Sustainable sanitation system in Ghana

Sustainable Sanitation System in Ghana: a Biogas Approach

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To my husband, Michael Osei-Marfo and children; Nana Ntiamoah, Naana Ntifua and Nana Acquah.

I appreciate your great support and sacrifices through my PhD journey. To my mother, Dorothy Antobam, for all the support.

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Chapter 1

General Introduction

INTRODUCTION

Sanitation is basically the protection of a community from diseases associated with poor waste management practices and improvement in the overall environmental quality (Awuah, 2014). Sanitation is thus, an important and basic need for any individual or group of people in any home, community or country as a whole. While sanitation is broad and generally encompasses safe collection, storage, treatment and disposal/reuse of human and animal dung (WHO, 2008), and is comparable to potable water supply, it is mostly disregarded and rarely receives attention (Monney and Antwi-Agyei, 2018).

Sanitation includes the provision of facilities and services to ensure safe disposal of human excreta (WHO, 2008). This definition implies making sure human excreta is safely collected, well treated and properly disposed of, to prevent human contact with its associated hazards (flies and stench nuisance) or threat to public health. The definition of sanitation for this research will focus on the use of biogas plant/digester for the treatment or management of human excreta. Managing human excreta is essential in everyday life hence people resort to all kinds of sanitation systems to meet their everyday needs, whether they are approved or unapproved.

Growing population and rapid urbanization have given rise to sanitation challenges and public health risks all over the world, and this is not limited to only the developing countries. This challenge has necessitated the use of different sanitation systems, ranging from open defecation to septic tank and sewer systems, although the latter is almost non-existent in Ghana (NESSAP, 2010-2015). Human excreta (HEx) management has always been a public health concern due to its potential public health risk, yet in Ghana, HEx is mostly discharged into the environment (water bodies or dump sites) with little or no treatment.

However, it is important to note that adequate sanitation and socioeconomic development including good health are correlated. Quoting Mahatma Gandhi, "sanitation is more important than independence'' (as cited in Mara *et al.,* 2010 pp1). It implies that adequate sanitation is a premise for freedom from all sanitation related diseases and stunted socioeconomic development.

The Environmental Sanitation Policy of Ghana (2010) identified certain basic elements and plan of actions to promote an accelerated development in the sanitation sector. These include: encouraging researchers to review sanitation technologies, and the identification and dissemination of cost-effective, appropriate, affordable and environmentally friendly technologies that can address environmental sanitation needs (MLGRD, 2010).

This has become necessary considering the emerging challenges with site allocation for treatment and disposal of waste coupled with urbanization and population growth. One sanitation technology which is considered as environmentally friendly and has many benefits is biogas technology. Aside obtaining biogas for renewable energy, it has the potential to reduce emissions which cause global warming, it produces bio-fertiliser from the digestate, it improves the health of especially women by reducing indoor air pollution from the use of wood fuel (Arthur et al, 2011), and also improves sanitation. Although diverse sanitation technology options exist, the benefits and sustainability of a technology are vital to consider. Sustainability is not just about the means of reducing cost of management of a system, but also considers measures taken to improve social impact while reducing environmental consequences (DWAF, 2002), and in all, biogas technology meets these criteria.

In spite of the many benefits associated with biogas technology, a major campaign programme that seeks to advance the dissemination of biogas plants/digesters at the household and community/institutional level, including on large scale, is yet to be formulated (Bensah et al., 2010). This is an indication that Ghana is at the starting point of marketing biogas technology.

Challenges with sanitation improvement in developing countries like Ghana, can be linked to social and behavioural change processes (Jenkins and Scott, 2007). In attaining any meaningful progress in sanitation improvement, it is important to address the poor behaviour of people toward the environment (MLGRD, 2010). To address or explain this poor behaviour, Ajzen's (1991) theory of planned behaviour (TPB) is adopted in the present thesis. Meanwhile, according to Ajzen (1991), one's behaviour can be predicted by their intentions, which in turn is dependent on three aspects: attitude towards the behaviour, which is the degree of one's favourable or unfavourable evaluation of the behaviour in question; subjective norm, that is the perceived social pressure to perform or not to perform the behaviour (Ajzen, 1991); and perceived behavioural control, that is an individual's perception of ease or difficulty in performing the behaviour of interest (Ajzen, 2002). In the present context, the target behaviour of interest is the use of biogas technology to sustainably manage human excreta.

Furthermore, the Energy Commission (EC) of Ghana developed a Strategic National Energy Plan (SNEP) (2006), which indicated that, apart from wood fuel which accounts for 60% of traditional energy use, the country is yet to exploit biomass based energy. Hence, the need to support the development of other renewable energy alternatives including biogas, to reduce the use of wood fuel from 60% in 2006 to 40% by 2020 and also to sustainably deal with the sanitation challenges confronting Ghana. Although such target has been set, there is no policy on biogas technology in Ghana, making its dissemination and achievement a challenge.

Despite the lack of biogas technology policy and the dissemination challenges, few biogas service providers (individuals, companies and government institutions) have been diffusing it. However, a majority of the biogas service providers are not engineers but trained artisans, who install unstandardized biogas plants/digesters resulting in a number of design challenges. With regards to the design challenges, a standardized design can be floated by the relevant authorities/institutions to control the frequent failures/challenges usually encountered.

Finally, the risk of public health, environmental pollution including water pollution as well as ecological imbalance and poor sanitation, resulting in the loss of GH¢ 420 million (US$ 290 million) annually by the government of Ghana (Water and Sanitation Program, 2012) can be reduced through harnessing biogas technology development and dissemination. It is against this context that the present research is being conducted to investigate the limitations to the dissemination and adoption of biogas technology for the management of human excreta since its introduction about three decades ago.

Global and Africa's Sanitation Trends

Sanitation is not a new concept but a tradition of thousands of years of actual experience and application (Welch, 1945). It is as old as human beings because it deals with human environment. Global access to basic sanitation is a fundamental need and a human right, and access for all will reduce illness and preventable death, especially among children (WHO/UNICEF JMP, 2021). It is worthy to note that between 2000 and 2020, 2.4 billion people gained access to safely managed sanitation facilities which are not shared with other households whereas in 2020 3.6 billion people still lacked safely managed sanitation facilities (WHO/UNICEF JMP, 2021), with 673 million of them practicing open defecation (WHO/UNICEF JMP, 2019).

Sanitation services, categorized as safely managed (private improved facility where faecal matter is safely disposed on-site or transported off-site), basic (private improved facility which separates faecal matter from human contact), limited (improved facility shared with other households), unimproved (unimproved facility which does not separate faecal matter from human contact) and open defecation. Fig. 1 shows the global trend of household sanitation services (WHO/UNICEF JMP, 2021).

