UNIVERSITY OF GHANA

COLLEGE OF HUMANITIES

ASSESSING THE POTENTIAL OF BIOGAS AS A CLEAN HOUSEHOLD ENERGY SOURCE FOR COOKING: A COMPARATIVE STUDY OF THE NSAWAM ADOAGYIRI MUNICIPALITY AND THE AWUTU SENYA EAST MUNICIPALITY

BY

BOAPEAH OHENEBENG

(10404926)

THIS DISSERTATION IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF ARTS DEGREE IN DEVELOPMENT STUDIES

INSTITUTE OF STATISTICAL, SOCIAL AND ECONOMIC RESEARCH

DECEMBER 2021

DECLARATION

I, Boapeah Ohenebeng, hereby declare that except for the references of other people's work which have been duly acknowledged, this dissertation titled "Assessing the potential of biogas as a clean household energy source for cooking: A comparative study of the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality" is my original work carried out under the supervision of Dr. Andrew Agyei-Holmes. To the best of my knowledge, this work has neither in full nor part been submitted for any degree in this University or elsewhere.

13th December, 2021

Boapeah Ohenebeng　　　　Date

(Student)

13th December, 2021

Dr. Andrew Agyei-Holmes　　　　Date

(Supervisor)

ABSTRACT

The study aimed at assessing the potential of biogas as a clean household energy source for cooking in two municipalities. A mixed method approach of research was employed to compare between the two municipalities under study, peoples' willingness to adopt biogas technology, the cost efficiency of domestic biogas and the likely challenges confronting the use of biogas to cook. Quantitative data was elicited from 271 respondents sampled from both municipalities with the aid of a survey. Rich qualitative data was elicited from eight experts through key informant interviews with the aid of semi-structured interview guides. The study revealed that there are vast varieties of feedstocks readily available to feed household biodigesters for the production of biogas for cooking. The fixed-dome biodigester type widely installed in Ghana was found to be the most suitable to digest the vast varieties of feedstocks available in Ghana. To bridge the technical expertise gap, biogas service providers in recent times have begun training artisans in the design, construction and maintenance of biodigesters. Majority (74.9%) of the respondents were willing to adopt biogas technology. Their decision to adopt biogas was influenced by their knowledge of biogas, annual expenditure of cooking fuel and gender. Biogas technology was found to be economically viable in a 20 years' time period at a discount rate of 13.5% indicating that biogas is cheap in the long term. Some likely challenges confronting domestic biogas usage included high initial and maintenance cost which makes the technology not affordable for low-income households. Also, it was revealed that poor regulation of the Ghanaian biogas industry has led to the proliferation of substandard biodigesters which poses lots of challenges to users and deters potential adopters from adopting the technology. The study recommends that for low-income households and rural settlements, community shared biodigesters will be more feasible than household biodigesters. It also recommends effective regulation of the biogas industry and the

standardization of biodigesters. Moreover, the study recommends to government to develop a national policy aimed at promoting domestic biodigesters/plants and make available subsidies in the form of tax waivers and rebate to reduce the high-cost components of biogas plants installation.

ACKNOWLEDGEMENT

I thank the good Lord for how far he has brought me. I am extremely grateful to my supervisor Dr. Andrew Agyei-Holmes for his careful suggestions and guidance that enabled me to successfully complete this dissertation. I am grateful to all friends and family for their unflinching support throughout my period of studies.

DEDICATION

To God and Country.

Table of Contents

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AD	Anaerobic Digestion
ASEM	Awutu Senya East Municipality
BAG	Biogas Association of Ghana
CSIR	Centre for Scientific and Industrial Research
EPA	Environmental Protection Agency
GHG	Green House Gas
GSS	Ghana Statistical Service
GTZ	German Agency of Technical Assistance
IAP	Indoor Air Pollution
LPG	Liquefied Petroleum Gas
NAMA	Nsawam Adoagyiri Municipal Assembly
RE	Renewable Energy
SDGs	Sustainable Development Goals
UNEP	United Nations Environmental Programme
WBA	World Biogas Associatio

CHAPTER ONE

INTRODUCTION

1.0 Background of Study

Energy is indispensable as it is a prerequisite to achieve basic needs necessary for the survival and existence of humanity (Atuguba & Tuokuu, 2020). Energy provides the basis through which other human activities thrive and improve (Kumi, 2017). For instance, energy is needed in the health sector for quality delivery of health services. In the hospitals, electricity is used to power fridges to safely store blood, it is used to power information communication technology equipment such as computers which enhances quality healthcare delivery. In the domestic setting, energy is needed to improve living conditions. Electricity is used to power home appliances such as televisions, air conditioners, computers and cookers which make life comfortable. Also, energy is needed in the education sector to improve the quality of teaching, learning and researching. In schools and other academic related institutions, electricity is used to power computers and projectors to improve teaching and learning. Moreover, energy is needed in the communication sector to improve effective communication services. Without sustainable electric power supply, communications tools such as phones, internet servers, satellites and telecommunication masts will not function effectively which will adversely affect information dissemination. Finally, energy is needed in the industrial sector for powering machines for the exploration of mineral resources. Heavy industrial machines such as excavators, mine carts, hydraulic mining shovels and rock drills need fuel and electricity to be able to function. Without electricity and fuel these earth moving machines cannot function for the proper exploration of mineral resources.

Despite these myriad merits of energy, a great number of people in the world especially in developing countries do not have access to quality energy supply. It is estimated that nearly 1.2 billion people do not have access to electricity and even a greater number of people of about 2.7 billion do not have access to clean cooking fuels (IEA, 2019). Also, it is estimated that fossil fuels contribute to 88% of the world's primary energy demand (Ohnmacht et al., 2021). Fossil fuels are not clean, non-renewable and largely not sustainable as they increase the emission of green-house gases (GHG), contributes to global warming and climate change.

In recent times, the significant consequences of global environmental problems such as global warming, emission of green-house gases, climate change, land degradation and pollution threatens human existence. This urgently calls for the global exploration and adoption of clean/renewable energy sources. Again, the Paris Climate Agreement (PCA) gives a strong imperative for the world to transition from the use of unsustainable fossil fuels to sustainable renewable fuels (Ankrah & Lin, 2020). Also, embedded in the 2011 Green Economy Initiative (GEI) of the UNEP is the global adoption of green/clean energy sources which will improve human wellbeing and social equity while significantly reducing environmental risks and ecological scarcities. Renewable energy (RE) includes tidal and thermal energy, solar energy, wind energy, hydro energy and bioenergy. Renewable energy is very essential for reducing global emissions of GHGs and overcoming current and future energy crisis as it forms an alternative and supplementary energy source to augment the global energy mix (Yan et al., 2021).

Albeit, the dominant source of household energy for cooking in sub-Saharan Africa is traditional biomass mainly in the form of charcoal and fuelwood (IRENA, 2017; Msibi & Kornelius, 2017). An estimated number of over 700 million people in Africa rely on traditional biomass for cooking (Kornelius, 2017). Also, Issah et al., (2020) observed that biomass accounts for approximately

74% of total energy consumption in sub-Saharan Africa. There are numerous disadvantages associated with these traditional fuels. They include but not limited to, adverse impacts on human health, adverse impacts on the environment and sustainable development. In 2019 alone, Over 700, 000 deaths in sub-Saharan Africa were as a result of household Indoor Air Pollution (IAP) caused by smoke from the use of traditional biomass for cooking (Fisher et al., 2021). Again, more than 300 million tonnes of wood are consumed annually in sub-Saharan Africa from the production and use of biomass for cooking (Venkata Ramana et al., 2015). This causes forest degradation, loss of biodiversity and the emission of GHGs which compound the problems of global warming and climate change. Stephenson (2021), observed that recent data suggests fuelwood use in certain parts of sub-Saharan Africa of which Ghana is included is unsustainable. Thus, the rate of depletion of wood is faster than the rate of regrowth. These concerns have extremely awoken the discussions on biogas technology and its adoption in Africa to supplement the energy demand deficit at a cheaper cost whiles protecting the environment to promote sustainable development (Issah et al., 2020).

Biogas technology is an environmentally sustainable technology used for the production of biogas. It is a clean and renewable energy source. It is largely adopted in Asia especially China and India to improve access to clean energy, reduce the health and environmental risk of fuelwood use and provide energy for rural low income households (Chen et al., 2012; Panwar et al., 2011; Stephenson, 2021). Biogas is produced through the anaerobic digestion (AD) of biodegradable/organic waste materials such as animal manure, agricultural waste, food waste and human excreta (Msibi & Kornelius, 2017). This makes biogas very ideal for a developing country like Ghana which have problems with accessibility of affordable energy, sanitation and waste management.

1.1 Statement of Problem

Access to sustainable energy sources is a prerequisite for sustainable development. This was made even more clearer by the immediate past United Nations (UN) Secretary General Ban-Ki-Moon in his statement that “Sustainable development is not possible without sustainable energy” during his press conference on ‘Sustainable Energy Initiative in 2011.

Accordingly, a goal to improve access to affordable and clean energy was included in the Sustainable Development Goals (SDGs). Specifically, SDGs goal seven, promotes the adoption of clean and affordable household energy which is environmentally friendly and improves sustainable development. The goal was set in 2015 with specific targets to be met by 2030. These targets included among others access to affordable, clean, sustainable and reliable energy sources. Also, goal seven of the first ten-year implementation plan of African Union’s Agenda 2063 suggests the use of renewable energy sources to promote sustainable development in Africa (AU, 2015). Equally in Ghana, the 2011 Renewable energy Act (ACT 832), legalizes the adoption and use of renewable energy sources such as solar and biogas to diversify the local energy mix. The act was to make provision for the development, management and utilization of clean/renewable energy sources in an efficient and environmentally friendly manner. Again, the Act projected to reduce the over reliance on wood fuel from 72% to 50% by 2020 (Agyekum, 2020). Ghana being a member of the UN has internalized the SDGs in its national policy and has enacted the RE energy Act. This should have changed Ghana’s energy situation from the rest of sub-Saharan Africa.

However, the situation in Ghana is not any different from that of sub-Saharan Africa. Ghana is still far behind in meeting energy targets.(Antwi et al., 2019; Asibey et al., 2021). The dominant energy source for cooking is traditional biomass in the form of charcoal and fuelwood. Charcoal and fuelwood use in households account for approximately 34.1% and 33.3% respectively(GSS, 2019).

Fuelwood is used in most rural households which constitutes 63% of all rural households whiles charcoal is more important in urban and peri urban households. Similarly, in both the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality, more than 50% of households use fuelwood as a source of fuel for cooking.(GSS, 2019). Though wood is cheap, it comes with enormous health and environmental problems (IRENA, 2017). For instance, over reliance on wood fuel has been cited as a major cause of the depletion of forest reserves in Ghana (Oduro et al., 2012). Depletion of forest reserves lead to forest degradation and the destruction of the carbon sink which increase the emission of GHGs that cause global warming and adverse climate change. Again, wood is not a clean energy source for cooking and not sustainable.

Meanwhile, both municipalities under study have vast biomass resources as one's economy is largely Agrarian whiles the other is noted for cattle farming (GSS, 2019; Kemausuor et al., 2014). The Nsawam Adoagyiri municipality is noted for the cultivation of non -traditional export crops such as pineapples, pawpaw and mangoes. Also, animal husbandry especially medium scale poultry farming and small-scale livestock farming is very common in the municipality. The Awutu Senya East municipality is noted for cattle farming especially in the Walantu Zonal council. This means there is readily available vast organic waste and agricultural waste in the form of animal manure, crop waste, food waste, solid waste and all biodegradable municipal waste to serve as feedstocks to feed biodigesters for the production of biogas. In both municipalities, household waste such as kitchen waste and human excreta are also available to serve as feedstocks to feed biodigesters. Also, preliminary investigation reveals that both municipalities are confronted with the problem of energy deficit and waste management as they are rapidly urbanizing making them viable for a comparative study. These problems of energy deficit and waste management has rekindled the interest in biogas technology (Arthur, Baidoo, Brew-Hammond, et al., 2011; Bensah & Brew-Hammond, 2010).

Biogas technology presents a unique opportunity to efficiently manage waste and produce cheaper and cleaner energy which can be used for cooking. The residue (digestate/bio-slurry) from biogas production can be used as organic fertilizer to ameliorate soil conditions to increase agricultural yields (Arthur & Brew-Hammond, 2010). A unique characteristic of biogas is its storability. This according to Antwi et al., (2019) & Ohnmacht et al., (2021) makes biogas a perfect alternative source of energy. At instances where other sources of energy are in short supply, biogas is able to fill the emerging supply gaps. Biogas is produced through anaerobic digestion of biodegradable matter in an oxygen-free air-tight tank called biodigester (Agyekum, 2020; Bond & Templeton, 2011). All agricultural waste, biodegradable municipal waste, animal manure and human excreta can be used as feedstocks to feed the biodigesters for the production of biogas. Fortunately, these feedstocks are in abundance in the two municipalities under study.

A plethora of studies have been conducted to investigate the potential and feasibility of biogas production in Ghana (Arthur, Baidoo, & Antwi, 2011; Arthur, Baidoo, Brew-Hammond, et al., 2011; Cudjoe et al., 2021; Kamp & Østergård, 2016; Kemausuor et al., 2014, 2016; Mensah et al., 2021; Mohammed et al., 2017; Präger et al., 2019). However, none of these works concentrated on the potential of biogas as a clean household energy source for cooking. For instance, Arthur, Baidoo, & Antwi (2011) conducted a study aimed at biogas generation potential from sewage in four public universities in Ghana. A study conducted by Cudjoe et al (2021) aimed at forecasting the potential and economic feasibility of power generation using biogas from food waste in Ghana. Kemausuor et al (2016) conducted a study aimed at analyzing the ex-ante socio-economic impacts of biogas systems using a remote community in Ghana. Against this backdrop, this research investigates the potential of biogas as a clean household energy source for cooking in two municipalities, examines the socio-economic and technical factors that influence the adoption of biogas, examines the cost-efficiency of domestic biogas and examines the likely challenges of domestic biogas. The research will contribute to the limited literature on domestic biogas in Ghana. Also, it will make policy contributions to renewable energy sources, domestic biogas, clean cooking energy and sustainable development.

1.2 Research Objectives

Main Objective

1. To assess the potential of biogas for cooking in the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality

Specific Objectives

1. To examine the socio-economic and technical factors that influence the adoption of biogas.
2. To examine the likely challenges confronting the use of biogas to cook.
3. To determine the cost-efficiency of domestic biogas.

1.3 Significance of Study

It is estimated in Ghana that over 21 million people which constitutes over 4 million households use solid fuels/fuel woods for cooking which results in 13 000 deaths per year from exposure to cookstove smoke (Lambe et al., 2015; World Bank, 2014). As such, this research seeks to reduce the use of wood fuels for cooking which is inimical to human health as well as the environment.

To replace wood fuels is biogas which is a clean source of renewable energy and highly environmentally friendly. Fortunately, there exist vast biomass resources in the two municipalities under study to serve as feedstocks for the production of biogas.

Also, numerous studies have been conducted to ascertain the feasibility of institutional large-scale biogas plants in Ghana (Bensah & Brew-Hammond, 2010; Hanekamp & Ahiekpor, 2014). However, research is scanty on the use of domestic small-scale biogas plants to enhance cooking with cleaner fuels in households. Thus, this research will contribute to academic literature by filling a knowledge gap on the use of domestic biodigesters to enhance cooking with clean fuels in households. This will reduce Indoor Air Pollution (IAP), emission of GHGs and also provide a sustainable mechanism to efficiently manage household waste. This will improve the health and wellbeing of individuals especially women and children and safeguard the environment to be able to resist existential threats.

Moreover, empirical studies on biogas technology are usually done in the departments of physical sciences and environmental studies. However, due to the wake of the discussions on sustainable development to promote development which considers environmental health and posterity's well-being, it is even more relevant now for clean/renewable energy sources to be researched in the development studies field to promote sustainable development. Again, the heart of the discourse of sustainable development is the equitable access to affordable and clean energy sources. It is only when empirical works such as this are conducted that academic knowledge is broadened on alternative clean energy sources. This can help remedy energy deficit problems as well as waste management problems faced in Africa.

In a nutshell, the findings of this study will expose and expound the potential, the willingness to adopt, the cost-efficiency and the likely challenges that may confront domestic biogas.

Accordingly, this relevant information will contribute to policy recommendations on the efficient promotion and dissemination of domestic biogas targeted at the government and relevant stakeholder agencies such as the Biogas Association of Ghana (BAG) and the Environmental Protection Agency.

1.5 Organization of Study

The study is made up of five chapters. The first chapter concentrates on the background of the study, statement of the problem and the research objectives. Chapter two concentrates on thematic review of literature based on the objectives of the research. Chapter three thoroughly expounds the research methodology adopted. Chapter four concentrates on presentation and discussions of findings. Finally, chapter five concentrates on the summary, conclusion, and recommendations.

CHAPTER TWO

LITERATURE REVIEW

2.0 Introduction

This chapter thoroughly examines relevant studies that cover the domestic use of biogas, the willingness to adopt biogas, the challenges associated with the use of biogas and the cost efficiency of biogas. It is categorized into various sections based on the objectives of this study. These sections include the following: definition of terminology, energy demand in Ghana, historical antecedents of biogas in Ghana, potential for domestic biogas usage, challenges of biogas usage, willingness to adopt biogas, cost efficiency of domestic biogas and theoretical framework.

2.1 Definition of Terminologies

A review of previous understandings of key concepts that relate to the objectives of the research is necessary to enhance the understanding of various variables of the study. Also, this review will serve as a yardstick for some variables that are peculiar to the study. Specifically, this section will review the following terminologies: Clean/Renewable energy, Domestic Biogas, and Biodigesters.

2.1.1 Clean/Renewable energy

Clean energy is derived from renewable, zero emission sources that do not pollute the atmosphere when used. Renewable energy is any form of energy that is produced again and again without exhausting the source of generation (Panwar et al., 2011).Examples of renewable energy include among others solar energy, biomass energy, wind energy and geothermal energy. Though, sometimes used interchangeable, all renewables energies are considered clean but not all clean energies such as LPG are renewable (Stephenson, 2021).

For this study, clean/renewable energy is any form of energy that does not pollute the atmosphere when used and it is derived from renewable sources. An example is biogas which is a clean energy source derived from renewable sources such as organic waste, biodegradable municipal waste, animal manure and human excreta.

2.1.2 Domestic Biogas

Domestic biogas is simply the production of biogas for domestic use. Biogas is a mixture of gases produced during the anaerobic digestion of biological or organic materials (Hamid & Blanchard, 2018; Putra et al., 2019; Sarker et al., 2020). Anaerobic digestion means the breakdown of biodegradable materials without oxygen. Biological or organic materials are materials that can be acted upon by bacterial to cause a decay. The major chemical component of biogas is 50-75% Methane (CH_4) and 30-45% Carbon dioxide (CO_2).

2.1.3 Potential

Potential is derived from the Latin word "*potentia*" meaning power. It describes the ability to do something. Again, it describes something achievable or possible but not yet actual. "Potential of biogas" is simply the ability of biodegradable materials or substrates to produce sustainable energy for diverse utilization such as cooking, heating and power generation. Arthur, Baidoo, & Antwi, (2011) in their study of biogas as a potential renewable energy source in Ghana, revealed two forms of assessing biogas potential. They included the theoretical and technical potential.

The theoretical potential is based on the availability of feedstocks for the production of biogas. The available feedstocks in Ghana include agricultural residuals, livestock manures, slaughterhouse waste, municipal solid waste, municipal sewage sludge and human excreta. Their study concluded that, Ghana has a higher theoretical potential as there is readily available vast organic waste to serve as feedstocks for the production of biogas.

The technical potential concerns itself with the existing biogas technology for the production and utilization of biogas produced. It includes technical expertise, technology transfer options and the specific biogas technology needed in Ghana. It is noted that Ghana has the technical potential to construct about 278, 000 biogas plants. However, only a little over 100 have been constructed and functioning properly (Arthur, Baidoo, & Antwi, 2011; Awafo & Agyeman, 2020).

2.1.4 Feedstocks

This refers to all biodegradable materials that have the potential to generate biogas. Different kind of feedstocks have different characteristics (Awafo & Agyeman, 2020). These difference in characteristics influence a particular feedstock's ability to produce biogas. This means some feedstocks have higher biogas generation potential than others. Some examples of feedstocks include agricultural waste, food waste, animal manure, municipal waste, organic waste, human excreta and many more.

2.1.5 Biodigesters

Biogas is usually produced in a plant called biodigester. It is commonly referred to as biogas plants. A biodigester is a covered vessel in which anaerobic digestion of organic/agricultural matter occurs (Chen et al., 2012). Also, it is referred to as a bio-reactor or anaerobic reactor mainly because various chemical and microbiological reactions occur within it. The biodigester's major function is to provide anaerobic conditions for biogas production which must be air and water tight (Singh, 2017). Biodigesters come in various types and forms with different materials. The three most common types used in developing countries include the Chinese fixed dome, Indian floating drum and the Taiwanese plastic tubular (Msibi & Kornelius, 2017).

2.2 Energy Demand in Ghana

Energy is extremely crucial for the economic growth of any country. It plays a significant fundamental role in executing daily activities such as cooking, heating, lighting and powering of machines in the industrial sector (Owusu & Asumadu-Sarkodie, 2016). Again, the energy sector serves as the bedrock of which other sectors thrive to ensure economic growth and development. This is because energy is vital for the delivery of quality healthcare, transport, education, effective communication, mineral exploitation etc. This shows how important and indispensable energy is to ensure the survival and progress of humanity in our world today. Therefore, it is very obvious that energy is a determinant of economic growth and development as postulated by Kumi, (2017) and; Owusu & Asumadu-Sarkodie (2016).

Despite the enormous relevance of energy, many people in the world still suffer from lack of access to quality energy supply. An estimated number of 1.2 billion people do not have access to electricity and even more people of 2.7 billion do not have access to clean cooking energy of which majority of them are living in rural areas of sub-Saharan Africa (Asumadu-Sarkodie & Owusu, 2016). A hindrance to economic and social development is the lack of access to modern energy services and this menace surely needs to be remedied in order to achieve the United Nations sustainable development goals specifically, goal seven by 2030.

