be used to reduce the overall costs of investing in biogas technology.

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APPENDICES

Appendix A: Letter of Introduction

UNIVERSITY OF GHANA
CENTRE FOR CLIMATE CHANGE AND SUSTAINABILITY STUDIES (C_3SS)

Ref. No.: ....

19th February, 2018

TO WHOM IT MAY CONCERN

Dear Sir,

LETTER OF INTRODUCTION

I would be very grateful if you could provide Mr. John Leonard Doghle with information for his research work.

Mr. John Leonard Doghle is a student at the University of Ghana Centre for Climate Change and Sustainability Studies pursuing a Master of Philosophy degree in Climate Change and Sustainable Development.

He is undertaking a research on the topic "**Assessing the efficiency and potential of biogas as a sustainable source of renewable energy for institutions: A case study of senior high schools in the Greater Accra Region of Ghana**" as part of his studies.

I would very much appreciate your assistance in any form to enable him complete his work.

Thanks very much.

Yours Sincerely,

Prof. Erasmus Owusu
Director, C_3SS

COLLEGE OF BASIC AND APPLIED SCIENCES
P.O. Box LG 25, Legon, Accra, Ghana
Telephone: +233-302905269 Email: C3SS@ug.edu.gh Website: www.ug.edu.gh

Appendix B: Request for Information on Biogas Technology in Ghana

University of Ghana
Centre for Climate Change & Sustainability Studies
College of Basic & Applied Sciences
P. O. Box LG 25
Legon, Accra-Ghana
13th March, 2018

Tel: 0243134046/ 0501301449

The Director
Council for Scientific & Industrial Research
(East Legon)
P. O. Box LG 576
Accra

Dear Sir

REQUEST FOR INFORMATION ON BIOGAS TECHNOLOGY IN GHANA

I write to humbly request your good office to furnish me with information on biogas technology in the country.

I am a student of the above University pursuing Mphil in Climate Change and Sustainable Development and wish to undertake my research work as per attached introductory letter.

Counting on your support

Yours faithful

(John Leonard Doghle)

Appendix C: Request for Permission to Administer Questionnaire

GHANA EDUCATION SERVICE

In case of reply the number and date of this Letter Should be quoted.

REPUBLIC OF GHANA

Shai-Osudoku District Office
Post Office Box 45
Dodowa

My Ref. No.: GES/DDO.5/ 89/184
Your Ref. No.:

21st May, 2018

JOHN LEONARD DOGHLE
U G
P. O. BOX LG 25
LEGON, ACCRA – GHANA

REQUEST FOR PERMISSION TO ADMINISTER MY QUESTIONNAIRES IN SENIOR HIGH SCHOOLS IN YOUR DISTRICT
JOHN LEONARD DOGHLE U. G

We write to acknowledge receipt of your letter on the above subject and grant you permission to undertake a research in Senior High Schools in the Shai – Osudoku District.

You are entreated to discuss samples of the questionnaires with the Headmaster of the Senior High School chosen before administering it to the intended participants.

However, you must ensure that the exercise does not interfere with contact hours.

We wish you a fruitful exercise.

....
ELIZABETH AWOONOR-WILLIAMS (MRS.)
DIRECTOR OF EDUCATION
SHAI-OSUDOKU DISTRICT
DODOWA

Cc: Dep. Director (HRMD) – GES – Dodowa
Senior High Schools
Subject File

Appendix D: Biogas User Institutions Interview Guide

UNIVERSITY OF GHANA
SCHOOL OF BASIC APPLIED SCIENCE
DEPARTMENT OF CLIMATE CHANGE AND SUSTAINABILITY UNIT
INTERVIEW GUIDE FOR SHS WITH BIOGAS PLANTS

RESEARCH TOPIC: Assessing the Potentials of Biogas as a Sustainable Source of Renewable Energy for Institutions: a Case Study of Selected Schools in Greater Accra Region, Ghana

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Introduction:

I am a student of the University of Ghana and carrying out a study on the topic stated above for the award of an academic degree. I would therefore be very grateful if you could spend some time with me on this interview which might last for about an hour.

I assure you that all responses will be treated as confidential and used only for academic purpose without disclosing your identity. You reserve all rights to either respond or decline any question in the course of our interaction.

Thank you in advance for your cooperation.

Start Time: ……………….