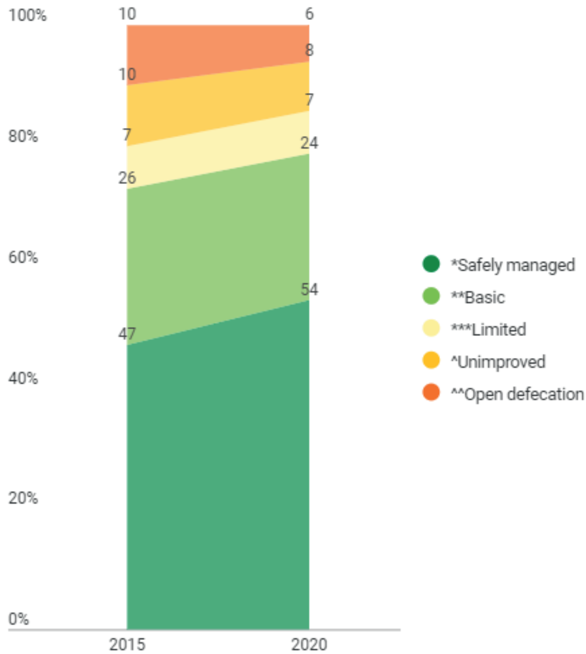

Fig. 1 Global trend of sanitation services (Source: WHO/UNICEF JMP, 2021)

According to WHO/UNICEF JMP (2021), in 2020, 1.9 billion people used basic sanitation services, 580 million used limited services, while 616 million used unimproved services. Although there is progress in sanitation services, large disparities still exist. While the developed regions have achieved universal access, the developing regions lag behind with the lowest coverage concentrated in Sub-Saharan Africa and other low income countries (WHO/UNICEF JMP, 2021) (Fig. 2).

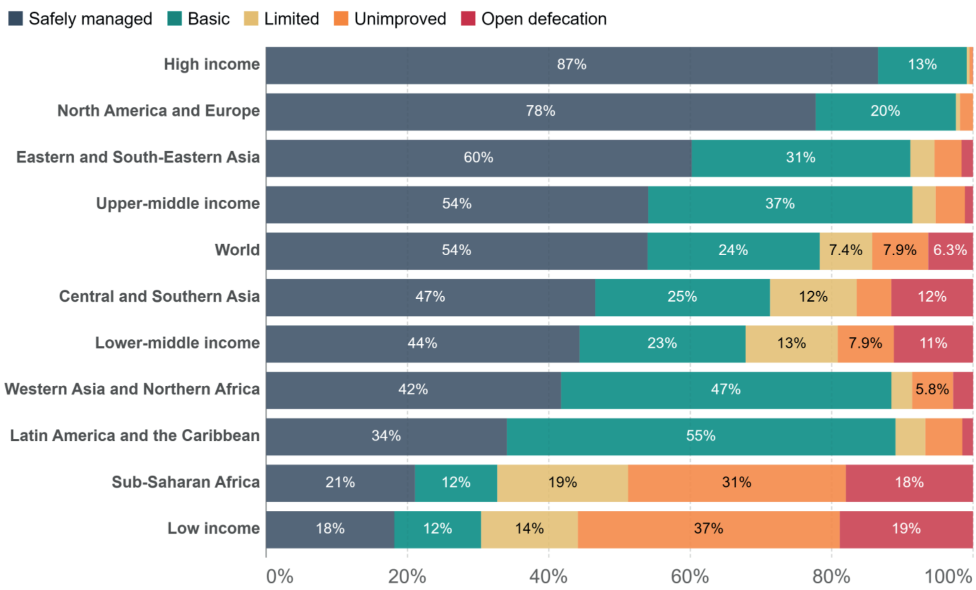

Fig. 2 Share of the population with access to sanitation facilities, 2020 (source: WHO/UNICEF JMP, 2021)

Low coverage of sanitation in Africa can be attributed to political neglect almost at every level because it is seen as insignificant. Due to this perception, it is not considered a high profile political issue, though it affects many. Political will is key to ensuring increased access to sanitation for all (SWA, 2013).

International organisations recognise sanitation crises as a global issue that requires political will or commitment to improve its access. Therefore, Sanitation and Water for All (SWA) was formed in 2010 to catalyse political leadership and action with member countries mostly from Africa. In spite of their meetings and discussions on how to improve access, Africa is yet to improve on its sanitation coverage.

Impact of Poor Sanitation: Global and Africa

It is now a common knowledge that poor sanitation leads to poor health and preventable deaths (Lixil/Oxford Economics/WaterAid, 2016). The impact of poor and inadequate sanitation leads to a number of financial and economic costs. These include direct medical costs associated with treating sanitation-related diseases, lost income through reduced or lost productivity, clean-up costs, time loss due to distant facilities, lower product quality as a result of poor water quality and reduced tourism income owing to high risk of contamination and diseases (WHO, 2019). Additionally, women and girls suffer the risk of sexual assault because they need to find a secluded place away from their homes to relieve themselves, lost educational opportunities because there is no place for girls to manage their menstruation with dignity while children also suffer malnutrition through diarrhoea (WHO/UNICEF, 2004).

The 2015 World Bank report revealed that the lack of access to sanitation cost the global economy US$ 222.9 billion which is an increase from US$ 182.5 billion in 2010, thus an increase of over US$ 40 billion in just five years (Lixil/Oxford Economics/WaterAid, 2016).

Poor sanitation also impacts on the environment. Sewage and excreta left in the open due to open defecation end up in water bodies and wetlands affecting coastal and marine ecosystems, degrading the environment resulting in loss of valuable biodiversity and exposing the vulnerable, especially children to diseases. Poor sanitation provides conducive environment for breeding communicable disease vectors and contributes to air, water and land (soil) pollution (WHO, 2004).

Sanitation in Ghana

History of institutional transformations

Ghana occupies a land surface area of 238.533 square kilometres with a population of about 31 million, of which 49.1% and 50.9% are rural and urban dwellers (GSS, 2019). Sanitation in Ghana is no different from what prevails in other developing countries with several transformations taking place. It started with public water supply system in 1928, operated by the Hydraulic Division of the Public Works Department (PWD). Over a period of time, the PWD had the responsibility to include the planning and development of water supply systems in other parts of the country. In view of this, the Department of Rural Water Development was established in 1948, to see to the development and management of rural water supply through bore holes drilling and wells construction. In 1958, the Water Supply Division was separated from PWD and placed under the Ministry of Works and Housing (MWH) to be responsible for both rural and urban water supplies.