Low-income households usually found in rural agricultural communities, urban slums and peri-urban communities lack access to clean energy (Msibi & Kornelius, 2017). In fact, it is estimated that the number of people who rely on traditional biomass for cooking will rise to 2.8 billion by

2030 of which 82% reside in rural areas (Kaygusuz, 2012). Rapid population growth, quest for economic and social development and technological advancement are factors that pose major challenges to the long-term sustainability of the global energy system. If governments do not implement policies to curb the menace, it is estimated that by 2030 energy consumption will increase over half (53%), the global energy mix will remain fairly stable and dominated by fossil fuels (80% share), energy related CO_2 emissions will increase by over half (55%) and a greater number of poor people in the world will continue to lack access to modern cooking and heating services (about 2.5 billion).

Though, Ghana is very successful in Sub-Saharan Africa with respect to improving electricity access, the recent cyclical erratic power supply and the discomforts it creates reiterates the need to adopt alternative renewable energy sources to augment the energy mix of the country to meet the increasing energy demand of the rapidly growing population (Hussein et al., 2020). Kaygusuz, (2012) opined that rapid population growth especially in Africa will lead to over doubling in primary energy usage of which much is unsustainable. This will increase Africa's carbon footprint as a result of over reliance on unsustainable high CO_2 emission energy sources.

In Ghana, rapid population growth coupled with increased rural urban migration exerts much pressure on already stifled energy sources in urban areas (Asumadu-Sarkodie & Owusu, 2016; Energy Commission, 2015). This according to Kumi, (2017) is one of the major factors aside others such as over dependence on hydro and thermal power for electricity, poor tariff structure and high level of losses in the energy distribution system that has contributed to Ghana's energy crises over the years. The peak of this energy crises was experienced between the year 2013 and 2016 where Ghana lost about US$ 2.1 million in cost of production losses per day as a result of severe electricity supply challenges (Energy Commission, 2015; IEA, 2019). This severe electricity supply challenges resulted in erratic power supply which affected many businesses and households which negatively impacted economic growth and development.

In 2013, the World Bank ranked access to uninterrupted electricity as the second most relevant factor constraining business activities in Ghana and further projected that about 1.8% of Ghana's GDP was lost during the period of the power crisis. Also, in a study conducted by the Institute of Statistical, Social and Economic Research (ISSER) in 2014, it was estimated that Ghana on the average lost production worth of about US $55.8 million per month throughout the whole period of the power crises (ISSER, 2015). This constitutes about US $670 million per annum which formed 2% of Ghana's GDP in 2014 (World Bank, 2015). This means Ghana lost 2% of its GDP in 2014 due to power crises alone.

Apparently, energy demand in Ghana is increasing insistently and huge investment ought to be made in alternative renewable energy sources to help curb energy related crises. The introduction of the Renewable Energy Act, 2011 was a major stride on the part of the Ghanaian government to show its commitment to alternative renewable energy sources and promote sustainable energy for posterity's sake. However, this policy though looked good on paper, its implementation failed awfully. This is because the main aim of the policy which was to increase the contribution of RE sources by 10% in 2020 to augment the energy mix of the country has not been achieved. Currently, RE sources contribute only 0.1% of the whole country's energy mix (Energy Commission, 2015; GSS, 2019).

For Ghana to be able to implement successfully its renewable energy Act, RE policies should attract private investment and development assistants from donor countries. This will go a long way for the Ghanaian government together with investors and donors to discover more efficient and less expensive mechanisms of producing and distributing RE services. Consequently, RE sources will augment the country's energy mix to help curb any energy related crises.

2.2.1 Renewable Energy Demands

The lack of clean and affordable energy has caused the over reliance on insufficient unsustainable use of biomass fuels such as charcoal, fuelwood, animal waste and animal dung in sub-Saharan Africa especially Ghana (Kamp & Østergård, 2016; Präger et al., 2019). This is a clear manifestation of the high level of energy poverty and the share negligence of the potentials of RE sources in diversifying the energy mix on the continent (Awafo & Agyeman, 2020; Msibi & Kornelius, 2017). Renewable energy technologies are extremely vital for social and economic development. Though, they cannot single-handedly alleviate poverty, they are essential for the attainment of the sustainable development goals.

The target of sustainable development goal 7, (affordable and clean energy) is to facilitate access to clean energy through international cooperation, research and technology development by 2030. A major objective for the achievement of this goal by 2030, is to promote RE sources as alternative sources of energy which will diversify the global energy mix and most importantly safeguard the environment. This means RE sources are sustainable as they replenish themselves naturally at a rate faster than they are depleted. Energy transition from other unsustainable energy sources such as fossil fuels to RE sources such as biogas protects the environment now and the future. As such, global environmental problems such as global warming will be curbed and prevent any potentially irreversible threat to human societies.

RE sources can enhance the living conditions of people in many ways (Ankrah & Lin, 2020). For instance, installed solar panels can power lights when there's power outage from the regular electricity grid. In rural communities where the regular electricity grid does not reach, RE sources such as biogas could be explored for heating, cooking and to power lights. RE sources such as biogas for cooking in rural communities will prevent indoor air pollution, thereby improving the health conditions of rural people. Also, women and children will be saved from wasting much time and going far distances just to search for fuelwood to cook. The time and energy of rural women and children will then be channeled into other productive activities such as farming, pottery and baking (Arthur & Brew-Hammond, 2010; Kemausuor et al., 2014). This will improve living conditions and enhance economic growth and development.

Ghana is endowed with enormous renewable energy resources (Kemausuor et al., 2014; Mensah et al., 2021; Mohammed et al., 2017). With the need to increase access to clean energy in Ghana and promote sustainable development, one will think much has been or is been done to enhance the deployment of RE services given the enormous RE resources the country has. The major stride achieved in RE services and deployment is the establishment of the Renewable Energy Act of 2011 by the government of Ghana. Even that, Ankrah in a 2020 study referred to the Renewable Energy Act as generic and lack implementation plan. The main objectives of the Act have not been achieved. The worst of it, is the gradual shift from hydro generated power to thermal energy which is not clean and sustainable (Asumadu-Sarkodie & Owusu, 2016; Kemausuor et al., 2016; Kumi, 2017).

Subsequently, the foremost energy sources utilized in Ghana are not sustainable. The dominant energy source for cooking is traditional biomass namely charcoal and fuelwood (GSS, 2019). The leading energy source for electricity is thermal energy (Energy Commission, 2015). The situation in the two municipalities under study is not different from that of the national level. In both municipalities, traditional biomass (charcoal and fuelwood) is the dominant energy source for cooking (GSS, 2019).There are no records of renewable energy sources being used for cooking in the Nsawam Adoagyiri municipality (GSS, 2013). However, in the Awutu Senya East municipality, there is evidence of biogas technology being utilized to generate biogas from human excreta from a public toilet facility (Osei-Marfo et al., 2018). Even that, the biogas generated was not used for cooking but to power lights of the facility in case of power outages. According to Kaygusuz, (2012), fossil fuels are the dominant energy source constituting about 82% of global energy demand in 2008 and forecasted at 78% in 2030. This implies the need to transition from fossil fuels to renewable energy sources to safeguard the global environment. Again, reducing fossil fuel use will highly alleviate the emission of GHGs to curb global warming and climate change issues.

Consequently, RE options such as solar and biogas are very critical in the provision of sustainable energy to safeguard the environment especially, mitigating climate change. However, the global share of RE in energy consumption is still very low. RE contributes about only 12.9% exajoules (EJ). Interestingly, there is more room for Ghana to improve its RE technologies to produce and deploy RE services cheaply and efficiently given the higher potential of RE resources to produce sustainable energy (Ankrah & Lin, 2020; Kamalimeera & Kirubakaran, 2021; Kemausuor et al., 2014; Marie et al., 2021).

2.3 Historical Background of Biogas

It is believed that as early as 900 BC, the Assyrians used biogas for heating water to bath (Bond & Templeton, 2011). At a point in history, the Chinese are reported for transporting biogas through pipes made of bamboo for heating (Edem Cudjoe, 2010). However, Van Helmont in 1630 observed flammable gases coming from decaying vegetables and accordingly attributed to modern biogas.

Consequently, further research has been done to improve the development of biogas plants and the production of large-scale biogas to supplement the global energy mix.

In the context of Africa, as a result of rapid population growth, the demand for energy surpasses the supply of energy (Parawira, 2009) which intensifies the energy poverty situation in Africa as more people lack access to energy. This demonstrates the dying need of Africa to diversify energy sources since there is large potential for renewable energy sources such as biogas (Khan, 2020). Albeit, biogas development, its acceptance and adoption is largely low in Sub-Saharan Africa (Ali et al., 2020). 'Biogas for a better life', an African biogas initiative by the African Biogas Partnership Programme in 2007 envisioned to change the lives of over two million Africans through the use of biogas as a clean energy source for cooking (Patinvoh & Taherzadeh, 2019). As a follow up, many biogas plants were developed but many of them failed due to poor technical ability and poor maintenance culture (Edem Cudjoe, 2010; Holt & Pengelly, 2008). This made the biogas technology very daunting and many more people lost interest in the technology. Presently, many African countries are realizing the enormous benefits of the technology which has led to many installations of biogas plants across the continent (Patinvoh & Taherzadeh, 2019). Leading biogas technology Sub-Saharan countries such as Kenya, Rwanda and Tanzania are gradually using the technology efficiently to provide energy for rural low-income households (Mukeshimana et al., 2021).

Biogas evolution in Ghana is categorized into three stages namely, experimental stage (before 1990), non-supportive stage (1990-1999) and current/private initiative state (2000s-to date) (Arthur, Baidoo, & Antwi, 2011; Bensah et al., 2011).

Experimental Stage (before 1990)

The use of cow dung, charcoal and wood fuel as a source of energy for cooking has been an age long practice in Ghana, especially in rural and peri-urban communities. The need for alternative fuel arose due to the continuous depletion of wood fuel sources for cooking and its adverse effect it has on the environment and human health (Arthur, Baidoo, & Antwi, 2011). Biogas technology was quickly noticed as a viable alternative energy source for cooking especially in rural agricultural communities where there is abundance of feedstocks. This new interest in biogas technology according to Arthur, Baidoo & Antwi, (2011) began in the 1960s but it was until the 1980s that it got the necessary attention from the Ghanaian government. The focus of the government in the deployment of the technology in the 1980s was to provide alternative fuel source for household cooking. Also, State-led research and development into the biogas technology began. Also, training of engineers and technicians in the design, construction and management of biogas plants/biodigesters.

Subsequently, a 10 m^3 Chinese fixed doom demonstration biogas plant was established in 1986 at Shai Hills in the Greater Accra Region by the Ministry of Energy with the support from the Chinese government. A year on in 1987, a couple of two household demonstration biogas plants were constructed in Jisonayili and Kurugu in the Northern region through the support of the United Nations Children's Fund (UNICEF). Another milestone achieved by the government in the deployment of biogas technology within this same time period was the state-led community biogas project at Appolonia, Appolonia is cattle rearing village located some 46km from Accra. The Appolonia biogas plants relied on cow dung and human excreta as feedstocks to generate 12.5KW electric power for cooking and heating. The bio-slurry was used as organic fertilizer to boost agricultural produce in the community. A total of 19 fixed doom biogas plants were constructed in Appolonia (Arthur, Baidoo, & Antwi, 2011; Bensah & Brew-Hammond, 2010). These biodigesters were constructed by engineers of Ministry of Energy (MoE) and the Institute of Industrial Research (IIR) (Arthur & Brew-Hammond, 2010).

Non-Supportive Stage (1990-1999)

In this second stage, government suddenly pulled out from the promising biogas technology deployment that had begun. This according to Bensah & Brew-Hammond, (2010) was as a result of the breakdown of many of the established biogas plants. Some of the reasons cited for the breakdown of these plants included inter-alia, bad maintenance culture, expensive cost of maintenance, poor biodigester designs and unavailability of feedstocks.

However, NGOs such as the German Agency for Technical Assistance (GTZ) and the Catholic Secretariat took off from where the government left off to promote the deployment of biogas technology in Ghana (Awafo & Agyeman, 2020; Awuah & Oduro-kwarteng, 2020; Bensah et al., 2011). Subsequently, GTZ trained and built the capacity of Ghanaians to become biogas technicians. They also funded the construction of many biogas plants in the country. Notable amongst them is the Ejura slaughterhouse biogas plant and the department of Animal science biogas plants of the Kwame Nkrumah University of Science and Technology (KNUST) (Awafo & Agyeman, 2020; Bensah et al., 2011). Moreso, the Catholic Secretariate funded a number of biogas projects in Catholic-administered hospitals in Battor, Nkawkaw and Akwatia (Kemausuor et al., 2014).

Current/Private Initiative State (2000s-to date)

This stage is characterized by the involvement of private biogas companies as the main promoters of biogas technology dissemination. Biogas Technology West Africa Limited (BTWL), is the leading biogas company promoting the dissemination of the technology in Ghana (Arthur & Brew-Hammond, 2010). Their success in the biogas industry is a result of their marketing strategy which focuses on promoting biogas as a means of managing waste. Thus, biodigesters are able to replace septic tanks and also produce an alternative energy source (Kemausuor et al., 2014). As such, their customers are mostly satisfied with the waste management aspect and careless about alternative energy provision. Also, their customer base is largely made up of institutions rather than households. This indicates that biogas technology dissemination in recent times, is more institutional focus and not household focused (Aklaku et al., 2006; Awafo & Agyeman, 2020; Edem Cudjoe, 2010; Kemausuor et al., 2018).

2.4 Potential for Domestic Biogas Usage

Access to affordable and clean energy in Africa and Ghana especially is very essential for the attainment of sustainable development (Kaygusuz, 2012; Owusu & Asumadu-Sarkodie, 2016). The type of energy and how it is technically utilized has direct impact on the livelihood of the people. For instance, the energy sources employed by people affect their health. Cooking with biomass increases indoor air pollution which can sometimes be fatal. It is estimated that about 13 000 people per year die as a result of exposure to cookstove smoke (Lambe et al., 2015). This explains why the source of energy employed is very fundamental to promoting sustainable development. In the view of Kemausuor et al., (2014), acess to clean energy has a direct effect on the development agenda of the country as well as the achievement of the sustainable development goals.

Biogas, a RE source in recent times has gained much popularity in the discussions of sustainable clean cheaper energies especially in Africa. This is because, there is evidence of energy poverty in the continent (Diouf & Miezan, 2019; Dumont et al., 2021), over reliance on traditional biomass (Khan, 2020; Präger et al., 2019) and the vast availability of feedstocks to feed biodigesters for the production of biogas (Arthur, Baidoo, & Antwi, 2011; Cudjoe et al., 2021; Issah et al., 2020). Biogas provides a unique opportunity for Africa to increase its clean energy access, safeguard the environment and efficiently manage waste. Biogas is obviously the answer to Africa's long-lasting problem of energy poverty, energy related environmental pollution and poor waste management.

Kemausuor et al., (2014), in their study of the assessment of biomass availability and bioenergy yields concluded that Ghana has higher potential for the production of biogas. The abundance of food waste, organic waste, animal manure and the general problem of sanitation and waste management in Ghana creates a viable condition for the production of both domestic biogas and industrial biogas (Cudjoe et al., 2021; Kamp & Østergård, 2016; Scarlat et al., 2018). This is because, the abundant municipal waste, food waste and organic matter will serve as feedstocks to feed biodigesters for the production of biogas. Again, the age-old problem of sanitation will be solved as waste will be turned into clean gas to be used by low-income household. Moreover, the digested sludge from anaerobic digesters will be used as highly rich nutrients organic fertilizers to fertilize farm lands (Präger et al., 2019).

The adoption of clean and renewable sources of energy enhances the achievement of many of the SDGs for Ghana. This means adopting biogas as a clean and renewable energy source for cooking is very vital to ensure Ghana's sustainable development (Mensah et al., 2021). Table 2.1 below throws more light on how biogas contributes to the achievement of many SDGs.

Table 2.1: Contribution of Biogas to SDGs Achievement

SDGs	**Contribution of biogas to goal achievement**
Goal 2 No Hunger	Highly rich in nutrients (Nitrogen and Phosphorous) digestate is used as organic fertilizer which serves as soil ameliorator. Soil rich in nutrients will increase agricultural yields and further improve food security. • The bio-slurry is used as insecticides and pesticides to fight against insects, army worm and rodents which attack plants and cause low agricultural yield. This practice is very common in Tanzania and Kenya where biogas is very popular. Effectively repelling plant insects and pests attack will increase agricultural yield and lead to bumper harvest. • Bio-slurry is used for fish farming. Rich nitrogen and phosphorous embedded in the slurry are used to enhance the growth of zooplankton and phytoplankton which fishes feed to grow healthier and bigger for human consumption. • Digestate can be sold by biogas plant owners as organic fertilizer. This will increase income which can be used for business or buy food to feed the family.

Goal 3 Good health and wellbeing	• Household energy transition from fuelwood to biogas completely eradicate Indoor Air Pollution (IAP). This improves the health and wellbeing of especially women and children as they are not exposed to cookstove smoke. • Biogas readily available for household cooking reduces time waste of women and children who go far distances in search of fuelwood to cook. This will reduce neck, back and spinal cord pain which is associated with carrying heavy loads on the head. This will improve the wellbeing and health of children and women. • Anaerobic digestion (AD) of bio-degradable materials has proven to be an effective and efficient way of managing waste. This prevents various forms of pollution such as water pollution, air pollution and land pollution. Prevention of pollution improves human health and wellbeing. • Also, using biogas to cook do not emit greenhouse gasses which causes global warming. This safeguards the environment and makes it wholesome for human survival and development.
Goal 6 Clean water and sanitation	• AD is an effective and efficient way of managing waste. This prevents waste from being washed into water bodies to contaminate it. This improves sanitation and makes water clean. • AD is used to recycle waste water for reuse. Untreated sewerage washes down to water bodies and cause pollution. Recycling waste water prevents it from being washed into water bodies to cause pollution.

Goal 7 Affordable and clean energy	• Biogas usage prevents the over reliance on fossil fuels which are not clean. Fortunately, biogas is a clean renewable energy source which poses no threat to the environment. • Biogas is a sustainable energy and its utilization have no adverse effect on the environment now and future.
Goal 9 Industry, Innovation and Infrastructure	• Biogas is an innovation which brings together industries, bio-digester installers and adopters of biogas to design innovative digesters for mutual benefit. • Biogas technology creates an avenue for innovative employment. Different categories of artisans are needed in the value chain of biogas production. It includes technicians, installers, carpenters, masons, steel benders etc.
Goal 13 Climate Action	• AD prevents the emission of GHGs such as CO_2 into the atmosphere. Biogas usage prevents the over dependence on fossil fuels which emits GHGs which causes global warming. • Biogas usage prevents deforestation. Energy transition from fuelwood to biogas prevents the cutting down of tress for fuelwood purposes. Prevention of deforestation reduces the emission of GHGs which are very harmful to the environment.
Goal 15 Life and Land	• Eutrophication and algal formation which causes environmental challenges to water bodies are prevented through the AD treatment of biodegradable waste.

	• AD prevents land pollution.

Source: (World Bioenergy Association, 2016); and www.africabiogas.org

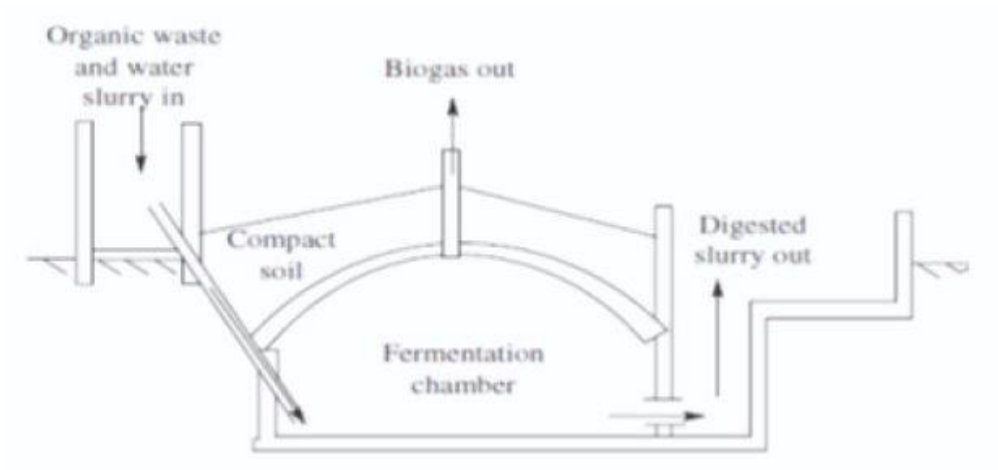
2.4.1 Types of Biodigesters/Plants in Ghana

Three main types of biodigesters have been constructed and efficiently diffused in Ghana. They are the Chinese fixed-dome, Indian floating drum and Chinese Puxin biodigesters.

Chinese Fixed-dome

Fixed-dome biodigesters are comparatively cheaper than the other types of biodigester. As such, many fixed-dome biodigesters are constructed in Ghana (Arthur, Baidoo, & Antwi, 2011; Arthur, Baidoo, Brew-Hammond, et al., 2011). Its major components include a dome-shaped biodigester, gasholder and a displacement pit also known as 'compensation tank'. Gas is usually stored in the upper part of the biodigester and the slurry is displaced into the compensation tank.

Figure 2.1: Chinese Fixed Dome

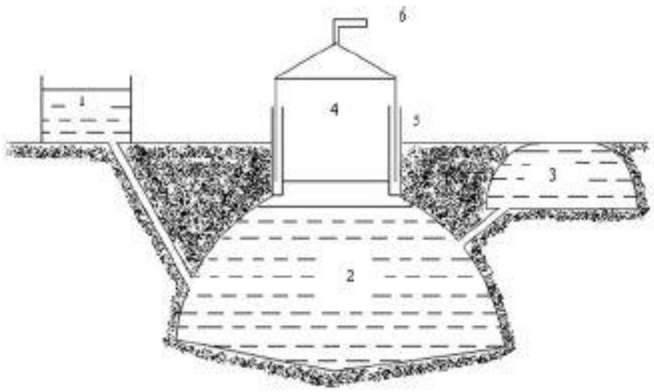


Source: (Gautam et al., 2009)

Indian Floating Drum

The floating drum is mostly suitable for digesting fibrous feedstocks such as slaughterhouse waste (Amankwah, 2011). This is because the gasholder can be detached and cleaned to remove scums whenever it forms. The major components of the floating drum are an underground digester and a removable gasholder as shown in figure 2.2. Gas is usually collected in the gas drum. This type of biodigester is relatively expensive because of the steel-drum. As such, it is costly to construct and maintain (Bensah et al., 2011). Hence, it is not advisable as a household digester (Edem Cudjoe, 2010; Kemausuor et al., 2014; Osei-Marfo et al., 2018). From figure 2.2 below, 1 is the mixing tank with inlet pipe, 2 is the biodigester, 3 is the compensation tank, 4 is the gasholder, 5 is the water jacket and 6 is the gas pipe.

