UNIVERSITY OF CAPE COAST

THE USE OF BIOGAS BY HOUSEHOLDS: A CASE STUDY IN AKWATIA, EASTERN REGION, GHANA

NANCY BAKA

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BY

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Thesis submitted to the Department of Vocational and Technical Education of the Faculty of Science and Technology, College of Education, University of Cape Coast, in partial fulfilment for the award of Master of Philosophy degree in Home Economics

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature ……………………… Date: ……………….............

Name………………………………………………………………………..

Supervisor's Declaration

I hereby declare that the preparation and presentation of this thesis were supervised in accordance with guidelines on supervision of thesis laid down by the University of Cape Coast.

Supervisor's Signature…………………………… Date…………………

Name…………………………………………………………………………
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ABSTRACT

This study sought to examine the use of biogas among households in Akwatia. It assessed the extent of household willingness to adopt biogas as domestic fuel, identified factors influencing its adoption and evaluated the influence of the use of biogas in the home on household finances using the Technology Acceptance Model (TAM). The mixed-methods approach was used to collect and analyse qualitative and quantitative data, using a sample size of 357. Stratified and convenience sampling were used for the quantitative phase while purposive sampling was used for the qualitative study. Questionnaire and interview guide were used for data collection. Quantitative information collected were analysed with SPSS version 20 and presented using descriptive statistics. Descriptive analysis was used to present the qualitative data obtained. There was some level of awareness (more than 77.6 %) on the use of biogas as a domestic fuel source among households while most households (89.5 %) in the study area were willing to use biogas as their domestic fuel source for economic reasons. The cost of installing biogas plants, lack of adequate knowledge on biogas, inadequate substrate to fuel digesters, lack of technical services, and difficulty in operating biogas plants were identified as factors negatively affecting the use of biogas as a domestic fuel source. The use of biogas as domestic fuel was seen to influence household finance. It reduced household expenditure on fuel by 65 % as well as the cost of healthcare and waste management, as well as aided income generation among households. There is the need for government to subsidise household biogas construction costs and invest in the adoption of biogas technology to address some of the challenges faced by households.

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DEDICATION

Dedicated to Dr. Manasseh Edison Amu. You inspired me that the work was doable and you have been with me through it all.

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LIST OF ACRONYMS

AD:	Anaerobic Digestion
B4BL:	Biogas for Better Life
BoG:	Bank of Ghana
BT:	Biogas Technology
CNG:	Compressed Natural Gas
CHP:	Combined Health Power
CSIR:	Centre for Scientific and Industrial Research
EREDPC:	Ethiopian Rural Energy Development in promotion Centre
EU:	European Union
GDP:	Gross Domestic Product
GHG:	Green House Gas
GPRS:	Ghana Poverty Reduction Strategy
GTZ:	German Agency for Technical Cooperation
HDI:	Human Development Index
IDCOL:	Infrastructure Development Company Limited
IIR:	Institute of Industrial Research
KITE:	Kumasi Institute of Technology in Environment
KNUST:	Kwame Nkrumah University of Science and Technology
LBG:	Liquefied Biomethane Gas
LCA:	Life Cycle Analysis
LNG:	Liquefied Natural Gas
LPG:	Liquefied Petroleum Gas
MMDAS:	Metropolitan Municipal and District Assemblies
MoE:	Ministry of Education
MSW:	Municipal Solid Waste
NDO:	Netherlands Development Organisation

NGO:	Non-Governmental Organisation
R&D:	Research and Development
SMMEs:	Small, Medium, and Microscale Enterprises
SSA:	Sub-Saharan Africa
TAM:	Technology Acceptance Model
TRA:	Theory of Reasoned Action
UNDP:	United Nations Development Programme
UNICEF:	United Nations International Children Emergency Fund
WHO:	World Health Organisation

CHAPTER ONE

INTRODUCTION

Background to the Study

Energy plays a pivotal role in the lives of individuals and households (Hu et al., 2017). Most emerging countries face an increase in energy demand due to rising populations, increasing urbanisation, and expanding industrialisation resulting in an energy crisis (Osei-Marfo et al., 2020; Bryant, 2019). According to Nunes et al., (2018) households in Africa mostly rely on firewood and charcoal for domestic purposes. The reliance on wood fuel, natural gas, and thermal energy has dire consequences on the environment (Nunes et al., 2018). Indoor air pollution is one of the top five leading causes of death in developing nations; its prevalence was mostly attributable to the extensive use of biomass fuels (WHO, 2014).

Eco-friendly alternative energy sources which emit little or no greenhouse gases into the atmosphere include biogas, solar, tidal, geothermal, biomass, and wind energies, of which biogas is the most suitable for domestic use (Nunes et al. 2018). Biogas has gained attention as a way of addressing the energy challenges, reduced the environmental impact of non-sustainable fuel sources, and promoted the well-being of households (Vishwanathan, 2021). Biogas Technology (BT) involves recycling domestic, municipal and industrial organic waste into biogas and bio-fertilizer. The resulting biogas is used for cooking, heating, lighting, and refrigeration by household (Nunes et al. 2018). Other advantages of biogas include improved sanitation, less indoor smoke, the conservation of resources (trees), the reduction of greenhouse gas emissions, and the development of new jobs (Osei-Marfo et al., 2020; Bryant, 2019). To further emphasise the significance of renewable energy for national growth and development, nine of the seventeen Sustainable Development Goals (SDGs) (i.e., SDGs 1, 2, 3, 5, 6, 7, 8, 13, and 15) have a direct link to renewable energy (McCollum et al., 2018).

Given the potential for renewable energy and the risk of climate change from greenhouse gas emissions of non-renewable fuels, households should switch to greener energy sources

According to the United States Environmental Protection Agency (US-EPA) (2006), changes in weather over an extended timeframe (including variations in rainfall, wind, and temperature) are considered to be examples of climate change. Any substantial shift in the earth's typical weather pattern qualifies as climate change. Human-caused climate change poses a growing danger to human civilization (US-EPA, 2006). Stronger storms and hurricanes, hotter temperatures, more frequent and intense wildfires, higher water levels during floods, and longer and drier periods of droughts are all consequences of climate change (Ebi et al., 2021). Climate change is a threatening global security challenge alongside hunger, poverty, and war (Garfinkel, 2021). Asthma and cardiovascular diseases from air pollution, respiratory diseases from increased allergens, food and water supply insecurities, and injuries and deaths from extreme weather are just some of the ways that climate change can negatively impact people of all ages, locations, and socioeconomic backgrounds (Ebi et al., 2021).

This study focused on biogas as an alternative energy source for household cooking in Ghana in the face of the current hikes in the price of Liquified Petroleum Gas (LPG). Cooking is the most energy-intensive activity for households in developing countries, and Ghana is no exception (WHO, 2014). The widespread reliance on biomass is time-consuming, resulting in an opportunity cost and a strenuous activity for women and children (Shane et al., 2017). Indoor use of fuelwood causes respiratory diseases, heart disease, and cancer from air pollution (Bryant, 2019; Kanchongkittiphon et al., 2015). This means most families currently live under conditions harmful to their health.

Statement of the Problem

About half of households in Akwatia use firewood and charcoal for domestic activities. The use of firewood and charcoal by households in the study area could result in deforestation, soil erosion, and indoor air pollution. Anecdotal evidence in the community indicated households in the study area used dug out pits from their small-scale mining activities as waste disposal sites. These pits get filled with water in the event of heavy rains and the wastes are washed into waterbodies in the community as well as serving as breeding grounds for mosquitoes, which pose a health risk to inhabitants of the community. The oldest operating biogas plants in the country are found at the St. Dominic hospital in Akwatia. However, awareness about the benefits of BT has not yet been established in Akwatia. The barriers preventing households from adopting BT are unknown.

Putting the above discussions into perspective coupled with the current increases in the prices of LPG in Ghana, and the risk of climate change resulting from the use of firewood and charcoal and the fact that BT has been in the study area for over a decade give a cause for study. The researcher wants to find out if households in the study area are aware and willing to use biogas as their domestic fuel source, and how its usage impacts their finances.

Purpose of the Study

The purpose of study was to examine the use of biogas as an alternative energy source for the home, its contribution to household finances, and the barriers mitigating against household use of biogas.

The specific objectives of the study is to assess the level of biogas awareness, examine the extent household heads are willing to adopt it, factors influencing its adoption and ascertain the contribution of biogas usage to household's finances.

Research Questions

1. What is the level of household heads awareness of biogas as domestic fuel source?
2. To what extent are household heads willing to adopt biogas as a domestic fuel?
3. What are the factors influencing the adoption of biogas as a domestic fuel among households?
4. How does the use of biogas in the home contribute to household finances?

Research Hypotheses

In addition to the research questions, the following hypotheses were tested:

Ho1: Perceived usefulness (cooking, lighting, heating, and refrigeration) significantly influences the household heads willingness to adopt biogas for domestic use.

Ho2: Perceived ease of use of biogas (maintenance free, less skill required) significantly influences household heads' willingness to accept biogas for domestic use.

Significance of the Study

1. The study, if published would create awareness about the use of household biodegradable waste to generate energy for cooking, lighting, space-cooling, among others.
2. The study would educate the populace on the contribution of household biogas use on household finances.
3. In addition, the study highlighted the safety concerns of using biogas as a household fuel. This would enable individuals and families make informed decisions on their fuel choices for domestic purposes.
4. Finally, if published, the study would contribute to literature by making its findings available to the general public.

Delimitation

The study was delimited to household heads in Akwatia in the Denkyembour District of the Eastern Region that use different types of fuels for domestic purposes. It focused on household use of biogas as a domestic fuel source.

Limitation

The interviews were conducted in the local dialects (Twi, Hausa, Ewe). The researcher ensured the questions were asked to deduce similar meaning of items in the different vernacular languages. However, the language difference is likely to affect data collected.

Organisation of the Study

The study was organised into five chapters. Chapter One presented the background to the study, problem statement, purpose of the study, research questions, research hypotheses, significance of the study, delimitation and limitations encountered during the administration of instruments. Chapter Two dealt with a review of related literature. Chapter Three presented the methodology of the study which comprised the research design, population, sample and sampling procedure, instruments for data collection and analyses. Chapter Four presented findings of the study and discussed the findings in relation to literature. The final chapter summarised and concluded the study and also made recommendations for further studies.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This section of the study sought to review literature on biogas adoption by households. The purpose of this part of the study was to establish support for the study's findings by drawing on research done by authorities in the field. It was organised into various sub-headings including: overview of household fuel, determinants of fuel choices among households in Ghana; concept of biogas; overview of the use of biogas by households; biogas technology in Ghana; extent of household biogas adoption; factors influencing the adoption of biogas by households; and the influence of household biogas usage on household finances.

Overview of Household Fuel

Studies have predicted shifts from traditional fuels such as fuel wood and charcoal towards more modern fuel choices such as kerosene, electricity, and Liquified Petroleum Gas (LPG) (Ackah, 2018). He suggested that households' choice of domestic fuel was based on the cleanliness and convenience of the said fuel. He further argued that changes in household fuel choices were also influenced by availability of improved fuel options and increased household income. Therefore, when access to more advanced fuels improved, users would upgrade their energy infrastructure to take advantage of the more powerful fuels (Msibi & Kornelius, 2017). About 72% of Ghanaian households relied on firewood and charcoal, according to the Population and Housing Census conducted by the Ghana Statistical Service (GSS) (2021). According to the GSS (2021) census, the percentages of households that burned wood, charcoal, and

LPG were 41.3%, 32.1%, and 22.0%, respectively. Bensah & Brew-Hammond (2010) further argued household fuel choices were influenced by affordability, convenience, and accessibility of the fuel. These factors, according to them, were interrelated and also influenced by household income. In urban households, Msibi & Kornelius (2017) indicated LPG availability, higher educational levels, and higher household income levels influenced the shift to modern fuels, usually LPG. Scarlet et al. (2018) came to a similar conclusion after studying residential fuel use, finding that people typically switched from one fuel type to another gradually over time.

Determinants of Fuel Choices among Households in Ghana

Arthur et al. (2018) identified some of the factors that affected Ghanaian households fuel choices. Quick cooking tasks, including boiling water and frying, were LPG's primary use. Unreliable LPG deliveries and the volatile nature of LPG prices influenced the use of biogas and wood fuel stoves as back-up stoves. Households that relied solely on a single fuel, such as LPG, are especially susceptible to price fluctuations and poor services; fuel stacking provided a feeling of safety.

Bensah and Brew-Hammond (2010) also asserted households with irregular incomes could not afford to refill their LPG supply once the cylinder was empty. They therefore advocated for the need for increased investment in the BT in the home to enable households enjoy its full benefits.

Concept of Biogas

Biogas is a mixture of gases produced by the fermentation of organic waste, principally methane. Biogas is the outcome of anaerobic digestion (AD) of various organic materials, including agricultural waste, mixed municipal waste and dedicated energy crops (Nayal et al., 2016).

Figure 1 illustrates the process of AD for biogas production.

Figure 1: Anaerobic Digestion (AD) for Biogas Production

Source: Twinomunuji, et al. (2020)

The utilisation of Anaerobic Digestion (AD) technology and the generated biogas have become increasingly important in waste management and generating renewable, clean energy options for a wide range of applications worldwide (Dalke et al., 2021). To recycle organic substances, AD is used (Twinomunuji et al. 2020). Other oxygen-free habitats in which AD can take place include water-logged soils (such as paddy fields), bodies of water, the digestive systems of other living creatures, landfills and other waste storage systems.

Methane-rich biogas could be converted into electricity, and the resulting slurry could be utilised as biofertilizer and soil conditioner to increase crop yields with properly managed AD systems (Peng & Pivato, 2019). From animal slurries and specialised crops to food waste and lipids, the biogas yield per tonne of fresh ingredients can range from 10 to 2200 m^3 (Korbag et al., 2020). The amount of biogas produced could be altered totally in response to factors such as the accessibility of feedstock, level of investment, and mechanisms put in place to encourage its production. Biogas in its raw form could be used for same purposes as natural gas, but could also be converted into biomethane, a cleaner-burning form of methane (CH_4) (Kapoor et al., 2020). Biomethane is derived from biogas through a purification process that includes washing the gas collected from AD. With the right conversion technology, biogas could be utilised as a gaseous car fuel and as a replacement for natural gas in gas grid systems, power and heat generation (e.g., combined heat and power (CHP), and other applications (Wu et al., 2019).

Instead of using methane from natural gas, manufacturers could switch to biomethane as a feedstock (Assunço et al., 2021). The bacterial flora used to initiate AD plays a regulatory role as well. Depending on the application and scale of the system (for example, small-scale household/farm waste management or large-scale municipal waste treatment (solid or water waste), slurry treatment, agro-processing waste, and food waste treatment), the AD process facilities would be of a different type and design (Kang et al., 2021). According to Kay et al., (2021), biogas technology offered a practical solution for meeting some of Africa’s energy needs and reduced the detrimental effects of energy poverty on the continent’s economic growth.

Raw biogas could be utilised as cooking fuel, in addition to meeting local demands for heat and light, according to a 2020 study by Twinomunuji, et al. (2020). In India and China, AD technology was used for direct cooking consumption (without biogas clean-up) as part of small-scale household and/or agriculture waste management (Twinomunuji et al., 2020). Waste treatment on a massive scale, including solid or liquid waste, slurry treatment, agro-processing, and food waste, had become commonplace in many nations, resulting in the production of energy and bio-fertilizer (Gue et al., 2020). Therefore, while smaller-scale biogas electricity applications could function without connectivity to the grid, larger-scale ones require it (Greene et al., 2020). Because of the importance placed on waste management, renewable energy, and climate change by many nations, AD and biogas use have been actively promoted in several nations. Biogas was expected to make up 25% of the EU-28's renewable energy targets by 2020, and it was included in the Renewable Energy Directive, the Alternative Fuels Infrastructure Directive, and the EU's climate change commitment. (Gustafsson & Anderberg, 2021). Historically, China had been a major user of biogas, and since 2003, the country's government had aggressively subsidised its use through various policies and incentives, resulting in the broad adoption of biogas technology on both the local and national levels (Zheng et al., 2020). In 2013, Giwa et al., (2020) estimated 10,000 large-scale biogas plants and 43 million small-scale (home) biogas users in China.

Through the National Biogas and Manure Management Strategy and a national programme for energy recovery from urban trash, industrial waste, and agricultural waste, India had actively encouraged biogas use in rural regions since the early 1970s (Kemausuor et al., 2018).

Kulkarni & Ghanegaonkar (2019) indicated India's overall biogas production was 2.07 billion m3/year, with a potential of 29–48 billion m3/year. Small-scale AD had not received special attention in Africa, where rural communities relied heavily on conventional fuels (wood and charcoal) (Branch & Martiniello, 2018).

Overview of the Use of Biogas by households

Scarlet et al. (2018) highlighted the development and perspectives of biogas in Europe. Scarlet et al. (2018) indicated that Europe was the leading biogas electricity producer, with over 10GW installed and 17400 biogas plants in operation. They also contended that 50% of total biogas consumption in Europe was devoted to heat production in residential buildings.

Similarly, Msibi & Kornelius (2017) researched into the potential of biogas to solve the domestic energy problem faced by low-income households in South Africa. Case studies of existing biogas digesters were undertaken which indicated a low adoption rate (Msibi & Kornelius, 2017).

Arthur et al. (2020) on their part studied the feasibility of the use of biogas for domestic purposes in Ghana. They concluded that most of Ghana's garbage was biodegradable; therefore, could be utilised to make biogas and help alleviate the country's power outages and improved sanitation.

Hurd et al. (2017) further indicated waste treatment facilities in Ghana were inadequate; thus, refuse and excrement were sometimes spilled directly on bare land at dumpsites. They therefore advocated for increased household investment in BT as a treatment option because most of the wastes were generated by households.

Rao & Min (2018) argued that using biogas as an energy source could help reduce the social, economic, health, and environmental costs associated with conventional biomass energy. According to them, energy consumption issues in rural areas of developing countries could be alleviated through biogas for energy production. They asserted rural areas could benefit greatly from using manure and other waste products as substrates for biogas production since biogas could lead to greater energy independence and, ultimately, a more sustainable life.

Meeting the energy needs of a rapidly growing global population and advancing towards sustainable development would present formidable difficulties in the twenty-first century (He & Liao, 2018). To meet their energy needs, more than 2.4 billion people (almost a quarter of the world's population) do not have access to electricity and instead made use of biomass energy, which was not sustainable (Shallo et al., 2020). As a result, 1.4 billion homes might use biomass as their major energy source by 2030 if current energy policies and investment patterns in energy infrastructure were maintained (Vishwanathan, 2021).

According to Khare, et al. (2020), most developing countries' energy strategies had prioritised massive capital investments in generating and transmitting electricity, petrol, and petroleum products to enable the commercial expansion of energy supply sectors. Generally speaking, the needs of industry, transportation, and urban infrastructure received the bulk of governmental attention, whereas rural areas and their energy demands were mostly overlooked. Many rural locations had access to simple sustainable energy options like solar power and biogas generators (Scarlet et al., 2018).