A. Background Information

1. Name of institution: ……………………………………………
2. Position of interviewee: ………………………………………………
3. Total Numbers of Students: Boys …………… Girls ………………………..

B. Reliability of Biogas as an alternative source of energy for SHS in Accra

1. Briefly tell me about the energy sources of your school and how they have been met over the years
2. How much do you spend on these sources?
3. What is your general perception on biogas plants as a source of energy?
4. Tell me something briefly about your biogas plant (Its construction, operation and usefulness)
5. How reliable is your biogas plant(s) in meeting the energy needs of your school?

6. How has your school benefitted from the biogas plant since its installation?
    i. Are these benefits worthwhile for other schools to adopt the technology?
    ii. What were the overriding reason for the biogas plant
7. To what extent has the use of biogas complemented the usage of conventional fuels in your school?
8. To what extent has feedstock influencing the biogas plant operations?
9. i. Will you recommend a large-scale implementation in all SHSs in Ghana?
    ii. What are your reasons

C. The Environmental Impact of Biogas Plants in SHS in Accra

1. What feedstocks are available for your biogas plants and do you incur cost in acquiring the feedstock?
2. What is your general assessment of the impact of the biogas plant on the environment?
3. To what extent do these environmental impacts affect health, quality of air, and pest in your school?
4. To what extent has the installation of biogas plant contributed to sanitation in the school

D. The Challenges faced with the installation and operation of biogas plants in SHS in Accra.

1. Did you face any challenges in getting your biogas plant installed in your school?
2. Do you face any challenges in operating the biogas plant?
3. Which among these is your biggest challenge?
4. Do you think these challenges limit the full potential benefits of these biogas energy?
5. What are some of the operational risk associated with running a biogas plant
6. How appropriate will it be for government to embark on nationwide biogas project for SHSs in Ghana?
7. Please suggest any measures to minimize the impact of anticipated challenges should government embark on such a policy.

Appendix E: Questionnaire for Biogas Non-User Institutions

UNIVERSITY OF GHANA

COLLEGE OF BASIC & APPLIED SCIENCE

CENTRE FOR CLIMATE CHANGE AND SUSTAINABILITY STUDIES

QUESTIONAIRE FOR INSTITUTIONS NOT USING BIOGAS

RESEARCH TOPIC: Assessing the Cost Efficiency and the willingness to adopt Biogas as a Sustainable Source of Energy: The Case of Senior High Schools in the Greater Accra Region of Ghana

---

Introduction:

I am a student of the University of Ghana and I am carrying out a study on the topic stated above for the award of an academic degree. I would therefore be very grateful if you could spend some time in answering the following questionnaire for me.

I wish to assure you that your identity would not be disclosed. Your responses would be treated as confidential and used solely for academic purpose. You reserve all rights to respond or decline answering any question (s) in this questionnaire you are not comfortable with.

Thank you in advance for your cooperation.

1. Name of Institution: ……………………………
2. Total Population ……………………………
3. What is the total number of Males………………… Females……………………?
4. What is the total number of Boarding Students ……………… Day Students ……………
5. Position: ………………………………………………………………………

A. Energy Consumption

6. Which of these energy sources is your institution currently using for lighting, cooking, heating etc

Energy Type	Purpose (s)	Source	Amount (M)
Fire wood (Amount/Bundle per month)			
Charcoal (Amount/Bags per month)			

Solar energy			
Electricity (Bill per month)			
LPG (Liters per/Tons)			
Diesel/Petrol for Gen Set (per Liters)			
Others (Specify)			

7. How do you manage your institutional waste?

Types of waste	**Disposal method**	**Frequency (monthly/quarterly)**	**Amount/cost per session**
Kitchen waste			
Solid waste			
Night soil (Septic tank)			
Liquid waste			

B. Potential of Biogas

6i. Have you heard about biogas technology? Yes [ ] No [ ]

ii. If yes, where did you get the information from?

a. Government/NGO [ ]
b. TVs/Radio/ Newspapers/Web Advert [ ]
c. Friend/neighbor [ ]
d. Researcher/Academia [ ]
e. An installer [ ]