Figure 2.2: Floating drum Biodigester

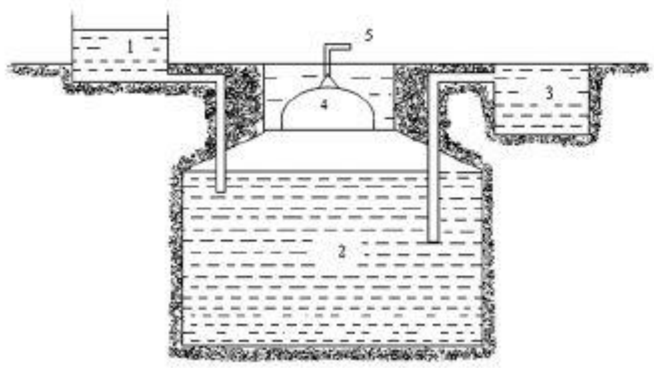


Source: (Arthur, Baidoo, & Antwi, 2011).

Chinese Puxin Biodigester

This is a hydraulic pressure biodigester. It is made up of a fermentation tank built with concrete, a gasholder made with glass fibre reinforced plastic and a digester outlet cover made with glass fibre reinforced plastic (Arthur, Baidoo, Brew-Hammond, et al., 2011; Mohammed et al., 2017). As shown in figure 2.3 below, the gasholder is fixed within the digester neck. According to Arthur, Baidoo, & Antwi, (2011), the mesophilic temperature range for biogas production is 20-40 degrees Celsius. Ghana's annual temperature is 25 degrees Celsius which means most biodigesters operate well within mesophilic temperature (Amankwah, 2011; Bensah et al., 2011; Kemausuor et al., 2015). From figure 2.3 below, 1 is the mixing tank with inlet pipe, 2 is the biodigester, 3 is the compensation tank, 4 is the gasholder, 5 is the water jacket and 6 is the gas pipe.

Figure 2.3: Chinese Puxin Biodigester



Source: (Arthur, Baidoo, & Antwi, 2011).

2.5 Challenges of Biogas Dissemination

Despite the high potential and opportunities for biogas production in Africa and Ghana as a specific case in point, challenges associated with the technology has really limited the diffusion of the technology to the larger population (Abunde Neba et al., 2020). These challenges have stifled the adoption, spread and acceptance of biogas technology for both domestic and industrial scale production of biogas. These challenges can be categorized broadly under four themes namely, Technical and Infrastructure challenges, Financial challenges, Socio-cultural challenges and Policy and Institutional Challenges (Abunde Neba et al., 2020; Mukeshimana et al., 2021; Patinvoh & Taherzadeh, 2019).

2.5.1 Technical and Infrastructure Challenges

A major barrier to the dissemination of biogas technology in Africa likewise Ghana is the nonexistence of an established sustainable technology. There exist in Africa vast biomass resources to serve as feedstocks to feed biodigesters for the production of biogas. However, due to inadequate technology these rich biomass resources are not utilized efficiently. For instance, Mukeshimana et al., (2021) identified poor biodigester designs resulting from the lack of standards for the construction of biodigesters as the main technical challenge that limit the dissemination of biogas technology. They argued that biogas technicians in Africa do not have the requisite skill to construct standardized biodigesters for the efficient and sustainable production of methane gas. A wrong biodigester design reduce the production of biogas. This is because every feedstock type requires a specific biodigester design as feedstock composition determines the rate of biogas production. For example, a biodigester designed to degrade cow dung for the production of biogas differs from the one designed to degrade food waste. Nonetheless, through research and development, new biodigesters that can degrade different types of feedstocks are available but not common in Africa (Bensah & Brew-Hammond, 2010; Kemausuor et al., 2014).

Kemausuor et al., (2018) observed that adopters of biogas technology do not necessarily understand the rudiments of the technology. Hence, the poor maintenance of biodigesters which accounts for the breakdown of many biodigesters in Africa. This makes biogas technology very daunting which adversely affect the diffusion of the technology.

2.5.2 Financial Challenges

Lack of capital is central in many developmental challenges faced in Africa. The diffusion of biogas technology into the larger population is highly limited by inadequate funds. The initial and maintenance cost of biodigesters is noted to be very expensive in Africa (Arthur, Baidoo, Brew-Hammond, et al., 2011; Awafo & Agyeman, 2020). This makes it very difficult for potential adopters who are usually from low-income households to adopt the technology. Additionally, there is lack of adequate financial mechanisms such as subsidies instituted by African governments to augment the diffusion rate of biogas technology (Patinvoh & Taherzadeh, 2019). For instance, the government of Ghana specially has no structured subsidies to absorb the costs components of biodigesters to increase the adoption rate of biogas technology (Amankwah, 2011; Bensah et al., 2011; Edem Cudjoe, 2010; Osei-Marfo et al., 2018).

Moreover, it is extremely difficult to access financial services such as loans to finance biogas project from commercial banks in Africa (Kemausuor et al., 2018; Mukeshimana et al., 2021). This is due to the low rates of investment returns and the long payback period associated with biogas projects. This renders biogas projects economically inviable. Hence, biogas projects are considered by commercial banks as high-risk ventures of which they are not willing to invest.

2.5.3 Policy and Institutional Challenges

Biogas is a renewable energy source which can be used singled-handedly to solve Africa's waste management problem and energy poverty. However, there are little and sometimes no governmental commitment in the renewable energy space (Patinvoh & Taherzadeh, 2019). Such governmental commitments include inter alia renewable energy policy and clear implementation plan, strong institutional support to biogas technology, provision of biogas information through knowledge sharing and adequate financial mechanisms to support biogas development. (Mukeshimana et al., 2021) noted that Tanzania, Rwanda and Kenya who are amongst the leading countries in Africa with the highest adoption of biogas technology, owe their success to having a strong institutional support to biogas programmes and projects. This in the views of Mukeshimana et al., (2021), heightened the promotion of biogas technology which increased awareness and led to increased adoption of the technology.

In Ghana, there exist a renewable energy Act which legitimizes the promotion, adoption and utilization of biogas technology. However, this Act has been described as generic and lacks implementation plan (Ankrah & Lin, 2020). This is as a result of the lack of a clear implementation plan to ensure the objectives of the RE Act are achieved.

2.5.4 Socio-Cultural Challenges

A major barrier to the dissemination of biogas technology in Africa is socio-cultural challenges such the preference to cook with cheap biomass resources, lack of formal education and environmental health illiteracy and the low involvement of women in the adoption process of biogas technology (Issah et al., 2020; Mukeshimana et al., 2021; Patinvoh & Taherzadeh, 2019).

In the African continent, most women prefer to cook with cheap biomass resources such as cow dung, charcoal and wood fuel (Issah et al., 2020). This preference of biomass resources competes with feedstocks availability for the production of biogas. This is because theoretically every biomass resource is a penitential feedstock for the production of biogas. A shortage of feedstock which is likely to arise because of this competition will lead to low biogas production.

Also, lack of education and environmental illiteracy limits the dissemination of biogas technology (Mukeshimana et al., 2021). The level of education of an individual is directly proportional to his or her knowledge about environmental health which influences the adoption of biogas technology. A lower level of education will lead to adverse perception of biogas technology which will limit its adoption and diffusion in the larger population.

Moreover, the low involvement of women in the adoption process of biogas technology is identified as one of the challenges confronting biogas dissemination in Africa. Usually in Africa, the number of women who cook is higher compared to men. This requires thoroughly targeting and involving women in any technology adoption process which improves cooking fuel. However, this is not the case as many women are not involved in the adoption process of biogas technology

(Mukeshimana et al., 2021). This has resulted in the lack of awareness and the social acceptance of biogas technology.

2.6 Willingness to adopt Biogas

Biogas technology is widely known as a clean RE which is environmentally friendly and can help African countries to diversify energy sources to curb the lack of access to clean energy problem. However, biogas technology has not really diffused into the larger populations in the continent (Mukeshimana et al., 2021).

Many research works conducted on the factors that influence the adoption of biogas suggest a host of reasons that influence the willingness of Africans to adopt biogas (Arthur, Baidoo, Brew-Hammond, et al., 2011; Hamid & Blanchard, 2018; Putra et al., 2019; Sarker et al., 2020; Stephenson, 2021). They include feedstocks availability, availability of subsidies, environmental concern, knowledge of biogas, cost of other energy sources and the educational levels of people.

2.6.1 Feedstocks Availability

All biodegradable materials are suitable as feedstocks so far as they are readily available in vast quantity. Feedstocks are usually classified based on their sectors of origin. Such classifications include agricultural, industrial, aquatic waste and municipal waste (Putra et al., 2019). Feedstocks do not only differ based on classification of origin. They also differ by their potential to provide biogas. Theoretically, every feedstock can be degraded through AD for the production of biogas (Bond & Templeton, 2011).

However, some feedstocks/substrates are more potent than others with respect to the production of methane which is the major gas component in biogas. For instance, Bond & Templeton, (2011) argue that animal manure especially that of pig and cow is very potent for the production of biogas. This is because of the presence of methanogenic bacteria in the stomach of ruminants. Abunde Neba et al., (2020) observed that the abundance of animal manure as feedstocks for the sustainable production of biogas in rural Kenya, Rwanda and Tanzania is part of the reasons why biogas is quite popular in these African countries. The unsustainable production of methane gas resulting from low potent feedstocks discourage the adoption of biogas technology (Amankwah, 2011). In his studies among farmers in the Northern region of Ghana, Amankwah (2011) revealed that the unsustainable production of methane gas from low potent feedstocks makes biogas technology unreliable. Also, the type of feedstock available determines the type of biodigester to use and the amount of gas to be generated. The combination of the type of biodigester and its associate feedstock material determines the retention period for gas to be produced. For instance, the use of livestock biodigesters to degrade cow dung takes approximately 60 days as the retention time for biogas to be produced (Khan, 2020).

Furthermore, Feedstocks with nitrogen to carbon ratio ranging between 20 and 30 is preferably easy for microorganisms to act on substrates for the production of biogas. Roubík & Mazancová, (2020) posit that such biogas produced under the correct ratio of nitrogen to carbon is optimized in nature and does not require further treatment to remove excess carbon or nitrogen. They further revealed that feedstocks with either excess nitrogen or carbon have a high potential of causing damage to biodigesters. A typical example of feedstocks with high nitrogen and carbon content is straw and urine. Human excreta, cow and pig dung are examples of suitable feedstocks with optimum nitrogen to carbon ratio. In fact, animal manure and human excreta are feedstocks which fall within the required solid content of feedstocks for the optimum production of biogas which is between 5-10% (Dumont et al., 2021; Silaen et al., 2020). The solid content of feedstocks is very necessary especially in Africa where biodigesters are of low standard and quality. Biogas technology thrives in areas where there is enough animal manure and human excreta which are potent feedstocks for the sustainable production of biogas (Abunde Neba et al., 2020; Amankwah, 2011).

In recent times, through research and development particularly in Europe, the cultivation of energy crops to serve as feedstocks is being exploited (Kamp & Østergård, 2016). Subsequently, crops such as maize, sugar beet, barely, etc. are being cultivated as energy crops to be used as feedstocks for the optimum production of biogas. Again, through research and development, much attention is been given to biodigesters with the capability to degrade two different types of feedstocks for the efficient and sustainable production of biogas (Mohammed et al., 2017). Table 2.2 below shows the general characteristics and the biogas yield of various feedstocks.

Table 2.2 Characteristics of Feedstocks

Feedstocks Type	**% DM**	**Biogas Yield (m^3/kg DM)**
Pig manure	17	3.6-4.8
Cow manure	16	0.2-0.3
Chicken manure	25	0.35-0.8
Human excreta	20	0.35-0.5
Maize	20	0.25-0.40
Barely	25	0.62-0.68
Rice straw	87	0.18

DM = dry matter. Biogas yield is based on mean biogas yield (m3/kg DM) which is calculated from methane yield based on biogas of 55% methane.

Source: Adopted from table 1 of the work of (Bond & Templeton, 2011) p. 350

2.6.2 Availability of Subsidy

Quite a number of studies have suggested that the initial cost of biodigester installation is very expensive especially in Sub-Saharan Africa where poverty is high (Asibey et al., 2021; Hussein et al., 2020; Parawira, 2009). This high initial cost is said to have deterred a number of numerous potential adopters of the biogas technology within the African continent (Arthur & Brew-Hammond, 2010; Bensah et al., 2011; Edem Cudjoe, 2010). Präger et al., (2019) argue that another cost component that deter potential adopters from adopting biogas technology is the high maintenance cost. These very high-cost components attached to biogas technology which is drastically limiting its dissemination can be resolved through the provision of subsidies.

In Asia, specifically China, Nepal and India where domestic biogas is very popular, the provision of subsidies by their respective governments to cover both initial and maintenance cost has been the major breakthrough for the mass adoption of the technology (Parawira, 2009; Präger et al., 2019). This makes subsidies indispensable in the strategies to enhance the dissemination of biogas technology. This is because, Parawira, (2009) observed that in Asia, subsidies were used to entice prospective adopters of biogas technology. This led to the massive adoption of the technology among low-income households. In Tanzania, Kenya and most recently Ethiopia, their respective governments have made available some subsidies to boost the dissemination of biogas technology (Ali et al., 2020). No wonder these countries are among the top three countries in Africa with the highest household biodigesters installed.

For the massive adoption and utilization of biogas technology, subsidies should be targeted at low-income households. These subsidies should cover the entire biogas installation process, maintenance cost and the provision of clean cooking biogas stoves (Diouf & Miezan, 2019; Kamalimeera & Kirubakaran, 2021). This will enhance the adoption of the technology and reduce the use of fuel wood for cooking which will safeguard lives and the environment. The absence of subsidies stifles the dissemination of biogas technology and makes the technology very expensive for people to adopt (Roubík & Mazancová, 2020). Hence, potential adopters become very reluctant to adopt the technology.

2.6.3 Environmental Concern

Globally, it is estimated that 2.7 billion people still rely on traditional biomass as an energy source for cooking (Kaygusuz, 2012). In Ghana, charcoal and wood fuel remain the dominant energy sources for household cooking with each accounting for 34.1% and 33.3% respectively (GSS, 2019). This heavy reliance on biomass sources for cooking has increase the depletion of forest cover in Ghana (Oduro et al., 2012). Forest degradation as a result of depletion of forest cover leads to the emission of GHGs which causes adverse climate change. Also, improper management of waste which is very common in major cities in Ghana have adverse effect on the environment (Kuuzegh, 2014). Municipal solid wastes which are not properly disposed end up being washed into the sea or on landfill sites which causes various forms of pollution which is inimical to human health and the environment. As such, to safeguard the environment and also meet energy needs for cooking, a RE source such as biogas is highly recommendable.

Biogas is a clean energy source that can be used as an alternative source of energy to augment the energy mix for cooking, heating and generating electricity (Aklaku et al., 2006; Edem Cudjoe, 2010). The bio-slurry from AD can be used as organic fertilizer to fertilize crops. This will increase agricultural produce and enhance food security. Again, bio-slurry in the form of organic fertilizer safeguards the environment as it has no adverse side effect to the environment. Arthur, Baidoo, & Antwi, (2011), posit that MMDAs are usually overwhelmed with the high tonnes of municipal waste such that its efficient management becomes problematic. Hence, the long-standing problem of sanitation which is due to the improper management of municipal waste. Biogas technology brings forth a unique mechanism to efficiently manage waste and produce cheaper and cleaner energy for cooking (Arthur, Baidoo, Brew-Hammond, et al., 2011; Cudjoe et al., 2021). This will be done through the replacement of septic tanks with biodigesters which will degrade biodegradable materials to produce clean biogas which will serve as an alternative source of fuel for cooking. This simple process is noted to be the most efficient and cost-effective way to manage municipal waste (Amankwah, 2011; Edem Cudjoe, 2010; Kemausuor et al., 2018). This is because waste will be converted to energy which will solve the problem of improper waste management and energy poverty in Ghana.

2.6.4 Knowledge of Biogas

Biogas is noted as a sustainable energy source with enormous benefits to humans and the environment. It drastically reduces IAP and improves the health and wellbeing of individuals especially women and children who are most vulnerable. It reduces the time spent by women and children in search for fuel wood for cooking. Biogas is smokeless and it does not emit GHGs which cause adverse climate issues such as global warming.

Nevertheless, the lack of knowledge of these enormous benefits of biogas adversely affects its dissemination and utilization by the larger population (Bensah et al., 2011; Hes et al., 2017).

Knowledge and perception are vital factors that influences an individual to adopt biogas technology. An individual's knowledge about the benefits and cost efficiency of biogas technology will determine his adoption rate. A positive perception which is gained through the increased knowledge of the potential benefits of biogas at a minimal cost will enhance its diffusion into the larger population (Marie et al., 2021). Putra et al., (2019), observed that knowledge and perception are influenced by one's educational level, publicity of the technology and demonstration results of the technology.

An individual's level of education is directly proportional to his adoption rate (Putra et al., 2019). This means individuals with higher levels of education have higher probability of adopting biogas technology. Individuals with higher levels of education have better understanding of the relevance of biogas as a sustainable energy source than individuals with lower levels of education. Putra et al., (2019) in their study of the diffusion process of biogas in India, realized that people with higher levels of education were among the early adopters of the technology. Conversely, they realized that the late adopters' category was dominated by people with lower levels of education.

Knowledge of biogas is greatly influenced by how the technology is publicized. Publicity of biogas technology is done through both traditional and social media. Yan et al., (2021) observed that knowledge of biogas increased among rural settlers in China after being exposed to media communication channels such as television, newspaper, radio, magazine and other social media platforms.

Diffusion of biogas technology is greatly influenced by demonstration results shared among peers. In India, positive information shared by users of domestic biodigesters increased the adoption rate of biogas technology in the rural agricultural areas (Panwar et al., 2011; Putra et al., 2019). Again, such demonstration results are sometimes shared by installers themselves. In Ethiopia for instance, installers of biogas companies are among the top communication channels through which biogas technology is disseminated (Marie et al., 2021).

2.6.5 Cost of other Energy Sources

Most households use different energy sources for different purpose. In Ghana for instance, hydro power is used to generate electricity to power electrical appliances whiles charcoal, LPG, fuelwood and animal manure is used for cooking. Even different energy sources are exploited for cooking in Ghanaian households. For instance, Hanekamp & Ahiekpor, (2014) posit that about 89% of LPG users use charcoal as alternative cooking fuel to serve as back up when there is shortage of gas or gas in the cylinder abruptly finishes. This implies that alternative energy sources for cooking do exist in Ghanaian households and a choice of a particular energy source is determined by its price.

Higher prices in clean sources of energy increases the adoption of other alternatives sources of energy. Bensah & Brew-Hammond, (2010) attribute the heavy reliance of many Ghanaian households on biomass sources for cooking due to the higher price of LPG. Biomass sources such as charcoal and fuel wood are very cheap as compared to LPG. This indicates that biogas will be adopted rapidly by the larger population when it is made cheaper than other sources of cooking fuel.

In Asia where biogas is heavily exploited, the cost components of biogas is mostly adopted by government and NGOs which makes biogas relatively cheaper for low-income households to afford and adopt the technology (Sarker et al., 2020; Stephenson, 2021).

2.7 Cost efficiency of Domestic Biogas

Biogas deployment usually comes with a high level initial cost which is considered a major hindrance to the wider acceptance of biogas technology in the African continent (Diouf & Miezan, 2019). Again, the high cost of maintenance is also considered a major hindrance for potential adopters to adopt biogas technology (Arthur, Baidoo, Brew-Hammond, et al., 2011; Kemausuor et al., 2014). Even though potential adopters may be willing to adopt biogas technology, these cost components attached to biodigesters deter them. This has sparked a big debate in the biogas technology literature as to whether "biogas is really cheap" (Ali et al., 2020; Cudjoe et al., 2021; Issah et al., 2020; Khan, 2020). This is due to the fact that biogas is often described as a cheap alternative source of energy. A handful of writers in the biogas technology space have questioned 'how cheap biogas is " (Diouf & Miezan, 2019; Kamalimeera & Kirubakaran, 2021; Roubík & Mazancová, 2020)

The later school of thought ground their arguments in the high initial cost of biodigester installation as well as the high maintenance cost of biodigesters. Diouf & Miezan, (2019) for instance, argue that the major hindrance of biogas diffusion into the larger population in the African continent especially is as a result of the higher cost components embedded in the installation and maintenance of biodigesters. They continue to argue that, the main reason for the over reliance on biomass sources for cooking in sub-Saharan Africa is as a result of Africans inability to afford other clean energy sources such as LPG. In their view, LPG is very expensive for majority of Africans to afford. Hence, the over reliance on biomass sources such as charcoal, fuel wood and animal manure for cooking (Kaygusuz, 2012; Venkata Ramana et al., 2015).

The former school of thought argue that the environmental benefits and the long term benefit of biogas usage is relatively cheaper than other sources of energy (Arthur & Brew-Hammond, 2010; Edem Cudjoe, 2010; Hes et al., 2017). They further argue that subsidies are very important to offset the higher cost components of biodigesters. Thus, subsidies should cater for both initial cost of installation and the maintenance cost of biodigesters. Scholars in this school of thought make use of economic valuation techniques to evaluate the environmental benefits of biogas (Hes et al., 2017). These environmental benefits are included in the overall cost computation of biogas. They conclude by saying, the environmental benefits outweigh the cost components of biodigesters, Hence, biogas is relatively cheaper compared to other sources of energy which are not clean and renewable.