The Ghana Water and Sewerage Corporation (GWSC) was later established by an Act of Parliament (Act 310) in 1965, as a legal public utility entity, responsible for rural and urban water supplies and sanitation. In 1991, the Government's National Environmental Action Plan was setup to ensure the establishment and implementation of environmental health standards (Awuah et al., 2009). Later in 1994, a semi-autonomous unit, Community Water and Sanitation Division (CWSD) was formed and tasked with the management of rural water and sanitation delivery, therefore the GWSC was no longer responsible for the operation of rural and small town water supplies and sanitation.

The CWSD was then converted to Community Water and Sanitation Agency (CWSA) after four years of existence by an Act of Parliament, Act 564 in 1998, with the mandate to manage the provision of safe drinking water and related sanitation services to rural communities and small towns. Then, in 1999, GWSC was transformed into a state owned liability, Ghana Water Company Limited, responsible for urban water while urban sanitation was transferred to the Ministry of Local Government and Rural Development (MLGRD). Over the years, the Ghana government has been trying to organise and improve sanitation services, however, it seems this objective is yet to be achieved. This could be attributed to population growth and increasing population densities in urban and peri-urban areas (Mara et al., 2010). Furthermore, many people who lack basic sanitation are unwilling to pay for improvement in sanitation due to their low income status. They see it as high cost, hence will resort to other inappropriate means which lead to the government spending millions of Ghana cedis on poor sanitation and its related consequences.

Since the MLGRD is responsible for sanitation, there was the need for a policy to guide the activities and management of sanitation in Ghana. An Environmental Sanitation Policy (ESP) was therefore published in 1999 aimed at the development and maintenance of clean and safe physical and natural environment in all human settlements (formal or informal) in order to promote socio-cultural, economic and physical well-being of all sectors of the population. Environmental sanitation comprises a number of complementary activities, including the provision and maintenance of sanitary facilities, public education, community and individual action, regulation and legislation backed by mandated institutions, adequate funding and, research and development (MLGRD, 2010).

Status of sanitation in Ghana

Ghana, like other developing countries, is faced with constraints to meeting the challenge of providing adequate basic sanitation services to its citizenry. Although access to basic sanitation is a critical component of people’s health and well-being, individuals/communities and the government at large do not fully appreciate its importance. Little or no consideration is given to the long-term financial, environmental and institutional implications of sanitation systems/facilities or services (DWAF, 2002).

The Sustainable Development Goal (SDG) 6 on water and sanitation is aimed at ensuring availability and the sustainable management of water and sanitation for all. However, access to basic sanitation only has 21% coverage, with 17% and 25% being the coverage for rural and urban areas respectively (Fig. 3) (GSS, 2018) while that of access to basic drinking water is 82% (Monney and Antwi-Agyei, 2018). There is no doubt that much progress has been achieved in access to basic drinking water but the same cannot be said about basic sanitation. This is a worrying situation and poses a serious public health risk, knowing that about 80% of the Ghanaian population lack access to improved sanitation facilities/services (Mariwah et al, 2017).

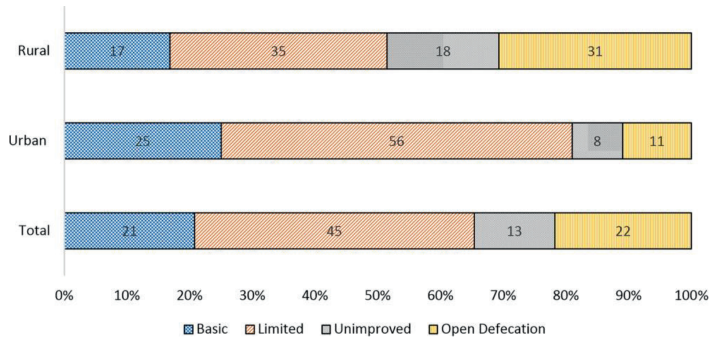

Fig. 3 Ghana's sanitation coverage level (adopted from Appiah-Effah et al, 2019).

In Ghana, many sanitation technologies exist, but there are basically two systems in use: on-site and off-site, that are used for the management of human excreta and the improvement of sanitation. Statistics of sanitation distribution by region are presented in Table 1 based on the Ghana Living Standards Survey Round 7 (GLSS7) (2019). According to GLSS7 (2019), majority of households use an on-site sanitation system. Many households use water closets (WC), Kumasi ventilated improved pits (KVIP) and pit latrines than the use of bucket/pan latrines. Also, those with no facilities resort to public toilet or open defecation. A comparison of the distribution of sanitation facilities between the regions shows some improvement, however, the disparities between the northern and southern parts appear to be large. Open defecation is significantly practised in Northern (57.5%), Upper East (77.2%) and Upper West (51.4%) regions. This practice has serious public health risks and could result in an epidemic of sanitation related diseases. Indeed, sanitation is linked to health and to socio-economic development, and affects many but is championed by few (Mara et al., 2010).

Since majority of the sanitation technologies are on-site systems, faecal sludge accumulates over time, therefore periodic desludging is required (Iwugo, 1981). This faecal sludge needs to be sent to a treatment plant, however, there is woefully inadequate or no treatment plant for this purpose.

Table 1: Sanitation Statistics by regions in Ghana

Region	Basic (Improved) (%)			Limited (%)	Unimproved (%)	Open defecation (%)
	WC	KVIP	Pit latrine	Public toilet	Bucket/pan	Open defecation
Western	17.1	16.4	29.2	28.0	0.1	9.2
Central	11.1	24.6	18.9	32.0	0.1	13.3
Greater Accra	36.0	15.6	9.7	34.6	0.1	4.0
Volta	7.6	11.7	28.9	25.1	0.1	26.6
Eastern	10.2	21.5	29.0	29.1	0.3	9.9
Ashanti	24.7	9.0	21.0	38.4	0.9	6.0
Brong Ahafo	10.4	12.0	18.0	44.1	0.3	15.2
Northern	2.6	5.4	6.4	27.7	0.4	57.5
Upper East	3.4	4.7	9.3	5.3	0.1	77.2
Upper West	4.9	8.7	22.1	11.8	1.1	51.4

Source: GLSS7, 2019

On the other hand, an off-site system separates excreta from the source and the sludge is drained through sewers to a treatment plant. Nonetheless, according to the National Environmental Sanitation Strategy and Action Plan (NESSAP) (2010-2015), Ghana's average sewerage coverage is as low as 4.5%, located in Tema municipality, some parts of Accra and Kumasi; thus other regions of the country have no sewerage/off-site systems and treatment plants.