Using today's technology, these materials might be unearthed, enabling the delivery of numerous valued services and, potentially, meeting the energy needs of rural areas.

Due to increased energy demand, fluctuating oil prices, and energy poverty, people were looking for affordable, egalitarian, and ecologically friendly alternatives to traditional energy sources (Scarlet et al., 2018). Cleaner energy solutions were necessary to solve all these issues and improve environmental sustainability (Shahsavari & Akbani, 2018). They claimed that climate change and the consequent lack of predictability in rainfall patterns were to blame for the harm to the ecosystem. Furthermore, they indicated that smoke emissions from poorly ventilated kitchens, mostly in rural areas, contribute to poor user health when using traditional biomass fuels for extended periods. By replacing current biomass usage with cleaner, greener technologies, we might benefit from a higher quality of life, better health, and a more pleasant local environment while simultaneously doing our part to slow global warming. The possibility of economic development would also rise. The use of biogas technology had the potential to reduce the negative effects of conventional biomass utilisation.

According to Boyd (2012), promoting biogas technology in Africa had been sparked by publications, meetings, and visits by numerous international organisations and external agencies. However, adoption rates were not proportional to attitudes and levels of awareness (Marie et al., 2021). Statistics indicated fuelwood was still the most commonly utilised fuel in most African households (Masekela & Semenya, 2021). According to a study conducted by the Centre for Renewable Energy Savings (Gielen et al., 2019), about 99 % of

African households utilised firewood, while only 1.2 percent used pellets. Another study by Lourens, (2018) concluded that fuelwood was still the most sought-after commodity in Botswana. LPG was next, followed closely by kerosene. The least desired source of energy for cooking was cow manure. For light, the villagers relied on kerosene or a candle (Wassie et al., 2021).

In a related Zimbabwean study, Al-Ghussain et al. (2020) looked at the use of several fuels as energy and found that electricity was only employed in a small percentage of cases. Their investigation revealed that a substantial portion of the country's population relied on biomass energy, with the majority relying on charcoal in urban regions and fuelwood in rural areas. It was also discovered that biomass was widely available across the country (Bär et al., 2021). Access rates were 79 percent in urban regions and 98 percent in rural areas. This indicated that most households relied heavily on biomass and charcoal (He et al., 2018). In both Eritrea and Ethiopia, biomass obtained from wood sources were the primary energy source in households as it accounted for up to 95% (Ang-Numbaala, 2020). It was 70 percent in Zambia. Uganda received 92 percent of the vote.

Furthermore, biomass was used to meet Tanzania's household energy requirements. Charcoal was used by 71 percent of households in the capital city. This equated to about half of the country's charcoal consumption (Stritzke & Jain, 2021). Mesagan et al. (2019) argued that Africa had a wealth of renewable natural resources. Ramier (2016) also posited that Africa was leading the charge for clean energy policymaking as millions become "food refugees" due to climate. In Rwanda, only a few households in cities used BT to cook (El-Halwagi, 2012). The Rwandan government, enraged by the country's continuous reliance on firewood as a domestic energy source, initiated the National Domestic Biogas Programme (NDBP) (Aklin et al., 2018).

To date, biofuels (biogas, biodiesel, and bioethanol) were widely used in Ghana. For instance, the Strategic National Energy Plant (SNEP) failed to acknowledge biogas technology's contribution to the growth of the energy industry when compared to other renewable energy options like wind and solar (Ramier, 2016). To meet the goal set by SNEP of decreasing wood fuel's share of the national energy mix from 60 percent in 2006 to 40 percent in 2020, further investment in Research and Development (R&D) into other renewable energy sources, such as biogas technology, was needed (Ramier, 2016).

BT was known for improving sanitation, generating clean energy, and producing high-quality organic fertilizer. Household and institutional biodigesters had attained significant adoption in China, India, and Nepal. Since 2001, China had distributed over 2 million household digesters annually, and the country's government had helped over 200 large and medium-sized animal farms to buy several and sophisticated biogas plants (Roopnarain & Adeleke, 2017). Between 2001 and 2007, over 18 million homes adopted the BT, resulting in over 7 billion m3 of biogas production; in addition, 3,556 biogas plants treated 87 million tonnes of animal waste, and over 300 Clean Development Mechanism (CDM) projects biogas energy production, with a total capacity of 1 GW and annual reducing emissions of over 20 Mt of CO_2, were completed (Sawale et al., 2020).

Over three million household digesters and three thousand community and institutional plants had been constructed by the end of 2002 in India, and since 2005, more than one hundred thousand biodigesters had been distributed annually. The use of biogas had also been widely adopted in the Asian nations of Nepal, Vietnam, and Thailand (Ekouevi & Tuntivate, 2012). They also argued that the dissemination of biogas technology across Africa had mainly failed. Poor digester design and construction, incorrect operation and lack of maintenance by users, inadequate dissemination strategies, lack of project monitoring and follow-ups by promoters, and a lack of ownership responsibility on the part of users were all reasons (Ekouevi & Tuntivate, 2012) as to why most biogas programmes failed to progress. The future still seemed bright for biogas programmes in Africa, notwithstanding their general stagnation.

Biogas facilities had been constructed as pollution abatement systems in Ghana, Kenya, Tanzania, Rwanda, Burundi, and South Africa in recent years (Sterner, 2009). These facilities provided energy for a variety of uses, including cooking and lighting, fuel replacement, and shaft power. As of October 2007, it was estimated that Kenya had disseminated over 2,000 digesters, while estimates placed the number of digesters built in Tanzania at between 4,000 and 5,000 (Sterner, 2009). There had been about 250 digester deliveries in Ghana (Arthur et al., 2018).

Biogas Technology in Ghana

Cow dung had been widely used as a cooking fuel in Ghana for many years (Akolgo et al., 2018). Firewood and charcoal for cooking were not readily available in the northern savannah regions (Akolgo et al., 2018). Rapid depletion of wood fuel resources, anticipated future increases in demand for wood fuel, and the social and environmental ramifications had heightened awareness of the importance of finding sustainable alternatives to using wood as a cooking fuel. Hence, biogas technology was selected as one strategy for cutting down on forest loss (Ekanade, 2018).

Ghana, a former British colony, uses English as the official language. The Republic of Togo is located to its east, Burkina Faso to its north, Côte d'Ivoire to its west, and the Atlantic Ocean to its south (Foucher, 2020). Compared to its estimated population of 18.9 million in 2000, Ghana's population in 2021 was estimated to be 30.8 million, an increase of 61.4% (or an intercensal population growth rate of 11.9%). An estimated 8.3 million houses would house an average of 3.7 persons (GSS, 2021).

On the basis of climate, which was reflected in natural vegetation and impacted by soils, the country was split into six agro-ecological zones. Sudan Savannah Zone, Guinea Savannah Zone, Transition Zone, Semi-deciduous Forest Zone, Rain Forest Zone, and Coastal Savannah Zone were the agro-ecological zones from north to south (Loh et al., 2019).

About 86% of Ghana's households were involved in agriculture, and 35% of all export revenues were generated from this sector (Teye & Torvikey, 2018). The importance of household businesses in the economy was highlighted by the fact that over 60 percent of economically active people would be employed in the informal sector in 2021 (Spillan & King, 2017). According to the 2019 Human Development Report published by the United Nations Development Programme (UNDP), Ghana's Human Development Index (HDI) value was 0.611, putting Ghana in the medium human development category and ranking it 138 out of 189. About 3.4 million of Ghana's population were engaged in the agricultural sector. More than half of country's farmers (1.8 million) employed workers. Maize, and cocoa were the two most crucial crops.

Wood fuels like firewood and charcoal met most of Ghana's energy needs (Yiran, Ablo & Asem, 2020). About 60 percent of the world's ultimate energy consumption and 71 percent of its basic energy supply came from wood fuels. More than 72 percent of the country's primary energy source in 2018 came from wood fuel, with the remaining coming from crude oil and hydro (Yiran et al., 2020). The residential sector accounted for about half of Ghana's total energy consumption. Ghana's household energy use relied heavily on wood fuels, especially firewood (almost 76 percent) and charcoal (Yiran et al., 2020).

The demand for wood fuels was expected to increase from about 14 million tonnes in 2000 to between 38 and 46 million tonnes by 2012 and between 54 and 66 million tonnes by 2025 if the Ghana Poverty Reduction Strategy (GPRS) targets of US$1000 per capita in 2015 were realised (Steele, 2020). The already dwindling forest resources of the country would be further stressed by this rise in demand, increasing the risk of widespread tree-cutting. The future of agriculture, water supplies, and the climate could be in jeopardy if action was not taken (Steele, 2020). Wood fuel and charcoal were in high demand since they were used by majority of Ghanaian households for both cooking and heating water (Yiran et al., 2020). If current consumption trends continued, Ghana would use more than 25 million tonnes of fuelwood by 2025.

Roughly 74 percent of Ghanaians used traditional biomass to power their homes (Mensah et al., 2021). In rural areas, however, 73.4 percent of the population still used logs as their primary cooking fuel, while 13.8 percent of the population in urban areas does (Naidu, 2021). Almost half (47.1 percent) of all urban households used charcoal as their primary cooking fuel (Cheng et al., 2014). For several decades, biogas could be a substantial energy source, especially for various regions, given current patterns in population increase, urbanisation, economic expansion, and the relative value of other energy sources (Ang-Numbaala, 2020). In many African countries, women were responsible for the majority of domestic energy usage in households (Naidu, 2021). People typically utilised kerosene or candles to illuminate their homes (Kimutai & Talai, 2021). Charcoal was the most used fuel for stoves (Naidu, 2021). Furthermore, Africa's biogas resources largely comprised farm residues, including crop and animal wastes (Sinha & Mukherjee, 2016). Rao and Gebrezgabher (2018) reported that the increasing scarcity of firewood in households had increased agro-waste utilisation for domestic heating and cooking purposes. Only a minority of city dwellers used electricity for cooking and lighting (Teariki et al., 2020).

Wealthier households, especially in metropolitan areas, could afford to utilise electric stoves for cooking due to the high cost of electricity (Blimpo & Cosgrove-Davies, 2019). The high cost of electricity prevented many people from utilising it in their homes, especially for cooking (Adwek et al., 2020). Interest in biogas technology began in Ghana in the late 1960s, but it was not until the latter 1980s that the government gave it the attention it deserved (Elliot, 2018). Before the mid-1980s, most dissemination efforts focused on providing domestic cooking energy (Nomanbhay et al., 2017). However, due to immature technologies and poor dissemination techniques, most plants collapsed soon after the project ended. Reviving the BT was the goal of the Ghana–China Cooperation Agreement of 1986, which led to the building of a 10-m3 plant at the Bank of Ghana (BoG) cattle ranch in the Shai Hills and the launch of the Appolonia Household Biogas Programme (Elliot, 2018).

Appolonia is a community in the Greater Accra region, and its Household Biogas Programme sought to provide residents with a means to cooking using renewable energy sources. A total of nineteen fixed-dome digesters, including six 15 m^3 and two 30 m^3 digesters, eight 10 m^3 and three 25 m^3 Chinese dome digesters (IIR), were constructed by engineers from the Ministry of Energy (MoE) and the Institute of Industrial Research (Osei-Marfo et al., 2018). In Jisonayilli and Kurugu in the Northern Region, household biogas demonstration plants were constructed in 1987 with support from the United Nations Children's Fund (UNICEF) (Osei-Marfo et al., 2018).

In June 1992, the MoE inaugurated the world's first large-scale community-based biogas facility in Appolonia which was known as the Appolonia Integrated Rural Energy Project. All of the homes in the neighbourhood were supposed to have access to street lighting and electricity for low-power appliances (Osei- Marfo et. al., 2018). Cow dung and human waste were used to fuel the digesters, and the resulting gas was used to fuel a 12.5 kVA generator that provided electricity for street and household lighting; the bio-slurry was used in the fields to increase crop yield (Bensah, 2009). The project faced a number of problems and so failed to attain its objectives owing to factors including lack of feedstock, kraals located far from the community (about 500 metres), sloppy upkeep, and the unwillingness of some residents to help.

Utilising the digested sewage as fertiliser for crops faced some difficulties. Liquid organic fertiliser produced at the facility was effectively used on farms, despite initial complaints from farmers about the laborious process of transporting the fertiliser from the plants to the farms (Branch & Martiniello, 2018). The long walking distances to collect manure from kraals was another major challenge. (Osei-Marfo et al., 2018). They further indicated Fulani herdsmen forbade women from collecting manure from the kraals because doing so could induce abortion in pregnant cattle.

According to Awafo and Agyeman (2020), Ghana had the potential to construct about 277,000 household biogas systems. According to Biogas for Better Life (B4BL) project for Africa, which was created by African development partners and inaugurated in Nairobi, Kenya, in May 2007, over two million African families would be provided with biogas plants to help alleviate poverty (Bawakyillenuo et al., 2021). These plants would also improve family health by reducing indoor pollution and the burden of gathering and storing firewood (Bawakyillenuo et al., 2021). Over 800 private biogas firms, 200 biogas appliance production workshops, and the installation of one million bio-toilets were all part of the initiative's broader scope.

Kumasi Institute of Technology and Environment (KITE), a local energy NGO, conducted interviews in 2007 as a first stage in the formulation of a nationwide biogas scheme (Johnson et al., 2020). Entrepreneurs with expertise in the construction of biogas plants worked together on this. About 250 biogas plants were found to have been built in Ghana throughout the study's time frame (Johnson et al., 2020). Most biogas plants were bio-sanitation interventions like waste treatment plants and bio-latrines, and they could be found in households and institutional settings in mostly urban areas (Awafo & Agyeman, 2020).

In a study to assess domestic biogas potential from cow dung in the three Northern and Ashanti Regions of Ghana, KITE estimated the technical potential of 80,000 household biogas installations and a market potential "(estimated based on the ability and willingness of users to pay) of about 8,000 (8 percent of 80,000) plants. According to KITE, most efforts to spread biogas technology had been concentrated in institutional settings". Families had not been enthusiastic about using biogas in their stoves or digested manure in their gardens (Bensah & Brew-Hammond, 2010).

Most of the first biogas plants to be built had to be shut down shortly after the start of the project due to distribution problems and outdated technology (Bensah & Brew-Hammond, 2010). The 'Integrated Rural Energy and Environmental Project were initiated in 1986 by the Ministry of Energy (MoE) in Appolonia, Accra, with the construction of 19 modest family digesters, making it one of the first large-scale communal biogas demonstration projects in Ghana (Arthur et al., 2018). The plan was to provide energy for public lighting and bio-fertilizer for farmers, especially cattle farmers (Arthur et al., 2018).

However, there were malfunctions in three digesters, leading to their demolition and thirteen others (Arthur et al., 2018). Around the same period, a 10 m3 digester was installed at the Bank of Ghana's cattle ranch in Shai Hills, Accra (Osei-Marfo et al., 2018). Between the 1980s and 1990s, the Ministry of Environment, the Institute of Industrial Research (IIR), the Catholic Secretariat, and the German Agency for Technical Cooperation (GTZ) were the most prominent players in the spread of biogas technology (Wandera, 2017). Since

2000, the technology has been promoted by mainly by biogas businesses (Awafo & Agyeman, 2020).

Level of Household Biogas Awareness

Energy for cooking and heating could be provided by biogas technology, which could help reduce the country's growing energy deficit, particularly in remote areas where extension of electrical grid presents significant technical and financial challenges (Ghimire & Kim, 2018). In addition to reducing greenhouse gas emissions and providing bio-fertilizer, Ghimire and Kim (2018) asserted biogas technology provided a clean, renewable energy source that might be utilised to supplement more conventional energy sources. According to them, methane was abundant in biogas because it was produced by anaerobic fermentation. Depending on the feedstock used, biogas could consist of about 40 to 75 percent methane, 25 to 40 percent carbon dioxide, and other components like nitrogen, oxygen, water, ammonia, and hydrogen sulphide (Aziz et al., 2019).

Biogas technology could provide a clean source of household energy, enhance environmental well-being, and boost agricultural output if properly managed (Logeswaram et al., 2020; Bryant & Afitiri, 2021; Bryant, 2019). Consequently, technological development in South Africa had optimistic outlook for the future. In the 1960s, the first experimental digester was installed in South Africa, marking the beginning of the country's long relationship with biogas technology (Logeswaram et al., 2020). Biogas technology in the country could generate 327,222 MW h /a of electricity and 420,714 MW h /a of thermal energy every year, based on the present number of cattle in the country (1764,000 Mg/a in total manure production) (Logeswaram et al., 2020).

In order to take full advantage of biogas technology, the South African government implemented a bottom-up strategy by distributing biogas digesters to homes in rural areas and implementing programmes like “Design, development, and monitoring of optimised sustainable clean, renewable energy and efficient mix system” to increase access to cleaner, more affordable energy sources for the country’s poor (Uhunamure et al., 2019). Government programmes like “Accelerating Biogas Market Development: Capacity Building for Domestic Biogas Digesters” are helping SMMEs adopt organic waste-to-energy and other low-carbon technologies (Uhunamure et al., 2019). According to Uhunamure et al. (2019), many biogas initiatives failed to provide desirable outcomes despite the government’s substantial investment in the technology.

The technological dissemination and development level according to Uhunamure et al. (2019) was low, despite the country’s relatively high expansion potential. About 700 biogas digesters had been installed across the country (Mutungwazi et al., 2018). Despite this, the anticipated benefits from the technology had not materialised, and the reasons for this remain were unclear. Mutungwazi et al. (2018) indicated while biogas was gaining popularity, there had been little research done in South Africa. However, none had centred on how people would use the technology (Mutungwazi et al., 2018). Economic, social, cultural, technological, and environmental factors influenced a family decision to embrace a particular technology; successful technology adoption required interventions and legislation (Uhunamure et al., 2019).

Adamou et al. (2021) stated that deforestation was a major problem in Africa due to the growing demand for fuel wood to meet household energy demands and the widespread lack of access to sustainable alternative energy sources. Several studies, including one by Shankar et al. (2020), pointed to a lack of alternatives as the primary reason accounting for the continuous reliance of rural cattle rearing households on biogas to power their homes. Tucho (2020) lamented that many people have been forced down the energy ladder due to energy challenges and a lack of economical alternatives as a result of shifting government policy. Some households who could previously afford cooking gas were forced to switch to kerosene because of its price increases (Kanu et al., 2020). According to Kanu et al. (2020) households who had no access to kerosene had made do with wood or charcoal.

Okopi (2021) claimed there was widespread use of fuel wood in cities which threatened the environmental sustainability of high-populated regions although residents were aware of biogas. Although countries continued to use unsustainable energy sources, it was believed it had a good potential for the development of cleaner and environmentally sound alternative energy sources, such as solar panels, biofuels, and wind turbines (Chandrasekhar, 2017).