Accordingly, scholars such as (Cudjoe et al., 2021; Khan, 2020; Mohammed et al., 2017) who made use of the cost-benefit analysis of the net present value argue that, though the initial cost of biogas is high, the long term benefits outweighs the initial cost making biogas especially small scale household biodigesters cost efficient. The cost-benefit analysis is an example of an economic evaluation tool used by economists to evaluate the viability of a project, programme or an environmental good. The Net Present Value (NPV) is the sum of the present values of all cash flows for the specific period of time of a project, programme or policy (Kemausuor et al., 2015). It usually includes both negative and positive cash flows during a lifespan of a project, programme or policy which is discounted to the present (Cudjoe et al., 2021). On cost-benefit grounds, a project, programme or policy is cost efficient when the NPV is greater than zero. In deciding among two alternative projects or programmes, you select the one with the highest NPV. A negative NPV means a project, programme or policy is not cost efficient, hence, not economically viable.

2.8 Theoretical Review

The theoretical underpinnings of the study of biogas are embedded in the theories and models of technology adoption. Technology adoption theories and models are used to predict the behaviour of people towards a new idea or innovation. It describes how an innovation or an idea will be accepted by prospective users to enhance their way of life. This means an innovation should improve the ways and methods of doing things in an individual's life. For instance, biogas technology as an innovation in the energy sector will enhance cooking and the wellbeing of prospective users as it is a clean energy source with no adverse effect on the environment.

In the literature of technology adoption theories and models, adoption and diffusion are many a times used interchangeable. However, these terms are not the same as they were clearly distinguished by Everett M. Rogers in his famous book 'Diffusion of Innovations' in 1983. According to him, adoption is where an individual or an organization accepts a new technology or innovation whiles diffusion is when a technology or new idea spreads to the lager population. This means adoption is at the individual level of technology acceptance whiles diffusion is the acceptance of a technology by the larger population in the society.

Two theories of technology adoption are very relevant to this study. They are the Diffusion of Innovation Theory (DIT) and the Technology Acceptance Model (TAM).

2.8.1 Diffusion of Innovation Theory (DIT)

This theory is very popular and widely used in the discussions of people's behaviour towards the acceptance of an innovation or technology. It was propended by Everett M. Rogers in the 1980s to predict the behaviour of rural farmers to accept new improved seeds for farming to increase agricultural yields. Everett Rogers himself was influenced by the writings of Gabriel Tarde in his book 'The laws of Imitation'. Gabriel Tarde, a French legal practitioner and a sociologist first discussed key concepts of diffusion such as opinion leadership and the S-curve of diffusion (Rogers et al., 2009). According to Rogers, diffusion is the process by which an innovation is communicated through certain channels over time among the members of a social system. An innovation can be an idea, behaviour or an object that is perceived as new by individuals or potential adopters. DIT provides three valuable elements that cause an innovation to be adopted and diffused. They are the qualities that make an innovation spread, the relevance of peer-peer conversations and understanding the needs of different user categories (Robinson, 2009).

DIT does not necessarily focus on persuading individuals to change in order to accept an innovation. It rather sees change as a radical reinvention of products and behaviour to suit the needs of people that will improve their way of life (Rogers, 2003). Thus, people do not change but innovations themselves change. As such, an innovation will successfully be diffused into the larger population based on five quality determinants namely relative advantage, compatibility, simplicity, trialability and observable facts (Robinson, 2009). Relative advantage is the degree to which a particular innovation is perceived as better than the one it supersedes. The greater the perceived relative advantage the greater the rate of adoption. For instance, if biogas is perceived as a better cooking energy source than other energy sources, its rate of adoption will be rapid. Compatibility is the degree to which an innovation is perceived as being consistent with existing values and practices. The greater the perceived compatibility of an innovation, the greater its rate of adoption. Simplicity is the degree of perceived difficulty to use an innovation. An innovation that is simple to understand and use is quickly adopted. Trialability is the degree to which an innovation can be examined thoroughly within a limited period of time. Observable fact is the ability for individuals to see the end results of an innovation. Hence, the easier it is for individuals to see the results of an innovation, the more likely they are to adopt.

For an innovation to spread, it must be communicated through both mass media and interpersonal communication channels (Rogers et al., 2009). However, Rogers posit that interpersonal communication amongst individuals is the most important channel through which an innovation spread faster. This is because accepting an innovation comes with risk and uncertainties. It is only through peer-to-peer communication where individuals who have adopted the innovation can clear any doubts, risks and uncertainties about the innovation. This gives potential adopters credible assurances that the innovation will not result in any financial loss, embarrassment and humiliation. This does not apply to first adopters of an innovation. According to Rogers, it is because first adopters are enthusiasts who are usually involved in inventing the innovation. This is why he refers to them as innovators.

Diffusion of an innovation does not occur the same time among individuals in a society. Some individuals adopt the innovation faster than others. As such, adopters are categorized into five groups based on their propensity to adopt a particular innovation (Dearing, 2009). These categories are chronological (Rogers, 2003; Rogers et al., 2009). The first category is innovators which is made up of few people who are visionary and very imaginative. They are the very first to accept an innovation and influence others to join. The second category is early adopters. They adopt an innovation once the benefits become very obvious. Early adopters are quite easier to convince to accept an innovation. As the benefits of an innovation becomes very obvious a large number of people jump onto the band wagon and accept the innovation. These large number of people are known as the early majority and they constitute the third category. The fourth category is made up of conservative pragmatists who do not want to take risk. They adopt an innovation which is mainstream and well established. They are called the late majority. The last category of adopters are called the laggards. They are individuals who see innovation as highly risky and they may end up not even adopting the innovation at all. All these categories of adopters have different needs and for an innovation to be successfully diffused, these needs must be addressed independently (Robinson, 2009; Rogers, 2003; Rogers et al., 2009).

2.8.2 Technology Acceptance Model (TAM)

In the 1970s, technology was rapidly evolving as the demand for Information Technology (IT) solutions in organizations and institutions increased. Consequently, many Information Systems (IS) were developed but their adoption by organizations and institutions failed. As such, predicting IS use became an area of interest for many researchers in the technology space. However, most of the studies conducted could not establish reliable variables that could explain the acceptance or rejection of IS (Davis et al., 1989). In 1985, Fred Davis proposed the Technology Acceptance Model (TAM) as a theory not only to predict the acceptance or rejection of IS but also to explain the reasons for either acceptance or rejection (Chuttur, 2009). The work of Fishbein and Ajzen (1975) which brought to bear the Theory of Reasoned Actions (TRA) influenced Fred Davis' TAM.

TAM has been the theoretical backdrop of many biogas diffusion studies conducted globally (Holt & Pengelly, 2008; Panwar et al., 2011; Sarker et al., 2020). Basically, TAM was introduced to predict the acceptance of information systems (IS) and provide reasons for its acceptance. This according to Davis was to provide relevant information for researchers and practitioners to identify why a certain IS may be acceptable or not. Such relevant information will enable researchers and practitioners to take appropriate corrective steps for IS to be accepted. Though, TAM developed in the field of computer studies, it has been adopted as a robust model to study user's acceptance of technology or innovation in my academic fields.

TAM posits that a user's motivation to accept a technology is explained by two beliefs (i.e., Perceived usefulness and Perceived ease of use) which is embedded in the user's attitude towards the technology or innovation (Chuttur, 2009; Davis et al., 1989). According to Davis, the attitude of a user towards an innovation or technology is a major determinant of whether the user will accept or reject the innovation or technology. This attitude of the user is considerably influenced by two variables namely Perceived Usefulness and Perceived ease of use. Perceived usefulness defined as the degree to which an individual believes that using a particular system would enhance his/her job performance (Davis et al., 1989). Perceived ease of use is defined as the degree to which an individual believes that using a particular system would be free of physical and mental effort (Davis et al., 1989). Perceived ease of use have a direct influence on perceived usefulness (Chuttur, 2009). Thus, both variables make a potential user form an attitude towards a technology or innovation. The attitude could be either positive or negative. A positive attitude means a user will adopt the technology whiles a negative attitude means a user will reject the technology.

2.9 Conceptual Framework

The study employs Rogers' (1983, 2003) Diffusion of Innovation Theory (DIT) and the Technology Acceptance Model (TAM) of Davis, Bogozzi and Warshaw (1989).

DIT seeks to illustrate how innovation is accepted (adopted) and gradually diffused (spread) into the larger population of the society (Dearing, 2009). An innovation can be an idea, technology object or behaviour which is observed as new by its observers (Robinson, 2009). Though, "adoption" and "diffusion" is many a times used interchangeably in the discussions of innovation, it connotes different things. Rogers (2003), noted that adoption is the acceptance of an innovation at the individual level and diffusion is when an innovation is widely accepted by the larger population of a society. The theory presents three essential processes for understanding social transformation. They are made up of qualities that make an innovation spread, the importance of interpersonal communication and peer networks and understanding the needs of different user segments.

The DIT theory offers a chronological comprehension of the adoption and diffusion(spread) of an innovation (biogas technology) into a social system (Nsawan-Adoagyiri and Awutu Senya East Municipalities). The outcome of the theory is that, individuals within a social system which in this case is households within the two municipalities understudy will accept an innovation (biogas technology) which will change the way they cook. Thus, there will be an energy transition from the use of other fuels to the use of biogas. An innovation (biogas technology) will be adopted due to the perceptions an individual forms regarding the relative advantage, compatibility, complexity, trialability, and observability of the innovation (Rogers, 2003). Rogers admitted that these elements alone do not influence an individual to adopt an innovation. In addition, an individual undergoes a five stage "innovation decision" process. These processes include information, suasion, decision, application, and verification.

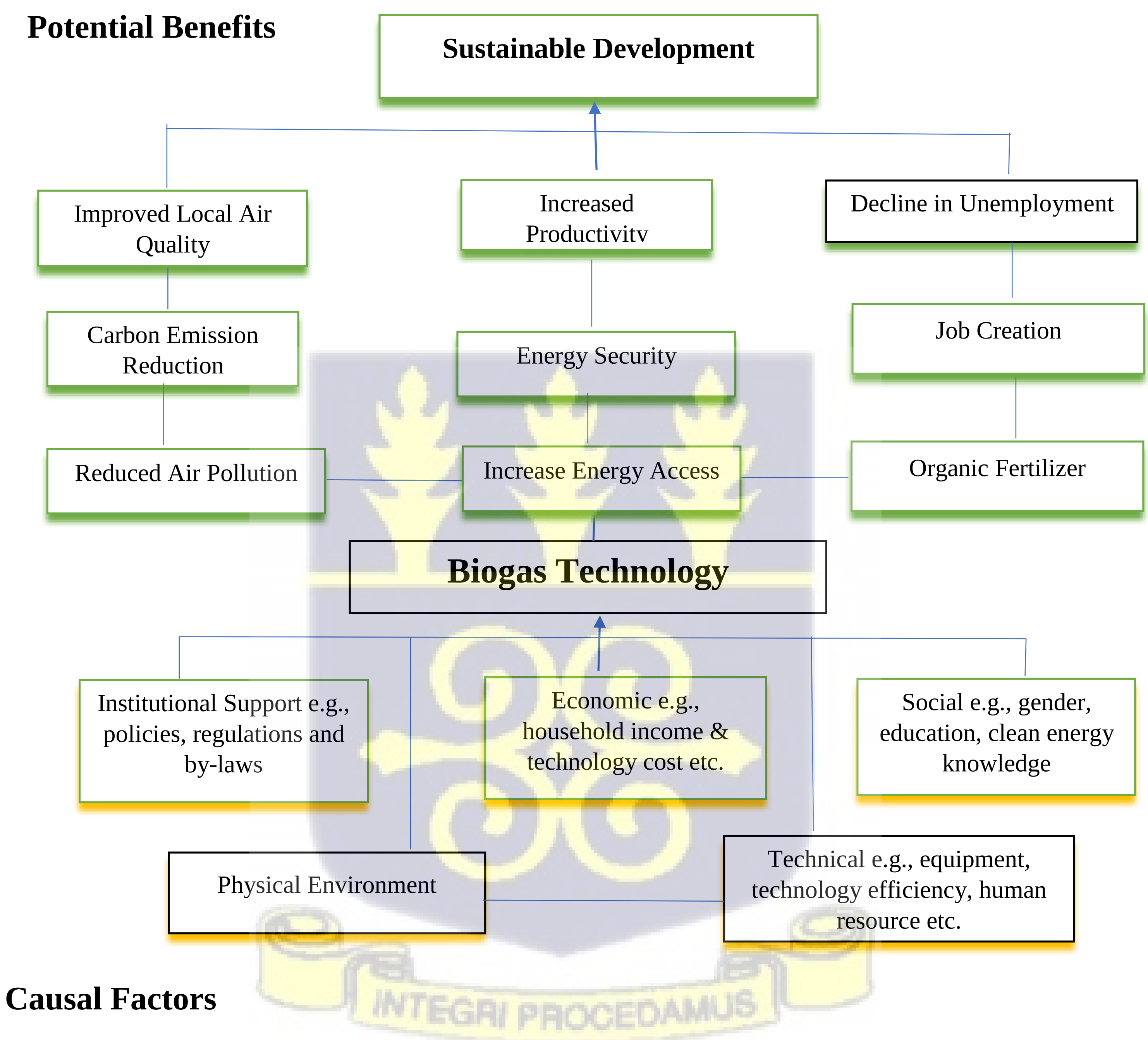
The Technology Acceptance Model (TAM) was introduced to predict user's acceptance of information technology and usage on the job (Chuttur, 2009). It is an information systems theory that seeks to understand how users accept and use technology. This theory is usually used to predict user's behaviour on whether to acceptance or not to accept a new technology. It assumes that user's acceptance of a new technology is reliant on two variables. Thus, Perceived Usefulness and Perceived ease of use (Davis et al., 1989). Perceived usefulness is the degree to which a task once accomplished is linked to the valued outcome (Chuttur, 2009). Perceived ease of use is how well an individual can accomplish a task required to deal with future situations (Chuttur, 2009).

Households in both the Nsawam Adogyiri and Awutu Senya East Municipality will adopt biogas technology for cooking based on its perceived ease of use and perceived usefulness. Thus, perceived ease of use and perceived usefulness will influence individuals to form an attitude about biogas technology. The attitude can be either positive or negative. This means, individuals within the two municipalities under study will either accept biogas technology or not.

Both DIT and TAM are used in the conceptual framework of the study. TAM illustrates individual's willingness to adopt biogas technology whiles DIT focuses on how biogas technology is adopted by households through effective communication channels. In tandem, both theories are used to depict how biogas will either be accepted or rejected by households in the two municipalities understudy.

From existing literature, the conceptual framework of this study is presented in a problem tree analysis. Accordingly, it is made up of three parts. They include the causal factors, the innovation (biogas technology) and the potential benefits of the adoption of biogas technology. Figure 2.4 presents the Conceptual Framework of the study.

Figure 2.4: Conceptual Framework



Source: Author's Construct, (2021).

The causal factors are circumstances that necessitate the adoption or non-adoption of biogas technologies. The causal factors include social, economic, institutional, technical and the physical environmental conditions which either enhances or prevents the adoption of biogas technology. In regards to the social factors, it includes the individual characteristics of potential adopters of biogas technology such as the educational level, the sex and knowledge of biogas. Though, potential adopters may be willing to adopt biogas, barring the knowledge of the existence of biogas technology adoption will not occur. In regards to the economic factors, it includes household income and the cost of biogas as an alternative energy source. Households with higher income levels may easily adopt biogas technology as compared to households with low-income levels.

With regards to the institutional factors, it includes all policies, regulations and laws which either allows or prohibits the adoption of biogas technology in the municipalities under study. In relation to the technical factors, it focuses on the availability of technical expertise. Available technical experts to construct, install and maintain biodigesters enhances the adoption of biogas technology. Technical expertise will ensure efficiency in work performance which will encourage potential adopter to adopt biogas technology. Barring technical expertise will mean low or no adoption of biogas technology. The physical environment ensures the appropriateness of the technology in its adopted environment. Biogas relies on the readily available abundant agricultural/organic waste which will serve as feed stocks for the production of gas. Fortunately, these organic wastes or biodegradable wastes are in vast quantities in the municipalities under study.

The focal innovation is biogas technology. It is the desired outcome of the influencing factors. Biogas technology is a clean renewable energy source that can be used for cooking. Biogas is produced through anaerobic digestion (AD) of biodegradable materials which are in vast quantities in Ghana. It provides a unique opportunity to transform waste into energy. Also, the bio-slurry which is the residual of the AD can be used as an organic fertilizer to increase crop yields. The ultimate goal of adopting biogas technology is to safe guard the environment as we meet our energy needs in the society. This will ensure sustainable development and decrease the incidence of adverse climate conditions.

Potential benefits are both private and social benefits which comes with the adoption of biogas technology. Adopters experiencing the benefits of biogas technology can influence other individuals to adopt the technology through inter-personal communication channels. The immediate benefits which are experienced at the household level include, reduced air pollution, increase energy access and the utilisation of bio-slurry as organic fertilizer. At the community level, adopting biogas technology can greatly reduce energy poverty in rural areas and low-income households and improve access to clean energy sources. Access to clean energy sources will reduce the emission of GHGs which will safeguard the environment and improve human health conditions. Sustained potential benefits will ultimately lead to sustainable development. Thus, development with no compromise to nature and the survival of posterity.

2.10 Conclusion

The existing literature has done a great deal of revealing the huge health and environmental benefits associated with biogas as a clean RE source which can be adopted to promote sustainable development. Generally, the various methodologies employed by the individual researchers really spoke to the issues and helped to achieve their respective research aims and objectives.

The existing literature in congruence informed the following,

- Energy is very crucial for the economic and social development of every country.
- The dominant global energy is fossil fuel which is not clean and contributes greatly to global warming and climate change.
- In order to mitigate climate change and global warming, RE sources such as biogas and solar must be adopted which will improve the attainment of sustainable development.
- Many people in the world suffer from the lack of access to clean energy of which more of them reside in sub-Saharan Africa.
- Biogas is a clean RE source that can be used to address energy poverty issues and waste management issues in Africa.
- Africa and as a matter-of-fact Ghana, has huge potential and opportunities for biogas technology to thrive and serve as alternate efficient RE source.
- Technology adoption theories and models are the theoretical backdrop of many biogas studies. Specifically, the Diffusion of Innovation Theory (DIT) and the Technology Acceptance Theory (TAM) influenced this study.

Despite the good work done by these researchers the following gaps were identified and this study seeks to address them

- Lack of standardized biodigesters.
- Major concentration on institutional biogas development rather than household biogas development.
- High initial and maintenance cost of institutional biodigesters (biogas plants).
- Lack of available feedstock to feed institutional biodigesters.
- Lack of clear government policy to support biogas development.
- Minimal collaboration between the public and private sector in the development of biogas in Ghana.

CHAPTER THREE

METHODOLOGY

3.0 Introduction

This chapter is made up of two major parts. First, the profile of the study areas adopted for the study. Thus, the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality. Second, the methodology adopted for the study. Specifically, the methodology will discuss the research design, data requirement and sources, methods of data collection and target respondents, sampling techniques and analysis of the data.

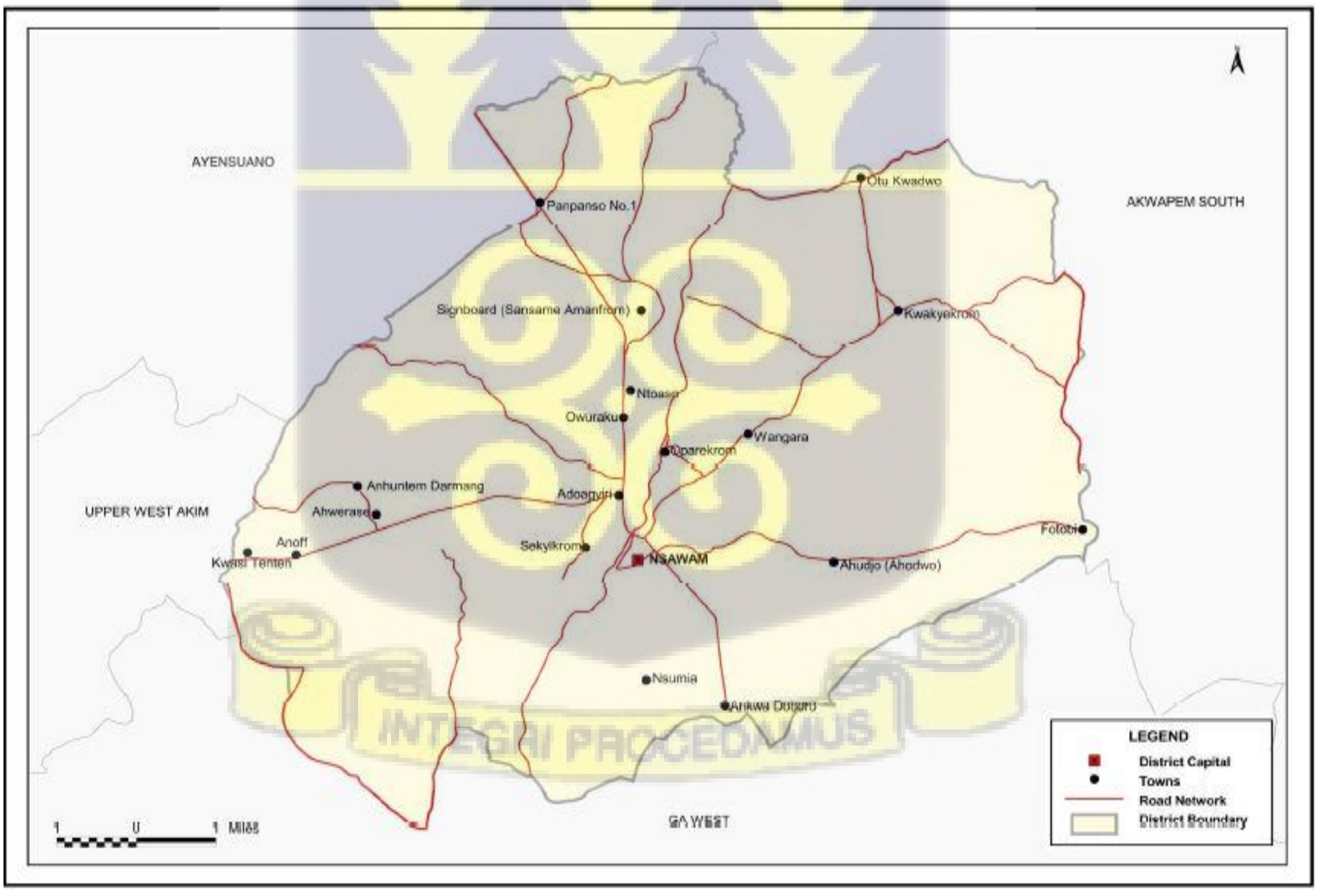
3.1 Profile of the Nsawam Adoagyiri Municipality

Established under LI 2047 in 2012, the Nsawam Adoagyiri Municipality was created from the Akuapem South Municipal Assembly. Between latitude 5.45'N and 5.58'N and longitude 0.07'W and 0.27'W, the municipality is situated in the South Eastern part of the Eastern Region. The municipality has about 175 square kilometres land area. The Municipal capital, Nsawam is about 23km from the national capital, Accra. Other key principal towns include Adoagyiri, Nkyenekyene and Fotobi (GSS, 2013).