It is clear therefore that a greater proportion of faecal sludge from on-site sources end up in the environment (bare land and/or water bodies) (see Fig. 4) without any form of treatment due to unavailability of faecal sludge treatment facilities. The act of dumping raw faecal sludge into the environment is a public health threat and negatively impacts the quality of the environment. With such poor sanitation practices, Ghana may miss SDGs 3 (good health and well-being) and 6 (sanitation) while achieving universal access to basic drinking water.

Fig. 4 Discharge of untreated faecal sludge into the environment (source: data from this study, 2019)

Economic impact of Ghana's poor sanitation

The poor sanitation results in Ghana government losing GH¢ 420 million (US$ 290 million) annually, or the equivalent of 1.6% of annual gross domestic product (GDP) due to sanitation related diseases (WSP, 2012). This reflects the adverse economic impact the country faces owing to poor sanitation and the attitude of indiscriminate dumping of faecal sludge into the environment. Poor sanitation is a social problem due to the large number of people that suffer the consequences. This problem could be mitigated if social behaviour is improved and investment is made towards sanitation improvement. Huge sums of money are lost by the government for lack of adequate investment in improved sanitation (WSP, 2012). The health impacts associated with poor sanitation include costs of medical treatment, loss of productivity due to sick individuals and others who care for them, and time spent to access services (Fig. 5) (WSP, 2012). This cost excludes environmental impacts and its effects on tourism and other business.

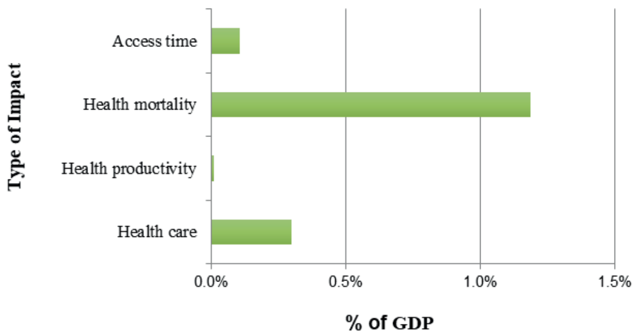

Fig. 5 Cost proportion of poor sanitation equivalent to GDP (WSP, 2012)

Biogas technology

Biogas technology forms part of biomass energy which includes wood, charcoal, agricultural residue, animal waste and municipal waste (including human excreta) (Mulinda et al, 2013).

Certain categories of biomass can provide or partially meet our energy needs when biogas technology is employed (Yadvika et al., 2004). Biogas is one of the end-products of anaerobic digestion which is obtained when organic substrate is anaerobically digested or decomposed. It is composed of combustible methane (60%-70%), carbon dioxide (30%-40%) and trace amounts of other gases (McKendry, 2002; Roopnarian and Adeleke, 2017).

Anaerobic digestion is the breakdown of biomass by a concerted action of a consortium of microorganisms in the absence of air (oxygen) and depends on certain factors such as pH, temperature, hydraulic retention time (HRT), carbon nitrogen ratio (C/N), loading rate etc. (Abdelgadir et al, 2014). Nowadays many biological treatment options exist that have shown positive treatment results by using biological processes essentially for the removal of contaminants in waste water. However, anaerobic digestion is a biological waste treatment practice, in which both energy recovery and pollution control can be achieved (Abdelgadir et al, 2014).

Among the sanitation technologies, anaerobic digestion (biogas digestion) has received considerable attention due to its ability to maintain environmental sanitation or quality, preservation of natural resources, generation of low amount of sludge that can be used as bio-fertiliser and low emissions (Abdelgadir et al., 2014; Aiyuk et al., 2006; Seghezzo et al., 1998).

In Africa, majority of households rely heavily on biomass (wood fuel) for the bulk of their energy requirements. However, the scarcity of wood fuel is on the rise due to population growth, deforestation, need for crop cultivation and high demand of wood for charcoal production. Biomass energy conversion could aid in mitigating the negative impacts of wood fuels and the high demand for fossil fuel importation, however, biomass energy resources are yet to be fully exploited due to limited biomass energy policy and lack of or low investment level (Mulinda et al, 2013). According to Bensah and Brew-Hammond (2010), the interest in biogas technology has been in existence over six decades, with majority of projects being at the pilot scale. Many biogas programmes have been slacking due to poor dissemination strategies, poor design and construction of plants/digesters, wrong user operation and lack of maintenance, poor ownership responsibility, lack of project monitoring and follow-ups by promoters and the failure by African governments to support biogas technology through a focused energy policy (Njoroge, 2002).

In Ghana, government attention and the active development of biogas technology started in the mid-1980s. However, before the mid-1980s, the focus of dissemination was on the provision of energy for cooking and electricity generation (Bensah and Brew-Hammond, 2010). Nonetheless, many plants/digesters failed shortly afterwards due to immature technology and poor dissemination approaches (Ahiataku-Togobo & Owusu-Obeng, 2016). In order to resuscitate the biogas technology, the Integrated Rural Energy and Environmental Project, a communal biogas demonstration project was established by the Ministry of Energy in 1986 at Appolonia (Arthur et al., 2011) and commissioned in 1992 (Bensah and Brew-Hammond, 2010). In spite of this effort, uptake has still been low. This could be attributed to non-existence of biogas policies, weak/inactive institutions governing dissemination and uptake of biogas technology, and lack of political will (Njoroge, 2002).

The future prospect of biogas technology is promising despite the relative stagnation in Ghana and Africa as a whole. Many countries like Ghana, Burundi, Kenya, Tanzania, Rwanda, Zimbabwe and South Africa have constructed biogas digesters as environmental pollution control systems in addition to using their energy for cooking and lighting (Bensah and Brew-Hammond, 2010; Ngoroge, 2002).

Several studies have shown that limitations to biogas technology dissemination in Ghana and other developing countries could be attributed to high initial investment costs, lack of financial support to small firms and individuals to set up effective business operation, lack of flexible community friendly credit schemes to help poor households own plants, lack of government commitment (in terms of policy) and limited private sector input because of low profit incentive, bad experience and poor image created by many failed biogas plants and lack of current research information on biogas technology from within and from countries where the technology has been successful (Ngoroge, 2002; Bensah and Brew-Hammond, 2010; Arthur et al;, 2011; Ahiataku-Togobo & Owusu-Obeng 2016).

Problem statement

A growing population and rapid urbanization have given rise to sanitation challenges and health risks due to poor sanitation systems in Ghana. Efforts to improve sanitation in the past years primarily focused on ambitious master plans which required huge investments in sewerage systems. There are woefully inadequate and unsustainable wastewater treatment plants in the rural, urban and peri-urban areas for the treatment of human excreta. Many households and institutions resort to diverse sanitation technology options, ranging from acceptable to unacceptable including water closet connected to a septic tank or sewer, pour flush, ventilated improved pit latrine, pit latrine, pan latrine and open defecation. These technologies accumulate faecal sludge over time and due to inadequate and/or lack of treatment plants in most of these areas, the faecal sludge ends up in the environment, posing a public health risks.