Some of these technologies could be quite expensive, there was therefore the need to look for less expensive yet eco-friendly substitutes. A major focus of the international community was the development of low-cost, sustainable alternatives to traditional energy sources that might be implemented in developing nations (Osuji & Amadi, 2020). If developing countries were serious about stopping desertification in Sub-Saharan Africa and global warming, switching to renewable energy sources was a sustainable alternative (Abegunde et al., 2019).

Rural and low-income city dwellers still relied on biomass to power their homes though there was increased advocacy for sustainable fuel such as biogas (Makonese et al., 2018). A biogas plant could use water lettuce, hyacinth, manure, cassava leaves and processing waste, urban garbage, solid (including industrial) waste, agricultural residues, and sewage as feedstock substrate (Usman et al., 2021). Due to the unsustainable nature of biomass, it was crucial to adopt an eco-friendly energy source, especially in regions where desert expansion and drought had already happened as a result of deforestation for both industrial and domestic purposes (Elagib & Al-Saidi, 2020).

Renewable energy was obtained from varied sources, such as the sun, wind, water, and energy crops like switchgrass. However, fuels like coal, oil, and natural gas were not replenishable. Cogeneration (CHP) plants had been utilised in the sugar, wood product, and chemical pulping (black liquor) industries (Demirbaş, 2001). He indicated South-East Asia had a wide variety of biomass resources, including forest residue from the region's rain forests, farm wastes and crop leftovers, animal dung or poultry droppings, industrial effluents (from the region's industrial cities), urban solid wastes, and sewage. Biomass energy could be produced through various processes, including combustion, gasification, and fermentation (Uzoma et al., 2010).

Liquid and gaseous fuels could be produced using these technologies from a variety of sources, including traditional crops (sugarcane, maize, oilseeds), crop residues, and trash (maize, stover, wheat straw, rice hulls, cotton waste), energy specialised plants (grasses and trees), and the organic component of urban garbage (Badger, 1999). Carbon emissions from fire wood burning in poorly ventilated domestic kitchens could be greatly reduced by converting solid biomass materials into biogas for use in upgraded cook stoves would significantly improve climatic conditions and reduced health risks associated with cooking in poorly ventilated smoky kitchens (Uzoma et al., 2010). Also, replacing natural gas with methane biogas could cut United States (US) greenhouse gas emissions by 99 million metric tonnes annually, or about 4% of total U.S. greenhouse gas emissions (Vergara et al., 2011).

Several countries in Asia, United State, and Germany have adopted biogas technology on a large scale (Cheng et al., 2014). Biogas systems were first implemented in India in 1960, but the widespread promotion did not start until 1981. Netherlands Development Organization (NDO) provided funding towards national household biogas programmes that helped families to buy, build, and maintain their biogas systems so that the sector could become economically sustainable (Joshua, 2014).

There were NDO initiatives according to Joshua (2014) in a number of Asian and African countries, including Nepal, Vietnam, Bangladesh, Cambodia, Pakistan, and Indonesia, as well as in Rwanda, Senegal, Burkina Faso, Ethiopia, Tanzania, Uganda, and Kenya. Compressed biogas was gaining popularity in countries like Sweden, Switzerland, and Germany (Joshua, 2014). Joshua (2014) asserted a biogas-powered train had been operating in Sweden since 2005 and it (biogas) had been used as a fuel source for some cars. In the British documentary "Sweet as a Nut," released in 1974, a method of creating biogas from pig droppings and using that biogas to fuel a combustion engine was shown (Prajwal, 2020).

In addition to the MoE, the Catholic Secretariat and German Agency for Technical Cooperation (GTZ) had shown enthusiasm for advancing biogas development in Ghana (Bensah, 2009). Bensah and Brew-Hammond (2010) indicated the Secretariat provided funding for the construction of biogas plants at the Catholic Mission at Kaleo in the Upper West Region and three Catholic hospitals in the Eastern and Volta regions between 1994 and 1995. These hospitals were the Holy Family Hospital, St. Dominic Hospital, and the Battor Hospital. Projects to convert slaughterhouse waste into biogas had been implemented at Ejura and KNUST with funding from the GTZ (Bensah & Brew-Hammond, 2010). Due to a shortage of donor funding and unrealised expectations from the Appolonia programmes, the MoE's direct involvement in biogas diffusion had declined since 1993 (Bensah, 2009).

Greater Accra, Volta, and the three Northern Regions' biogas potential were analysed in 1996 with funding from the Ministry of Energy, hoping to re-energize the sector (Bensah, 2009). This research was conducted to help lay the groundwork for a nationwide biogas initiative. Over a decade after the study was completed and the report was presented to the Ministry of Environment and Natural Resources, there had been little interest in launching a national biogas scheme (Doghle, 2018). In addition, the Institute of Industrial Research (IIR), a parastatal entity responsible for spreading biogas digesters, had failed to convince authorities in Ghana to offer the necessary support for the biogas industry (Doghle, 2018).

Beginning in the year 2000, a variety of Ghanaian private biogas companies had promoted the technology for purely economic reasons, with an emphasis on the purification benefits of their products. Biogas Technology West Africa Limited and Beta Civil Engineering Limited, the two most notable companies had been constructing fixed-dome digesters made of brick and Puxin digesters made of concrete, respectively (Mengistu et al., 2015). Dasbiogas Ghana had also introduced potable biogas plants onto the Ghanaian market (DAS Biogas, 2018).

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Biogas technology could provide a clean source of household energy, enhance environmental well-being, and boost agricultural output if properly managed (Logeswaran et al., 2020).

Government programmes like "Accelerating Biogas Market Development: Capacity Building for Domestic Biogas Digesters" were helping households to adopt organic waste-to-energy and other low-carbon technologies (Uhunamure et al., 2019). According to Uhunamure et al. (2019), many biogas initiatives failed to provide desirable outcomes despite the government's substantial investment in the technology.

Extent of Household Biogas Adoption

A person's decision to use a new piece of technology was the culmination of a multi-stage process that begins with education and continues through research and evaluation of the product's characteristics (Shafiq et al., 2017). This study emphasised the underlying and proximal elements that influenced a household's decision to utilise or reject biogas technology. Biogas improved energy security while decreasing pollution and greenhouse gas emissions; saved money in the process (Tucho, 2020). The vast majority of people in underdeveloped countries still used traditional energy sources, despite the many advantages of biogas technology (Tucho, 2020).

In Sub-Saharan Africa (SSA), wood fuel and charcoal were the most widely used forms of energy (Langat, 2019). Approximately 81.4% of Ethiopian households used firewood for cooking, followed by 11.5% who used leaves and dung cakes and 2.4% used kerosene. According to the Ethiopian Rural Energy Development and Promotion Centre (EREDPC) and the NDO, traditional fuels make up 99.8 percent of the total (rural and urban) domestic energy supply, with 88.1 percent coming from woody biomass, 10.2 percent from crop residues, 1.1 percent from dung, and 0.8 percent from charcoal (Shallo et al., 2020). This had increased the urgency with which the Ethiopian government, NGOs, and international players searched for new, sustainable energy sources (Shallo et al., 2020). This was important because, in developing countries like Ethiopia, where poverty and energy use are intertwined, there was a direct correlation between the two (Olsson, 2015).

Multiple researches were conducted to determine what factors affected the widespread use of household biogas worldwide. A study in a few Asian countries found that insufficient national policies, a lack of financing and subsidy facilities, and a lack of active private sector involvement were among the key determinants affecting national biogas growth (Khan & Martin, 2016).

Biogas technology adoption necessitated research on the bio-digester size, feedstock type, and other location-specific characteristics, while studies on capital and operational expenses for biogas production might generate profits that might be tolerated (Shallo et al., 2020).

Factors Influencing the Adoption of Biogas by Households

Cost of Installation

A number of nations were failing to keep up with energy demands in Africa (Khan & Martin, 2016). The use of traditional biomass fuels met most rural residents' energy needs (Khan & Martin, 2016). They reiterated about two-thirds of the energy used in the continent came from biomass as a result of large natural gas-fired power stations had experienced gas shortages due to increased demand since 2005. They argued biogas could be crucial in finding a solution to the energy shortages. Due to its extensive agricultural sector, Africa had abundant waste products and other biomass fuels that could be utilised to generate biogas to power the continent's economy. According to research by Ali et al. (2020), Bangladesh generated approximately 102.6 million tonnes of cattle dung annually from 25.5 million cows & buffaloes, 12.9 million tonnes of poultry waste from 291.5 million chickens & ducks, and 8.65 million tonnes of city trash.

Waste in this quantity had significant monetary value since it might be converted into biogas for food preparation, home heating, and power generation

(Ali et al., 2020). Since April 2016, the Infrastructure Development Company Limited (IDCOL) has funded the installation of almost 42,800 biogas plants across the country through its 43 partner organisations (Ikonya, 2018). Bio-fertilizer, a by-product of biogas production reduced the annual cost of chemical fertiliser by USD 7.6 million and saves USD 3.5 million in firewood costs by producing 165,000 metric tonnes of organic fertiliser (Ikonya, 2018). About 1,300 tonnes of kerosene were spared annually as a result.

Life Cycle Analysis (LCA) of renewable energy production systems could be conducted according to local conditions because one energy source cannot be sustainable for all geographical locations due to variations in resource availability, climate, environmental, economic, social, and policy conditions, etc. Rao (2018) investigated into whether or not biogas installations might provide enough energy for cooking and lighting in homes with three to six livestock. Paul (2021) claimed that replacing electricity with natural gas could enhance the energy efficiency of a biogas system by up to 65% while upgrading biogas to biomethane for injection into the natural gas network could increase the primary energy input for biogas utilisation by up to 100%.

According to studies conducted by Doghle (2018), a sizable financial investment was needed for the design, construction, operation, and maintenance of a biogas plant, although this cost could be readily covered by borrowing money or supplemented by the government or NGOs. Providing financial assistance and technical assistance for biogas technology was crucial for its effective deployment and adoption because the cost of installing biogas was high (Rao, 2018). Government incentives and continuous R&D leading to novel biogas plant designs and associated biogas accessory manufacture explained why countries like China and India had many household biogas plants (Hamid & Blanchard, 2018).

In Ghana, however, the situation was different because the stoves and utensils, as well as their installation and maintenance, would have to be paid for by individual users or future adopters. Thus, the introduction of biogas technology in Ghana was rather pricey (Bensah & Brew-Hammond, 2010). The average cost to construct a biogas plant in Ghana was GHC 5,050.00 in 2008 (Bensah & Brew-Hammond, 2010). However, biogas plants were being sold by the Centre for Scientific and Industrial Research (CSIR) for GHC 8,000.00. Most investors cannot afford the capital expense of setting up a biogas plant out of their usual income or savings alone (Ali et al., 2020).

Alternative Fuel Costs

Biogas was largely utilised to generate energy and heat in most nations. It could also be used for a variety of applications, including the production of motor fuels. Biogas was progressively being refined to compressed biomethane gas (CBG) as a renewable alternative to compressed natural gas (CNG) for use in vehicles, particularly cars, and buses, in many countries (Oladayo, 2016). Liquefied biomethane gas (LBG) had recently gained popularity as a replacement for liquefied natural gas (LNG) in heavier transportation. Other alternatives were also accessible. Biogas could be used to make syngas, which could then be used to make renewable fuels like hydrogen, methanol, CBG and LBG. These fuels differed from CBG and LBG in terms of characteristics and potential, making them potentially suited for various sections of the renewable energy system that needed to be developed.

According to the Rwanda Biogas Programme, which Mengistu cited, Simane et al. (2015), even though biogas users still used other sources of fuel, their total annual spending was significantly less than 31-32 percent of non-users, resulting in a reduction of roughly 1,825 kg of fuel wood use per year. They attributed it to less money being spent on fuel wood and charcoal because of the increased availability of biogas. It was advocated, biogas could replace more conventional fuels in Africa and other developing nations (Palaniappan & Annadurai, 2018).

The scarcity of wood fuel and other alternative fuels, such as LPG, was a driving factor for biogas system implementation (Paul, 2021). This could be worsened by an energy shortage, prompting people to seek low-cost fuel alternatives such as biogas (Paul, 2021). Because of the high initial cost, Mumbi (2017) found that higher-income households were more likely to adopt biogas digesters than lower-income households.

Knowledge and Usage of Biogas

According to Adnam et al. (2019), simple organic raw sources such as animal dung, food wastes, agricultural residues, municipal waste materials, and human wastes could be used to make biogas. The biogas produced from these materials might be utilised to create energy and heat, compressed for use in public transportation, and used as fuel for street lights in communities as a natural gas alternative (Aziz et al., 2019). Biogas generation was a sustainable waste management, sanitation, environmental protection option, and an economical fuel source due to the high cost of fossil fuels (Adnan et al., 2019).

Many rural areas who had difficulty connecting to the power grid had been able to meet their energy demands independently due to biogas (Paul, 2019). While it was generally accepted that agriculture contributed significantly to global warming, its environmental impact could be mitigated by recycling animal waste and other forms of agricultural waste (Adnan et al., 2019). According to Adnan et al., (2019), sustainable energy sources like biogas could help with climate change and the problems caused by increasing atmospheric CO_2 levels. While burning fossil fuels and wood fuels had led to current global warming, biogas does not add to the problem, and the methane it produces had no discernible effect on the atmosphere (Bryant & Afitiri, 2021; Bryant, 2019; Paul, 2019).

Biological or ecological farming, which used biogas technology, was expected to boost farmer income and make it simpler for the agricultural system to achieve high production at a cheap cost (Adnan et al., 2019). Many Ghanaians made a living in the agricultural sector. It was estimated that over 70% of Ghanaians were engaged in agriculture as their primary source of income (Aziz et al., 2019). Most of their income was earned from farming. Livestock husbandry was a crucial part of the agricultural system in Ghanaian homes. Most households in Ghana raised livestock such as cattle, chickens, pigs, lambs, and goats with most of the country’s cattle and half of its small ruminants kept in the north (Wilson, 2018).

Animals were used by smallholders to supplement their family’s meals and to provide sporadic cash revenue (Nayal et al., 2016). Backyard and bush farming were the two types of farming systems used in the country. Animal excrement from kraals and pens were the most important sources of organic matter for soil fertility; rarely were compost, pit rubbish, and agricultural wastes used (Olabode, 2018). Backyard farming was practised in places with limited farmland and dispersed settlements (Paul, 2018). Animal traction and other forms of labour-saving technology were used in crop farms. However, hoeing was still widely practised in some areas as a form of tillage. The lack of fertile soil was a major hindrance to agricultural output in the north (Osei-Marfo et al., 2020).

Surface soil organic matter was quite low because of the high temperatures and annual grass burning. Because of this, the soils' nutrient levels, particularly those of Phosphorus (P), Potassium (K), and Nitrogen (N), are low. Sheet erosion and soil leaching were worsened by the lack of grass cover and the heavy rain that falls over four to five months. Therefore, chemical fertiliser was widely used there. Connecting livestock farming with crop farming through biogas technology could pave the way to self-sufficient eco-farming (Osei-Marfo et al., 2020).

Knowledge and perception were important aspects that influenced an individual's or household's decision to embrace technology (Bryant & Afitiri, 2021; Yang, 2017). An increased understanding of biogas's cost-effectiveness and potential benefits would have a sustainable impact on the technology's deployment, adoption rate, and long-term use in households throughout Ghana (Arkoh, 2016). The educational level, publicity, and demonstration results all had an impact on knowledge and perception (Arkoh, 2016). How likely customers were to adopt a technology was heavily dependent on their level of familiarity with that technology, as well as their perception of its advantages.

On the other hand, the lack of understanding was a sustainable barrier to biogas uptake and long-term use (Bößner et al., 2019). The knowledge of biogas among many people was confined to its usage for sanitation to the exclusion of other biogas applications such as bio-slurry for farming and human health protection and Green House Gas (GHG) reduction. (Doghle, 2018). Doghle (2018) claims that people are more likely to adopt biogas technology if they were well-informed about its benefits and were given ample opportunities to learn about it through various media outlets.

Women's knowledge of the risks posed by smoke during cooking and food processing in rural areas was a potential factor in increasing support for implementing biogas technology and other clean energy solutions (Rupf et al., 2015). Pilloni and Hamed (2021) argued that biogas plants might help meet national renewable energy goals provided the necessary technology, policy drivers, and incentives were made available to convert methane to natural gas. Once this was achieved, biogas could be utilised as a fuel for automobiles and to fuel thermal power plants through natural gas pipes, resulting in the creation of electricity (Murray et al., 2017).

There was a positive relationship between educational attainment and knowledge of biogas use (Mengistu et al., 2016). People with more education and experience were more likely to be open to new ideas than those with less (Mengistu et al., 2016). It was claimed that higher-educated locals had a greater propensity to switch to more environmentally friendly fuel sources (Ranathunga et al., 2019).

According to Mengistu et al. (2016), knowledge and use were crucial elements in determining whether or not biogas systems were adopted in rural China. It was reported, biogas stoves and plants were more widely adopted in locations where users could run and maintain them with a low level of education, as opposed to more affluent communities (Mengistu et al., 2016). With regards to installation of biogas plants, Doghle (2018) claimed that installers were the ones who actively encourage their customers to do so. Most proponents of biogas point to the potential savings in electricity for household cooking, lighting, and appliances like refrigerators and freezers, as well as additional savings in the agricultural sector due to the elimination of waste.

Protection of the Environment

Major ecological and monetary costs were associated with the widespread use of wood fuel and fossil fuels. Municipal solid waste (MSW) management, and especially organic fraction management, was a major issue in many African nations. A threat to environmental health and sustainability was posed when this trash ends up in the ocean or poorly planned landfills (Vasco-Correa et al., 2018). As a result of broad demand, forest and wood resources in Ghana had been severely harmed, and forest cover was fast diminishing (Akolgo et al., 2018). Therefore, renewable technology, such as biogas, must be used to preserve the forest (Akolgo et al., 2018).

Anaerobic sludge could be used as organic fertiliser, and biogas could be used as a supplement to conventional energy sources for activities such as cooking, heating, powering vehicles, and generating electricity (Bharathiraja et al., 2018). Donor organisations built a lot of sewage treatment plants in Ghana and elsewhere in Sub-Saharan Africa, but many of them were collapsed, resulting in the daily dumping of more than 250,000 litres of human excreta from trucks onto the beach and into the water at Lavender Hill (Akolgo et al., 2018).

Waste disposal and wastewater treatment problems that had plagued the country could be alleviated with the use of biogas technology, which could be implemented by Metropolitan, Municipal, and District Assemblies (MMDAs) and other institutions. Biogas plants were more environmentally friendly and economical than septic tanks for treating municipal sewage and biodegradable waste (Wood et al., 2013). Schistosome flukes, found in water snails that typically thrive in paddy fields and ponds could be eliminated from a household biogas system at rates of 90 to 100 percent (Olabode, 2018). This meant less risk of flooding, improper garbage disposal, the spread of epidemic diseases, and unpleasant odours (Olabode, 2018).