With a population density of 465 persons per square kilometres, the Nsawam Adoagyiri Municipality is densely populated. Its total population of 86, 000 is made up of 42, 733 (49.7%) males and 43, 267 (50.3%) females. The municipality has one major government hospital, two police stations, two public senior high schools and thirty-seven public junior high schools. The major housing types in the municipality are compound houses, separate houses and few squatter settlements. In the municipality, more than 50% of households use fuelwood as a source of energy to cook especially in the rural settlements (GSS, 2013). Few households in the urban settlements use charcoal and liquefied petroleum gas as a source of energy to cook.

The main ecological zones of the Municipality are the semi-deciduous forest and the coastal savanna grassland (GSS, 2013). This supports the cultivation of many plant crops and improves agricultural activities. The major economic activity is agriculture followed by trade and commerce. In terms of agriculture, 31.4% of the total number of households in the municipality are engaged in agriculture. In the rural communities, the number is much higher where 71.7% of households are into agriculture. Crop farming is the predominant (94%) agricultural activity in the district. This is followed distantly by livestock rearing.

Figure 3.2 Map of the Nsawam Adoagyiri Municipality



Source: (GSS, 2013).

3.2 Profile of the Awutu Senya East Municipality

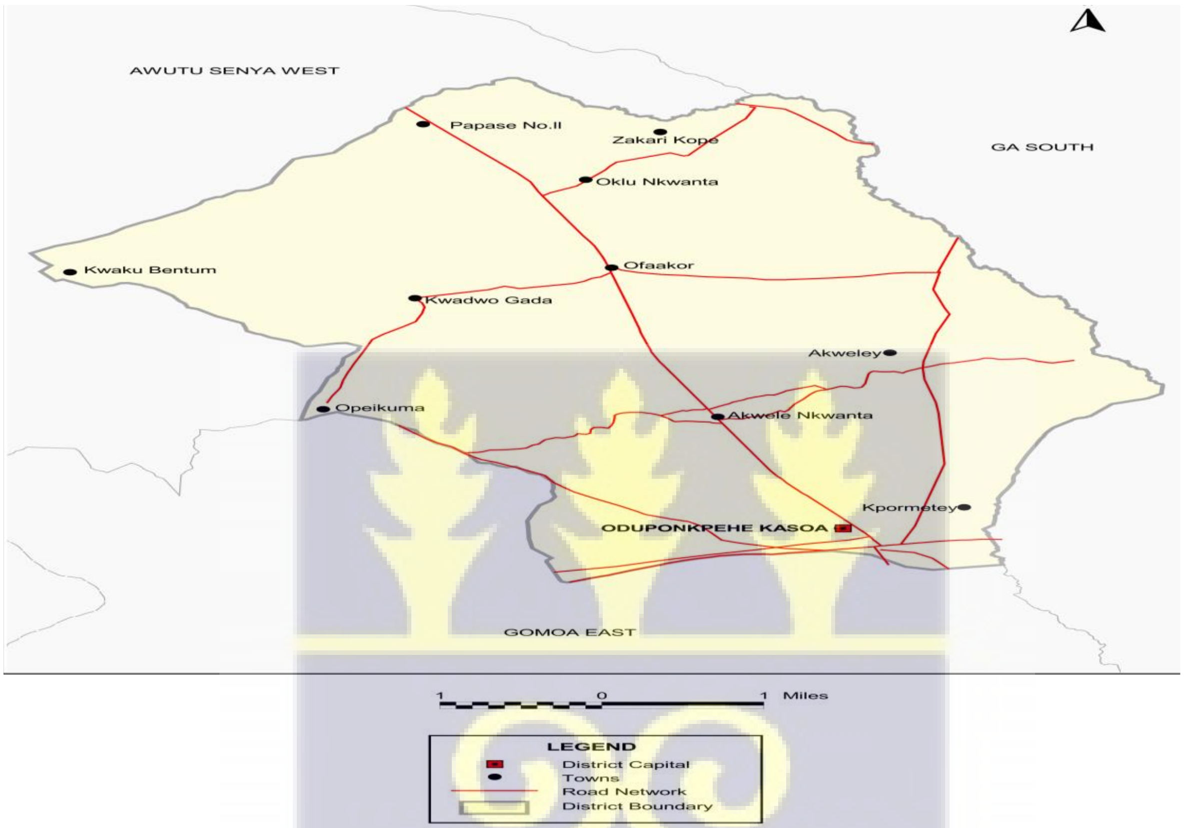
Approximately 24km from Accra, the Awutu Senya East Municipality is located. It is positioned in the Eastern part of the Central Region. It has a land area of about 108.004 square kilometres. This land area constitutes about 1.1% of the total land area of the Central Region. Kasoa is the municipal capital. Opeikuma, Adam Nana, Kpormertey, Ofaakor, Akweley and Walantu are other principal towns in the municipality (GSS, 2019).

The Awutu Senya East Municipality has a population of 143, 453 with a growth rate of 2.8%. The population of the municipality constitutes 4.9% of the total population of the Central Region. The Municipal is largely urban with few rural settlements (GSS, 2019). The ecological zone of the Municipality is semi-deciduous. Most of the land area in the Municipality is underlain by Birimian rocks making arable land very small. Nevertheless, the small arable land supports the cultivation of pineapple, citrus, pawpaw, maize and cassava (GSS, 2019).

The municipality has a housing stock of 15, 502 houses with overall household population of 105, 231 consisting of 99, 167 in urban areas whiles 6, 064 in rural areas (GSS, 2014). Compound houses (54.6%) and separate houses (26.8%) are the two predominant housing types in the municipality (GSS, 2014). The main source of fuel used by these households to cook include charcoal (54.3%), liquefied petroleum gas (34.3%) and fuelwood (11.4%). The commonest form of solid waste disposal among households in the Municipality is burning (43.4%) followed by collection by waste management companies (29.9%). Public dump using container, (8.3%) and public dump in open space (7.4%) are also common in the Municipality (GSS, 2014).

The major economic activity of the Municipality is trade and commerce. The Municipality's close proximity to the national capital boosts wholesale and retail of goods. The Municipality serves as transit point for goods from the Central Region to the national capital, Accra.

Figure 3.3 Map of the Awutu Senya East Municipality



Source: (GSS, 2019).

3.3 Research Design

A research design provides the conceptual structure within which the research is conducted (Kothari, 2004). Embedded in the conceptual structure is a detailed outline for collecting, measuring and analyzing data. Also, adopting a specific research design relies largely on the logical assumptions and the kind of data required for attaining the aims of a study (Bhattacheejee, 2012). A positivist research design emphasizes the use of rigid quantitative techniques for collecting and analyzing data to provide objective information. A non-positivist research design emphasizes the use of flexible qualitative techniques for collecting and analyzing data to provide rich but subjective information. A synergistic approach that blends quantitative and qualitative approaches enable in-depth understanding of an issue as the strengths of both are used in a single study (Creswell, 2007; Kothari, 2004).

Subsequently, the study employed a mixed methods approach of research. This research approach provides an in-depth understanding of the research problem than either research approach independently as it makes use of both quantitative and qualitative data (Creswell, 2007). This approach was adopted to enable the researcher to fully comprehend the research problem and cautiously generalize the research findings on the potential of biogas as an energy source for cooking taking into consideration the likely challenges, willingness to adopt and the cost efficiency of biogas. Albeit, the adoption of this approach is very time consuming and has the potential to generate large volumes of data sets.

3.4 Target Population

To achieve the aim and objectives of this study, the target population needed to be identified and clearly defined. The target population of a research refers to an individual, a group or organizations about which information is needed in order to achieve the aims and objectives of the research. (Kothari, 2004).

This study covered all households in both the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality. The study aimed at examining the potential of biogas as a clean energy source for cooking in homes, the likely challenges associated with the domestic use of biogas, the willingness of people to adopt biogas for cooking in their homes and the cost-efficiency of domestic biogas. To achieve this aim, it was very appropriate to elicit information from households which directly answer the research questions.

Respondents were selected from households of each of the zonal councils that make up the municipalities. The zonal councils are made up of small towns which are very close to each other. As such, respondents were selected from all the small towns that make up the zonal councils. The Nsawam Adoagyiri Municipality is made up of four zonal councils. They are, Nsawam, Adoagyiri, Kyenekyene and Fotobi. The Awutu Senya East Municipality is made up of six zonal councils. They include, Kasoa, Opeikuma, Kpormertey, Ofaakor, Akweley and Walantu. The respondents were selected from all zonal councils to ensure the target population is well represented. Thus, respondents are fairly selected from every area of the target population to be part the sample.

3.5 Sampling Techniques

In order to achieve the study objectives, a definite plan must be determined to select respondents from the target population into the study sample. The systematic process of selecting respondents from the population to be part of the study sample constitutes the sampling technique/procedure. According to Kothari (2004), sampling technique/procedure in a mixed methods methodology gives a researcher the latitude to adopt both quantitative and qualitative paradigms of sampling in a single study. Furthermore, he argues that such sampling technique/procedure enables a researcher to construct valid arguments and provide cogent generalizations about the whole population. As such, a concurrent sampling technique/procedure that employs both probability and non-probability sampling techniques work perfectly for a mixed methods approach of research.

Consequently, the study employed both probability (stratified random sampling) and non-probability (purposive) sampling techniques.

The purposive sampling technique was used to solicit vital information on biogas technology from eight experts within the field. Five of these experts were from Biogas technology Companies[1].This enabled me to elicit rich information from experts who install biodigesters in Ghana. The distribution of the remaining three experts are as follows; One from the Council for Scientific and Industrial Research (CSIR), One from the Nsawam Adoagyiri Municipal Assembly and One from the Awutu Seyna East Municipal Assembly. This enabled me to get diverse views about biogas as a clean energy source for cooking.

The stratified random sampling technique was adopted to select respondents from households within the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality. The respondents were first categorized into the existing zonal councils of the municipalities understudy. Subsequently, respondents were randomly selected from each of the zonal councils of the two municipalities adopted for the study. This sampling technique gave equal chance for every member in the zonal councils to be selected into the sample. As such, respondents were equally selected from the various zonal councils of the municipalities under study. This prevented selection biases and made the sample very representative of the population. Thus, the sample adopted the

1 A Biogas technology company is a company which considers waste as a resource to create value to improve the leaving conditions of people and promote sustainable development in Ghana. They have developed an affordable model that includes building and operating a recycling plants/biogas plants for organizations and households. Through their model, organic waste is converted to renewable energy (biogas) and organic fertilizer.

characteristics of the population. This means inferences made from the sample about the population is objective and valid.

3.6 Sample Size

The sample size refers to the number of respondents selected into the study sample. Kothari, (2004) noted that an appropriate determination of the sample size is very crucial for achieving the objectives of a study. A very small sample size may produce inconclusive results which will affect inferences made about the population. On the other hand, a very large sample size is expensive and may waste scarce resources. As such, a sample must be of an optimum size. Thus, the sample size should not be very large nor too small. This means a sample size should be appropriately determined.

The two municipalities under study have a very large population. To determine an appropriate sample size for a larger population, the level of confidence, the level of precision and the degree of variability of the population needs to be specified. The level of confidence adopted for the study was 90%. This means the researcher has a 10% chance of being wrong about estimating the mean of the population. The equivalent Z-score for 90% confidence level is 1.645. The level of precision or the margin of error adopted for the study was +/-5%. This means the researcher is willing to allow the sample mean to fall either 5% lower or higher of the population mean. The degree of variability adopted for the study is 50%. This means the researcher expects 50% (0.5) variance in the response of respondents. The degree of variability was measured by the standard deviation. Therefore, the standard deviation is 0.5.

To attain an appropriate sample size for a larger population, the Z -score sample size estimation was employed. The formular for the estimation is below.

n= (Z-score)^2 * StdDev* (1-StdDev) / (margin of error)^2

Where:

n= Sample

Z-score= 1.645

StdDev (Standard Deviation) = 0.5

Margin of error= +/-5%

n= ((1.645)^2 X 0.5(0.5)) / (0.05)^2

n= (2.7060 X 0.25) / 0.0025

n= 270.6025

n= 271 respondents

The result of the sample size estimated is 271 respondents. In accordance with the objectives of the study, the sample size is distributed among the two municipalities under study. Table 3.1 below presents the distribution of the sample.

Table 3.1 Distribution of the Sample

Municipality/	**Sample Size**
Nsawam Adoagyiri Municipality	135
Awutu Senya East Municipality	136

Total	**271**

Source: Author's Construct (2021)

The sample size of the two municipalities under study was equally distributed amongst its various zonal councils to have a fair representation of the population. Table 3.2 and 3.3 shows the sample distribution amongst the zonal councils.

Table 3.2 Sample Distribution of the Nsawam Adoagyiri Municipality

Zonal Council	Sample Size
Nsawam	34
Adoagyiri	34
Kyenekyene	34
Fotobi	33
Total	**135**

Source: Author's Construct (2021)

Table 3.3 Sample Distribution of the Awutu Senya East Municipality

Zonal Council	Sample Size
Kasoa	23
Opeikuma	23
Kpormertey	23
Ofaakor	23
Akweley	22
Walantu	22
Total	**136**

Source: Author's Construct (2021)

3.7 Data and Sources

Primary data both qualitative and quantitative was solicited from respondents and experts involved in the study. Secondary data sources such as online information, articles, newspapers and formal documents from the municipalities were used to complement the primary data sources.

3.8 Methods of Data Collection

In order to solicit vital information from respondents to address the objectives of the study, the specific techniques for data collection needed to be determined. Due to the mixed methods approach adopted for this study, the methods of data collection employed served the needs of both qualitative and quantitative research. As such, both qualitative and quantitative data collection techniques were employed.

In terms of qualitative data collection, eight key informant interviews were conducted with the aid of a semi-structured interview guide to solicit in-dept information from biogas experts. The interview focused on the availability of feedstocks, biodigesters design, technical ability, rate of gas production and challenges likely to confront the utilization of biogas as a source of energy for cooking.

Quantitative data was solicited through administering semi-structed questionnaires to 271 respondents in the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality. Thus, closed ended and open-ended questions were used in the questionnaire to solicit information from household heads. The questionnaire was used to solicit information concerning the potential of biogas as a cooking fuel, respondent's willingness to adopt biogas technology and the cost efficiency of biogas usage. These questionnaires were administered based on the zonal councils that make up the municipalities under study.

3.9 Methods of Data Analysis

Data analysis requires employing appropriate techniques to make meanings out of information gained from the field in order to achieve the objectives of a study/research. Both qualitative and quantitative data elicited require precise techniques to analyse, interpret and present them in such a manner that meet the objectives of a study. The techniques/strategies employed to analyse data for this study was done according to each research objective. Hence, the methods that were employed to analyse data according to each specific objective of the study includes the following;

3.9.1 To assess the potential of biogas as a clean fuel for cooking

A thematic analysis was conducted by taking into consideration the key variables below. These key variables were evident in the works of Bensah et al., (2011) & Kemausuor et al.,(2018) to assess the theoretical potential of biogas. Data elicited from the eight key informants (biogas technology experts) was use to conduct the thematic analyses. The theoretical potential of biogas as a source of clean cooking fuel was assessed by looking out for the difference, similarities and trends from the qualitative data elicited from biogas experts. The thematic analysis conducted took into consideration the following key variables listed below in both municipalities understudy.

- Availability of feedstocks
- Biodigester designs
- Availability of biogas technicians
- Rate of gas production/Sustainable gas production

3.9.2 To examine the socio-economic and technical factors that influence the adoption of biogas

To efficiently analyse objective two, a logistic regression model was employed. This was due to the dichotomous nature of the dependent variable. A logit model is used to describe the relationship between one dependent variable and one or more independent variables of any kind. In this case, the dependent variable was willingness to adopt. The independent variables were knowledge of biogas, environmental concern, cost of other energy, availability of subsidy and availability technical expertise. The mathematical equation of the model is explained below.

$ln\ (P1-P)=a+bx$

$P= ea+bx1+ea+bx$

Where;

P represents the likelihood of the event occurring, X represents the independent variables, e represents the base of the natural logarithm, a and b represents the parameters to be predicted by the model.

The formular of the logit model:

$PrY= 1/1+ e-(a+bx)$

Where;

Y represents log of the dependent variable

The log prediction equation:

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

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

$=ba+b1x1+ b2x2+\cdots+bnxn$

The dependent variable Y= willingness to adopt biogas technology.

P(Y) = (1 if respondents select to adopt and 0 if respondents select not to adopt)

Therefore, the expectation of the independent variables are as follows:

X1= Knowledge of biogas technology: household heads with knowledge of biogas have higher probability of adopting biogas than those who have not.

X2= Environmental concern: household heads with higher environmental concern have higher probability of adopting biogas technology than those who have not.

X3= Cost of other energy sources: the probability for household heads adopting biogas technology is higher when the cost of other energy source is high.

X4= Expenditure of cooking fuel: households with higher expenditure of cooking fuel have higher probability to adopt biogas technology than those with lower expenditure of cooking fuel.

X5= Household size: households with larger sizes have a higher probability to adopt biogas than households with smaller household sizes.

3.9.3 To determine the cost-efficiency of biogas as a clean cooking energy source

The cost-benefit analysis (CBA) was used to determine the cost-efficiency of biogas. The cost-benefit analysis is an economic tool for assessing the economic viability of a project by comparing the economic benefits with the economic costs of the activity (Cudjoe et al., 2021). Again, Cudjoe et al (2012), continued to argue that benefits increase human wellbeing whiles cost decreases human wellbeing. Therefore, if a project's benefits exceed its social cost, that particular project qualifies on cost-benefit grounds. The specific cost-benefit tool used to determine the cost-efficiency of biogas in the two municipalities under study was the Net Present Value (NPV).

The Net Present Value (NPV) is the current value of all projects or programmes net benefits. Thus, the sum of benefits minus cost. The formula for calculating NPV is below.

$$NPV = \sum_{t=1}^{T} \frac{(Benefit_t - Cost_t)}{(1+r)^t}$$

Where: Bt = the benefit in year t, Ct = the cost in year t, r = discount rate (interest rate) and t = number of years from the present year. The decision rule when using the NPV is to accept a project or a programme when NPV is greater than zero. In choosing among alternatives, you select the project or programme with the highest NPV.

Information gained from the biogas experts and respondents formed the basis for estimating the cost and benefits of biogas. In determining the cost which included the investment cost and maintenance cost, a cost estimate from a reputable biogas company involved in the study was used as a reference point. In estimating the cost components, 2021 market prices were adopted. According to Mohammed et al., (2017), the cost element for biogas is influenced by the size of the biodigester. The biodigester adopted for this study is a 10 cubic metre Chinese fixed doom biodigester. This biodigester type is very common in Ghana and its small size makes it suitable for domestic use (Arthur, Baidoo, & Antwi, 2011; Arthur, Baidoo, Brew-Hammond, et al., 2011).

In estimating the benefits of the domestic biodigester, an annual cash flow was calculated. The elements considered in calculating the income flow was adopted from the work of Mohammed et al., (2017). It included the annual expenditure savings on alternative fuel, environmental protection, cost savings from avoidance of septic tank construction and annual savings from treatment of waste water. A cashflow table was developed based on the lifespan of a biodigester. The lifespan of a biodigester is 20 years (Arthur & Brew-Hammond, 2010; Bensah et al., 2011; Edem Cudjoe, 2010).

The number of years considered for the project was 20 years which is the normal lifespan of a biodigester. A discount rate (interest rate) was estimated for 20years based on the average interest rate of the Ghana Commercial Bank for year 2021.

3.9.4 To examine the likely challenges of using biogas for cooking

A thematic analysis was conducted to examine the likely challenges that confront the use of biogas to cook. Rich information gained from biogas experts through key informant interviews were recorded, transcribed and reviewed to look out for trends to develop themes. The frequency of a particular theme was used to rank the likely challenges from the most to the least influential. Subsequently, the identified challenges were discussed and compared with existing literature to draw accurate conclusions. The thematic analysis conducted took into consideration the following key variables listed below in both municipalities understudy.

- High investment cost
- High maintenance cost
- Inadequate Technicians

- Poor biodigester designs
- Cultural Stigma

3.10 Ethical Consideration

First, an introductory letter was obtained from the Institute of Statistical, Social and Economic Research (ISSER) which was presented to the offices of the two municipalities under study and all the respondents involved in the research. All respondents and experts involved in the study were informed about the purpose of the research. Also, respondents were made to sign consent forms to give permission for information to be elicited. They were made aware that they were at liberty to stop answering questions during the interviewing process. Finally, all authors of scholarly works used in the study were credited and cited.

CHAPTER FOUR

PRESENTATION OF FINDINDS AND DISCUSSION

4.0 Introduction

This chapter focuses on the findings of the study. The findings are discussed in accordance with the existing literature on biogas as a clean source of energy for cooking. It is made up of four sections. Thus, the socio-demographic characteristics of respondents, the potential of biogas as a clean cooking fuel, the socio-economic and technical factors that influence the adoption of biogas, the cost efficiency of biogas and the likely challenges of using biogas to cook.