Premeable: *Biogas Plants are known to have many benefits to users because they can give gas from the plant to supplement their energy consumption-reducing expenses on cooking/lightening; use the bio-slurry on their farm as a rich organic fertilizer; the water from the biogas plant can be recycled for flushing of toilets and watering of lawns-reducing water bills; the burning of the gas is smokeless and does give indoor air pollution; and finally, it treats municipal waste (faecal and kitchen waste). The disadvantage of biogas plants is the supposed upfront cost; high cost on maintenance and sometimes low output of gas*

7i. Will your institution be willing to install a biogas plant? Yes [ ] No [ ]

ii. If Yes, please indicate what time frame do you see your institution adopting one?

a. 1-3 years [ ]

b. 4-6 years [ ]

c. 7-9 years [ ]

d. 10-12 years [ ]

e. 13-15 years [ ]

7i. Will your institution pay for the cost of biogas plant installation?

Yes [ ] No [ ]

ii. If Yes, indicate your source of fund for financing the cost of installation and maintenance?

a. Credit /Loan from financial institutions [ ]

b. Sponsorship from Old students [ ]

c. Levies and contribution Parents [ ]

d. Subsidy from the Government [ ]

e. Internally generated funds [ ]

f. Other sources (Specify) ………………………………………..

iii. If No, please give your reason (s)

………………………………………………………………………………………

…………………………………………………………………………

8. Why would you like to install the biogas plants in your institution?

Reasons for installation	**(√)**
For cooking	
For lightening	
To improved hygiene and sanitation	
For Environmental Protection	
To produce organic fertilizer for farming	
To save cost on LPG/Wood fuel	
To recycle water for use	

C. Challenges

9. What do you consider to be the main challenges of adopting biogas energy in your opinion? *(Rank the following where 1 is lowest and 5 is highest.* ***Items should not bear the same number more than once)***

Items	**1**	**2**	**3**	**4**	**5**
High initial cost					
High cost of maintenance					
Low level of knowledge/awareness of biogas technology					
Inadequate technicians,					
Poor promotion					

10i. Do you think that institutions (schools, hospitals, prisons, etc) in Ghana are well aware of the biogas technology and its importance as a source of sustainable energy?

Yes [ ] No [ ]

iii. Give reasons for your choice.……………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………………………………

……………………………………………

Appendix F: Interview Guide for Biogas Installer

UNIVERSITY OF GHANA
SCHOOL OF BASIC APPLIED SCIENCE
DEPARTMENT OF CLIMATE CHANGE AND SUSTAINABILITY UNIT
INTERVIEW GUIDE FOR COMPANIES/ EXPERTS FOR BIOGAS PLANTS INSTALLATION

RESEARCH TOPIC: Assessing the Potentials of Biogas as a Sustainable Source of Renewable Energy for Institutions: a Case Study of Selected Schools in Greater Accra Region, Ghana

---

Introduction:

I am a student of the University of Ghana and carrying out a study on the topic stated above for the award of an academic degree. I would therefore be very grateful if you could spend some time with me on this interview which might last for about an hour.

I assure you that all responses will be treated as confidential and used only for academic purpose without disclosing your identity. You reserve all rights to either respond or decline any question in the course of our interaction.

Thank you in advance for your cooperation.

Start Time: ……………….

1. Name of institution/company:

   ………………………………………………………

2. Year of establishment:

   ……………………………………………………………

3. Position of interviewee:

   …………………………………………………………

4. Year of biogas plant installation company establishment

   ……………………………

5. Number of biogas plants installed: Household…..……… Institutions ……………?

6. What type of biogas plants does your company install for clients?

7. What is your general perception on biogas plants as a source of renewable energy?

8. What sources of feedstocks are available users and potential users of biogas plant operators?
9. Do biogas plants could complement the use of conventional fuels in SHSs in Accra and how?
10. What are some of the likely impact on the environment from the installation of biogas plant?
11. How will the installation of biogas plants have on the environmental relation to health, Quality of Air and Sanitation?
12. What are some of the major challenges that confront biogas installation and dissemination?
13. What accounts for the slow pace of biogas technology despite its long historical presence in the country?
14. What role should government, academia, private biogas companies, NGOs, and other stakeholders play in the dissemination programmes in Ghana?
15. Would you recommend a nationwide rollout of biogas plants in SHSs to address their energy needs?