Rising greenhouse gas emissions, primarily from wood and fossil fuels, and poor waste management were key causes of concern around the world. Biogas technology provided clean fuel for cooking and lighting and produced excellent manure for farming from slurry. Every piece of machinery that ran on natural gas could be converted to run on biogas and organic fertilisers could be used for farming instead of inorganic chemical fertilisers (Lohri et al., 2016).

Pilloni and Hamed (2021) reported that an average Indian household used 71.29 GJ annually and produced 646.1 kg of carbon dioxide. However, when biogas plants were operated, GHG emissions were cut by 7.62 tonnes of carbon dioxide equivalent per biogas plant. A total of 638.82 metric tonnes of CO_2 GHGs and 217.32 metric tonnes of fuelwood per household could be avoided annually by installing 84 biogas plants with a 6m3 capacity. This suggested that biogas technology would help reduce deforestation and mitigate climate change and global warming. Biogas technology offered a long-term solution to the problems of organic waste management and municipal sewage, two main contributors to pollution, while also helping preserve wood supplies. The utilisation of bio-slurry in farming made biogas technology essential for environmental sustainability, human and animal health, and food security (Agarwal et al., 2015).

Influence of Household Biogas Usage on Household Finance

It was possible to create biogas from organic waste generated in households, making it a cleaner and more cost-effective energy option.

However, despite several efforts to promote the technology over the years, households had not yet reaped its full benefits. Many households had not yet investigated the potential financial benefits of the use of biogas technology (Garfi et al., 2019).

According to Garfi et al. (2019), the use of biogas by households improved their living conditions and economy while reducing environmental impacts; annual income was increased by 3-5.5% due to fertiliser savings and increased crop yield. They noted that these numbers might rise if digester performance and the longevity of the technology were both improved. Langat (2019) found that when households used biogas, it decreased their energy expenses, boosted their agricultural revenue, and improved their quality of life.

Rate of Biogas Adoption among Households

The use of biogas technology by households accrues a number of benefits to households in particular and society in general. It helped people save money by reducing their dependence on wood fuel for cooking and by providing bio-slurry for use in fertiliser. Despite government and NGO efforts to promote biogas technology, its estimated adoption rate was low, at only 25.8 percent of its potential (Agarwal et al., 2015). They found that the likelihood of adopting biogas technology decreased with an increase in family size, feedstock, and the age of the household head. Additionally, Tucho (2020) found that households with land holdings above 0.6 hectares were more likely to use biogas systems than those below the threshold.

Theoretical Review

The study adapted the Technology Acceptance Model (TAM) developed by Davis et al. (1989). The TAM was developed based on the Theory of Reasoned Action (TRA) developed by Ajzen and Fishbein (1969), to explain the relationship between attitudes and behaviours within human action. The original TAM is presented in Figure 2 while the adapted one is presented in Figure 3.

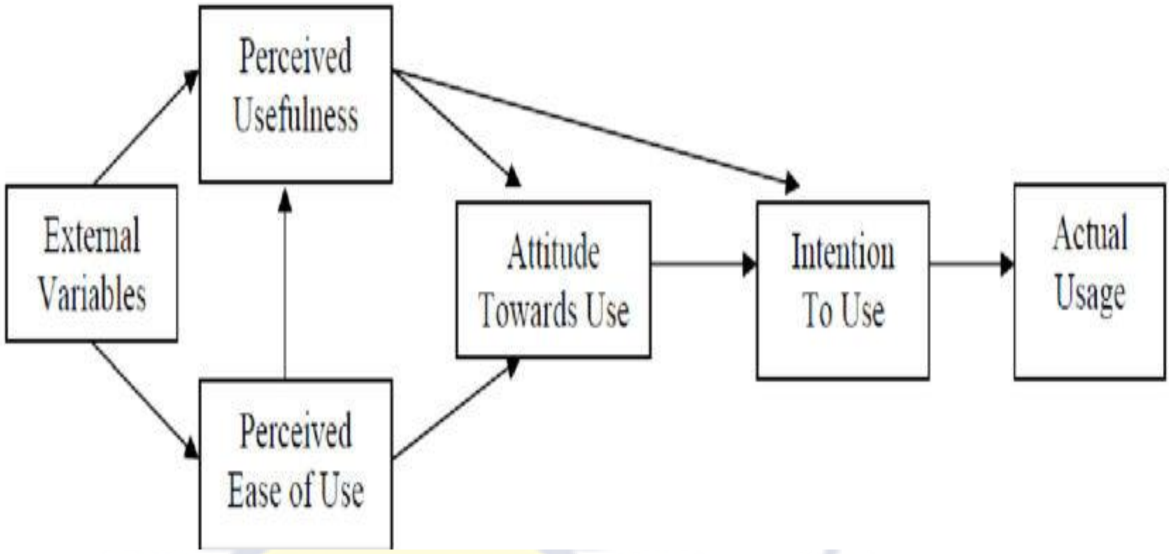

Figure 2: Original TAM: Davis, Bagozzi & Warshaw (1989).

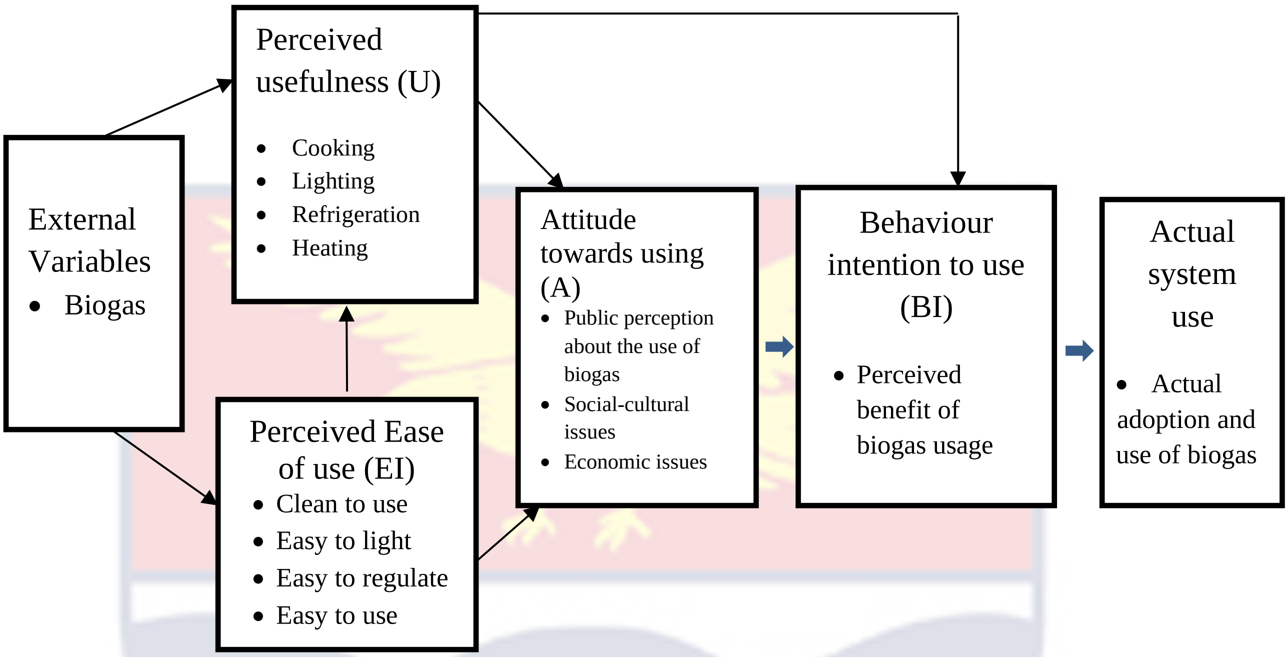

Figure 3: Adapted TAM as conceptual framework

TRA comprises interaction between behaviour, attitudes, subjective norms, and external variables as determinants of human action. These factors according to Ajzen and Fishbein (1969) were crucial in determining the effect of attitude on actions. TAM on the other hand asserted the presence of two conditions namely perceived usefulness and perceived ease of use as the dominant factors that determined whether or not a technology would be accepted by its potential users. Thus, according to the hypothesis, Perceived Usefulness (U) and Perceived Ease of Use (E) played a role in whether a technology was adopted or rejected (EI). Attitude towards (A) a technology was a function of the interplay between (U) and (EI) (Davis et al., 1989).

However, the interaction between U and A was responsible for influencing Behaviour Intention (BI) (Davis et al., 1989). The interaction between U and BI eventually led to technology's actual use or rejection. In adapting this model, the external variable referred to biogas technology. The perceived usefulness of biogas might include cooking, lighting, heating, and refrigeration. Perceived ease of use of biogas might include ease of lighting, regulating, and cleaning. Attitude toward using had to do with public perception about the use of biogas and sociocultural and economic issues pertaining to biogas usage (Choosri, 2016). Behaviour intention to use was the perceived benefits of biogas use which would lead to actual system use where the adoption of biogas by households would take place. This was the end-point where people used the technology (Anditi, 2018). Behavioural intention, according to Davis et al. (1989), was the factor that propelled people to use a technology.

In applying TAM to the current study, the focus was on identifying the factors influencing the acceptance and use of biogas technology by households, in terms of perceived usefulness of biogas to household energy generation, household waste management, and reduction in indoor air pollution. The perceived ease of using biogas in terms of the simplicity of the biogas production process, its user friendliness was studied as part as of the extent of household willingness to produce biogas for domestic use. Again, the attitude of household heads towards biogas use, in terms of social, economic, religious, psychological, and their personal perceptions of biogas use were studied as part of the factors mitigating against biogas use. In this study, the BI to use biogas was studied by eliciting responses from household heads on the contribution of biogas to household finances as a way of providing some insight into the likelihood of its successful use. Finally, TAM recognised the impact of some external variables on biogas use. In this study, the external variable studied was whether or not household heads were aware of biogas as a domestic fuel source.

Hypotheses Development Based Theory

Two hypotheses were developed to bring into perspective the Theory of Reasoned Action and Technology Acceptance model as follows:

Ho1: Perceived usefulness (cooking, lighting, heating, and refrigeration) significantly influences the household heads willingness to adopt biogas for domestic use (Anditi, 2018).

Ho2: Perceived ease of use of biogas (maintenance free, less skill required) significantly influences household heads' willingness to accept biogas for domestic use (Bryant, 2019).

CONCLUSION

From the reviewed literature, it could be said biogas use had been tackled by households, institutions, and governments for various reasons. There was a promising and sustainable outlook to biogas use as an eco-friendly solution for addressing energy needs in both rural and urban settings. Reductions in greenhouse gas emissions, conservation of forest, improved waste management, and the generation of clean, renewable energy were main benefits of biogas use. Although the literature portrayed an optimistic view, it also underscored the need to address problems associated with biogas adoption. Awareness of biogas use for domestic purposes, financial, social, and technical challenges associated with biogas use must be overcomed to ensure widespread acceptance and sustained usage. The variability in success factors across different regions and communities emphasised the need for context-specific approaches in promoting biogas technology.

CHAPTER THREE

RESEARCH METHODS

Introduction

The section presents the research approach, research design, population, sample and sampling procedure, data collection instrument, data collection procedures, data analysis procedures, and ethical issues.

Philosophy and Research Approach

The philosophy underpinning this study is the creation of awareness towards provision of clean and sustainable renewable energy for all, as found in SDG 7 which states 'Ensure access to affordable, reliable, sustainable and modern energy for all'.

The mixed method approach was used for the study. Creswell (2014) suggested the mixed method to be appropriate when studying identifiable groups such as households in their natural setting. Again, the cause-and-effect associations between the variables of interest and respondents' opinions on the subject of household biogas usage as a domestic fuel in the view of the researcher could better be explored with the mixed method. In other words, the researcher wanted to obtain a broad base information on whether or not households use biogas for domestic purposes, how households use biogas in their homes and the possible reasons for their choice. The researcher therefore combined both quantitative and qualitative approaches to investigate the topic with the aim of obtaining in-depth information upon which conclusions were drawn.

Research Design

This research was guided by the mixed-method design. According to Clark & Creswell (2014), all mixed methods research gather both quantitative and qualitative data. These data are classified as sequential or concurrent depending on the order in which they were gathered. When comparing concurrent and sequential mixed methods, the former collects and analyses qualitative and quantitative data simultaneously, while the latter collects and analyses them at various periods.

In using the mixed method for the data collection, the researcher first administered questionnaire to a number of respondents and based on the responses obtained some were selected for the qualitative aspect of the research using an interview guide, an audio recorder and a transcribing machine.

For each of the three research questions (R1 to R3) and the null alternative hypotheses, Ho1 and Ho2, quantitative data were collected from all the household heads who participated in the study and analysed using frequencies, percentages, mean, and standard deviation. For the two null hypotheses, chi-square test of independence was run to establish the existence of a statistically significant relationship between the identified variables or otherwise. Interviews were used to obtain qualitative data which were aimed at answering Research Question (RQ) 4.

Study Area

The study area for the study is Akwatia in the Eastern region of Ghana located at 6°3′00″N 0°48′0″W / 6.05000°N 0.80000°W and the capital of the Denkyembour District. It is West of Atewa Range, and bounded by the Kwaebibirem Municipality to the North, Biriam Central Municipality to the South. It is the main centre of diamond extraction in Ghana. Akwatia has a population of 23,766 people and covers a land area of largely 1,310 square kilometers, largely peri-urban and approximately 86km from Accra. The area is cosmopolitan, the people are largely engaged in small scale mining, agriculture, and farming. The study area fills within the forest zone of the country and has many streams that serve as tributaries to Biriam river.

There are good road networks that link the study area to their parts of the country. It has a number of basic schools, a TVET institute, and a SHS to provide education to the residents. It has two hospitals to cater for the health needs of residents. It is connected to the national electricity grid, Ghana water supply and home to the defunct Ghana Consolidated Diamonds (GCD) limited.

Population

The population of the study was all households in Akwatia who use different types of domestic fuel for different domestic purposes. The number of these households was 5166 (GSS, 2021). The population was broken down based on the domestic fuels the households used. The breakdown is presented in table 1.

Table 1: Households and the domestic fuels used by the households

Types of fuel used by household	Number of households
Wood fuel	353
Cooking gas (LPG and biogas)	2795
Charcoal	2003
Electricity	11
Kerosene	3
Cooking gel	1
Total	**5166**

Source: Ghana Statistical Service (2021)

Sample and Sampling Procedures

This study involved both quantitative and qualitative phases. Different sampling approaches were adopted for selecting participants for the qualitative and quantitative data collection. To get households for quantitative data, stratified sampling was used. According to Leedy and Ormrod (2016), the stratified sampling technique becomes appropriate when the population comprises different strata. To get a fair representation of each stratum, appropriate proportions were sampled from each of the stratum since the various strata were different in size. The use of proportionate stratified random sampling for this study was to ensure households that used different types of domestic fuels were equally represented in the study. Households were categorised depending on their fuel type, as determined by the "Ghana statistics Service data on the Population and Housing Census (2021)".

The final study sample was broken down based on the statistics from GSS using the formula:

$$nh = \frac{Nh}{N} * n$$

Where nh is the sample size in stratum h,

Nh is the population size in stratum h,

N is the total population size and n is the overall desired sample size

(Kumar & Vishwakarma, 2023).

After using the stratified sampling approach to select the required number of respondents, the researcher used convenience sampling for each stratum. The researcher visited churches, mosques, market, and information centres in the community to inform the residents about the study. Follow-ups were made every week to pick up the phone numbers and house addresses of people who had expressed interest in the study in order to contact them. For each stratum, any household that agreed to participate in the study was sampled until the required number for that stratum was met. The same activity was repeated for all other strata.

Qualitative sample was selected using purposive sampling. The criteria that qualified a household to participate in the qualitative aspect of the study was having a biogas plant in the household. Therefore, any household that indicated it had a biogas plant in the quantitative phase was sampled purposively for the qualitative study. Following the selection of a household, purposive sampling was used to sample the household head for the study. This was because, it was anticipated household heads had a greater influence over the household's decision about the fuel used (Adusah-Poku & Adjei-Mantey, 2023).

Sample Size

Krejcie & Morgan (1970) table for determining sample size was used to select the number of respondents for the study. According to Krejcie and Morgan's (1970) table for sample size determination, if a population size is around five thousand, a sample size of 357 was enough to represent that population in a quantitative study. The population size for this study was 5166, around the 5000 mentioned by Krejcie and Morgan (1970). Hence, the researcher's decision to use a sample size of 357 households for the quantitative aspect of the study. The researcher moved around the community to visit households that had expressed interest in the study to identify the different types of fuel they use and this is presented in Table 2.

Table 2: Sample sizes selected from the various domestic fuels used by households

Household fuel	Number of households	Sample selected
Wood fuel	353	24
Cooking gas (LPG and biogas)	2795	194
Charcoal	2003	138
Other fuel sources	15	1
Total	5166	357

Source: Field Data (2023)

A sample size of six household heads were used for the qualitative data collection. This was based on the assertion by Crouch and Mckenzie (2019) that better data would be derived in qualitative research if the researcher used a small sample size, preferably a sample size less than twenty participants. Budiu (2021) also noted when working with identifiable populations like households, a small sample size of around five participants would be necessary for getting in-depth information for the study. The researcher's decision to use six household heads for the qualitative data collection was because the population of the study was households. Therefore, in order to obtain in-depth information as suggested by Budiu, (2021) a sample size of around six participants were used because they consented to participate in the interview and ready at any time convenient for both the researcher and them. As a result, choosing six household heads gives accurate data since it was more than the five suggested by Budiu (2021).

Data Collection Instruments

A questionnaire and interview guide were the main instruments used to collect data from the respondents. A closed-ended questionnaire was used to collect quantitative data from the respondents. The questionnaire was divided into four parts. The first part aimed at collecting demographic information, including gender, age, and occupation of household heads, income, and educational levels of respondents as well as the household size. Respondents were expected to provide the needed information by ticking the appropriate options. Refer to Appendix A.

Questionnaire items on the awareness of various household heads on biogas as a domestic fuel source constituted the second part. Respondents ticked among the options to indicate their level of agreement with the given statements. The third part contained items on the extent to which respondents were willing to accept and adopt biogas as domestic fuel. These items also required respondents to tick among the options provided. Respondents were however given the opportunity to write their specific responses if not included in the options provided. Part I and II of the questionnaire helped to answer Research Question 1, Ho1, and Ho2, Part III helped in answering Research Question 2, while Part IV helped in answering Research Question 3 by eliciting from respondents the factors influencing the adoption of biogas as fuel among households.

The questionnaire was prepared and distributed by the researcher and the two trained assistants for self-administration by the participants. The researcher made arrangements with household heads who requested for assistance to administer the questionnaire at respondents' convenience. The questionnaire was translated and recorded into the most preferred local languages of respondents by a team of Language experts at the Denkembour District Education Directorate, Akwatia and reviewed by another team of experts from the Department of Languages at the University of Education, Winneba to eliminate the possibility of researcher bias that could affect the data collected. The translated questionnaire was played to respondents. The responses of household heads were ticked for them.