4.1 Socio-Demographic Characteristics of Respondents

From Table 4.1 below, a total of 271 respondents (heads of household) participated in the study. A total of 135 respondents were sampled from the Nsawam Adoagyiri Municipality (NAMA) and 137 respondents sampled from the Awutu Senya East Municipality (ASEM). From the Nsawam Adoagyiri Municipality, 72.6% of the respondents were males and 27.4% were females. From the Awutu Senya East Municipality, 59.6% of the respondents were males and 40.4% were females. This indicates that in both municipalities under study, males dominate as the heads of households. The Ghana Living Standards Survey round 7, reported that a higher proportion of households (66.6%) are headed by males (GSS, 2019). Taking into consideration the age of respondents, the mean age of respondents was 47.2 and 44.3 representing the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality respectively. The mean age of respondents falls within the working population of Ghana which is between ages 16 and 65. With regards to the level of education of respondents, majority of the respondents (37.8%) from the Nsawam Adoagyiri Municipality had senior high as their highest level of education which is not different from the

Awutu Senya East Municipality where majority of the respondents (35.3%) had senior high school as their highest level of education. Also, the percentage of respondents who had tertiary as their level of education is higher (25%) in the Awutu Senya East Municipality and lower (14.8%) in the Nsawam Adoagyiri Municipality. Likely, the percentage of respondents who had no formal education as their level of education is higher (18.5%) in the Nsawam Adoagyiri Municipality and lower (16.9%) in the Awutu Senya East Municipality. Furthermore, the mean of respondents' household size was 3.8 and 3.2 in the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality respectively. The higher mean of household size in the Nsawam Adoagyiri Municipality is due to many rural settlements within the municipality. The Ghana Living Standards Survey round 7, revealed that rural settlements have higher household sizes (GSS, 2019).

Table 4.1 Socio-Demographic Characteristics of Respondents

Socio-Demographic Characteristics	NAMA		ASEM		All Households	
	Freq	Per %	Freq	Per %	Freq	Per %
Gender						
Male	98	72.6	81	59.6	179	66.1
Female	37	27.4	55	40.4	92	33.9
Total	135	100	136	100	271	100
Age						
Mean Age	47.2		44.3			45.8
Educational Background						
No Formal Education	25	18.5	23	16.9	48	17.7
Junior High/Middle School	39	28.9	31	22.8	70	25.8
Senior High	51	37.8	48	35.3	99	36.5
Tertiary	20	14.8	34	25	54	20
Total	135	100	136	100	271	100

Household Size			
Mean of household size	3.8	3.2	3.5

Source: Field data, 2021.

4.2 Household Energy Consumption

This section focuses on the types of household energy used for cooking, the amount of money spent on household energy per annum and the cost of household waste management per annum in the municipalities under study.

4.2.1 Types of Household Cooking Fuel Sources

Table 4.2 below shows the different types of household energy used for cooking in the municipalities under study. All households sampled made use of more than one energy type for cooking. The dominant energy type used for cooking in both municipalities was charcoal representing 50.4% and 44.9% in the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality respectively. The second dominant energy type used in the Nsawam Adoagyiri Municipality was firewood representing 24.4% whereas that of the Awutu Senya East Municipality was LPG representing 25.7%. This disparity in the second dominant energy type used in the municipalities under study is due to the rural nature of the Nsawam Adoagyiri Municipality as compared to an increasingly urbanizing Awutu Senya East Municipality. This indicates that energy poverty is higher in rural settlements as compared to urban settlements[2] (Agyekum, 2020; Asibey et al., 2021). In both municipalities, others (electricity, solar and biogas) was the least selected as

2 Firewood is not a clean source of energy. Using firewood as the dominant energy type for cooking means such individual lacks access to clean sources of energy. Hence, that individual can be said to be energy poor.

the dominant energy type representing1.5% in the Nsawam Adoagyiri Municipality and 6.6% in the Awutu Senya East Municipality. It was realized that the dominant household energy sources used for cooking in both municipalities are not renewable. This confirms the observation of (Asumadu-Sarkodie & Owusu, 2016) that the bulk of Ghana's renewable energy potential is undeveloped. Again, this confirms the Ghana Living Standards Survey round 7 report that wood and charcoal is the dominant household energy source used for cooking in Ghana (GSS, 2019).

Table 4.2 Types of Household Cooking Fuel Sources

Energy Type	NAMA		ASEM		Total Sample (All Households)	
	Freq	Per %	Freq	Per %	Freq	Per %
Firewood	33	24.4	29	21.3	62	22.9
Charcoal	68	50.4	61	44.9	129	47.6
LPG	28	20.7	35	25.7	63	23.2
Animal Manure	4	3	2	1.5	6	2.2
Others	2	1.5	9	6.6	11	4.1
Total	135	100	136	100	271	100

Source: Field data, 2021.

4.2.2 Annual Expenditure of Cooking Fuels

From Table 4.3, the minimum amount of money spent on cooking fuel per annum in the Nsawam Adoagyiri Municipality is GH₵ 840.00 whereas that of the Awutu Senya East Municipality is GH₵ 950.00. The difference in the minimum amount of money spend on fuel per annum in the municipalities under study is accounted for by the higher prices of goods and services in the Awutu Senya East Municipality which is largely an urban settlement. Furthermore, the maximum amount of money spent on cooking fuel per annum in the Nsawam Adoagyiri Municipality is GH₵ 2 450.00 whiles that of the Awutu Senya East Municipality is GH₵ 2 640.00. The wide disparity between the minimum and the maximum amount of money spent on cooking fuel in both municipalities is accounted for by the variance in household sizes. Households with larger sizes spend more on cooking fuels.

Table 4.3 Annual Expenditure of Cooking Fuels

Municipality	Average (GHC)	Minimum (GHC)	Maximum (GHC)
NAMA	1 280.61	840	2 450.00
ASEM	1 455.25	950	2 640.00
All Households	1 367.93	840	2 640.00

Source: Field data, 2021.

To further investigate the difference in the annual expenditure of cooking fuels between the two municipalities under study, a two sample T test was conducted at 95% confidence interval. The test was conducted to test whether the difference between the averages of the two municipalities are significant or not. From Table 4.4, the p-value of 0.0265 (2.65%) is less than the significance level of 0.05 (5%) indicating that the difference between the two municipalities average in annual expenditure of cooking fuels is significant.

Table 4.4 Two- Sample T test of Annual Expenditure of Cooking Fuels

Variable	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf. Interval]	
NAMA	135	1280.582	30.56104	355.0871	1228.738	1349.627
ASEM	136	1455.181	70.30059	819.8387	1321.648	1599.714
combined	271	1367.881	38.70716	637.2003	1299.042	1451.454
Diff		-174.5991	76.85051		-332.8036	-20.19369

diff = mean (NAMA)- mean (ASEM)		t = -2.2316
Ho: diff = 0		degree of freedom = 269
Ha: diff < 0	Ha: diff != 0	Ha: diff > 0
Pr(T < t) = 0.0132	Pr(T > t) = 0.0265	Pr(T > t) = 0.9868

Source: Field data, 2021.

4.2.3 Household Waste Management

Table 4.5 shows the annual cost of household waste disposal in both municipalities under study. In both municipalities, the cost of disposal of human excreta was the most expensive as it ranged from as low as GH₵ 650.00 to as high as GH₵ 3 650.00 in the Nsawam Adoagyiri Municipality and as low as GH₵ 720.00 to as high as GH₵ 3 855.00 in the Awutu Senya East Municipality. This large disparity in the cost of human excreta disposal is accounted for by the difference in household sizes, the disposal method employed and the type of household toilet facility used. The cost of kitchen waste disposal in both municipalities was moderately high as it ranged from as low as GH₵ 350.00 to as high as GH₵ 1 850 in the Nsawam Adoagyiri Municipality and as low as GH₵ 425.00 to as high as GH₵ 2 214.00 in the Awutu Senya East Municipality. The disparity in the cost of kitchen waste disposal is accounted for by the different household sizes and the mechanism employed to dispose waste. The least cost of household waste disposal in both municipalities was the cost of liquid waste disposal. It ranged from as low as GH₵ 220.00 to as high as GH₵ 800.00 in the Nsawam Adoagyiri Municipality and as low as GH₵ 265.00 to as high as GH₵ 873.00 in the Awutu Senya East Municipality.

Table 4.5 Annual Expenditure of Household Waste Management

Type of Waste	NAMA	ASEM	All Households

	Average (GHC)	Minimum (GHC)	Maximum (GHC)	Average (GHC)	Minimum (GHC)	Maximum (GHC)	Average (GHC)
Kitchen Waste	875.2	350	1 850.00	955.51	425	2 214.00	915.4
Human Excreta	1 245.56	650	3 650.00	1 535.71	720	3 855.00	1 390.6
Liquid Waste	57.32	220	800	61.32	265	873	59.3

Source: Field data, 2021.

4.3 Knowledge of Biogas

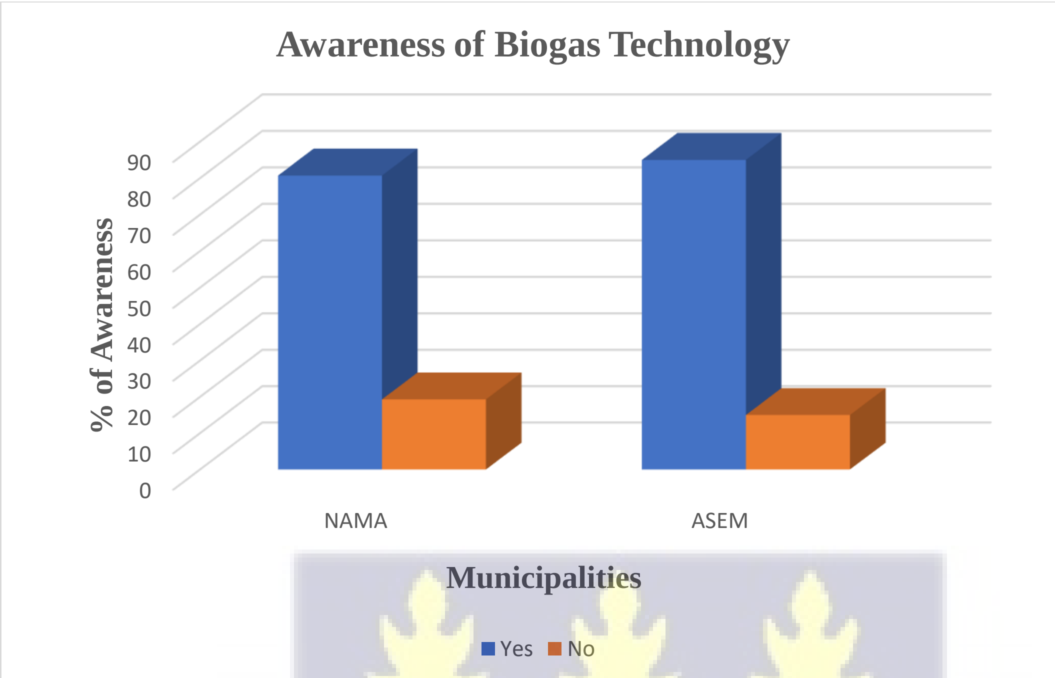
This section focuses on the assessment of the awareness of biogas technology and the sources of information on biogas technology among respondents in both the Nsawam Adoagyiri Municipality and the Awutu Senya Municipality.

4.3.1 Awareness of Biogas Technology

Respondents' knowledge of biogas as a clean energy source was tested. Respondents were asked in a binary question whether they have heard of biogas technology. From Figure 4.1, majority of respondents from both municipalities under study indicated that they are aware of the existence of biogas technology. Specifically, 80.7% of respondents from the Nsawam Adoagyiri Municipality had knowledge of biogas technology whereas 85% of respondents from the Awutu Senya East Municipality had knowledge of biogas technology.[3] This shows that biogas technology is quite popular in the Awutu Senya East Municipality than the Nsawam Adoagyiri Municipality.

3 Further investigation of respondents' knowledge of biogas revealed that some respondents confused biofil toilet digesters as biogas plants/biodigesters. A preamble containing summarized information about biogas was read to them at a point of the data collection exercise to clear any misconstrued information about the technology.

Figure 4.1 Awareness of Biogas Technology



Source: Field data, 2021.

A cross tabulation of the sex of household heads and awareness of biogas technology was tabulated for all households in the two municipalities under study. From Table 4.6, 11.8% of females and only 5.6% of males were not aware of biogas technology whiles 22.1% of females and 60.5% of males indicated that they are aware of biogas technology. This shows that majority of males are aware of biogas technology in the municipalities under study.

Table 4.6 Cross Tabulation of Sex and Awareness of Biogas

	Awareness					
Gender	No		Yes		Total	
	Freq	Per %	Freq	Per %	Freq	Per %
Female	32	11.8	60	22.1	92	33.9
Male	15	5.6	164	60.5	179	66.1

Total	47	17.4	224	82.6	271	100

Source: Field data, 2021.

4.3.2 Sources of Biogas Information

Table 4.7 below shows the sources of information of biogas technology as indicated by respondents from the municipalities under study. Majority of the respondents, 34.9% from the Nsawam Adoagyiri Municipality and 34.8% from the Awutu Senya East Municipality heard of biogas technology from TVs/Radio/ Newspapers/Web Advert. This indicates that the media landscape is enabling the dissemination of biogas technology in Ghana. Furthermore, 25.7% of respondents from the Nsawam Adoagyiri Municipality and 26.1% of the respondents from the Awutu Senya East Municipality heard of biogas technology from installers. This shows that biogas service providers are actively promoting biogas technology in the municipalities under study. Further investigation revealed that biogas service providers are responsible for the advertisement of biogas technology on the various media platforms. Only 11.9% of respondents from the Nsawam Adoagyiri Municipality and 13% of respondents from the Awutu Senya East Municipality heard of biogas technology from Government/NGOs. This affirms the assertion that the government is not doing enough to support the Ghanaian biogas industry (Edem Cudjoe, 2010; Kemausuor et al., 2018). Also, few respondents 5.5% from the Nsawam Adoagyiri Municipality and 6.1% from the Awutu Senya East Municipality heard of biogas technology from researcher/academia. This is not surprising as there is a gap between academic and industry in Ghana (Awafo & Agyeman, 2020).

Table 4.7 Sources of Biogas Information

Sources of Biogas Information	NAMA		ASEM	
	Freq	Per %	Freq	Per %

Government/NGO	13	11.9	15	13
TVs/Radio/ Newspapers/Web Advert	38	34.9	40	34.8
Friend/Neighbour	24	22	23	20
Researcher/Academia	6	5.5	7	6.1
An installer	28	25.7	30	26.1
Total	109	100	115	100

Source: Field data, 2021.

4.4. Potential of Biogas for Cooking

This section assesses the theoretical potential of biogas as a source of clean fuel for cooking. Information gathered from experts through key informant interviews was used to assess the theoretical potential of biogas. These experts are made up of engineers from biogas companies, regulatory bodies (MoE and EPA) and environmentalists from the Nsawam Adoagyiri Municipal Assembly and Awutu Senya East Municipal Assembly. A table of distribution of these experts is attached as appendix 4.1.

To determine the theoretical potential of biogas, the following variables were considered from the rich information gathered from experts through key informant interviews. They include, the availability of feedstocks, Biodigester design, availability of biogas technicians and sustainable rate of gas production which was evident in the works of Bensah et al., (2011) & Kemausuor et al.,(2018).

4.4.1 Availability of Feedstocks

Biogas is produced through the anaerobic digestion of organic/biodegradable materials. These biodegradable materials form the feedstocks that feed biodigesters for the production of methane gas that can be used for cooking. Feedstocks include all organic or biodegradable materials such as food waste, animal manure, human excreta, liquid waste and slaughterhouse waste. All experts interviewed indicated that Ghana has abundant sources of feedstocks capable for the production of biogas for cooking. This assertion is in congruence with works of (Arthur & Brew-Hammond, 2010; Bensah et al., 2011; Kemausuor et al., 2014) which also revealed that Ghana has vast biodegradable sources for the sustainable production of biogas. I t was observed that the two municipalities under study have vast biodegradable sources to serve as feedstocks for the production of biogas. Peculiar to the Nsawam Adoagyiri Municipality is agricultural waste, chicken droppings and pig manure whiles the Awutu Senya East Municipality is peculiar with municipal waste and cow manure. However, for household biodigesters, the main sources of feedstocks are human excreta and organic household waste which is available in every household. As such, the quantity of feedstocks for household biodigesters is largely dependent on the household size. Households with larger size will produce more human excreta and organic household waste.

Feedstocks are organic waste materials which are usually difficult to be efficiently disposed. Using organic waste as feedstocks provides an environmentally friendly efficient means of managing waste. One expert an environmentalist from the municipal assembly opined that

> "Biogas production provides a unique mechanism to convert waste to energy and the technology has a higher potential to liberate Africa from its major problem of waste management as organic waste constitutes about 50-60 % of all forms of waste created in the continent".

All feedstocks can undergo AD for the production of biogas. However, some feedstocks have a higher potential of producing methane gas than other feedstocks types. This is due to the varying retention time of these feedstock types. All experts revealed that in Ghana, the dominant feedstock type that has higher potential of producing methane gas include cow dung, pig manure, human excreta and agricultural waste such as food waste. This confirms the observation of Roubík &

Mazancová, (2020), that different types of feedstocks have varying rate of methane production. One expert an engineer from a biogas company even puts it more succinctly and states that

> "The higher moisture content of animal manure such as cow dung makes it easier for microorganisms to act on it for the production of methane gas in a reduced retention period".

4.4.2 Biodigester Design

The biodigester or biogas plant is the covered vessel within which AD of organic or biodegradable materials occur. The major function of the biodigester is to provide anaerobic conditions for the production of biogas. Thus, the breakdown of organic or biodegradable materials in the absence of oxygen in an air-tight tank for the production of methane gas. There exist many types of biodigesters such as the floating drum, the puxin digester and the Taiwanese plastic tubular. However, it was observed that the fixed-dome type biodigester is the most convenient and widely used in Ghana. This confirms the findings of Arthur & Brew-Hammond, (2010) & Bensah et al., (2011), that the fixed-dome biodigester type is widely installed in Ghana. This biodigester type is relatively cheaper and suitable for the African terrain. Also, all the materials used for the construction of the fixed-dome biodigester are local materials except the gas holder balloon. This gas holder balloon is either imported from the Netherlands or Germany. One expert from a biogas company revealed that

> "The fixed-dome type is widely installed in Ghana not only because it is relatively cheaper but also, its design makes it very suitable to digest the vast varieties of feedstocks available in Ghana".

The size of the fixed-dome type biodigester is dependent on the quantity of feedstocks available to feed biodigesters for the production of biogas. Usually, the size of household biodigesters range between 4 cubic metres to 25 cubic metere whiles the size of industrial and community biodigesters range above 30 cubic metres. The life span of a fixed-dome biodigester if constructed well could last more than 50 years. However, all experts indicated that 20 years is the minimum life span of biodigesters which confirms the findings of Cudjoe et al., (2021).

A well-constructed biodigester provides an environmentally friendly mechanism to properly manage organic waste especially human excreta which is quite difficult to manage. However, it was revealed that ill-constructed biodigesters easily crack and spill out stinking waste which pollutes the surrounding air quality. Similar observation was made by Arthur et al., (2011), which was sighted as a major setback in the Ghanaian biogas industry.

4.4.3 Availability of Biogas Technicians

Technical expertise in the design, installation and maintenance of biodigesters is very vital for the sustainability and development of the Ghanaian biogas industry. Availability of well-trained biogas technicians or experts mean the high potential for biogas to thrive and be adopted by the masses. It was revealed that the Ghanaian biogas industry lacks the necessary technical expertise in the design, construction and maintenance of biodigesters. This is largely due to the fact that the Ghanaian biogas industry is wholly controlled by the private sector. One expert from a biogas company bemoaned that

> "Frankly, in this biogas industry of ours, we are on our own. The Government only pretends to care about biogas, all the necessary attention on RE sources are geared towards only solar energy".

As such, the very few qualified biogas experts in the biogas industry are challenged in terms of financial resources to train more artisans to become biogas technicians or experts. This confirms the observation made by Osei-Marfo et al., (2018), in their investigation of the professional background of biogas service providers that only 21% of the surveyed providers were certified engineers whiles 58% were artisans (plumbers, masons and carpenters) and the remaining 21% were graduates from other disciplines such as arts and commerce.

Nevertheless, there are few biogas companies training more artisans to become biogas experts to work in their respective companies. This is gradually closing the technical expertise gap in the Ghanaian biogas industry as more artisans are being trained.

4.4.4 Rate of gas production/Sustainable gas Production

For biogas to be a reliable energy source for cooking, its production should be consistent. This means the daily quantity of methane gas produced should be equal. However, it was realized that for some household biodigesters, the production of methane gas was not sustainable. This inconsistency in the production of methane gas was due to insufficiency of feedstocks. The problem of insufficient feedstocks occurs when feedstocks are not directly connected to biodigesters. This makes feedstocks readily not available as they need to be collected manually from one destination to the other. One expert reports it even more vividly by saying

> "The transfer of feedstocks from one destination to the other which involves the use of energy to generate energy defeats economies of scale. This has a higher tendency to cause not only unsustainable gas production but also increase the cost of biogas production".

Osei-Marfo et al., (2018), revealed that unsustainable production of gas deters potential users from adopting biogas technology.

4.5 The socio-economic and technical factors that influence Biogas Adoption

This section will focus on the analysis of respondents' willingness to adopt biogas and the socio-economic and technical factors that influence biogas adoption.

4.5.1 Willingness to Adopt Biogas

From Table 4.8 below, 71.1% of respondents from the Nsawam Adoagyiri Municipality and 78.7% of respondents from the Awutu Senya East Municipality were willing to adopt biogas as a clean energy source for cooking. In both municipalities, respondents who were not willing to adopt biogas technology cited the lack of funds as the major reason. Moreover, further probing revealed that some were just not interested in the biogas technology as they were not willing to embrace change. Also, the misconstrued perception of biogas as being the same as biofil toilet digesters account for the reason why some respondents were not willing to adopt biogas. This is because, the problems associated with biofil toilet digesters are considered to be the problems associated with biogas plants/biodigesters.[4]

Further investigation on the sources of funds of respondents who were willing to adopt biogas was conducted. Majority of the respondents 61.5% and 58.9% from the Nsawam Adoagyiri Municipality and the Awutu Senya East Municipality respectively indicated subsidy from the government as their source of funds to finance biogas technology. Many studies have posited that the availability of subsidies from the government is very necessary to boost the adoption of biogas technology in Africa (Bensah et al., 2011; Edem Cudjoe, 2010; Kemausuor et al., 2018; Osei-Marfo et al., 2018). In Asia where domestic biodigesters have been largely adopted especially in rural areas, the success of this high adoption rate has been attributed to the availability of subsidies from their respective governments (Putra et al., 2019; Sarker et al., 2020). Only few respondents 20.8% and 25.2% from the Nsawam Adoagyiri Municipality and the Awutu Senya East

4 The problems associated with biofil toilet digesters included bad smell coming from toilet digesters and the inability to properly flash away human excreta after using the water closet.