Appendix G: Interview Guide for Regulatory Institutions

UNIVERSITY OF GHANA

SCHOOL OF BASIC APPLIED SCIENCE

DEPARTMENT OF CLIMATE CHANGE AND SUSTAINABILITY UNIT

INTERVIEW GUIDE FOR INSTITUTIONS CONCERNED WITH ENVIRONMENTAL PROTECTION

RESEARCH TOPIC: Assessing the Cost Efficiency and the willingness to adopt Biogas as a Sustainable Source of Energy: The Case of Senior High Schools in the Greater Accra Region of Ghana

---

Introduction:

I am a student of the University of Ghana and carrying out a study on the topic stated above for the award of an academic degree. I would therefore be very grateful if you could spend some time with me on this interview which might last close an hour.

I wish to assure you that your identity would not be disclosed. Your responses would be treated as confidential and used solely for academic purpose. You reserve all rights to respond or decline answering any question (s) during the course of our interaction.

Thank you in advance for your cooperation.

Start Time: ……………….

A. Background Information

1. Name of Institution:

   …………………………………………………………………………

2. Year of establishment

   ……………………………………………………………………….

3. Staff strength

   ……………………………………………………………………………

4. Position of interviewee: ………………Number Years Served………………

B. Environmental impact of Installation and Use of Biogas Plants

5. What is your institutional role in biogas programme in Ghana?
6. Are there any regulatory or guidelines biogas installers are expected to fulfil from your institutional?
7. What are some of the known environmental risk (s) associated with the use of biogas plants among institutions?
8. What environmental guidelines or standards are provided for the installation and use of biogas plants in institutions?
9. Do you receive complains from users of biogas plant and how are they resolve?
10. What plans are the for biogas in Ghana especially schools?
11. How does the installation and use of the biogas plants contribute to the following environmental challenges?
    a) Air pollution
    b) Wastes and water contamination
    c) Food contamination
    d) Pests and diseases
12. Are there any training sessions or workshops or seminars organized by your institution for the installers and users of biogas plants?
13. Has any of the user institutions/installers of biogas requested a permit prior to the installation of the plant?
14. What environmental recommendations can be made to improve the installation and use of biogas plant (s) among institution?

Appendix H: List of Boarding SHS

GHANA EDUCATION SERVICE						
GREATER ACCRA REGION						
LIST OF SENIOR HIGH SCHOOLS WITH BOARDING OR HOSTEL FACILITIES						
PUBLIC SCHOOLS						
S/N	**DISTRICT**	**TYPE**	**SCHOOL NAME**	**LOCATION**	**GENDER**	**STATUS**
1	Accra Metro	Public	Accra Academy	Kaneshie	Boys	Day/Boarding
2	Accra Metro	Public	Accra Girls Senior High	Mamobi	Girls	Day/Boarding
3	Accra Metro	Public	Achimota Senior High	Achimota	Mixed	Day/Boarding
4	Accra Metro	Public	St. Mary's Senior High	Korle Gonno	Girls	Day/Boarding
5	Accra Metro	Public	Wesley Grammar Senior High	Dansoman	Mixed	Day/Boarding
6	Ada East	Public	Ada Senior High	Ada-Foah	Mixed	Day/Boarding
7	Ada West	Public	Ada Senior High/Technical	Sege	Mixed	Day/Boarding
8	Ga Central Municipal	Public	Odorgonno Senior High	Awoshie	Mixed	Day/Boarding
9	Ga South Municipal	Public	Ngleshie Amanfro Senior High	Ngleshie Amanfro	Mixed	Day/Hostel
S/N	**DISTRICT**	**TYPE**	**SCHOOL NAME**	**LOCATION**	**GENDER**	**STATUS**
10	Ga West Municipal	Public	St. John's Grammar Senior High	New Achimota	Mixed	Day/Boarding
11	La Dade-Kotopon Municipal	Public	Labone Senior High	Labone	Mixed	Day/Boarding
12	La Nkwantanang Madina Municipal	Public	Presby Boys Senior High	Legon	Boys	Day/Boarding
13	Ledzokuku-Krowor Municipal	Public	Nungua Senior High	Nungua	Mixed	Day/Boarding
14	Ningo Prampram	Public	Ningo Senior High	Old Ningo	Mixed	Day/Boarding
15	Shai-Osudoku	Public	Ghanata Senior High	Dodowa	Mixed	Day/Boarding