A semi structured interview guide was used to collect qualitative data from participants. The interview guide was made up of four items that sought to establish from household heads who; owned biogas plants, had ever generated biogas for domestic purposes, and had ever used biogas for domestic purposes, the contribution of household biogas use to household finances. These items helped in answering Research Question 4. Refer to Appendix B.

Pre-testing of Instruments

The instruments were pre-tested on two household heads in Boadua which is the second biggest community in the Denkyembour District, close to Akwatia. The people there share similar characteristics with the people of Akwatia.

Validity and Reliability

The study sought to collect empirical information on the research topic. Thus, the researcher ensured the information gathered was easily accessed to answer the research questions. This was achieved by determining the study's research instrument's validity and reliability. As proposed by Creswell and Creswell (2017), a valid and trustworthy data collection instrument satisfied all the parameters the researcher expected. In addition, validity and reliability were the two most essential and crucial features of a data collection instrument needed to obtain precise results (Mohajan, 2017). Reliability and validity worked together to enhance the entire data quality. A reliable instrument provided consistent measurements, and a valid instrument ensured the measurements were accurate representations of the intended construct. This ensured greater confidence in the integrity of the data.

For this reason, a validity test was done on the data-gathering tools to ensure its reliability. The instruments were given to five peers and specialists for review. The errors in the instruments were identified and fixed. The feedback from peers and experts review focused on clarity of questionnaire language, number of items for each research question, limitations of the instruments and the ability of the instruments to achieve the study's aims.

The validity of the data-gathering methods was examined using Cronbach's alpha. For data to be trustworthy, the instrument used for collection must be capable of eliciting answers that remain constant after being polled repeatedly (Vaske et al., 2017). The researcher employed Cronbach's alpha to ensure that questionnaire items were internally consistent, making them suitable for managerial usage in making choices and providing suggestions. Creswell and Clark (2017) noted a value closer to 1 indicated a more reliable data collection tool. Cronbach's alpha values of 0.7 and higher were considered reliable. The study's Cronbach's alpha was reported to be 0.86.

To ensure believability and trustworthiness of the qualitative instrument, member checking was used. The researcher transcribed all the responses from the interviews into English. Data from the interviews were transcribed into English Language using Application Programming Interface (API) Software, read thoroughly and familiarization and identify similar responses. The transcribed responses were sent to the participants to ascertain if what the researcher had written was a true reflection of what the participants said. This was done to eliminate bias on the part of the researcher in presenting the information obtained from participants.

Recruitment and Training of Field Assistants

Two field assistants with first degree and some experience in data collection were recruited to help the researcher gather data from all sampled household heads in the study area. The field assistants were taken through a four-day training session where they were briefed about the purpose of the study, the data collection process, research ethics such as confidentiality, anonymity, informed consent, among others; and data management to refresh their memories and keep them up-to-date with the conduct of fieldwork.

The recruitment and training of the field assistants aided in the effective distribution of questionnaires to all the sampled household heads in the study area and ensured that the questionnaire were retrieved. The field assistants were also involved in the pre-testing of the instruments to learn how the questionnaires should be administered and retrieved. The training took place two weeks before data collection begun.

Data Collection Procedure

A familiarisation visit was paid to households in the study area in December, 2022 between 2 pm and 5 pm to establish rapport and administer the consent form. The researcher visited the selected households with the two trained field assistants in January, 2023 between 2 pm and 5 pm to administer the questionnaire. This was done by handing over the afore-stated instrument to respondents willing to answer them in their free time. The researcher made follow-ups every three days until the required number of questionnaire representing the study's sample size were retrieved. For respondents who needed assistance due to language barrier because they were not literate, arrangements were made for times convenient to them to meet up to play the translated questionnaire to them. Their responses were ticked on their behalf by the researcher. After answering the questions, their responses were repeated to them to confirm if the researcher captured their responses accurately. The questionnaire took between 20 to 30 minutes to answer.

For the qualitative data collection, the researcher, together with the trained field assistants, arranged with participants a place and time that was convenient for the participants to be interviewed. The interviews were conducted in Twi, Hausa and Ewe for Household Head 1 and 3, 2 and 4 respectively based on the preferences of participants. To ensure questions were asked to deduce the same meaning in the various languages, the questions were translated by language experts who were fluent in both English and the target languages. This was done to ensure the questions were translated accurately to convey the same meaning. Again, the instrument was pre-tested on two household heads in Boadua who were proficient in the target languages and English to identify potential challenges with translation and understanding the questions in order to adapt the questions. The interviews were recorded with the aid of an audiotape and manual notes after permission was sought from participants in that regard. The researcher asked the interview questions while the field assistants looked out for non-verbal cues as participants responded to the questions and took note of them. The interview lasted on average between 45 minutes to 1 hour. The researcher listened to each of the audiotapes from the interview sessions and transcribed each participant's responses into English.

This was read to the participants to confirm whether the transcribed information represents the responses they had provided. The notes taken by the field assistants during the interview sessions were also revised for insights into the responses in order to determine if any relationships existed between the responses and the notes.

Data Processing and Analysis

The data collected from the respondents were pruned. Coding was done for the purpose of entering data for analysis. Appropriate statistics were run for each of the research questions in the quantitative study. For research questions 1, 2 and 3, descriptive statistics in the form of frequencies, percentages, mean and standard deviations were used for analysis. Quantitative data was processed and statistically analysed using the Statistical Package for Social Sciences (SPSS) version 20.0. Research question 4 sought to collect qualitative data. Data from the interviews were transcribed into English Language using Application Programming Interface (API) Software, read thoroughly and familiarization and identify similar responses. Thematic analysis was manually used for analysing the data from the interviews. Codes were assigned to similar responses to group these responses. Themes were generated from the responses of participants and were used as bases for verbatim comments.

Research Hypotheses

The chi-square test of independence was ran to test the two null hypotheses: Ho1: Perceived usefulness (cooking, lighting, heating, and refrigeration) significantly influences the household heads willingness to adopt biogas for domestic use (Anditi, 2018).

Ho2: Perceived ease of use of biogas (maintenance free, less skill required) significantly influences household heads' willingness to accept biogas for domestic use (Bryant, 2019).

Ethical Considerations

Informed consent

The researcher, as indicated above, visited household heads in December, 2022 to explain the purpose of the study to them and to ask whether they were willing to participate. When they expressed their willingness to participate in the study, they were given the consent form to sign at their convenience. The Field Assistants explained aspects of the consent form to the prospective respondents who did not understand. After a fortnight, the researcher returned to the household heads to collect the signed forms.

Ethical clearance

The Institutional Review Board (IRB) of the University of Cape Coast issued ethical clearance for the conduct of the study. Refer to Appendix E.

Anonymity

Respondents were assured that any information related to their identity, including their names, location, telephone numbers, and ethnic group, would not be disclosed to anybody. Again, their responses would not be linked to them. This implied that their identities were concealed from any third party.

Confidentiality and Privacy

Respondents were assured that their data would be used solely for academic work. Participants were also assured the information provided would not be disclosed to third parties without their prior consent. Again, they were not under any obligation to provide information they were not willing to disclose. The views of respondents were respected on what they wanted to keep private and what they wanted to share. The interviews were also conducted at a place and time chosen by the participant. They had the right to answer or decline to answer questions posed to them.

Chapter Summary

The chapter presented and discussed the study's research methods, including research approach, research design, population, sampling procedure, data collection instruments, data collection procedure, and data processing and analysis of the study.

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter presented and discussed the study's main findings in accordance with the study's objectives in the chapter one of the study. The findings covered in this section included but was not limited to respondent demographics and history, the level of biogas awareness, the extent to which various households are willing to adopt biogas as a domestic fuel, various factors influencing biogas adoption, as well as the relationship between household income level and their willingness to adopt biogas for domestic use. A possible relationship was also explored between household heads' educational level and their willingness to adopt biogas for domestic use. Discussions were done and compared with relevant literature about the study to establish contradictions or otherwise of the findings with other studies conducted. The findings of the study were then summarised.

Background information of the respondents

The demographic data of respondents were presented on Tables 3 - 6. The tables showed demographic information such as gender, age range, education level, monthly income, household size, and occupation of household head.

Table 3: Distribution of household heads by gender, age and level of education

Variable	Frequency (n=357)	Percentage
Gender		
Male	236	66.1
Female	121	33.9
Total	**357**	**100.0**
Age (years)		
Below 30	9	2.5
30-39	60	16.8
40-49	129	36.1
50 and above	159	44.5
Total	**357**	**100.0**
Level of Education		
No formal education	46	12.9
Primary	111	31.1
Secondary	133	37.3
Tertiary	67	18.8
Total	**357**	**100.0**

Source: Field Data (2023)

Table 3 presents background information on the respondents sampled. A total of 357 household heads served as respondents to the study. Data as presented on table 3 indicates majority of the respondents were men. The gender distribution of the respondents relates to data for Akwatia from the Ghana Statistical Service, (2021) where about 37.9 percent of households have female heads.

The age distribution of respondent household heads indicated majority of household heads were above 50 years, while few of the respondents were seen to be below 30 years. This means respondents of the study were generally old with 80.6 percent of respondents being at least 40 years old.

Household heads were distributed at different levels of the educational ladder. While 46 of the household heads representing 12.9 percent of the total respondents sampled, had received no formal education, 111 of the respondents representing 31.1 percent had received primary education, 133 respondents representing 37.3 percent had received secondary education, and 67 of the respondents representing 18.8 percent had received tertiary education. From this result, 200 respondents representing 56 percent of the total number of household heads, were literate as they had received at least secondary education. As a result, the vast majority of the study's respondents were educated. Presented in the table 4 are the income distribution of respondents.

Table 4: Monthly income of household heads in the study area

Income of Household head (GH₵)	Frequency (n=357)	Percentage
Below 1000	74	20.7
1001-1500	122	34.2
1501-2000	90	25.2
Above	71	19.9
Total	**357**	**100.0**

Source: Field Data (2023)

Table 4, shows 283 household heads, representing 79.3 percent earned incomes above the daily national minimum wage of GHC 14.88. Moreover, 74 of the household heads, representing 20.7 percent, earned below 1000 Ghana Cedis. The result revealed that about 55 percent of household heads earn below 2000 Ghana Cedis. Mumbi (2017) asserts higher income households (those earning more than GHC 2000) are more likely to adopt biogas than lower income households (those earning less than GHC 1000). It can be deduced from Table 4 that 19.9 percent of households can be considered as high-income household since they earn incomes above 2000 Ghana Cedis and so are more likely to use biogas than the vast majority representing approximately 80.1 percent of households who earn either 2000 Ghana Cedis or less. Table 5 shows the distribution of household heads by household size.

Table 5: Distribution of household heads by household size

Household size	Frequency (n=357)	Percentage
1-3	32	9.0
4-6	163	45.7
7-9	131	36.7
10 and above	31	8.7
Total	**357**	**100.0**

Source: Field Data (2023)

Table 5, indicates that 162 households, representing 45.4 percent, had a household size of at least 7 individuals, 163, representing 45.7 percent, had a household size of 4- 6 people, while 32 of the respondents representing nine percent, had a household size of 1-3 members.

They indicate that a large sized household would consume much more energy compared to small sized households. It can therefore be said that about 45.4 percent of the participants are heads of large households and are more likely to consume more energy compared to those with fewer members. Thus, such households can either supplement their energy consumption by adopting biogas for domestic use or can reduce their energy expenditure through the use of biogas.

Respondent household heads were engaged in varied occupations. Table 6 presents details of the occupations of respondents.

Table 6: Distribution of household heads by occupation

Occupation	Frequency (n=357)	Percentage
Farming	92	25.8
Artisan	68	19.0
Trading	61	17.1
Teaching	26	7.3
Driving	26	7.3
Security Services	26	7.3
Mining	20	5.6
Nursing	18	5.0
Administrative work	17	4.8
Truck pushing	3	0.8
Total	**357**	**100.0**

Source: Field Data, (2023).

The findings as indicated in Table 6 show majority 75.6% of the respondents were active participants of the informal sector, engaged in occupations such as farming, mining, artisan, driving, truck pushing and trading. It was evident also from the data, 24.4 percent, were employed in the formal sector and engaged in professions such as nursing, teaching, administrative work, and security services. This result confirms the findings of a study by Bryant & Afitiri (2021) and Arthur et al. (2018) which states about 80 percent of the Ghana's labour force is employed by the informal sector of the economy with the remaining 20 percent with the formal sector.

Household heads sampled for the qualitative study comprised four males and two females. One was aged between 30-39 years, three of them were aged between 40-49 years and the remaining two were aged 50 years and above.

Two of the participants indicated they had received primary education, three had received secondary education and one of them was educated up to the tertiary level. One participant each indicated they earned between GHC 1000-GHC 1500 and GHC 1500- GHC 2000 monthly, while four said they earned above GHC 2000 monthly. The findings of this study agree with what was obtained by Bryant & Afitiri (2021) who quoted similar income levels for some residents of Elmina when they assessed the income levels of some residents. Participants had varying household sizes. Two participants had household sizes of 6, one had a household size of 7 and three had household sizes of 10. With regards to their occupations, three participants were engaged in farming, two were into trading and one was engaged in mining.

Research Question 1: What is the level of household awareness of biogas as a domestic fuel source?

This research question sought to establish the level to which household heads in the study area were aware of the use of biogas as a domestic fuel source. The responses of the heads of households are summarised in Table 7.

Table 7: Domestic uses of biogas

Domestic use	Frequency	Percentage
Generate electricity	108	30.3
Pumping water for domestic use	36	10.1
Domestic heating	29	8.1
Fuel for cooking	23	6.4
Waste Treatment	23	6.4
N/A	138	38.7
Total	**357**	**100.0**

Source: Field Data, (2023).

Data in Table 7 showed majority of the household heads claimed that biogas could be used to produce electricity and for cooking, indicating that the respondents in the study area were aware of other uses of biogas. This finding is contrary to that of Doghle (2018) who indicated in assessing the cost-efficiency and willingness to adopt biogas as a sustainable source of renewable energy in Senior High Schools in the Greater Accra Region asserts knowledge of biogas among households was confined to its usage for sanitation to the exclusion of other biogas applications. In this study, however, 196 (89.5%) heads of households indicated biogas had other domestic uses in addition to its use as a waste treatment system. Household heads were also asked about their source of information about biogas as a domestic fuel source. Their responses were presented in Table 8.

Table 8: Source of Information on Biogas as a Domestic Fuel

Source of Biogas information	Frequency	Percentage
Media	109	30.5
Books/Magazines/Journals/Films	47	13.2
Family/Friends/ Colleagues/Neighbours	40	11.2
Businesses	9	2.5
School	2	0.6
N/A	150	42.0
Total	**357**	**100.0**

Source: Field Data, (2023).

The finding from Table 8 is a confirmation of results of a study conducted by Doghle (2018) who claimed installers engaged the media to encourage their customers to install biogas plants. According to Doghle (2018), the media did this by informing their patrons biogas was an environmentally friendly waste treatment system that brokedown organic matter including excreta. Respondents were further asked how long they were aware of biogas as a domestic fuel source. Table 9 provides a summary of their responses.

Table 9: Period of awareness of biogas as a domestic fuel

Period (years)	Frequency	Percentage
Less than 1	49	13.7
Between 1-3	100	28.0
between 4 and 6	27	7.6
7-9	28	7.8
10 and above	15	4.2
N/A	138	38.7
Total	**357**	**100.0**

Source: Field Data, (2023).

As presented in Table 9, responses showed that a significant minority (45.7%) of the household heads had heard of biogas as a domestic fuel between 1-3 years. In addition, only 31.9 % of the total respondent indicated having knowledge of biogas in at least the last 4 years. This gives an indication that most respondents (77.6%) had heard about biogas as a domestic fuel. This means that biogas as a domestic fuel has gained popularity within the last few years in the study area. This result was in agreement with findings as indicated by Huber (2019). Huber (2019) was of the view the production of biogas from biodegradable materials on small scale basis is a promising technology that was gradually gaining popularity in recent times as a way of resolving contemporary waste management issues and energy recovery among households.

Based on household heads further asked about awareness on domestic biogas plants, 357 household heads responded. From the responses majority (77.6) of respondents were in affirmation to the question. This finding showed a positive correlation with assertions made by Bensah and Brew-Hammond

(2010) in their work on the dissemination of biogas technology in Ghana. Bensah and Brew-Hammond (2010) indicated the oldest operating biogas plants in Ghana were found at St. Dominic Hospital in Akwatia. This meant that respondents might not own biogas plants themselves but might have seen that of the hospital.

Household heads (219) also responded to a four-point Likert scale item that aimed at exploring the level to which they agreed or disagreed with statements on biogas as a domestic fuel. The Household heads ticked “1- Strongly Agree”, “2- Agree”, “3- Disagree”, and “4- Strongly Disagree”. A summary of their responses was presented in Table 10. From Table 10, the overall mean was 2, presupposed that with the exception of the statement which stated ‘biogas pollutes land and groundwater’ respondents disagreed with, however, they agreed with all statements in relation biogas. These findings were similar to findings of studies by Arthur et. al. (2020), Garfi et. al. (2019), Scarlet et. al. (2018).

Table 10: Household heads level of agreement with statements on Biogas (%)

Statements		SA (1)	A (2)	D (3)	SD (4)	Mean	S. D
i.	Biogas is a household produced fuel	22.7	55.7	19.9	1.7	2.02	0.728
ii.	Biogas is a renewable fuel	17.4	59.1	19.9	3.6	2.16	0.821
iii.	Biogas produces less air pollutants	14	37.5	28.6	19.9	2.14	0.930
iv.	Biogas aids in household waste management	19.3	48.5	23.5	8.7	2.01	0.914

Table 10 continued…

v.	Biogas can enhance agricultural production	17.6	61.1	16.5	14.8	2.08	0.851
vi.	Biogas pollutes land and groundwater	6.2	18.8	54.1	21	2.81	0.923

Source: Field Data, (2023).

From Table 10, a mean score of 2 was obtained for all the statements except the last one which had a mean score of 2.81, where the statement was 'Biogas Pollutes Groundwater'. The respondents also produced diverse responses on the second item. This asserted that most of the respondents were aware biogas is a renewable energy source that might not pose any future environmental risk. Garfi et al. (2019) expresses similar view when they argued that the use of biogas improves living conditions and economy while reducing environmental impacts.

According to Rupf et al. (2015), women's knowledge of the risks posed by smoke during cooking and food processing in rural areas is a potential factor in increasing support for implementing biogas technology (BT) and other clean energy solution. This assertion may imply that the use of biogas provided a cleaner energy source for use in cook stoves, which may reduce air pollution caused by smoke when conventional wood stoves are used.

Respondents were of the view that biogas contributed to effective household waste management. This finding has a strong correlation with results of a study by Arthur et al. (2020) when they assessed possible substrate for sustainable biogas generation in Ghana. Arthur et al. (2020) further contends Ghana's waste is mainly biodegradable and could be used to generate biogas which could help eradicate the country's waste management issues.