This worrying situation could be salvaged by biogas technology which will treat the faecal sludge and also sustainably improve environmental sanitation among many other friendly environmental outcomes. Though active development of biogas technology started in the mid-1980s in Ghana, its dissemination and uptake/adoption has been low.

Apart from the Appolonia biogas project which took place between 1986 and 1992, government involvement in promoting biogas technology collapsed since 1993 due to lack of support from donors (Bensah and Brew-Hammond, 2010). There are no policies and designated institutions governing the dissemination and uptake of biogas technology, and biodegradable waste, animal dung and human excreta which could be managed with biogas technology are dumped in the environment, posing risks to public health and causing environmental pollution with the economic consequence being loss of some GH₵ 420 million (US$ 290 million) annually (WSP, 2012). This amount could be used to harness biogas technology development and dissemination.

The goal of the present research is to study the feasibility and acceptability of biogas solutions in sanitation.

Research objectives

This research aims to study the feasibility and the acceptability of biogas solutions in sanitation in Ghana. The specific objectives formulated to achieve this aim are:

- To give an overview of biogas technology dissemination in Ghana described in chapter 2.
- To assess the performance of existing biogas plants/digesters in Ghana described in chapter 3.
- To propose an alternate model to the existing biogas plants/digesters described in chapter 4
- To assess the social perception of biogas technology: the use of human excreta for biogas production described in chapter 5
- To assess the willingness of household heads to adopt biogas technology described in chapter 6.
- To assess the institutional involvement in promoting biogas technology in Ghana described in chapter 7.

Outline of this dissertation

This dissertation gives an overview of the sanitation challenges and the barriers to promoting and adopting biogas technology in Ghana. The research has led to the development of interventions to improve these identified challenges and barriers.

In all six studies were conducted during the dissertation period. The studies and their outputs have been published independently, forming chapters 2 through to 7 of this dissertation. These chapters have been arranged to provide a linkage with the main aim and specific objectives of the study. The following paragraphs give a comprehensive account of each of the chapters of this dissertation.

Chapter 2 is a reference point to the study that gives an overview of biogas plants/digesters and assesses factors affecting the dissemination of biogas technology (BT) in Ghana. This study was conducted to identify the challenges and shortfalls associated with the dissemination and uptake of the technology. Data collection was by physical observation and personal interview to ascertain the successes and failures, and the state and functionality or otherwise of the plants/digesters. Furthermore, based on the study outcomes, some measures were recommended for implementation.

Chapter 3 evaluates the performance of existing biogas plants (Mfantsipim, University of Cape Coast (UCC) and Ankaful) with unique characteristics. Their uniqueness lie in the fact that Mfantsipim is a second cycle institution, UCC is a tertiary institution and Ankaful is a correctional centre. The evaluation was achieved by characterising the wastewater, assessing the quality of the treated effluent as well as the treatment efficiency of the biogas plants/digesters. Physical (pH, total suspended solids etc.), chemical (chemical oxygen demand, nitrates etc.) and biological (Escherichia coli, vibrio cholera etc.) analyses were conducted on the raw wastewater and the treated effluent. The study further assesses the performance of the plants by calculating the level of reduction in the concentration of loads in the treated effluent in relation to the influent (raw wastewater).

Chapter 4 proposes an alternative model to the existing biogas plants/digesters which seeks to address the challenges identified. This model concept was based on the outcomes and recommendations of chapters two and three which resulted in a re-design of a biogas plant for improved performance.

Chapters 5 and 6 each present a behavioural study on social perceptions and willingness to use BT. **Chapter 5** discusses the perceptions people have regarding the use of human excreta (HEx) for biogas generation based on the theory of planned behaviour (TPB). Data collection was by questionnaire designed with the TPB constructs and other demographic information (education and gender), and the analysis was done by structural equation modelling (SEM). Based on the findings, appropriate interventions were proposed.

Chapter 6 investigates the willingness and the dynamics of household heads' behavioural intentions to adopt BT using a behavioural based framework, TPB. Data was collected by questionnaire designed with the TPB constructs and other demographic information (education and ethnicity), and the analysis was done by structural equation modelling (SEM). Mapped out interventions were recommended based on the study outcomes.

Chapter 7 assesses the level of institutional involvement and collaboration in promoting BT. This involves the role government and non-governmental organisations play in promoting biogas technology in Ghana. It further discusses barriers to the promotion and proposes interventions. Data collection was by interview which was transcribed into written form for descriptive analysis. Interventions that would help improve the promotion of BT were proposed.

Chapter 8 provides a general discussion and summarises the findings of the studies conducted in this dissertation, the methodological strengths and limitations, implication of findings for policy formulation and recommendations for further research and practice.

2

Chapter 2

Biogas technology diffusion and shortfalls in the Central and Greater Accra regions of Ghana

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Biogas technology diffusion and shortfalls in the Central and Greater Accra regions of Ghana. Water Practice & Technology13 (4): 932-946. DOI: 10.2166/wpt.2018.100.

Abstract

The current status of biogas technology in Ghana, a developing, country was explored focusing on factors affecting diffusion and the associated challenges. Data collection was by personal interview and physical observations, and was conducted between July and October 2017. Non-probabilistic sampling procedures were used to select 61 respondents from 162 users, while 54 digesters were selected from 120 digester sites. The findings revealed that: initial installation and maintenance costs appear high; the needs of most biogas users had not been fully met, thus, they were only partially satisfied with the outcome of the technology; and 21% of the biogas service providers were engineers and 79% from other disciplines (plumbers, masons, carpenters, and graduates from arts, social sciences, business, etc.). These factors affect technology diffusion. In addition, bottlenecks for more intense use of biogas technology that need to be addressed include lack of government subsidies or financial support, poor or unstandardized digester design, lack of gas production, lack of follow-ups, lack of maintenance, lack of monitoring, and market value for bio-fertiliser (digestate). It is recommended that financial institutions support individuals and institutions with soft loans to acquire biogas digesters/plants, and that a regulatory body be formed for the activities of biogas service providers in developing countries.