16	Shai-Osudoku	Public	Osudoku Senior High/Tech	Asutsuare	Mixed	Day/Boarding
17	Tema Metro	Public	Tema Senior High	Tema Comm 5	Mixed	Day/Boarding
PRIVATE SCHOOLS						
S/N	**DISTRICT**	**TYPE**	**SCHOOL NAME**	**LOCATION**	**GENDER**	**STATUS**
18	Accra Metro	Private	City Senior High/Business Coll	Kpehe	Mixed	Day/Boarding
19	Accra Metro	Private	Dansis Senior High Sch	Mamprobi	Mixed	Day/Boarding
20	Accra Metro	Private	Evangelical Business High	Mamobi	Mixed	Day/Hostel for Girls
21	Accra Metro	Private	Galaxy Int. School	East Legon	Mixed	Day/Boarding
22	Accra Metro	Private	Harvard Senior High *	Kokomlemle	Mixed	Day/Boarding
23	Accra Metro	Private	Salem Senior High	KukuHill	Mixed	Day/Hostel
24	Accra Metro	Private	Seven Great Princess Academy	Accra	Mixed	Day/Boarding
25	Accra Metro	Private	The Lincoln School	New Town	Mixed	Day/Hostel
26	Ada East	Private	Anmchara Senior High School	Kajanya-Saga, Ada	Mixed	Day/Boarding
27	Adentan Municipal	Private	Delcam Senior High School	Adentan	Mixed	Day/Boarding
28	Adentan Municipal	Private	Eastbank Senior High School	Oyibi	Mixed	Day/Boarding
S/N	**DISTRICT**	**TYPE**	**SCHOOL NAME**	**LOCATION**	**GENDER**	**STATUS**
29	Ga Central Municipal	Private	Apostle Safo Sch of Arts and Science	Awoshie, Last Stop	Mixed	Day/Boarding
30	Ga Central Municipal	Private	Commonwealth College	Chantan, Lapaz	Mixed	Day
31	Ga Central Municipal	Private	Ghana College Senior High	Ga Central	Mixed	Day/Boarding/Hostel
32	Ga Central Municipal	Private	Hill Top Senior High	Ga Central	Mixed	Day/Boarding

33	Ga Central Municipal	Private	Pank Sec/Business College**	Awoshie	Mixed	Day/Boarding
34	Ga East Municipal	Private	The Masters Senior High School	Atomic Rd, Marey Area	Mixed	Day/Boarding
35	Ga South Municipal	Private	Anson Senior High Sch	Gbawe	Mixed	Day/Hostel
36	Ga South Municipal	Private	Darius Senior High/Tech.	Amanfrom	Mixed	Day/Boarding/Hostel
37	Ga South Municipal	Private	Hazelway International School	Opposite, Weija Dam	Mixed	Day/Boarding
S/N	**DISTRICT**	**TYPE**	**SCHOOL NAME**	**LOCATION**	**GENDER**	**STATUS**
38	Ga West Municipal	Private	Firm Foundation Senior High	Sapeiman	Mixed	Day/Boarding
39	Ga West Municipal	Private	Rev. John Teye Mem.Inst.	Accra	Mixed	Day/Boarding
40	Ga West Municipal	Private	Victoria College	Pokuase	Mixed	Day/Boarding
41	La Nkwantanang Madina Municipal	Private	Action Senior High/Tech School	Madina	Mixed	Day/Boarding
42	La Nkwantanang Madina Municipal	Private	Elim Senior Senior High	Madina	Mixed	Day/Boarding
43	La Nkwantanang Madina Municipal	Private	Madina Senior High	Madina	Mixed	Day/Boarding
44	La Nkwantanang Madina Municipal	Private	Preset Pacesetters Institute	Madina	Mixed	Day/Boarding
S/N	**DISTRICT**	**TYPE**	**SCHOOL NAME**	**LOCATION**	**GENDER**	**STATUS**
45	Ningo Prampram	Private	Global Senior High	Old Ningo	Mixed	Day/Boarding
46	Shai-Osudoku	Private	The Golden Sunbeam Col.of Sc. & Tech.	Ayikuma	Mixed	Day/Boarding
47	Tema Metro	Private	Witsand Senior High	Tema	Mixed	Day/Boarding

48	Tema Metro	Private	Tema International School	Tema Com 22	Mixed	Boarding
49	Tema Metro	Private	Tema SOS Germain Herman Inter. College	Tema Com 10	Mixed	Boarding