Respondents had some knowledge about the use of bio-fertilizer in farming as a way of promoting plant growth, increasing crop yield and enhancing food security. This finding is, however, contrary to a view shared by Bryant and Afitiri (2021) where they indicated households in Ghana are not enthused about using bio-fertilizer in their gardens.

Respondents disagreed with the statement that biogas polluted land and groundwater, data presented in Table 10. This suggests, respondents are unaware of the possibility of excessive biogas slurry that enters the soil can seep into groundwater. A study by Nayal et al. (2016) lent some support to the findings that biogas generation had no negative impact on water. Weishen et al. (2022) however contended biogas slurry was a potential source of groundwater pollution. They argued that a porous substance like soil allowed nitrate pollution to groundwater. They further indicated organic pollutants such as fulvic acid, microbial protein molecules and humic acid compounds biogas slurry could also leach into groundwater.

The researcher further calculated the average mean in Table 10. A value of 2.20 was obtained. This implied when all responses of household heads were summed up and their average found, respondents generally agreed to the various statements. This gives an indication of the general awareness of biogas as a domestic fuel source among respondents.

For each of the statements in Table 10, a standard deviation value below 1 was obtained. This gives an indication that responses of household heads were clustered around the mean. This suggest respondents generally agreed to the statements in Table 10. Generally, data gathered, as evident in Tables 6-10, sought to indicate some level of biogas awareness among household heads. Out of the household heads sampled for the study, 170 of them had no idea that biogas could be used as a domestic fuel option but were aware of biogas's potential as a household fuel source, though a sizeable minority (22.4 %) knew nothing about the fuel's existence. This finding is contrary to findings in a study conducted by Agarwal et al. (2015) who realized that biogas awareness as a household fuel source is generally low. Agarwal et al. (2015) examined biogas generation as part of waste management initiatives in India as a way of ensuring the welfare of society. They sought to make suggestions biogas could help enhance waste management in Indian urban communities. In Agarwal et al. (2015) attempted to find the scope for enhancing waste management for the wellbeing of society, they identified the role of the formal waste management sector in educating the public on biogas as a waste management strategy that could produce fuel for the home as a way of increasing public awareness about the use of biogas as a domestic fuel which is generally low among households.

Research Question 2: To what extent are households heads willing to use biogas as a domestic fuel?

This research question sought to determine whether households were willing to use biogas for domestic purposes. Majority (98%) of the household heads, indicated they did not have biogas plants installed in their households. This presupposed only a minority (2%) indicated had biogas plants. Responses to a follow-up question on whether the biogas plants installed in their homes were in use and the number of years those plants had been in use revealed that four (4) of them were in use, while the remaining two (2) were not. This simply meant that households in the study area relied on other sources of fuel other than biogas for their domestic fuel needs. This contradicted with the findings of

Makonese et al. (2018) who asserted that rural and low-income city dwellers relied on biomass to power their homes.

Therefore, the 98% of heads of households without installed biogas plants were asked whether they would like to construct biogas plants. About 90 % of the total non-biogas plant owning household heads, indicated they were willing to construct biogas plants. Household heads representing 10.5 %, were unwilling to construct biogas plants in their households at all. This decision of the participants could be due to increase in the price of LPG as cited by Uhunamure et al. (2019) who identified economic factors as one of the determinant factors that influenced a family's decision to embrace a particular technology.

As indicated in their responses, 90.1 % of respondents were willing to construct biogas as a domestic fuel source, 9.9 %, indicated they were unwilling to use biogas as a domestic fuel source. The number of respondents decreased as some of them were unwilling to respond to the questionnaire. This simply means majority of the respondent household heads may want to switch to biogas for domestic activities because LPG and charcoal have generally become more expensive. This finding lends some support to assertions made by Uhunamaure et al. (2019) who contended that families who could previously afford cooking gas were forced to switch to kerosene because of its price increase.

The 2 % household heads who had installed biogas plants, which were in use, were also asked how long they had engaged in biogas production. From their responses, three of them had engaged in biogas production within 1- 3 years, while the other had engaged in biogas production within 4 -6 years. This connotes that, even with those with installed biogas, biogas production had not exceeded 6 years, with most of them engaging in biogas production between 1-3 years. This suggests that biogas is a technology that is gradually gaining popularity in the study area.

Respondents were asked what was or would be their source of initial capital for constructing their biogas plants. Table 11 presents information on the responses of the household heads.

Table 11: Source of Initial capital to construct Biogas plant

Source		Frequency	Percentage
	Own savings	110	30.8
	NGO support	32	9.0
	Government support	115	32.2
	Cost sharing with NGO or Government	63	17.6
	NA	37	10.4
Total		**357**	**100.0**

Source: Field Data, (2023).

From Table 11, it was evident that, majority (58.8) of them were unwilling to spend their own savings for the construction of biogas plants. The number of respondents decreased as some of them were unwilling to respond to the questionnaire. This implies that respondents would want some extent of funding from sources outside the household for constructing biogas plants. This may be because biogas plants might be expensive for various household heads to construct or they were unwilling to depend solely on their income to construct their biogas plants. This observation confirmed the findings of Doghle, (2018) who suggested a sizeable financial investment was needed for the design, construction, operation and maintenance of biogas plants. The households suggested they needed support from NGO, government, and other cost-sharing agreements with NGOs or governments, in the construction of biogas plants. The findings were in agreement with that of Bryant (2019) who reported that households needed financial support to adopt and construct biogas digesters. Household heads were also asked what type of substrate they used or would use in generating biogas. Their responses presented in Table 12.

Table 12: Sources of Substrate for biogas generation

Substrate sources for biogas	Frequency	Percentage
Animal waste	96	26.9
Human excreta	211	59.1
Forest residue	10	2.8
Palm kernel cake	3	0.8
NA	37	10.4
Total	**357**	**100.0**

Source: Field Data, (2023).

Table 12 showed that substrate sources such as animal waste, human excreta, forest residue, and palm kernel were considered for biogas generation. It was apparent, however, from their responses that majority (59.1 %) of the household heads preferred human excreta as the source of substrate for biogas production as against animal waste, forest residue, and palm kernel. This notes that majority of household heads preferred faecal matter because it was readily available to them. It could also be that 26.9 % of the respondents preferred animal waste because livestock farmers with sizeable flocks which could produce adequate dung as feedstock for biogas production. Palm kernel cake preferred substrate households may be households engaged in oil palm processing and so may readily obtain adequate quantities of the substrate for sustainable biogas production. The current study shared similar findings with

Uzoma et al. (2010) who stated, farm waste, animal droppings, industrial waste, urban solid waste and sewage were substrates used for biogas generation due to their availability to biogas users. This implies households use biogas as a way of cutting down on household fuel cost. Therefore, substrates used are basically inexpensive, readily available biodegradable household waste materials.

Generally, it could be observed that majority of household heads may be willing to use biogas as a domestic fuel source. The household heads, as per their responses as captured on Table 12, were willing to use human excreta as their main source of substrate for biogas production even though the use of animal waste, forest residue, and other substrate sources was also considered.

Research Question 3: What are the factors influencing the adoption of biogas as a domestic fuel among households?

This research question sought to determine motivating forces for household adoption of biogas as a domestic fuel. Majority (63.1 %) of household heads were unwilling to use biogas as their main domestic fuel source, while those willing to use biogas as their main domestic fuel source belongs to the minority group. This finding compared to household heads willingness to use biogas for domestic purposes gives an indication that while 90.1 % respondents were willing to use biogas as domestic fuel, only 36.9 % were willing to use it as their main domestic fuel source. This indicated that although respondents were willing to use biogas, they might be unwilling to use it as their main fuel source. This may be due to their uncertainty about the use of biogas as the sole source of fuel for meeting household domestic energy needs. The uncertainty may border on unreliable biogas production due to inadequate substrates. This finding lends some support to assertions made by Arthur et al. (2018) that fuel stacking provides a sense of fuel safety.

The reasons affecting the use of biogas were studied using a 4-point Likert scale questions. Heads of households were asked to rate their level of agreement with the assertions. Respondents ticked to indicate the extent to which they agreed or disagreed with each statement presented in Table 13.

Table 13: Reasons that negatively influenced biogas adoption as domestic fuel by respondents (%)

Items	SA (1)	A (2)	D (3)	SD (4)	M	S.D
Expensive to install	18.5	52.1	21.3	8.1	2.07	0.910
Health risk	5.9	25.5	52.4	16.2	2.84	0.843
Difficult to operate	8.7	49.9	34.2	7.3	2.68	0.834
Available cheaper sources of fuel	9.0	33.6	48.4	9.0	2.59	0.914
Lack of Technical services	25.5	45.4	23.5	5.6	2.16	1.008
High cost of maintenance	14.6	25.2	52.4	7.8	2.54	0.914
Lack of water	5.9	14	56.9	23.2	2.85	0.932
Lack of adequate knowledge on digester	16.8	55.7	21.3	6.2	2.38	0.900
Access to substrate to fuel bio-digester	16.2	44.5	31.9	7.4	2.56	0.836
Lack of adequate source of labour	16.8	49.3	26.3	7.6	2.43	0.932

Source: Field Data, (2023).

Respondents agreed with four (4) statements and disagreed with six (6).

On the statement that biogas is expensive to install, it could be seen from the responses that, majority of the household heads at least agreed with the statement while those who strongly disagreed or disagreed that biogas is expensive to install belong to the minority group. The mean score of 2.07 recorded for the item implied respondents generally agreed to the statement. In their view, the construction of domestic biogas plants was costly. As per the number of household heads who responded to the item, there is a possibility that some household heads who did not own household biogas plants had indicated the cost of constructing biogas plants was high. This connotes the responses of these household heads were based on perception and not on their experiences with biogas installation. This further suggest the need to reconsider recommendations made by Doghle (2018) who reiterated successful technology adoption requires intervention and legislation. According to Doghle (2018), government could develop a national policy on biogas as a renewable energy source, disseminate factual information on it to the public, institute measures that would reduce the cost of installing and running domestic biogas plant to make the technology affordable to all households. The standard deviation value of 0.901 obtained indicated the responses of household heads were at least (70.6) in agreement, that biogas was expensive to install which was closely related to the view expressed by the mean.

Table 13 showed the responses of household heads on whether they agreed with the statement, biogas usage had health risks. The responses indicated by the mean (2.84) indicated the respondents generally disagreed. This means respondents disagreed with the statement although a significant minority agreed that the use of biogas has health risks. It could be seen from the table that about a third of the respondents agreed biogas use had health risks. This could imply respondents may have some safety concerns with the use of biogas in the household. That aside, majority of respondents who disagreed with the statement that biogas has health risks may have done so comparing the possibility of respiratory disease associated with indoor use of biomass with biogas which provided smokeless flames. As Shahsavari & Akbani (2018) asserted, replacing biomass usage with cleaner and greener technologies would lead to higher quality of life, better health and a pleasant environment. This finding suggest to be in agreement with responses provided by respondents of the current study. A standard deviation value of 0.834 obtained generally lends support to the fact that respondents disagreed to the statement under discussion.

Respondents also express diverse views in relation to the statement that there were difficulties in operating biogas digesters. A mean of 2.68 was recorded. The responses indicated that even though most of the household heads stated there were difficulties in operating biogas digesters, a good number of the household heads also disagreed with the statement. The difficulty in operating biogas digesters may be related to difficulty in obtaining substrate for biogas generation. This result is similar to findings made by Osei-Marfo et al. (2018) when she researched into biogas technology diffusion and shortfalls in the Central and Greater Accra Regions of Ghana.

Osei-Marfo et al. (2018) asserted biogas users walked long distances to collect manure from kraals suggests kraals were located far from communities and so biogas users had to commute there anytime they needed manure for biogas production. This was a major challenge especially if access routes to kraals were unmotorable. It was also emphasized by Osei-Marfo et al. (2018) that herdsmen prevented women from collecting manure from kraals with the excuse that the practice could induce abortion in pregnant cattle. This means that women found it difficult obtaining manure for biogas production and so need to identify other sources of substrate that may be readily available to the household instead of constantly relying on cow manure for biogas production. Again, the standard deviation value recorded was a confirmation that respondents answers were closely related to the mean.

Respondents were asked to indicate their level of agreement or disagreement with the statement on whether there were other cheaper alternative sources of fuel. The results as shown in Table 13 indicated that while 42.6% of the respondents at least agreed that were cheaper alternative fuel sources, 57.4% of respondents, representing the majority of household heads, disagreed with the statement. The mean score recorded implied that though respondents generally disagreed with the statement, a significant minority of the respondents agreed. This implied household heads could be using fuels that were more expensive compared to biogas. It could also be, respondents views were based on the initial construction costs of biogas plants which were generally considered to be high. The cost of transporting substrates to biogas production sites could also be a contributory factor to the views expressed by respondents especially during a period Ghana was experiencing rapid increases in the prices of petroleum products and for that matter transport fares.

Mengistu et al. (2015), however, presented a divergent view on the subject. According to Mengistu et al. (2015), the technology involved in the production of biogas was inexpensive. Mengistu et al. (2015) argued biogas plants required little investment to construct on a small scale for the household. They indicated household biogas plants paid for themselves after a while and the substrate used for producing biogas came at little or no cost to households.

Respondents were tasked to respond to the assertion, there is lack of technical services. This item sought to gather information on whether or not technical support services were available to biogas users. From the result, about 70.9% of respondents at least agreed there was lack of technical services, while a minority (29.1%) of the household heads disagreed with the statement. This suggested that even if technical services existed, they might not be easily accessible to most households. This assertion was premised on the fact that biogas technology had seen few technological advancements in the provision of technical services. The responses presented a mean of 2.16 which gave an indication that majority of respondents agreed to the statement under consideration. A standard deviation value above 1 as obtained, indicated some level of spread of the responses from the mean. This implied respondents shared divergent views on the subject of availability of technical services. While some household heads were of the view that technical services were available, others stated the service was absent. In a similar way, Mengistu et al. (2015) emphasised biogas production systems are inefficient due to limited availability of technical services that employed new technologies to simplify the process of biogas production and made it accessible at low cost.

There was also a statement relating to a possible high cost of maintenance of biogas plants. From Table 13, it can be observed that most respondents perceived a high cost of maintenance of biogas digesters, with only a few of the respondents disagreeing with such an assertion. The mean and standard deviation for the item were 2.54 and 0.914 respectively. This finding is positively correlated to results from Omar, (2017) which stated installation and maintenance of biogas systems in Ghana were controlled by individuals leading to households incurring high maintenance costs.

Water played an important role in the usage of biogas digesters. A statement that there is lack of water was presented to explore respondents' level of agreement or disagreement. From the data presented on Table 13, it could be observed that majority of the respondents disagreed to the statement that a lack of water in households in the study area was negatively influencing their ability to adopt biogas for domestic purposes. The standard deviation value lent further support to the mean score as it gave an indication that the responses were generally clustered around the mean.

From the result, it could be said, water supply to various households could not hinder the adoption of biogas, as over 80% of the respondents alluded to the fact that there was an adequate supply of water to their households. This finding was supported by results of Adamou et al. (2021) who indicated that water increased production of biogas. According to Adamou et al. (2021), water and manure when used in the ratio of 3:1, a bio-digester produced the highest volume of biogas.

Again, household heads expressed their views on the statement that they lacked sufficient knowledge of biogas digesters. With this item, majority of the respondents representing indicated their knowledge on biogas digesters were insufficient. This suggested that inadequate information about biogas digesters was a barrier to the widespread use of this fuel source as Marie et al. (2021) suggested. According to them, biogas adoption rates are not proportional to awareness level among households. This showed that households were not using biogas because they were not adequately informed about the plant that generated the biogas fuel. The standard deviation also confirmed the fact that responses of household heads were clustered around the mean.

Table 13 showed that, at least 60.7% agreed, while the remaining 39.3% disagreed, with the assertion that there was insufficient substrate to feed biogas digesters. Based on these results, it seemed most respondents were concerned about the availability of substrates to feed biogas digesters. If there were inadequate suitable substrate sources, constructing and operating a sustainable biogas digester could be challenging. Adamou et al. (2021), therefore, encouraged households to construct biogas plants where feedstock substrates were in abundant supply.

Generally, it was observed that the majority of the respondents were in agreement with the statements that biogas was expensive to install, operating biogas plants were difficult, there was a lack of technical services, there was a high cost of maintenance, lack of adequate knowledge on biogas and an inadequate substrate to fuel biogas plants. However, there was a disagreement with the statements that biogas usage had health risks, there were other cheaper sources of alternative fuel, and lack of water. Table 13 suggested that the high cost of biogas installation, difficulties in operating biogas plants, lack of adequate technical services, high cost of maintaining biogas digesters, lack of adequate knowledge on biogas digesters, lack of adequate substrate to fuel biogas plants, and lack of adequate labour were factors that negatively influence the adoption of biogas. Additionally, Heads of households were asked to use a 4-point Likert scale to express their views on statements about what influenced people to use biogas as a domestic fuel. Their responses are presented in Table 14.

Table 14: Positive influence of biogas adoption as domestic fuel

Factors affecting the adoption of biogas	SA (1)	A (2)	D (3)	SD (4)	M	S.D
Biogas is easy to use	40.3	52.9	4.5	2.2	1.76	0.750
Low running cost after installation	18.8	56.9	19.6|	4.8	2.27	0.886
Clean source of fuel as compared to wood	27.2	63.6	7.3	2.0	1.83	0.778
Save time for fire collection	31.9	54.1	13.4	0.6	1.67	0.664

Table 14 continued...

Adequate awareness of biogas technology	10.4	39.8	43.1	6.7	2.75	0.786
Adequate technical support	16.0	33.9	39.2	10.9	2.60	0.949
Biogas usage is more hygienic	18.2	52.7	25.5	3.6	1.95	0.840

Source: Field Data, (2023).

Respondents agreed with five statements and disagreed with two statements. From Table 14, majority of the respondents supported the statements that biogas was easy to use, it had low running cost after installation, and a clean source of fuel as compared to firewood. Again, Table 14 suggested biogas usage saved time used for fire collection, there was adequate awareness of the biogas technology and, that biogas usage was more hygienic. The majority of the respondents, however, did not support the statements that there was adequate technical support for the construction and maintenance of biogas plants. This suggested that, as per the data gathered, the factors that positively influenced biogas adoption included the ease of using biogas, the low running cost of biogas after installation, the cleanliness of biogas as a domestic fuel as compared to wood, the time saved by biogas which otherwise could have been used in firewood collection, awareness of biogas technology and the hygienic nature of biogas usage.

It was observed from Table 14 that biogas was easy to use as per the responses obtained from household heads, although some held a contrary view on the issue. Most household heads alluded to the fact that biogas was easy to use. These findings support an assertion Mengistu et al. (2016) made pertaining to the ease of biogas use. Mengistu et al. (2016) indicated that biogas stoves were ran easily with a low level of education.

Regarding the statement, there was a low cost of running biogas after installation, respondent household heads generally agreed as per the mean score obtained. This was contrary to the opinions of a significant minority whose responses indicated they disagreed with the statement. These findings presented a divergent view to Byrne et al. (2020) who indicated the operation cost of a bio-digester with professional management was as high as construction cost.