Keywords: Biogas technology; diffusion; digester; Ghana; investment

Introduction

The United Nations in its report (2011) stated that there is a need to provide sustainable energy for all, especially in developing countries, to satisfy rapid energy demand growth due to the rapid population growth and to reduce the negative impacts of climate change. Renewable energy sources are central, inducing a paradigm shift towards green economies, poverty eradication/reduction and eventual global sustainable development. Authorities' attention on renewable energy sources is mostly focused on solar, wind, geothermal, ocean, and hydro power, and other biofuels (biodiesel, ethanol) with less emphasis on biogas. However, biogas technology has many benefits. It is a biological technique employing anaerobic digestion or processing as a means of treating organic or biodegradable matter (biodegradable solid waste, sewage, animal dung, faecal matter). It takes place in the absence of oxygen, to stabilise the organic matter with simultaneous biogas production. According to Mata-Alvarez *et al*. (2014), sewage sludge treatment is its oldest application. Dahiya and Joseph (2015) reported that biogas technology is generally used for waste management, and that all other options are either energy intensive, inconvenient or environmentally unsafe. Biogas technology is environmentally friendly, and has been adopted and is being used in many countries. While its use is growing steadily in some Asian and South American countries, the same cannot be said about Africa, specifically Ghana. In Nepal, China, India and Latin America, both household and institutional biogas technology have gained extensive acceptance (Bensah & Brew-Hamond 2010; Garfi e*t al.* 2016). Several studies have shown that the technology provides various benefits including a sustainable energy source, improved sanitation, a rich bio-fertiliser and reduced emissions (Surendra *et al.* 2014; Rupf *et al* 2015; Khann & Martin 2016; Ahiataku-Togobo & Owusu-Obeng 2016). However, Sasse (1988) emphasizes that biogas technology becomes usable only when there is a biogas digester or plant, hence, the design, construction and operation of a biogas digester play significant roles in its acceptance. Since the construction of a digester is essential for biogas technology, the investment cost cannot be ignored. Several researchers have indicated that the high initial cost of constructing digesters is a major challenge to its adoption in Africa, where many people are within or below the low income group level (Karekezi 2002; Bensah & Brew-Hamond 2010; Amigun & Blottnitz 2010; Smith 2011; Mulinda *et al* 2013; Rupf *et al.* 2015). The investment costs of biogas digesters in some countries are presented in Table 1, which is based on data retrieved from (Amigun & Blottnitz 2010), and (Bensah *et al.* 2011), as well as that collected for this study. Conceptually, biogas technology is deceivingly simple and straightforward, and the raw materials are abundant (Karekezi 2002). Many projects have been unsuccessful or faced challenges soon after diffusion, however. This can be attributed to the failure of African governments to support the technology through focused energy policies, poor diffusion/dissemination strategies, poor digester design and construction, incorrect operation and lack of maintenance by users, lack of project monitoring and follow-ups by promoters, and poor ownership responsibility by users (Njoroge 2002). A biogas digester can only meet client/user expectations if it is well designed. Many people with different backgrounds see biogas business as lucrative and anecdotal evidence suggests that most digesters are installed or maintained not by biogas technologists but by other professionals who are also service providers. These service providers (biogas technologists) may or may not be formally trained by a recognised institution/organisation to construct biogas digesters. It is therefore important to investigate the degree of satisfaction of biogas technology users, who have diverse motivations for adopting it.

This study explores the different biogas designs in use, the average initial investment cost for digester installation for both institutions and households, the professional backgrounds of biogas service providers, users' satisfaction, and, finally, the challenges facing digester designs.

Table 1: Fixed capital investment costs for biogas installations in selected African countries (1996-2017)

Location	Capacity/m^3	Year built	Original cost USD
Burkina Faso	6	2004*	1,209
Burundi	50	2002*	18,000
Ghana	20	1996*	750
Ghana	100	1999*	39,120
Ghana	20	2000*	7,974
Ghana	6	2004*	1,358
Ghana	300	2006***	191,792
Ghana	50	2009***	31,663
Ghana	6	2011**	2,189
Ghana	10	2011**	3,169
Ghana	2400	2012***	25M
Ghana	200	2014***	77,778
Ghana	6	2015***	851
Kenya	8	2004*	2,973
Rwanda	1000	2004*	220,000
Uganda	6	2004*	1,005

*Adapted from Amigun & Blottnitz (2010)
** Retrieved from Bensah & Brew-Hammond (2010)
***data from this study (2017)

History of dissemination of biogas technology in Ghana

Biogas technology has been disseminated in Ghana since the late 1960s, the main motivation being the provision of energy for cooking and electricity generation. Most "early" biogas plants failed shortly after project implementation (Bensah & Brew-Hamond 2010; Ahiataku-Togobo & Owusu-Obeng 2016) and this has been attributed to poor dissemination processes and immature technology (Bensah & Brew-Hamond 2010). In 1986, one of the first major communal biogas demonstration projects in Ghana was established by the Ministry of Energy (MoE), as the "Integrated Rural Energy and Environmental Project" (Arthur e*t al.* 2011) at Appolonia, Accra, in which 19 small household digesters were installed. The objective was to provide electricity for street and home lighting, fuel for cooking and bio-fertiliser for agriculture (Bensah & Brew-Hamond 2010; Bensah *et al* 2011; Arthur e*t al.* 2011), especially for cattle owning households. Three (3) digesters were dysfunctional and sixteen (16) destroyed for fear of explosion. Around the same time, a 10 m^3 digester was constructed at the Bank of Ghana cattle ranch in Shai Hills, Accra (Arthur, Baidoo, & Antwi, 2011; Bensah, Mensah, & Antwi, 2011). A study accompanied the implementation. The dissemination continued with the construction of two demonstration household digesters in Jisonayilli and Kurugu, in the Northern Region in 1987, with sponsorship from the United Nations Children Fund (UNICEF) (KITE 2008; Arthur *et al.* 2011).

From the 1980s to 1999, the most important organisations involved in biogas technology dissemination were MoE, the Institute of Industrial Research (IIR), the Catholic Secretariat and the German Agency for Technical Cooperation (GTZ) (Bensah & Brew-Hamond 2010). From 2000 to date, several individuals and biogas companies, either registered or unregistered, have been promoting the technology.

Review of types of biogas digesters

Three main types of biogas digesters can be distinguished: balloon, fixed dome and floating drum, respectively (Sasse 1988). Modifications to meet contemporary needs have resulted in other types. In Ghana, the three main types designed, tested and disseminated are the fixed dome, floating drum and Puxin digesters (Arthur *et al.* 2011). The fixed-dome is basically an underground chamber built in brick with a fixed, non-movable dome on top for gas storage (Fig. 1). They are mostly built because they are considered relatively cheap.

The floating-drum type comprises an underground digester and a movable gas holder, comprising a mild steel drum on top of the digester, as shown in Fig. 2. In other words, it has separate structures for gas production and collection. The gas holding drum floats either directly on the fermentation slurry or in a water jacket of its own (Sasse 1988). According to Bensah *et al.* (2011) floating drum digesters are ideal for digesting fibrous wastes – e.g. from slaughter houses especially the stomach content of cow or goat (inedible offal, lairage washings, sludge, blood etc.), because the gasholder can be removed to remove scum that has formed at any time. The advent of the fixed-dome digester, however, has rendered the floating-drum obsolete due to its high investment and maintenance costs (Mulinda *et al.* 2013).