Municipality respectively indicated that they could finance biogas technology with their own funds. This shows that biogas technology is quite expensive for people in the municipalities under study.

Table 4.8 Willingness to Adopt Biogas

	NAMA		ASEM		All households	
Willingness to adopt	Freq	Per %	Freq	Per %	Freq	Per %
Yes	96	71.1	107	78.7	203	74.9
No	39	28.9	29	21.3	68	25.1
Total	135	100	136	100	271	100
Sources of Funding						
Credit /Loan from financial institutions	2	2.1	5	4.7	7	3.4
Sponsorship from relatives	15	15.6	12	11.2	27	13.3
Subsidy from the Government	59	61.5	63	58.9	122	60.1
Self-funding	20	20.8	27	25.2	47	23.2
Other sources	0	0	0		0	
Total	96	100	107	100	203	100

Source: Field data, 2021.

4.5.2 Factors that influence respondents' willingness to adopt

A logistic regression was conducted to assess a number of factors that influence respondents' willingness to adopt biogas technology. Therefore, the dependent variable was willingness to adopt biogas technology. The independent variables derived from literature included knowledge of biogas, cost of other energy, environmental concern, annual expenditure of cooking fuel and household size. Also, the demographic characteristics of respondents such as sex, age, municipality and level of education were included in the model as independent variables.

Table 4.9 below presents the results of the logit model. The full model was statistically significant as the P-value of the model was 0.0000. This indicates that model has a good fit of being able to distinguish between respondents who were willing to adopt and those who were not willing to adopt biogas technology. The Pseudo R^2 of 0.8307 means the full model explains 83.07% of the total variance in respondents' willingness to adopt biogas technology. This also proves that the model is fit in determining the likelihood that a particular independent variable will be selected or not.

From the model, three independent variables were statistically significant. Thus, knowledge of biogas at 0.1%, annual expenditure of cooking fuel at 4.8% and males at 0.6%. This means that willingness to adopt biogas among respondents in the municipalities under study is influenced by their knowledge of biogas technology, the annual expenditure of cooking fuel and the male gender. However, cost of other fuel, environmental concern, household size, municipality, age and educational level were not statistically significance to the model. This suggests that willingness to adopt biogas in the municipalities under study is not dependent on cost of other fuel, environmental concern, household size, municipality, age and level of education.

Table 4.9 Factors influencing Respondents Willingness to Adopt

Number of obs = 271
LR chi2(11) = 166.78
Prob > chi2 = 0.0000
Log likelihood = -16.997477
Pseudo R2 = 0.8307

Willingness to adopt biogas	Odds Ratio	Std. Err.	z	P>z | z |	[95% Conf.Interval]	
Knowledge of Biogas	409.4632	735.8548	3.35	**0.001**	12.09213	13865.22
Cost of other energy	8.130906	15.66544	1.09	0.277	0.1862809	354.9029

Annual Expenditure of cooking fuel	84.97461	137.5208	2.74	**0.006**	3.562264	2026.993
Age	3.884267	26.50601	0.2	0.842	6.04E-06	2499530
Environmental Concern	1.453954	2.186346	0.25	0.803	0.0763095	27.70277
Males	555.0528	1774.44	1.98	**0.048**	1.054728	292097.8
Females	0.170744	0.1785168	-1.69	0.091	0.0219987	1.325244
Household Size	0.099534	0.1538925	-1.49	0.136	0.0048073	2.060824
NAMA	10.4186	22.98067	1.06	0.288	0.1381286	785.8414
ASEM	0.753883	1.494453	-0.14	0.887	0.0154857	36.70083
Education	2.331565	3.687027	0.54	0.592	0.1050987	51.72467
_cons	0.000335	0.0012999	-2.06	0.039	1.65E-07	0.6788821

Source: Field data, 2021.

Knowledge of biogas technology has been revealed as a socio-economic factor which influences potential adopters to adopt biogas. This means lack of knowledge of biogas will decrease the diffusion of the technology among Ghanaians. Knowledge of biogas technology involves the in depth understanding of the technology, its operations, relevance and shortfalls. Therefore, to boost the diffusion of biogas technology among Ghanaians to increase rate of adoption, thorough education and publicity of the technology should be made. This can be championed by the government and other development organizations such as the GIZ which is known for its immense contribution in the development of biogas in Ghana (Bensah et al., 2011).

Annual expenditure of cooking fuel has been revealed as a socio-economic factor which influences potential adopters to adopt biogas. This means households with higher expenditure of cooking fuel will adopt biogas technology. Households with higher expenditure on cooking fuels have higher household income making biogas very affordable for them to easily adopt.

The male gender was statistically significant to the model. This means that men in the municipalities under study are more willing to adopt biogas than females. As such, education, sensitization and promotion of biogas technology should be geared towards the female gender.

4.6 Cost Efficiency of Biogas

The cost efficiency of biogas was assessed using a cost and benefit assessment tool called the Net Present Value (NPV). Based on information gathered from experts, the parameters for calculating the cost efficiency of biogas was developed taking a cue from the work of Cudjoe et al., 2021 & Mohammed et al., 2017. The parameters were developed for the construction of an in situ 10 m^3 fixed-dome household biodigester with a filter bed. This family size biodigester is suitable for the domestic production of biogas from household waste. Also, it is an integrated biodigester which can breakdown human excreta, animal manure and food waste. Table 4.10 below throws more light on the parameters used for calculating the cost efficiency of biogas.

Table 4.10 Parameters for Calculating Cost Efficiency of Biogas

Parameter	**Nsawam Adoagyiri Municipality** Value (GH C)	**Awutu Senya East Municipality** Value (GH C)
Annual Cost Components		
Preliminary Expenses	1 200	1 500
Machinery and Infrastructure cost (Biodigester and Filter beds)	15 000	16 500
Biogas Accessories (Balloon Gas holder, Cooking stove)	10 000	10 000
	26 200	28 000
Maintenance Cost	11 000	12 500
Annual Benefit Components		

Annual cost savings from avoidance of cesspit emptying	12 050	13 050
Annual cost savings from other sources of cooking fuel	2 400	2 550
Cost savings from waste water recycle	8 500	8 550
Cost savings from avoidance of septic tank construction	18 000	20 000
Organic Fertilizer Production	5 000	5 000
Annual Cost savings from domestic waste management	3 500	3 700
Environmental Protection	3 000	3 000
Net Present Value Components		
Discount rate	13.5%	13.5%
Economic Period of the Project	20 Years	20 Years

Source: Field data, 2021.

From Table 4.11 below, the NPV for both the Nsawam Adoagyiri Municipality and that of the Awutu Senya East Municipality are greater than zero. Hence, the installation of household biogas is economically feasible in both municipalities under study. Mohammed et al., (2017), observed that the installation of biogas plants for cooking is economically feasible where the calculated NPV was found to be greater than zero. However, the NPV for the Awutu Senya East Municipality is greater than that of the Nsawam Adoagyiri Municipality. This means the installation of household biodigester is more economically feasible in the Awutu Senya East Municipality than the Nsawam Adoagyiri Municipality. This is due to the rapidly urbanizing nature of the Awutu Senya East Municipality where the prices of goods and services are relatively higher than the Nsawam Adoagyiri Municipality. This explains why the investment cost, total discounted cost, total benefits and the discounted benefits of the Awutu Senya East Municipality are higher.

Table 4.11 Summary of Cost Benefit Analysis of 10m^3 Biodigester

Components	**NAMA (GH₵)**	**ASEM (GH₵)**

Cost		
Investment Cost	26 200	28 000
Maintenance Cost	11 000	12 500
Total Cost	37 200	40 500
Total Discounted Cost	101 207.9437	113 236.2997
Benefits		
Total Benefits	52 450	55 850
Total Discounted Benefits	357 651.513	380 835.787
NPV	**256 443.5693**	**267 599.4873**

Source: Field data, 2021.

4.7 Likely Challenges confronting the use of Biogas to cook

This section assesses the likely challenges which could confront the use of biogas to cook. Information solicited from experts through key informant interviews was used to develop themes. Appendix 4.1 attached shows the distribution of these experts. The identified themes include the following; High initial cost, high maintenance cost, Inadequate technicians, Poor biodigester design and Cultural stigma.

4.7.1 High Investment Cost

Biogas, a renewable energy source is produced through the anaerobic digestion of biodegradable waste materials. It converts waste into energy which can be used for cooking and generating electricity. A such, it provides an opportunity to efficiently manage waste and improve access to clean energy.

However, the initial investment cost involved in the installation of biodigesters for the production of biogas is extremely expensive for potential adopters of the technology. Same assertion was made by Bensah et al., (2011) & Osei-Marfo et al., (2018), that the high initial cost involved in the installation of biodigesters is a major constrain to the mass adoption of biogas technology in Africa. One expert a CEO from a reputable biogas company recounted that

> "We often say that biogas is cheap and it is true but only in the long term. The process of converting biodegradable materials to energy is quite complex and not as easy as it has been portrayed over the years. It involves huge initial investment for the construction of biogas plants/biodigesters to provide anaerobic conditions for biodegradable waste to be broken down to provide biogas. It is only when this initial cost is settled that biogas becomes cheap".

This problem of high investment cost is attributed to the lack of subsidies available to potential adopters of biogas technology in Ghana. In Asia where household biodigesters are very popular especially in rural agrarian communities, their respective governments provide subsidies to potential adopters of the technology. This has been cited by many researchers as the main strategy behind the mass adoption of biogas technology in many Asian countries (Holt & Pengelly, 2008; Putra et al., 2019; Sarker et al., 2020). Government subsidies can be provided through tax rebates on imported materials for the construction of biodigesters to help reduce the cost involve in the high initial cost of installing biodigesters.

4.7.2 High Maintenance Cost

Another constraint identified was the high maintenance cost of biogas plants/biodigesters. For the sustainable production of biogas, a biodigester needs to be inspected for damages such as cracks or leaks on gasholders and fixed as early as possible. This process of inspection and repair of damages found on a biodigester constitutes a cost component often referred to as the maintenance cost. It is the responsibility of the owner of the biodigester to conduct periodic inspections and invite a biogas technician to come and fix any damage identified. It was realized that the cost involved in the maintenance of biodigesters is quite high which deters potential adopters from adopting the technology. This confirms the assertion made by Mukeshimana et al., (2021) & Patinvoh & Taherzadeh, (2019), that the huge financial component involved in the construction, operation and maintenance of biodigesters is a major constraint that hinder the adoption of biogas technology in African continent. Depending on the magnitude of the damage identified on the biodigester, an individual is likely to pay between GH₵ 250 to GH₵ 600 for minor damages and pay between GH₵ 1 200 to GH₵ 2 000 for major damages that may require a complete change of a biogas accessory. Damages caused are sometimes attributed to poor biodigester designs and poor maintenance culture of biodigester owners. The frequency of damages depends on the quality and the age of biodigesters. Older biodigesters from their fifth year of operation require much regular servicing as they are easily prone to damages. Despite this high maintenance cost, a good maintenance culture on the part of biodigester owners will reduce the cost of maintenance. For instance, if a crack on a biodigester is identified early and fixed it does not degenerate into a major problem where the cost involve may be high. Also, if a biodigester is constructed very well by a qualified technician, major maintenance works on it begins after the fifth year of construction and operation.

4.7.3 Inadequate technicians

The construction and maintenance of biodigesters require the requisite professional skill of engineers who are mostly referred to as biogas technicians. These biogas technicians are responsible for the design, construction and the performance of periodic maintenance works on biodigesters. It was revealed that the number of certified biogas technicians available in Ghana are not enough. This is due to the lack of government support for the research and development of biogas technology in Ghana. This hinders the adoption of the technology as there are no enough certified biogas technicians to meet the steadily rising demand for the technology in Ghana.

Mukeshimana et al., (2021) reported that the inadequate number of certified biogas technicians was a major barrier to the dissemination of the technology in Rwanda. Nonetheless, some reputable biogas companies have taken it upon themselves to train artisans in the design, construction and maintenance of biodigesters. Currently, many biogas service providers are located mainly in Accra and Kumasi but are able to take up projects in any part of the country.

4.7.4 Poor Biodigester Designs

In recent times, the number of biogas companies have increased. Only few of these companies have certified engineers as biogas technicians. Hence, the poor design and construction of biodigesters. Many researchers Arthur et al., (2011); Issah et al., (2020) & Scarlat et al., (2018) have cited poor biodigester design as a major constraint limiting the adoption of biogas technology in Africa. This is due to the lack of clear regulatory bodies. The Ministry of Energy (MoE) and the Environmental Protection Agency (EPA) are responsible to oversee the operations of biogas service providers but this is not effectively and efficiently done. As such, biogas service providers do not abide by any rules or regulations stipulated by these government agencies. Shockingly, biofil toilet digester services providers are regarding themselves as biodigester technicians and are gradually encroaching into the biogas space. Consequently, potential adopters are also finding it difficult to distinguish between biofil toilet digesters and biogas plants. They quickly assume the two technologies are the same. Though, the two technologies make use of AD, the production of gas differentiates them.

Also, the lack of standardized biodigesters attribute to the problem of poor biodigester design. In Ghana, the CSIR is responsible for research and development and come out with a standard biodigester design that works for Ghana but this has not been the case. In fact, the CSIR is not playing the role of government regulatory body/agency. It competes with biogas service providers for the design and construction of both household and institutional biogas plants. Biogas service providers have lost confidence in the CSIR as a credible government agency/institution in charge of research and development to come out with a standardized biodigester design. One expert from a biogas company stated unequivocally that

> "We do not trust the CSIR to come up with any standardized biodigester design. They compete with us for biogas projects and contracts. Their decision of a standardized biodigester will be biased".

4.7.5 Cultural Stigma

The production of biogas is through the AD of biodegradable waste such as animal manure and human excreta. Some potential adopters find it problematic to cook with energy derived from waste especially human excreta. This mentality is noted to be the least of the constraints that limit the adoption of biogas technology in Ghana. Osei-Marfo et al., (2018) asserted that the negative social perception of people finding it difficult to cook with gas generated from human excreta inhibits the adoption rate of the technology in Ghana. However, biogas service providers reveled that this issue of cultural stigma over the years is residing as more people have come into terms with the relevance of the technology to improve sanitation and protect the environment.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

This chapter is made up of three parts. Thus, summary of the findings of the study, conclusions, and recommendations based the findings of the study.

The aim of the study was to examine the potential, the likely challenges, willingness to adopt and the cost efficiency of biogas as a clean energy source for cooking in the Nsawam Adoagyiri Municipality and Awutu Senya East Municipality. To achieve the aim of the study, a mixed methods approach of research was adopted to compare largely the feasibility of biogas technology for household cooking and draw comprehensive conclusions. The mixed methods approach provided the latitude to use both quantitative and qualitative data sets to enhance the comprehension of the potential, likely challenges, willingness to adopt and the cost efficiency of biogas technology for household cooking in the two municipalities under study. Also, both primary (Key Informant Interview and Questionnaires) and secondary (Articles, Certified documents, Newspapers and Online information) data sources were employed for the study.

5.1 Summary of Key Findings

This section presents the key findings based on the objectives of the study.

5.1.1 Potential of Biogas for Cooking

- In both the Nsawam Adoagyiri Municipality and Awutu Senya East Municipality there is a high potential for the production of biogas for cooking. This is due to the vast varieties of feedstocks available in both municipalities to feed biodigesters for the production of biogas.

- The fixed-dome biodigester is widely installed in Ghana as it is the most suitable to digest the vast varieties of feedstocks available in Ghana. Most of the components of the fixed-dome biodigester are locally manufactured which makes it comparatively cheaper than other biodigester types.
- Biogas service providers in recent time have begun training artisans in the construction and maintenance of biodigesters. This is gradually bridging the gap of technical expertise in the operations and optimization of biogas technology.

5.1.2 Socio-Economic and Technical Factors that Influence the adoption of Biogas

- Majority of the respondents in both municipalities under study are willing to adopt biogas as a clean energy source for cooking. This will reduce the emission of greenhouse gasses and safeguard the environment as the dominant energy type (Charcoal and Firewood) used for cooking in both municipalities were not renewable.
- Knowledge of biogas was revealed to influence respondents to adopt biogas. This means understanding the operations and relevance of biogas technology is highly necessary to improve the adoption rate. Hence, concentrating on education and publicity of the technology will improve its dissemination among Ghanaians.
- Annual expenditure of cooking fuel was revealed to influence respondents to adopt biogas. This means households with higher expenditure of cooking fuels can afford biogas and will easily adopt the technology.

5.1.3 Cost Efficiency of Biogas

- In both municipalities a positive NPV greater than one was recorded. This means biogas technology for household cooking is economically viable in a 20 years' time period at a discount rate of 13.5%. This suggests that biogas is relatively cheaper in the long term. However, its high initial and maintenance cost components make the technology not affordable for low-income households.

5.1.4 Likely Challenges of Biogas

- High investment cost. The high initial and maintenance cost components of biogas technology deter potential adopters from adopting the technology. This limits the adoption rate of biogas.
- Poor regulation of the Ghanaian biogas industry. This has led to the proliferation of the installation of sub-standard biodigesters.
- Cultural stigma. Some potential adopters are not willing to cook with energy generated from waste especially human excreta. However, this problem is largely declining as people have come to appreciate the technology as a mechanism to improve sanitation and protect the environment.

5.2 Conclusion

The Nsawam Adoagyiri Municipality and Awutu Senya East Municipality have a great potential of producing biogas as a sustainable energy source for cooking while at the same time generating high quality organic manure to fertilize farm lands. Also, an added benefit is sustainable waste management as waste will be converted into a form of clean/renewable energy which will improve the sanitation situation of the municipality.

In both municipalities under study, people are willing to adopt biogas and transition from brown energy sources for cooking to clean sources. However, the initial cost of biogas installation as well as the cost of routine maintenance of biodigesters are expensive for low-income households to afford limiting the adoption of the technology.

Finally, biogas is cost efficient in the long term and can be used strategically as a cheap clean energy source to augment the Ghanaian energy mix to decrease energy poverty and effectively manage waste to safeguard the environment for sustainable development. Nonetheless, the high-cost investment of the technology makes it extremely difficult for the technology to be adopted for household cooking especially among low-income households. At best, in place of household biodigesters, community shared biodigesters will be more feasible for low-income households and rural settlements.

5.3 Recommendations

To fully optimize the potential of biogas as a clean energy source for cooking in households and to effectively reduce the use of firewood and charcoal for cooking, the following recommendations are made:

1. Effective regulation of the biogas industry by the MoE or EPA and the standardization of biodigester designs by the CSIR or GSA.
2. There is the need to develop a national policy aimed at promoting domestic biogas plants installation for a cluster of low-income households and rural settlements. The policy should

include detailed mapping of communities, the type of feedstocks available and the size of community biodigesters to be installed/constructed.

3. The government should make provision of subsidies and tax waivers on biogas plant/biodigester accessories to reduce the cost of installation. This will create an enabling environment for the promotion and dissemination of the technology in Ghana.
4. There is the need for education and sensitization to raise awareness on the multiple benefits of biogas technology. Currently, there is limited awareness on the economic, social and environmental benefits of biogas technology in Ghana. The awareness campaign aside the major benefit of environmental protection and sustainable development should also include;
   a) The alternative energy potential.
   b) Sanitation improvement potential.
   c) High quality organic manure/fertilizer production potential.
5. Biogas service providers should offer consistent routine training on biogas technology on the various biodigesters designs, maintenance and repair works. This will bridge the technical expertise gap and improve the adoption rate of the technology.

5.4 Areas for Further Studies

1. Assessing the factors that influence the adoption of biogas technology among women.
2. Assessing the role played by women in the adoption process of biogas.

3. Assessing the power generation potential of biogas for the electrification of rural settlements.

REFERENCES

Abunde Neba, F., Asiedu, N. Y., Addo, A., Morken, J., Østerhus, S. W., & Seidu, R. (2020). Biodigester rapid analysis and design system (B-RADeS): A candidate attainable region-based simulator for the synthesis of biogas reactor structures. *Computers and Chemical Engineering*, *132*, 106607. https://doi.org/10.1016/j.compchemeng.2019.106607

Agyekum, E. B. (2020). Energy poverty in energy rich Ghana: A SWOT analytical approach for the development of Ghana's renewable energy. *Sustainable Energy Technologies and Assessments*, *40*(January), 100760. https://doi.org/10.1016/j.seta.2020.100760

Aklaku, E. D., Jones, K., & Obiri-Danso, K. (2006). Integrated Biological Treatment and Biogas Production in a Small-Scale Slaughterhouse in Rural Ghana. *Water Environment Research*, *78*(12), 2335–2339. https://doi.org/10.2175/106143006x111925

Ali, M. M., Ndongo, M., Bilal, B., Yetilmezsoy, K., Youm, I., & Bahramian, M. (2020). Mapping of biogas production potential from livestock manures and slaughterhouse waste: A case study for African countries. *Journal of Cleaner Production*, *256*, 120499. https://doi.org/10.1016/j.jclepro.2020.120499

Amankwah, E. (2011). Integration of biogas technology into farming system of the three Northern regions of Ghana. *Journal of Economics and Sustainable Development*, *2*(4), 76–86.

Ankrah, I., & Lin, B. (2020). Renewable energy development in Ghana: Beyond potentials and commitment. *Energy*, *198*, 117356. https://doi.org/10.1016/j.energy.2020.117356

Antwi, E., Engler, N., Nelles, M., & Schüch, A. (2019). Anaerobic digestion and the effect of hydrothermal pretreatment on the biogas yield of cocoa pods residues. *Waste Management*, *88*, 131–140. https://doi.org/10.1016/j.wasman.2019.03.034

Arthur, R., Baidoo, M. F., & Antwi, E. (2011). Biogas as a potential renewable energy source: A Ghanaian case study. *Renewable Energy*, *36*(5), 1510–1516. https://doi.org/10.1016/j.renene.2010.11.012

Arthur, R., Baidoo, M. F., Brew-Hammond, A., & Bensah, E. C. (2011). Biogas generation from sewage in four public universities in Ghana: A solution to potential health risk. *Biomass and Bioenergy*, *35*(7), 3086–3093. https://doi.org/10.1016/j.biombioe.2011.04.019

Arthur, R., & Brew-Hammond, A. (2010). I NTERNATIONAL J OURNAL OF study of the sewage treatment plant at Kwame Nkrumah. *International Journal of Energy and Environment*, *1*(6), 1009–1016.