On the statement that biogas was a clean source of fuel compared to wood, at least 90.7% of respondent household heads agreed, while the remaining 9.3% disagreed. The mean obtained, it suggested that even though a few of the household heads whose responses belonged to the minority expressed their disagreement, the majority of the respondents agreed with the statement that biogas was comparatively a cleaner source of domestic fuel than wood. It could be respondents considered biogas as a clean source of fuel compared to firewood in terms of absence of smoke, ashes and soot. This finding was not different from the result of Nunes et al. (2018) when they researched into anaerobic digestion of sugarcane residue. Nunes et al. (2018) asserted biogas was a clean energy source because it was an eco-friendly alternative energy source that produced little or no green house gases (GHG). Kanchongkittiphon et al. (2015) further indicated indoor use of biomass caused respiratory diseases, heart diseases and cancer from air pollution. According to Kanchongkittiphon et al. (2015), indoor environmental exposures such as smoke increased the incidence of Asthma. This was be a positive factor that influenced the adoption of biogas as a domestic fuel source among households considering the threat the use of biomass posed to the health of individuals and families.

On the statement, that biogas saved time used for firewood collection, respondents generally agreed that using biogas saved time for firewood collection. This implied that biogas, as a domestic fuel source, might be more convenient to use as users might not have to go in search of it. When this happens on a regular basis, it could become tiresome for household members particularly women and children. This might save a lot of time households spent on firewood collection. This result is similar to finding of Shane et al. (2017) who argued that the use of biomass was time consuming resulting in an opportunity cost and a strenuous activity for women and children.

Regarding the statement, there was adequate biogas technology awareness, the mean indicated that the majority of the respondent disagreed with the statement that there was adequate awareness of biogas technology. This meant, although majority of the respondents were not using biogas as their domestic fuel source, they were aware of the existence of the biogas technology. This finding lent some support to that of Makonese et al. (2018) who observed there was increased biogas awareness among households when they studied the use patterns and determinants of household cooking fuels.

The information on Table 14 suggested 49.9% of the respondents either strongly agreed or disagreed with the statement that there was adequate technical support for biogas. However, 50.1% of the respondents, at least disagreed with the statement that there was adequate technical support. This indicated that there was inadequate technical support for biogas.

Household heads also responded to question about reasons for accepting or rejecting biogas as a domestic fuel source. Table 15 presented a summary of the responses of the household heads.

Table 15: Main reasons for Household heads acceptance/rejection of biogas adoption

Reasons to accept/reject biogas adoption	Frequency	Percentage
Economic	294	82.4
Table 15 continued		14.8
Psychological	8	2.2
Religious	2	0.6
Total	**357**	**100.0**

Source: Field Data, (2023).

The reasons for respondents' acceptance or rejection of biogas as their domestic fuel were economic, personal, psychological, and religious with the main reason being economic (82%) and the least being religious (0.6%). Other reasons such as psychological (2.2%) and personal (14.8%) reasons could influence the household heads willingness to accept the biogas technology. The economic reasons for accepting or rejecting biogas adoption related to the cost involved in the use of biogas, the possible savings or increase the use of biogas might have on household fuel expenditure, the possibility of reducing climate change and the possibility of biogas increasing energy sustainability. Personal reasons for accepting or rejecting biogas sought to identify the number of respondents who would accept or reject biogas for reasons they preferred to keep private. The findings of this study related to what was reported by Bryant (2019) who confirmed that various factors like economic, social, religious and education influenced residents of Elmina's perception in accepting or rejecting biogas as a fuel source.

Psychological reasons for biogas acceptance or rejection also related to respondents' decision to use or otherwise based on possible dangers associated with biogas use, pleasant or unpleasant sensations associated with biogas use, reasons relating to environmental responsibility and social norms.

Religious reasons also sought to gather data on respondents whose reasons for accepting or rejecting biogas were based on the dictates of their faith. Many religions had rules related to cleanliness, and whether or not their religion permitted them to use waste particularly excrement to produce fuel for domestic uses.

From Table 15, it was evident that out of the opinions sampled, majority of the household heads 294 (82.4%) would accept or reject biogas adoption based on economic reasons. This suggested that, issues such as cost of installing biogas, its maintenance, cost of substrate, cost of labour, and other components of biogas construction and/or usage affected the decisions to either accept or reject the adoption of biogas. It also suggested that, the income level of respondents, together with the cost of alternative fuel might influence their decision because they had economic implications.

Ho1: There is no statistically significant relationship between income levels of household heads and their willingness to adopt biogas for domestic use.

This hypothesis sought to establish whether there was a significant relationship between income levels of household heads and their willingness to adopt biogas as their source of domestic fuel. A chi-square test was used to test the relationship between these categorical variables. A significant relationship was established between the variables. This suggested that the income levels 0f household heads influenced their decision to use biogas for domestic purposes. The data obtained from respondents is presented in Table 16.

Table 16: Relationship Between Income Levels of Household heads and Willingness to Adopt Biogas for Domestic Use

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	14.488	3	0.002
Likelihood Ratio	13.614	3	0.003
Linear-by-Linear Association	1.850	1	0.174
No. of Valid Cases	357		

Source: Field Data, (2023)

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.76.

Ho2: There is no statistically significant relationship between educational levels of household heads and their willingness to adopt biogas for the home

The hypothesis aimed at exploring if there was a possible relationship between the level of education of household heads and their willingness to adopt biogas as a domestic fuel.

Table 17: Relationship Between Educational Levels of Household Heads and their willingness to Adopt Biogas for the Home

	Value	Df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1.355[a]	3	0.716
Likelihood Ratio	1.416	3	0.702
Linear-by-Linear Association	.114	1	0.736
N of Valid Cases	357		

Source: Field Data, (2023).

The relationship between the variables was not seen to be statistically significant, χ^2 =1.355, df = 3, p = 0.716. That is, a sig. value of 0 .716 is greater than the alpha value of 0.05 which implied that there was no statistically significant relationship between the level education of household heads and their willingness to use biogas as a household source of domestic fuel. This finding indicated the level of education of a household head did not determine their desire to adopt biogas as a domestic fuel source.

Research Question 4: To what extent will household biogas use contribute to household finances?

Based on the data gathered, four main themes emerged from the research question as follows

1. Cost of biogas compared to alternative fuel sources
2. Influence of biogas on the cost of healthcare
3. Influence on household waste management and income
4. Influence on household income generation

Cost of biogas compared to other alternative fuel sources

For easy analysis, the participant household heads were represented with P and the researcher with R. In this work, P1 represented a trader, P2 represented a teacher, P3, P4, and P6 were poultry farmers while P5 represented a small-scale miner. The Household heads gave diverse accounts on the cost of biogas compared to other alternative fuel sources. For example, when the respondents were asked how cost effective biogas was as compared to other alternative fuel sources, some of the typical responses were:

"The cost of Liquified Petroleum Gas (LPG) cylinders and stoves is higher than the portable biogas plant my household

uses. It is made from a 30 cm capacity plastic bucket with a tight-fitting lid which is filled with about four kilograms of organic waste weekly. The portable plant is connected to a 2-burner cooker with a hose. So, you see, biogas is not expensive at all compared to LPG. The cost of the LPG cylinder alone can cater for the entire biogas installation cost. Again, the use of LPG will require constant refilling of cylinders after the initial cost which is the case with biogas. Biogas require the use of waste which comes at no cost to my household." (P4; 26th January, 2023)

Participant 4 further indicated that his biogas plant was capable of producing gas for preparing the household's breakfast, and for heating water needed for preparing his children for school. He also indicated that due to the limited size of his biogas plant, the household was unable to obtain enough gas for cooking the household's supper and so they tend to rely on charcoal for the purpose. This according to Participant 4 costs his household one hundred and ten Ghana cedis (GHC110) every fortnight. This notwithstanding, he indicated the little available biogas in the evenings was used to complete the cooking process in order to cut down on the cost of charcoal which according to Household Head 4 was high.

This response was not any different from the response from Participant 3 who opined that

"My sister, biogas has helped me immensely. With biogas, I do not buy anything like fuel every now and then. Biogas has

reduced my household expenditure on fuel and helps me save money for other uses." (P3; 26th January, 2023)

These responses reflected many other responses from other participants who indicated biogas was a cheaper energy source as compared to other domestic fuel sources. Participant 2 for example stated:

> *"The cost of biogas production is relatively low. All a household needed to generate biogas was an airtight container for receiving the mixture of organic waste and water, if it cannot afford the conventional biogas plant, which in her case was a plastic barrel connected to a balloon to store gas and a stove."* (P2, 19th January, 2023)

Participant 2 indicated she mixed manure with water and stored it in an airtight barrel which according to Participant 2, started producing biogas after twenty-four hours. She further stated that, her biogas plant provided her household with adequate biogas for almost all her household fuel needs except towards the evening when the gas level reduced. The household therefore supplemented biogas with LPG which according to him was more expensive owing to the current increases in price of LPG. Participant 1 also indicated:

"Biogas is an inexpensive clean fuel source compared to LPG and electricity. The production of biogas in my household required the use of agricultural field residue, solid kitchen waste and waste water from the kitchen and washroom." (P1; 19th January, 2023)

In contrast, the maintenance cost, which was very high put extra cost on the family budget when maintenance was required. Participant 5 for example posited, the cost of maintaining biogas plants had become unbearable that he had reverted to firewood and charcoal. He stated that,

> "*These technicians are mostly not available and hence when you call them, they could charge you amounts which are too exorbitant. I could not bear it so I had to revert to firewood. To me, biogas usage is expensive especially due to cost of maintenance"*. (P5, 5th February, 2023)

Even though some of the respondents alluded to the responses from P5. It was observed that, notwithstanding the high cost of maintenance of biogas plants, it was seen to be cost effective as compared to other alternative source of fuel such as LPG, firewood and charcoal. This meant that the use of biogas was seen to impact positively on household finances as it helped participants to cut down on their expenditure on fuel for domestic use.

Influence of biogas on healthcare

Some respondents also in addressing the influence of biogas on household finance also highlighted strongly the influence of biogas on healthcare. The following are excerpts from the interview

R: In what way do you think biogas affect your household income

P3:

> "*When my household was using firewood as our domestic fuel source, we spent a considerable portion of the household income in treating respiratory diseases. My wife's asthma attack was mostly triggered when she got closer to smoke*". (P3, 26th January, 2023).

Participant 3 opined further that upon the advice of a medical doctor to use an alternative fuel, they changed to the use of LPG which was comparatively costly than the firewood they were using. He however, chanced on an advertisement on biogas and decided to contact the company. He was introduced to the biogas digester, which had been helpful. He stated that

> *"After my brother-in-law abroad assisted with the construction of the biogas plant, I can say, my wife's condition has improved. I spend on inhalers less frequently. My only challenge with its use is the odour it emits in the event of leakages. I will be happy if something can be done about it".* (P3, 26th January, 2023)

From the response of P3, it could be said, the initial cost of constructing his biogas plant was relatively high. This could have put some strain on the finance of his household had it not been for the intervention of his brother-in-law. Secondly, it could be said that the reduction in medical cost as a result of biogas use was yet another influence of biogas use on household finance as it freed some money for the household to spend of other things. The concern expressed about the odour from the occasional leaking biogas pipe could also pose a health challenge to the household which could result in the household spending money which could have otherwise been spent on other needs of the household in treating such possible health challenges.

From the account of P6, the use of biogas has led to a reduced healthcare cost. They had runny nose, headache and eye irritation when using firewood. He indicated, "*We visit the eye clinic and buys medications to help ease the discomfort. Since we started using biogas, there is some improvement. We are using the money we were spending on eye medications on other needs.*" (P6; 6th February, 2023)

P6 asserted that domestic use of biogas has led to a monthly decrease in the cost of accessing healthcare by about 50%.

According to majority of the participants, the use of biogas had saved them some money they would have used in treating ailments associated with using other fuel sources. They observed the use of biogas had led to an overall improvement in their health. They were of the view, biogas had resulted in improvement in the air they breathe leading to an improvement in their respiratory health. However, some concerns were also raised about the stench emitted by biogas plants in the event of leakages. They were unsure if the odour could cause serious ailments in the future. Some participants implied from their responses that the cost of constructing domestic biogas plants was high, and in some cases, required the intervention of people outside the household to assist them financially to install it. This suggested that the household finance of such participants could have been impacted negatively if help was unavailable. That notwithstanding, biogas was generally seen to contribute positively to household finance as it helped in reducing the cost incurred in assessing healthcare.

Influence of biogas on waste management and household income

Household income was also seen to receive much attention in the conversation concerning the extent to which biogas influenced family finance.

The respondents indicated bio-fertilizer produced as a by-product of bio digestion was useful in increasing crop yield which helped increase the family's income in kind. From the responses of household heads interviewed, it was evident bio fertilizers had contributed immensely to their household production activities. According to Participant 2,

> "*Bio-fertilizer is used in cultivating plantain, cassava and other staple foods in our backyard for consumption which has helped the household to reduce its expenditure on foodstuff* ". (P2, 19th January, 2023)

It was further stated the household also sold some of the foodstuffs which generated some income for the household.

P3 commented,

> "*Litter from my poultry farming business generate a lot of manure which I used to pay money to dispose off or sell to crop farmers sometimes on credit for which some people owe me for up to today. The use of biogas has enabled my household to make use of this manure as fuel and I have peace of mind. No payment of money in disposing it. Besides, I still get fertilizer which I use on my backyard garden*" (P3, 26th January, 2023).

Another participant, also stated he was able to produce multiple suckers of plantain for use as planting material on the family's five-acre farm.

From Participant 4 asserted:

> "*These poultry droppings were really making my environment stinking and dirty. I now have a use for these*

droppings as I use it as substrate for biogas production. My environment is now clean. I will not beg farmers to come and collect the poultry dropping for their farms because I have use for it in my home" (P4, 26th January, 2023).

P5 was of the view he could not eat food cooked with his own excreta. He constructed his biogas plant basically as a waste treatment plant. A friend later briefed him on the use of the bio-fertilizer and he had devoted his biogas plant to the production of manure for his oil palm plantation that had increased the yield from the plantation.

P6 indicated, that even though his biogas plant was not in use as domestic fuel source, he was hoping to make it operational due to the benefits he had heard some of his colleagues using biogas for the said purpose were enjoying. This might mean that, biogas usage had great impact on waste management and also helped in increasing household income.

Influence of biogas on income generation

From the interview, it was deduced that biogas was not only used for generating fuel for domestic use but was a major income generation source for households. P1 for example posited the household used biogas in heating water for sale to caretakers of patients on admission at a hospital located in their neighbourhood. According to this participant, the business would have been less lucrative if it was dependent on LPG, wood or charcoal due to the rising cost of those fuels. To P1, biogas plant had capacity to produce adequate gas which was used to heat water to sell to customers every day. This according to her, had become a source of income for the upkeep of the household. It was indicated, the use of biogas was faster than firewood and charcoal, hence the customers were always pleased with their services.

According to P1

> *"I use biogas to heat water for sale to my clients. Previously, I used fuelwood for heating water for sale, however, it was not really convenient, especially, during rainy season when I had difficulty in lighting fire".* (P1; 6th February, 2023).

P6 as indicated earlier that even though his biogas plant was not in use as a domestic fuel source, he had an alternative usage for it; brooding his day-old-chicks, thus helping in saving money he would have spent on charcoal or LPG for brooding.

According to P6

> "*I operate a poultry farm and I used to dispose off my manure or sell to crop farmers. I have a biogas plant now and I use in brooding my day-old-chicks which I sell after six weeks. This helps me in saving cost in purchasing LPG or charcoal for the said purpose and also enables me to make some money for the up-keep of my family*. (P6; 6th February, 2023)

This suggested that, biogas was a very important fuel source which helped various businesses who depended on it.

Generally, it was evident from the various responses that biogas influenced the various households in terms of cost compared to alternative fuel sources, cost of healthcare, household waste management and household production activities, and household income generation. It was observed household use of biogas was a considerable influence on household finances.

Discussions

This study sought to explore the level of awareness of the inhabitants of Akwatia in the Denkyembour District of the Eastern Region about household use of biogas as a domestic fuel source. It examined the extent to which household heads were willing to accept biogas as a domestic fuel, and also found out both positive and negative factors which influenced the adoption of biogas as a domestic fuel. It also sought to establish if there was a statistically significant relationship between household income level of household heads and their willingness to use biogas as their chief source of domestic fuel, and how biogas usage contributed to household finances.

Data obtained from the gender distribution of household heads sampled for the study is related to figures reported by the Ghana Statistical Service (GSS) in the 2021 Population and Housing Census for the study area. Respondents were of varying ages with the majority of them aged at least 40-60 years. That is to say, majority of the respondents were middle aged. There was, however, no indication as to the exact amount earned which suggested that the data on income levels of respondents were based on estimated amount of income and not on the actual amount earned by household heads. This connotes with the assertions made by Mumbi (2017) that higher income households were more likely to adopt biogas may be applicable in this study.

Respondents had varying household sizes with the majority of them having a household size of at least four individuals. Data gathered indicate about 45.4 percent of the respondents had large household sizes of at least seven individuals. Households that had biogas plants in the study area as indicated by the findings of the study had household sizes of at least six individuals which lends some support to assertions made by Uhunamure et al. (2019) that a household of at least seven members was large and capable of providing help in operating and maintaining biogas plants.

Respondents sampled for the study could generally be classified as literate as majority of them had received at least secondary education, though a significant minority had received primary or no formal education. Mengistu et al. (2016) identified level of education of household head as a factor that influenced a household decision to use biogas in Ethiopia. Their finding is in line with that from this study which also revealed that the majority of the household heads in the study area are more likely to use biogas for domestic purposes. This is because they may be able to read materials on the operations and maintenance of the system.

Findings from the study revealed that, there was some level of awareness of biogas as a domestic fuel in the study area as expressed in the responses of majority of the respondents. The media was found to be the main source of information on biogas with about half of the total number of the respondents indicating the media was their source of information on biogas. Majority of the household heads who expressed their awareness of biogas indicated they had been aware of biogas within the last one to three years. It is also evident from the responses of household heads, most of them had a low level of awareness of biogas as a source of domestic fuel. Majority of the respondents indicated that there is lack of adequate knowledge on biogas. This suggests that, even though there is some level of biogas awareness among households, this knowledge is inadequate. This low awareness is however, in line with findings of some researches conducted across the continent Shane et al., (2015). Findings from a research by Shane et al., (2015) suggested that there was low level of awareness of the benefit of biogas production in Zambia. These findings are not any different from the finding from a study conducted by Hnyine et al. (2016) in Nigeria. In all these researches, it was observed there was low level of biogas awareness in the study area.

On the extent to which households were willing to adopt biogas as a domestic fuel, it was evident from the findings that 98.3% of respondents were willing to construct biogas in their households. This confirmed the work done by Bryant (2019) who proved that the majority of respondents (72 %) were willing to install the system in their households.