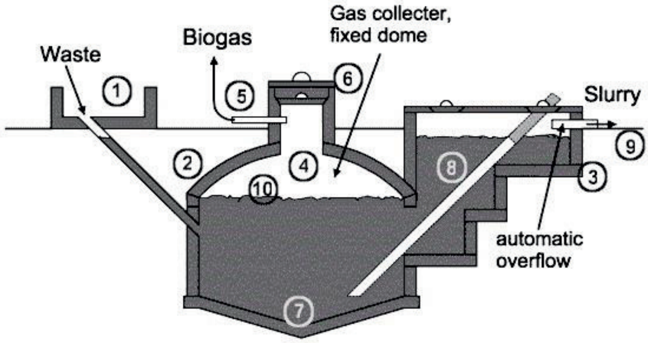

Fig. 1 Fixed dome digester 1. Mixing tank with inlet pipe. 2. Digester. 3. Compensation tank. 4. Gasholder 5. Gas pipe. 6. Entry hatch. 7. Accumulation of thick sludge. 8. Outlet pipe 9. Reference level. 10. Supernatant scum. (adapted from Kossmann et al, (1999)).

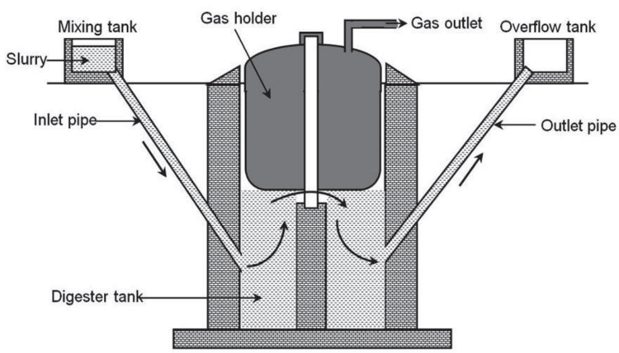

Fig. 2 Floating drum digester (adapted from Arthur et al. (2011)).

The Puxin digester is made of concrete with a carbon fibre gasholder (Bensah et *al.* 2011) (Fig. 3). It is constructed by assembling steel shuttering for casting all of its components in concrete, apart from the gasholder.

Other biogas systems in use apart from the three types commonly disseminated and noted above are the upflow anaerobic sludge blanket (UASB) and anaerobic baffled reactor (ABR). The UASB is an advanced system for treating industrial and municipal wastewater. A new version, known as the Lavender Hill faecal treatment plant (LHFTP) and a rehabilitated Mudor wastewater plant (MWWP) also UASB, were commissioned in November 2016, in Korle Gonno, Accra. The maximum capacity of LHFTP is 2,400 m^3/d (design capacity 2,000 m^3/d), which is equivalent to serving 2.4 million people, whereas MWWP has a maximum capacity of 21,000 m^3/d (design capacity 18,000 m^3/d), enough for a population equivalent of 105,000.

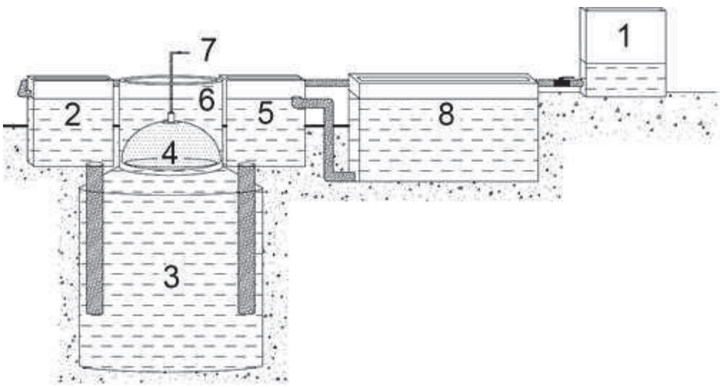

Fig. 3 Puxin digester 1. Mixer or Equaliser. 2. Inlet register. 3. Stomach or Reactor. 4. Biogas reservoir. 5. Outlet register. 6. Neck. 7. Biogas outlet. 8. Biodigestate reception cell (adapted from Laines-Canepa *et al.* (2017))

The MWWP receives faecal waste from some areas in and around Accra, and the biogas is expected to generate between about 400 and 500 kW of electricity for the national supply. LHFTP receives faecal waste from both private and public toilets in Accra, and some parts of regions close to Accra. The ABR looks like a traditional septic tank system (Fig. 4), and is being promoted by IIR for use by households, institutions and communities. According to the promoters, the aim of the design is to increase the acceptability of the technology since it looks exactly like the septic tanks already in use. However, unlike the septic tank the ABR produces gas as well as treating the wastewater. Table 2 gives the pros and cons of some of the types of digesters being disseminated.

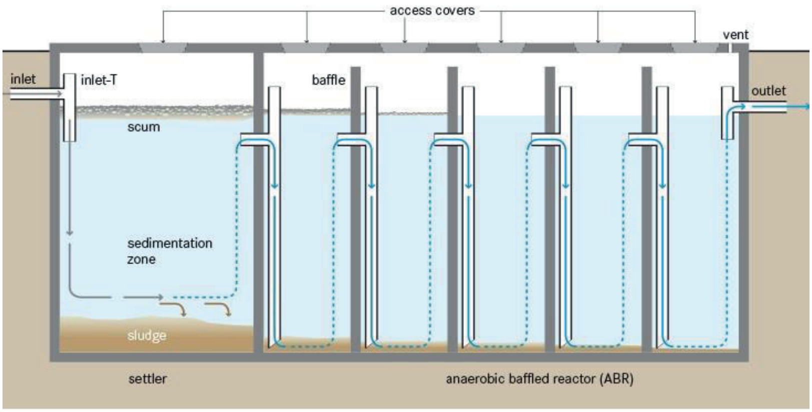

Fig. 4 ABR (adapted from Tilley *et al.* (2014))

Table 2: Types of digester

Type	Pros	Cons
Fixed-dome	Relatively low initial costs; Long useful life-span; No moving parts involved; Simple design.	Air tight is highly required; Gas leaks occur quite frequently; Inconsistent gas pressure makes gas use complicated; Amount of gas produced is not immediately noticed; Experienced biogas technician required.
Floating drum	Easy to understand and operate; Gas is provided at constant pressure; Volume of gas stored is easily notice by the position of the drum;	Relatively expensive steel drum; It is maintenance intensive; Rust removal and painting has to be done regularly.
Puxin	Easy and quick to build; Durable and easy to maintain; Rate of gas production is high.	Digested slurry consists of about 90% water
ABR	Low operating cost; Resistant to organic and hydraulic shock load; High BOD reduction; Low sludge production; Moderate area needed.	Expert required for the design and construction; Low pathogen and nutrients reduction; Effluent and sludge needs further treatment and/or proper discharge.