Asibey, M. O., Ocloo, K. A., & Amponsah, O. (2021). Gender differences and productive use of energy fuel in Ghana's rural non-farm economy. *Energy*, *215*. https://doi.org/10.1016/j.energy.2020.119068

Asumadu-Sarkodie, S., & Owusu, P. A. (2016). A review of Ghana's energy sector national energy statistics and policy framework. *Cogent Engineering*, *3*(1). https://doi.org/10.1080/23311916.2016.1155274

Atuguba, R. A., & Tuokuu, F. X. D. (2020). Ghana's renewable energy agenda: Legislative drafting in search of policy paralysis. *Energy Research and Social Science*, *64*(January), 101453. https://doi.org/10.1016/j.erss.2020.101453

AU. (2015). The African Union Commission Agenda 2063 Framework Document. *African*

Union, *April*, 201.

Awafo, E. A., & Agyeman, V. K. (2020). Development of biogas resources and technologies, a survey. *International Journal of Energy and Environment*, *11*(3), 167–178.

Awuah, E. S. I., & Oduro-kwarteng, S. (2020). *Cost-Benefit Analysis of Fecal Sludge Treatment Interventions in Ghana*. *May 2021*.

Bensah, E. C., & Brew-Hammond, A. (2010). Biogas technology dissemination in Ghana: history, current status, future prospects, and policy significance. *International Journal of Energy and Environment*, *1*(2), 277–294.

Bensah, E. C., Mensah, M., & Antwi, E. (2011). Status and prospects for household biogas plants in Ghana – lessons, barriers, potential, and way forward. *International Journal of Energy and Environment*, *2*(5), 887–898.

Bond, T., & Templeton, M. R. (2011). History and future of domestic biogas plants in the developing world. *Energy for Sustainable Development*, *15*(4), 347–354. https://doi.org/10.1016/j.esd.2011.09.003

Chen, L., Zhao, L., Ren, C., & Wang, F. (2012). The progress and prospects of rural biogas production in China. *Energy Policy*, *51*, 58–63. https://doi.org/10.1016/j.enpol.2012.05.052

Chuttur, M. (2009). Overview of the Technology Acceptance Model: Origins , Developments and Future Directions. *Sprouts: Working Papers on Information Systems*, *9*(37), 1–23. https://doi.org/10.1021/jf001443p

Creswell, J. (2007). Five Quality Approaches to Inquiry. In *Cresswell, J. (2007). Qualitative inquiry and research design* (pp. 53–84).

Cudjoe, D., Nketiah, E., Obuobi, B., Adu-Gyamfi, G., Adjei, M., & Zhu, B. (2021). Forecasting the potential and economic feasibility of power generation using biogas from food waste in Ghana: Evidence from Accra and Kumasi. *Energy*, *226*. https://doi.org/10.1016/j.energy.2021.120342

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User Acceptance of Computer Technology: A Comparison of Two Theoretical Models. *Management Science*, *35*(8), 982–1003. https://doi.org/10.1287/mnsc.35.8.982

Dearing, J. W. (2009). Intervention Development. *Research on Social Work Practice*, 503–518.

Diouf, B., & Miezan, E. (2019). The biogas initiative in developing countries, from technical potential to failure: The case study of Senegal. *Renewable and Sustainable Energy Reviews*, *101*(May 2018), 248–254. https://doi.org/10.1016/j.rser.2018.11.011

Dumont, K. B., Hildebrandt, D., & Sempuga, B. C. (2021). The "yuck factor" of biogas technology: Naturalness concerns, social acceptance and community dynamics in South Africa. *Energy Research and Social Science*, *71*(November 2020), 101846. https://doi.org/10.1016/j.erss.2020.101846

Edem Cudjoe, E. A. and C. A. (2010). Improving Sanitation in Ghana-The Role Sanitation Biogas Plant.pdf. In *Journal of Engineering and Applied Sciences* (Vol. 5, Issue 2, pp. 125–133).

Energy Commission. (2015). *Energy Commission of Ghana*. 1–29.

Fisher, S., Bellinger, D. C., Cropper, M. L., Kumar, P., Binagwaho, A., Koudenoukpo, J. B., Park, Y., Taghian, G., & Landrigan, P. J. (2021). Air pollution and development in Africa:

impacts on health, the economy, and human capital. *The Lancet Planetary Health*, *5*(10), e681–e688. https://doi.org/10.1016/S2542-5196(21)00201-1

GLSS 7. (2019). Ghana Living Standards Survey round 7 (GLSS7), Main Report. *Ghana Statistical Service*, 1–343. https://statsghana.gov.gh/gsspublications.php?category=MTAwMjg3Mzk3NC4zMDc=/webstats/1opr93rn57

GSS. (2013). *Nsawam-Adoagyiri Municipality*. 63.

GSS. (2014). *Awutu senya east municipality*.

GSS. (2019). Ghana Living Standards Survey round 7 (GLSS7), Main Report. *Ghana Statistical Service*, 1–343. https://statsghana.gov.gh/gsspublications.php?category=MTAwMjg3Mzk3NC4zMDc=/webstats/1opr93rn57

Hamid, R. G., & Blanchard, R. E. (2018). An assessment of biogas as a domestic energy source in rural Kenya: Developing a sustainable business model. *Renewable Energy*, *121*, 368–376. https://doi.org/10.1016/j.renene.2018.01.032

Hanekamp, E., & Ahiekpor, J. C. (2014). *Feasibility Study of Ghana Institutional Biogas Programme, Work Order 46: Technical assistance to the Ghana Energy Commission to develop a dedicated programme to establish institutional biogas systems in 200 boarding schools, hospitals and prisons, and to*. 1–76.

Hes, T., Mintah, S., Sulaiman, H., Arifeen, T., Drbohlav, P., & Salman, A. (2017). Potential of microcredit as a source of finance for development of Sri Lankan biogas industry. *Energy* *and Environment*, *28*(5–6), 608–620. https://doi.org/10.1177/0958305X17714173

Holt, A., & Pengelly, I. J. (2008). ITS and renewable energy. *15th World Congress on Intelligent Transport Systems and ITS America Annual Meeting 2008*, *6*, 3854–3862. https://doi.org/10.1049/ic.2008.0789

Hussein, H., Shamsipour, M., Yunesian, M., Hasanvand, M. S., & Fotouhi, A. (2020). Association of adverse birth outcomes with exposure to fuel type use: A prospective cohort study in the northern region of Ghana. *Heliyon*, *6*(6), e04169. https://doi.org/10.1016/j.heliyon.2020.e04169

IEA. (2019). *World Energy Outlook*.

IRENA. (2017). Biogas for domestic cooking: Technology brief. In *International Renewable Energy Agency* (Issue December).

Issah, A. A., Kabera, T., & Kemausuor, F. (2020). Biogas optimisation processes and effluent quality: A review. *Biomass and Bioenergy*, *133*(December 2019), 105449. https://doi.org/10.1016/j.biombioe.2019.105449

Kamalimeera, N., & Kirubakaran, V. (2021). Prospects and restraints in biogas fed SOFC for rural energization: A critical review in indian perspective. *Renewable and Sustainable Energy Reviews*, *143*(January), 110914. https://doi.org/10.1016/j.rser.2021.110914

Kamp, A., & Østergård, H. (2016). Environmental sustainability assessment of fruit cultivation and processing using fruit and cocoa residues for bioenergy and compost. Case study from Ghana. *Journal of Cleaner Production*, *129*, 329–340. https://doi.org/10.1016/j.jclepro.2016.04.065

Kaygusuz, K. (2012). Energy for sustainable development: A case of developing countries. *Renewable and Sustainable Energy Reviews*, *16*(2), 1116–1126. https://doi.org/10.1016/j.rser.2011.11.013

Kemausuor, F., Adaramola, M. S., & Morken, J. (2018). A Review of Commercial Biogas Systems and Lessons for Africa. *Energies*, *11*(11), 1–21. https://doi.org/10.3390/en11112984

Kemausuor, F., Addo, A., & Darkwah, L. (2015). Technical and Socioeconomic Potential of Biogas from Cassava Waste in Ghana. *Biotechnology Research International*, *2015*, 1–10. https://doi.org/10.1155/2015/828576

Kemausuor, F., Bolwig, S., & Miller, S. (2016). Modelling the socio-economic impacts of modern bioenergy in rural communities in Ghana. *Sustainable Energy Technologies and Assessments*, *14*, 9–20. https://doi.org/10.1016/j.seta.2016.01.007

Kemausuor, F., Kamp, A., Thomsen, S. T., Bensah, E. C., & Stergård, H. (2014). Assessment of biomass residue availability and bioenergy yields in Ghana. *Resources, Conservation and Recycling*, *86*, 28–37. https://doi.org/10.1016/j.resconrec.2014.01.007

Khan, I. (2020). Waste to biogas through anaerobic digestion: Hydrogen production potential in the developing world - A case of Bangladesh. *International Journal of Hydrogen Energy*, *45*(32), 15951–15962. https://doi.org/10.1016/j.ijhydene.2020.04.038

Kothari, C. R. (2004). *Research Methodology, Methods and Techniques* (Second Rev, Vol. 74). New Age International Publishers. https://doi.org/10.1016/j.indmarman.2017.09.022

Kumi, E. N. (2017). The Electricity Situation in Ghana: Challenges and Opportunities. *CGD*

Policy Paper. Washington, DC: Center for Global Development, September.

Kuuzegh, R. S. (2014). Sanitation country profile of Ghana - 2004. *United Nations Department of Economics and Social Affairs. Division for Sustainable Development. Ghana National Information and Reports*, 1–8.

Lambe, F., Jürisoo, M., Wanjiru, H., & Senyagwa, J. (2015). Bringing clean, safe, affordable cooking energy to households across Africa : an agenda for action. *The New Climate Economy*, 1–32.

Marie, M., Yirga, F., Alemu, G., & Azadi, H. (2021). Status of energy utilization and factors affecting rural households' adoption of biogas technology in north-western Ethiopia. *Heliyon*, *7*(3), e06487. https://doi.org/10.1016/j.heliyon.2021.e06487

Mensah, T. N. O., Oyewo, A. S., & Breyer, C. (2021). The role of biomass in sub-Saharan Africa's fully renewable power sector – The case of Ghana. *Renewable Energy*, *173*, 297–317. https://doi.org/10.1016/j.renene.2021.03.098

Mohammed, M., Egyir, I. S., Donkor, A. K., Amoah, P., Nyarko, S., Boateng, K. K., & Ziwu, C. (2017). Feasibility study for biogas integration into waste treatment plants in Ghana. *Egyptian Journal of Petroleum*, *26*(3), 695–703. https://doi.org/10.1016/j.ejpe.2016.10.004

Msibi, S. S., & Kornelius, G. (2017). Potential for domestic biogas as household energy supply in South Africa. *Journal of Energy in Southern Africa*, *28*(2), 1–13. https://doi.org/10.17159/2413-3051/2017/v28i2a1754

Mukeshimana, M. C., Zhao, Z. Y., Ahmad, M., & Irfan, M. (2021). Analysis on barriers to biogas dissemination in Rwanda: AHP approach. *Renewable Energy*, *163*, 1127–1137.

https://doi.org/10.1016/j.renene.2020.09.051

Oduro, K. A., Acquah, B. S., Adu-Gyamfi, A., & Agyeman, V. K. (2012). *Ghana Forest and Wildlife Handbook: A compendium of information about forests and wildlife resources, forestry-related issues and wood processing in Ghana* (Issue January).

Ohnmacht, B., Lemmer, A., Oechsner, H., & Kress, P. (2021). Demand-oriented biogas production and biogas storage in digestate by flexibly feeding a full-scale biogas plant. *Bioresource Technology*, *332*(January), 125099. https://doi.org/10.1016/j.biortech.2021.125099

Osei-Marfo, M., Awuah, E., & de Vries, N. K. (2018). Biogas technology diffusion and shortfalls in the central and greater Accra regions of Ghana. *Water Practice and Technology*, *13*(4), 932–946. https://doi.org/10.2166/wpt.2018.100

Owusu, P. A., & Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Engineering*, *3*(1). https://doi.org/10.1080/23311916.2016.1167990

Panwar, N. L., Kaushik, S. C., & Kothari, S. (2011). Role of renewable energy sources in environmental protection: A review. *Renewable and Sustainable Energy Reviews*, *15*(3), 1513–1524. https://doi.org/10.1016/j.rser.2010.11.037

Parawira, W. (2009). Biogas technology in sub-Saharan Africa: Status, prospects and constraints. *Reviews in Environmental Science and Biotechnology*, *8*(2), 187–200. https://doi.org/10.1007/s11157-009-9148-0

Patinvoh, R. J., & Taherzadeh, M. J. (2019). Challenges of biogas implementation in developing countries. *Current Opinion in Environmental Science and Health*, *12*, 30–37. https://doi.org/10.1016/j.coesh.2019.09.006

Präger, F., Paczkowski, S., Sailer, G., Derkyi, N. S. A., & Pelz, S. (2019). Biomass sources for a sustainable energy supply in Ghana – A case study for Sunyani. *Renewable and Sustainable Energy Reviews*, *107*(November 2018), 413–424. https://doi.org/10.1016/j.rser.2019.03.016

Putra, A. R. S., Pedersen, S. M., & Liu, Z. (2019). Biogas diffusion among small scale farmers in Indonesia: An application of duration analysis. *Land Use Policy*, *86*(November 2018), 399–405. https://doi.org/10.1016/j.landusepol.2019.05.035

Robinson, L. (2009). *A summary of Innovations*.

Rogers, E. M. (2003). Diffusion of innovations. In *THE FREE PRESS* (Third Edit). https://doi.org/10.4324/9780203710753-35

Rogers, E. M., Singhal, A., & Quinlan, M. M. (2009). Diffusion of Innovations. *An Integrated Approach to Communication Theory and Research*, 418–434.

Roubík, H., & Mazancová, J. (2020). Suitability of small-scale biogas systems based on livestock manure for the rural areas of Sumatra. *Environmental Development*, *33*(January), 100505. https://doi.org/10.1016/j.envdev.2020.100505

Sarker, S. A., Wang, S., Adnan, K. M. M., & Sattar, M. N. (2020). Economic feasibility and determinants of biogas technology adoption: Evidence from Bangladesh. *Renewable and Sustainable Energy Reviews*, *123*(November 2019), 109766. https://doi.org/10.1016/j.rser.2020.109766

Scarlat, N., Dallemand, J. F., & Fahl, F. (2018). Biogas: Developments and perspectives in

Europe. *Renewable Energy*, *129*, 457–472. https://doi.org/10.1016/j.renene.2018.03.006

Silaen, M., Taylor, R., Bößner, S., Anger-Kraavi, A., Chewpreecha, U., Badinotti, A., & Takama, T. (2020). Lessons from Bali for small-scale biogas development in Indonesia. *Environmental Innovation and Societal Transitions*, *35*(25), 445–459. https://doi.org/10.1016/j.eist.2019.09.003

Singh, I. (2017). *USE OF BIOGAS FOR COOKING PURPOSE IN A TECHNICAL INSTITUTE : A VIEW USE OF BIOGAS FOR COOKING PURPOSE IN A TECHNICAL INSTITUTE : A VIEW POINT 1 . 1 Mechanism of Biogas Fermentation Reactions : March*.

Stephenson, M. H. (2021). *Affordable and Clean Energy*. 159–182. https://doi.org/10.1007/978-3-030-38815-7_7

Venkata Ramana, P., Michael, T., Sumi, M., & Kammila, S. (2015). The State of the Global Clean and Improved Cooking Sector. *ESMAP and GACC*, 1–179.

World Bank. (2014). *Clean and Improved Cooking in Sub-Saharan Africa* (Issue 98664).

World Bioenergy Association. (2016). Global Bioenergy Statistics 2016. *World Bioenergy Association*, 40.

Yan, B., Yan, J., Li, Y., Qin, Y., & Yang, L. (2021). Spatial distribution of biogas potential, utilization ratio and development potential of biogas from agricultural waste in China. *Journal of Cleaner Production*, *292*, 126077. https://doi.org/10.1016/j.jclepro.2021.126077

APPENDICES

Appendix 4.1: Distribution of Experts

Category	Number of Experts
Biogas Service Providers	
Biogas Technology West Africa Limited (BTWAL)	1
Beta Civil Engineers Limited (BCEL)	1
Biogas Engineering Company Limited (BEL)	1
Safisana Ghana Limited (SGL)	1
Biosanitation Company Limited (BCL)	1
Regulatory Bodies	
Council for Scientific and Industrial Research (CSIR)	1
Nsawam Adoagyiri Municipal Assembly (NAMA)	1
Awutu Senya East Municipal Assembly (ASEM)	1

Appendix 4.2: Interview Guide for Experts

UNIVERSITY OF GHANA

INSTITUTE OF STATISTICAL, SOCIAL AND ECONOMIC RESEARCH

INTERVIEW GUIDE FOR BIOGAS EXPERTS

Dear Respondents, I am a student conducting research on the topic "**Assessing the potential of biogas as a clean household energy source for cooking. A comparative study of the Awutu Senya East Municipality and the Nsawam Adoagyiri Municipality**." Every information solicited will be used purely for only this research purposes. As such, every information solicited is confidential and anonymous. No response is right or wrong; so please feel free to tick [√] the correct answer or write your answer where space is provided for you to do so.

Do you agree to partake in this interview? Yes [ ] No [ ]

SECTION A

Preliminary Information

1. What is the name of your institution/company?

2. Which year was it established?

3. What is your position in your institution/company?

4. How many household biodigesters have you installed?

5. How many institutional biodigesters have you installed?

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

SECTION B

Potential of Biogas

7. What is your perception about biogas as a source of clean household energy for cooking?

8. What are the sources of feedstocks available to feed biodigesters?

9. What biodigester designs work for domestic biogas use in Ghana?

10. Does Ghana have the technical ability to produce large-scale household digesters?

11. How can household biodigesters produce sustainable gas for cooking?

SECTION C

Cost Efficiency of Biogas

12. How expensive is biogas technology?

13. Are all the materials used for biodigesters locally manufactured?

14. Are there any tax incentives for renewable energy sources especially biogas?

15. Please provide a complete budget for the installation of a household biodigester.

SECTION D

Challenges Confronting biogas technology

16. What limits the diffusion of biogas technology in Ghana?

17. What are the main likely challenges confronting the use of biogas to cook in Ghana?

18. What can be done to improve the diffusion of the technology in Ghana?

19. Can biogas technology adoption improve access to clean energy sources and help address household energy needs. What recommendations will you make for the mass adoption of the technology in Ghana.

Appendix 4.3: Questionnaire for Respondents

UNIVERSITY OF GHANA

INSTITUTE OF STATISTICAL, SOCIAL AND ECONOMIC RESEARCH

QUESTIONNAIRE FOR HOUSEHOLDS

My name is Boapeah Ohenebeng, I am a student conducting research on the topic "**Assessing the potential of biogas as a clean household energy source for cooking. A comparative study of the Awutu Senya East Municipality and the Nsawam Adoagyiri Municipality**." Every information solicited will be used purely for only this research purposes. As such, every information solicited is confidential and anonymous. No response is right or wrong; so please feel free to tick [√] the correct answer or write your answer where space is provided for you to do so.

Do you agree to partake in this interview? Yes [ ] No [ ]

Name of Municipality NAMA [ ] 1 ASEM [ ] 2

Name of Zonal Council……………………

SECTION A

Socio-Demographic Characters

1. Gender of household head: Male [ ] 1 Female [ ] 2

2. Please what is the age of the head of household? ………………

3. What is the level of education of the household head?

No Formal Education [ ]1 Junior high/Middle School [ ] 2 Senior High [ ] 3 Tertiary [ ] 4

4. What is the household size? ………………….

5. How many livestock do you keep in this household?

Type of Livestock	Number of Livestock
Pig	
Cow	
Chicken	
Goat	
Sheep	

SECTION B

Household Energy Consumption

6.What energy source do you use for cooking?

Firewood [ ] 1 Charcoal [ ] 2 LPG [ ] 3 Animal Manure [ ] 4 Others (Specify)………………. 5

7. How much do you spend on cooking fuel per annum? GHC…………………..

8. How do you manage household waste?

Type of Waste	Method of Disposal	Cost of waste management per annum GHC/If you do not pay, what do you think you would have paid?
Kitchen waste 1		
Human excreta 2		

Liquid waste 3		

SECTION C

Willingness to Adopt Biogas

9. Are you aware of biogas technology? Yes [ ] 1 No [ ] 2

10. If yes, what is the source of your information?

1. Government/NGO [ ] 1
2. An Installer [ ] 2
3. Friend/Neighbour [ ] 3
4. Researcher/Academia [ ] 4
5. TVs/Radio/ Newspapers/Web Advert [ ] 5

Preamble: *Biogas technology is an environmentally sustainable technology with numerous benefits to the society. Biogas is produced through anaerobic degradation of feedstocks which can serve as an alternative energy source for cooking. It is relatively cheaper and safeguards the health of the user as its combustion is smokeless and odorless. Bio-slurry as byproduct of anaerobic digestion can be used as nutrient rich organic fertilizer to improve crop yield. Biogas technology provides a unique way to efficiently manage waste and cheaply access an alternative energy source. As such, the technology is sustainable and protects the environment.*

11. Are you willing to adopt biogas technology? Yes [ ] 1 No [ ] 2

12. If yes, please what is influencing your decision? Please select all that applies.

1. Knowledge of biogas [ ] 1
2. Availability of subsidy [ ] 2
3. Environmental Concern [ ] 3
4. Cost of other energy sources [ ] 4

5. Availability of Technical Expertise [ ] 5

13. If No, please state your reason

……………………………………………………………………………………………………

……………………………………………………………………………………………………

……………………………………………………………………………………………………

14. How do you intend to finance the cost of biogas technology?

a. Self-funding [ ] 1

b. Sponsorship from relatives [ ] 2

c. Subsidy from the Government [ ] 3

d.Credit /Loan from financial institutions [ ] 4

e. Other sources (Specify) ………………………… 5