Factors that influenced biogas adoption as household fuel source in the study area were seen to be varied. The factors influenced biogas adoption both positively and negatively. One major negative factor which influenced biogas adoption included high cost of installation. This is in line with the findings of Kumar et al. (2015) when they researched into ways of improving biogas plants as a means of ensuring energy sustainability through the use of renewable energy. It is imperative to note that, high cost of biogas installation discouraged many households from installing biogas in their households. Seventy-one percent of the respondents agreed expensive cost of biogas installation affect it adoption which is not any different from the findings of Kumar et al. (2015) as well as Jan & Akram (2018). Other factors identified to influence biogas adoption negatively included lack of technical support, lack of adequate knowledge on biogas digester as well as lack of adequate substrate to fuel the digester. These findings are in line with findings from other researchers who also cited lack of technical support for biogas (Momanyi & Benards, 2016), high cost of maintenance (Ali et al., 2022), among other factors as factors that inhibited the use of biogas among households in different parts of the world.

The findings of the study also gave some support to the Technology Acceptance Model (TAM). The responses of household heads indicated the attitude of respondents towards the use of biogas for domestic purposes was influenced by the perceived usefulness of biogas and its ease of use (Bryant, 2019). Household heads also suggested as per their responses that, their intention to use biogas for their domestic fuel needs was influenced by the usefulness of biogas.

The study further established a significant relationship between household heads level of income and their willingness to adopt biogas as a domestic fuel source. The significant relationship established between the variables of interest, household level of income and willingness to adopt biogas as a domestic fuel source was in line with the findings of a research conducted by Uhunamure et al. (2019) as well as Amir et al. (2020). The current study therefore confirmed the findings that there was a significant relationship between household level of income and their willingness to adopt biogas as a domestic fuel source.

There was, however, no statistically significant relationship identified between the level of education of household heads and their willingness to adopt biogas as a domestic source of fuel. This finding is contrary to the findings of Jan et al. (2018) where a statistically significant relationship was found to exist between level of education and willingness to adopt biogas as a domestic fuel source. That is, while Jan et al. (2018) found an association between level of education of household heads and their willingness to adopt biogas as a domestic fuel, this was not the case as no association was found between level of education of household heads and their willingness to adopt biogas as a domestic fuel.

On the extent to which biogas adoption influenced household finances, four major themes were identified and used for the analysis. The themes were cost compared to alternative fuel sources; influence of biogas on cost of healthcare; influence of biogas on household waste management and food security; and influence on household income generation. From the various excerpts, it could be deduced biogas adoption contributed enormously to waste management in homes. Studies conducted elsewhere by other researchers also highlighted the role of biogas in waste treatment in households which has great impact on household finance (Roopnarain, & Adeleke, 2017; Obaideen et al., 2022).

Bio-fertilizer which is reported to be a by-product of the bio-digestion process also helped in ensuring food security. This is evident from the interviews that staple foods like cassava, plantain among others were cultivated by households with the aid of bio-fertilizer to increase yield. This suggested, the usage of biogas would help in ensuring food security as bio-fertilizer, could help lessen the burden of households in accessing chemical fertilizers and reduced the cost incurred in purchasing these fertilizers considering the price of fertilizers on the market. This finding was not any different from the findings of Guta et al. (2017) and Roopnarain et al. (2022) who reported on the contribution of biogas to ensuring food security. Others reported that biogas is a clean source of fuel which ensured environmental cleanliness (Pilloni, & Hamed, 2021; Garfí et al., 2019; Rathod et al., 2018). This was, however, contrary to the findings of Parihar et al. (2019) who found that ammonia generated from biogas contributed to environmental pollution. The cost incurred in maintaining biogas plants may also affect household income.

In summary, there was biogas awareness among residents of Akwatia in the Denkyembour District in the Eastern Region of Ghana even though the extent of the awareness was low. Majority of the household heads were willing to adopt biogas and may require support from Government or NGO's. A significant relationship was established between household level of income and willingness to adopt biogas as domestic fuel source. It was also identified that biogas generally impacted positively on household finances. No relationship was however found between the level of education of household heads and their willingness to adopt biogas as a domestic fuel.

CHAPTER FIVE

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Introduction

This chapter provided a general summary of the entire study. It did so by providing an overview of the research problem and the methodology employed in the study. It also provided conclusions based on the findings of the research as well as recommendations.

Summary

This study investigated biogas usage by households in Akwatia in the Denkyembour of the Eastern Region of Ghana. The focus of the study was to explore the level of awareness, willingness and the factors influencing the adoption of biogas as a domestic fuel source. The research further explored how biogas as a domestic fuel source influence household finances. The study assessed whether there was a statistically significant relationship between the income level of household heads and their willingness to adopt biogas as a domestic fuel source. In addition, the study investigated whether there was a statistically significant relationship between the educational level of household heads and their willingness to adopt biogas as a domestic fuel source. The mixed method was used for the study. The population of the study was 5166 households in Akwatia who used different types of domestic fuel for domestic purposes.

A sample size of 357 household heads were used for the study using the stratified sampling technique to sample household heads for the quantitative study. The various stratum from which respondents were sampled included households using firewood, charcoal, cooking gas, and other fuel sources.

Purposive sampling was used to sample household heads who had installed biogas plants for the qualitative study. A questionnaire and interview guide were the instruments for data collection. The data obtained were analysed using descriptive statistics and thematic analysis.

Summary of Key Findings

1. There was awareness about the use of biogas as a domestic fuel source among households in the study area, even though a good number of households (38.7%) did not know biogas was a source of domestic fuel.
2. Most households in the study area were willing to use biogas as their domestic fuel source for economic reasons.
3. There was odour from leaking biogas pipes at all the households visited.
4. The cost of installing biogas plants, lack of adequate knowledge on biogas, an inadequate substrate to fuel digesters, lack of technical services, and difficulty in operating biogas plants, among others, were identified as factors negatively affecting the use of biogas as a domestic fuel source.
5. The time saved when biogas was used for domestic purposes as compared to time spent in collecting firewood for the same reason, the low cost of running biogas plants, the ease of using biogas as domestic fuel, the cleanliness of biogas compared to firewood and charcoal were seen to positively influence biogas use as a domestic fuel source.
6. The use of biogas as domestic fuel was seen to influence household finance. It reduced household expenditure on fuel by 65%, the cost of healthcare, and waste management. It, however, increased income generation among households.

7. A statistically significant relationship was established between the income level of household heads and their willingness to use biogas as a domestic fuel source.
8. There was no statistically significant relationship between the level of education of household heads and their willingness to adopt biogas as a domestic fuel source.

Conclusions

This study investigated biogas usage by households in Akwatia in the Denkyembour of the Eastern Region of Ghana. The focus of the study was to explore the level of awareness, willingness and the factors influencing the adoption of biogas as a domestic fuel source. The research further explored how biogas as a domestic fuel source influence household finances. There was awareness (more than 77.6 %) on the use of biogas as a domestic fuel source among households in the study area.

Most households (89.5 %) in the study area were willing to use biogas as their domestic fuel source for economic reasons.

The cost of installing biogas plants, lack of adequate knowledge on biogas, an inadequate substrate to fuel digesters, lack of technical services, and difficulty in operating biogas plants, among others, were identified as factors negatively affecting the use of biogas as a domestic fuel source. The time saved when biogas was used for domestic purposes as compared to time spent in collecting firewood for the same reason, the low cost of running biogas plants, the ease of using biogas as domestic fuel, the cleanliness of biogas compared to firewood and charcoal were seen to positively influence biogas use as a domestic fuel source.

The use of biogas as domestic fuel was seen to influence household finance. It reduced household expenditure on fuel by 65 %, the cost of healthcare, and waste management. It, however, increased income generation among households.

Recommendations

Based on the findings of the study, the following recommendations are suggested

1. There is the need for the Ministry of Energy to intensify public education on biogas households for domestic purposes. The education should aim at creating awareness on its use as an alternative domestic fuel source. This would help households to learn about the benefits and risks associated with biogas use to enable households make informed choices. Through publications from this work, relevant stakeholders like Ministry of Energy and Metropolitan, Municipal and District Assemblies will be informed to use this work to influence policy decision.
2. Prospective users of biogas technology need to be educated by the Ministry of Energy and Metropolitan and Municipal and District Assemblies, to re-consider biogas plant designs thus minimising groundwater pollution.
3. Interventions should be put in place by Governmental and NGO's to address challenges that hamper households' use of biogas.

Suggestions for Further Studies

The findings of this study had highlighted the need to advance research into household biogas use. Future studies could research into what could be done to produce odourless biogas for households.

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APPENDICES

APPENDIX A

QUESTIONNAIRE

This questionnaire seeks to get objective responses from respondents on various concerns on biogas adoption captured under various thematic areas. You are assured that all information provided will be treated as confidential as possible. Kindly tick the most suitable response against the questions in order to answers them.

PART I: DEMOGRAPHIC CHARACTERISTICS OF RESPONDENTS

a. What is the Gender of should Male ( ) Female ( )
b. What is the age of house hold head? Below 30 ( ) 30- 40 ( ) 41-50 ( ) 51 and above ( )
c. What is the highest level of education of house hold head?
   No formal education ( ) Primary ( ) Secondary ( ) Tertiary ( )
d. What is the monthly income of the household head?
   Below Gh₵1000 ( ) Gh₵1001– 1500 ( ) Gh₵1501- Gh₵2000 ( )
   Above Gh₵2000 ( )
e. What is size of household? 1-3 ( ) 4-6 ( ) 7-9 ( ) Above 10 ( )
f. What is the occupation of household head?
   Farming ( ) Nursing ( ) Mining ( ) Teaching ( )
   Administrative work ( ) Artisan ( ) Security service ( ) Driving ( )
   Trading ( ) others (specify)……………………..

PART II: AWARENESS OF BIOGAS AS DOMESTIC FUEL SOURCE

2 (a) Biogas is a source of energy for domestic use?

Yes ( ) No ( )

(b) Indicate by ticking the options below what biogas can be used for in the home.

Generate electricity ( ) fuel for cooking ( )

Pumping water for domestic use ( ) domestic heating ( )

c) i. Which of the following is your source of information about biogas as a domestic source?

NGO ( )

Media ( )

Family/ Friends/colleagues/neighbors ( )

Books/magazines/journals/ Films ( )

Businesses (public/private) ( )

Lectures ( )

Other sources ( ) ………………………

ii. For how long have you been aware of biogas as a domestic fuel source?

a. Less than a year ( )
b. Between 1- 3 years ( )
c. Between 4- 6 years ( )
d. 7-9 years ( )
e. 10 years and above ( )

3. (a) Have you seen a biogas plant before?

Yes ( ) No ( )

4. What type of fuel source do you use in your household?

a. Kerosene ( ) LPG ( ) Charcoal ( ) Firewood ( ) Others ( ) specify ………………………………

5. Kindly tick (√) to indicate the level to which you agree or disagree with the following statement on biogas awareness as a household fuel.

1= Strongly agree, 2 = Agree, 3 = Disagree, 4- Strongly disagree

Biogas is household product fuel	**1**	**2**	**3**	**4**
Biogas is renewable fuel with no risk future environmental degradation				
Less air pollution generated by biogas				
Biogas contribute effective household waste management				
Biogas can enhance agricultural production through the use its by-products				
Biogas pollute and ground water				

PART III: EXTENT OF HOUSEHOLD WILLINGNESS TO ACCEPT AND ADOPT BIOGAS

6 . (a) Do you have biogas in your household?

Yes ( ) NO ( )

b) if your answer in 6 (a) is yes, is your biogas plant in use as a household source

of fuel?

Yes ( ) NO ( )

(c) if your answer in 6(b) is yes, how long have you engaged in biogas production

a) less than 1 year ( )

b) 1 to 3 years ( )

c) 4 to 6 years ( )

d) 7 to 9 years

e) 10 years and above ( )

7. What is/would be the source of initial capital for construction your biogas plant?

a) Own savings ( )

b) NGO support ( )

(c) Government support ( )

(d) Cost sharing with NGO or Government ( )

8. What type of substrate do you use for generating biogas?

a) Animal waste

b) Human excreta

c) Forest residue

d. others (specify) ……………………………………..

PART IV: ELEMENTS INFLUENCING THE ADOPTION OF BIOGAS AS HOUSEHOLD FUEL

9. (a) Would you like to use biogas as your chief source of domestic fuel?

Yes ( ) No ( )

b) if your answer in 10(a) above is No, kindly tick to indicate the level to which you agree or disagree with the following statements on factors that affect negatively affect the adoption of biogas digesters.

(1= Strongly Agee, 2= Agree, 3= Disagree, 4= Strongly Disagree)

Elements influencing the adoption of biogas technology	1	2	3	4
Biogas is expensive to install				
Biogas usage has health risk				
Difficulty in operating biogas digesters				

There are cheaper sources of alternative fuel sources				
Lack of technical services				
High cost of maintenance of biogas digesters				
Lack of Water				
Lack of adequate knowledge on biogas digesters				
Inadequate Substrate to fuel the digester				
Lack of adequate source of labour				

C. Kindly tick (√) to indicate the level to which you agree or disagree with the following statements on factors that positively affect the adoption of biogas in the home.

(1= Strongly Agee, 2= Agree, 3= Disagree, 4= Strongly Disagree

Factors affecting the adoption of Biogas digesters	1	2	3	4
Biogas is easy to use				
Low running cost after installation cost				
Clean source of fuel as compared to wood				
Save time for fire collection				
Adequate awareness of biogas technology				
Adequate technical support				
Biogas usage is more hygienic				

APPENDIX B

INTERVIEW GUIDE

Thank you for agreeing to participate in the study. You are being interviewed to appreciate experiences with biogas as a domestic source of fuel. There are no right or wrong answers to the questions. The researcher is interested in your views and experiences with biogas usage as household financier. You have signed to consent form and are aware of your rights as a participant. The interview will last for thirty minutes depending on how much information you would like to share. With your permission, I would like to audio record the interview because I do not want to miss any of your responses. All responses would be kept confidential. You may decline to answer any question or stop participating in the interview at any time and for any reason. May I turn on the digital recorder?

1. In what way does biogas usage affect your household?
2. How does the use of biogas affect your household's source of income?
3. To what extent does biogas adoption affect your household's health?
4. How will financial effect of the use of biogas affect its continuous usage?
5. What is the pay-back time for investing to have biogas in the household?

APPENDIX C

INFORMED CONSENT

Research Topic: Biogas Use by Households
Principal Investigator: Nancy Baka
Field Assistants: Mr. Emmanuel Atiglo Mensah
Mr. Ebenezer Dankwah

1. **Introduction and Purpose of the study**

   The researcher is a student of the University of Cape Coast who wants to find out if households in Akwatia are aware biogas can be used as fuel in the home. The study also wants to find out if households in Akwatia are willing to use biogas for their domestic activities and how the use of biogas in the home affects the finances of households.

2. **Description of the Research**

   If you agree to participate in the study, you would be required to complete a questionnaire by ticking from options provided as well as grant the researcher an interview when needed.

3. **Subject Participation**

   To participate in the quantitative study, you must be a household head who uses fuel for your domestic activities. To participate in the qualitative study, you must be a household head who has an installed biogas plant in your household.

4. **Potential Risks and Discomforts**

   You will be needed to answer some questions which will take between 30 minutes and one hour.

5. **Potential Benefits**

   You will have a better understanding about the use of biogas for domestic activities.

6. **Confidentiality**
   All information collected from you will be coded to protect your name. No identifying information will be used in the discussion. The researcher will keep all files safely and would destroy them when data is analysed.

Your audio recordings will be anonymous and would be destroyed after it is transcribed.

7. **Compensation**

You will be compensated with ten Ghana Cedis worth of airtime for participating in this study.

8. **Voluntary Participation**

Your decision to participate in this study is completely voluntary. You are not obliged to take part in the study if you do not want to do so.

9. **Withdrawal from the study**

You may decide to stop participating in the study at any time without any punishment.

10. **Cost**

There is no cost for participating in this study.

I voluntarily agree to participate in this study

Yes ……….

No ..…….

I understand that I will be given a copy of this signed Consent Form.

Name of Respondent………………………………………………   Signature ………………………………………..   Date …………………………………..
Name of Witness ………………………………………………..   Signature ………………………………………   Date …………………………………
Person Obtaining Consent ……………………………………..   Signature …………………………………...   Date …………………………………

APPENDIX D

INTRODUCTORY LETTER

UNIVERSITY OF CAPE COAST
COLLEGE OF EDUCATION STUDIES
FACULTY OF SCIENCE AND TECHNOLOGY EDUCATION
DEPARTMENT OF VOCATIONAL AND TECHNICAL EDUCATION

Direct: 03320-91097
Telegrams & Cables: University, Cape Coast

University of Cape Coast
Cape Coast

Our Ref: VTE/IAR/V.3/242

15th December, 20201

The Head
Institutional Review Board
UCC

Dear Sir,

REQUEST FOR ETHICAL CLEARANCE

We have the pleasure of introducing to you **Ms. Nancy Baka** who is an M.Phil. Student of this Department and working on the thesis topic **"Barriers and Opportunities of biogas adoption and utilization by rural households in the Eastern Region in Ghana."**
Currently, she is at the data collection stage of the thesis, and we would be most grateful if you could grant her an Ethical Clearance to enable her proceed with the collection of data.

We count on your usual cooperation.

Thank you.

Yours faithfully,

Dr. Augustina Araba Amissah
HEAD OF DEPARTMENT

APPENDIX E
ETHICAL CLEARANCE

UNIVERSITY OF CAPE COAST

INSTITUTIONAL REVIEW BOARD SECRETARIAT

TEL: 0558093143 / 0508878309
E-MAIL: irb@ucc.edu.gh
OUR REF: UCC/IRB/A/2016/1650
YOUR REF:
OMB NO: 0990-0279
IORG #: IORG0011497

7TH DECEMBER, 2022

Ms Nancy Baka
Department of Vocational and Technical Education
University of Cape Coast

Dear Ms. Baka,

ETHICAL CLEARANCE – ID (UCCIRB/CES/2022/108)

The University of Cape Coast Institutional Review Board (UCCIRB) has granted Provisional Approval for the implementation of your research on **Biogas adoption by households: The case of Akwatia in the Denkyembour District of the Eastern Region.** This approval is valid from 7th December, 2022 to 6th December, 2023. You may apply for a renewal subject to the submission of all the required documents that will be prescribed by the UCCIRB.

Please note that any modification to the project must be submitted to the UCCIRB for review and approval before its implementation. You are required to submit periodic review of the protocol to the Board and a final full review to the UCCIRB on completion of the research. The UCCIRB may observe or cause to be observed procedures and records of the research during and after implementation.

You are also required to report all serious adverse events related to this study to the UCCIRB within seven days verbally and fourteen days in writing.

Always quote the protocol identification number in all future correspondence with us in relation to this protocol.

Yours faithfully,

Kofi F. Amuquandoh

Ag. UCCIRB Administrator

ADMINISTRATOR
INSTITUTIONAL REVIEW BOARD
UNIVERSITY OF CAPE COAST