Source: (Tilley *et al* 2014; Kumar *et al.* 2015)

Research methodology

The Central and Greater Accra regions have 17 and 10 Metropolitan, Municipal and District Assemblies (MMDAs) respectively. According to the 2010 population and housing census, the Central and Greater Accra regions have estimated populations of 2,201,863 and 4,010,054 (GSS 2012), respectively. There were no records of biogas digesters in these regions but consultations showed that 2 and 3 MMDAs in the regions have relatively high numbers of digesters (n = 120), so an inventory of digesters was taken. On the basis of this, Cape Coast Metropolitan Assembly (CCMA), Komenda Edina Eguafo Abrem Municipal Assembly (KEEA), Accra Metropolitan Assembly (AMA), Tema Metropolitan Assembly (TMA) and Ashaiman Municipal Assembly (ASHMA) were selected for sampling for the study. An inventory of all individuals and companies engaged in the biogas business in Central and Greater Accra regions was also taken as well as all households and institutions owning biogas plants (n = 162). According to Godden (2004), Equation (1) can be used to determine the appropriate sample size if the population is less than 50,000, and its dealing with descriptive statistics (Berhe et al. 2017):

Sample size = $Z^2 * P (1-P)/C^2$…………………………………………………..(1)

where Z = confidence level
P = total number of digesters/respondents
C = confidence interval.

Assuming a 95% confidence level and 10% confidence interval, the sample sizes for biogas digesters are 54 and 61 for respondents - see Tables 3 and 4.

Table 3: Sample size distribution in selected study areas

Name of MMDA	Number of digesters	Percentage of total	Final sample size
AMA	55	46	25
TMA	25	20	10
ASHMA	9	8	4
CCMA	30	24	14
KEEA	1	2	1
Total	120	100	54

Table 4: Respondent status and sample size distribution

Respondent category	Total number	Percentage of total	Final sample size
Biogas technologists	37	23	21
Biogas consultants	5	3	3
Household heads	101	62	28
Institutional administrators	19	12	9
Total	162	100	61

Non-probabilistic sampling techniques were used in the study, and survey and field visits to biogas digesters/plants were conducted between July and October 2017. The observations made during site visits and interviews, were recorded and transcribed into written form for descriptive analysis. The biogas service providers and biogas consultants were selected to participate in the study based on their expertise, practical experience, and number of years (not less than five) in the industry. For households and institutions, household heads and institutional administrators were selected, using snowball and convenience sampling techniques. One-on-one face-to-face interviews were conducted with all biogas consultants, household heads, institutional administrators and 8 biogas service providers, while telephone interviews were granted by 13 other biogas service providers due to their locations and availability.

Results and discussion

State of Existing Biogas Plants

Of the 54 biogas digesters/plants surveyed, 34 (63%) were household digesters, 17 (31%) institutional plants, and 3 (6%) community-based. Of the plants, 15 (28%) and 39 (72%) respectively are in Central and Greater Accra regions. This distribution gives the impression that dissemination of the technology is higher in Greater Accra than in Central region, which is also a reflection of the number of service providers' advertisements (signposts and radios) in the respective regions. Accra, being the capital of Ghana is considered a booming city for businesses, leading to inattention for the other regions.

Household biogas digesters

During the field visits, 23 household biogas digesters were surveyed in Greater Accra while 11 were identified in Central region. All but 3 of the household plants were in good state and functioning, with respect to treating faecal matter; the other 3 were all in Appolonia and were abandoned. These digesters had been abandoned mainly due to lack of feed (cow dung) and maintenance. Distance to their cattle ranch was further away from the households and there was no motivation to continually travel that far. To solve this problem, their ventilated pit latrine (VIP) could have been constructed nearby to feed the digester instead of the cow dung. The major challenges observed with the household digesters include poor digester design (not having access to influent to the digester), absence of access to digester effluent because they are connected to soakaway, lack of a desulphuriser to clean the gas due to ignorance of its importance by both the service providers and users, failure of gas production even though gas was generated initially, absence of biogas stove (thus LPG stoves were being used), and lack of maintenance. Equally, the majority of gas pipe lines were not connected to the kitchens. Digester owners occasionally open the gas valve to test whether biogas has been produced. Respondents stated that the lack of gas production makes the technology unattractive to potential users. Fig. 5 shows household biogas digesters in the Central and Greater Accra regions.

Institutional and community biogas plants

During the study it was observed that no institutional plant had been abandoned; most were receiving biodegradable wastewater, although not producing biogas. The majority had broken down gas storage facilities due to lack of maintenance, so any gas generated was flared occasionally. Those plants that were not producing gas, due to either poor digester design or poor operational conditions (Dhoble & Pullammanappallil, 2014), were only functioning as wastewater treatment plant (treating human excreta). On the other hand, the majority of such plants had clean environments, while others were in bad condition and unattended, posing a roughly 30% health risk (low health risk). Unsanitary environment could have direct or indirect effect on the health of a population. According to Spickett et al. (2010), the possibility of something occurring that has a potential of affecting a health outcome is considered a health risk.

Fig. 5 (a) Remains of a fixed-dome digester at Appolonia, Accra, October 2017;
(b) fixed-dome digester not connected to a kitchen at Cape Coast, Central region, October 2017

Health risk could be expressed on a scale; extreme, high, medium, low or very low. The majority of institutions stated that they had not achieved their objective in building the biogas plant and were disappointed. This has been as a result of the plant not producing biogas as expected or as they were made to believe by the service providers.

Community-based biogas plant

During the survey, 3 community-based biogas plants were visited, the oldest being the Appolonia plant in Greater Accra, constructed in 1986, which was being rehabilitated. The KEEA municipal plant, constructed in 2014 and handed over in 2015, and sponsored by the Ghana-Netherlands WASH project, had been abandoned due to plant failure. It was built to solve the problem of disposal of human excreta on bare ground at the dump site, to generate gas for sale and to produce bio-fertiliser for farmers. None of these objectives materialised. Fig. 6 shows the state of the KEEA plant and how raw sludge is disposed of at the site.

The only community-based plant that was fully operational and functional was the Safisana waste to power and organic fertiliser plant commissioned in March 2017 in Ashaiman, Greater Accra.

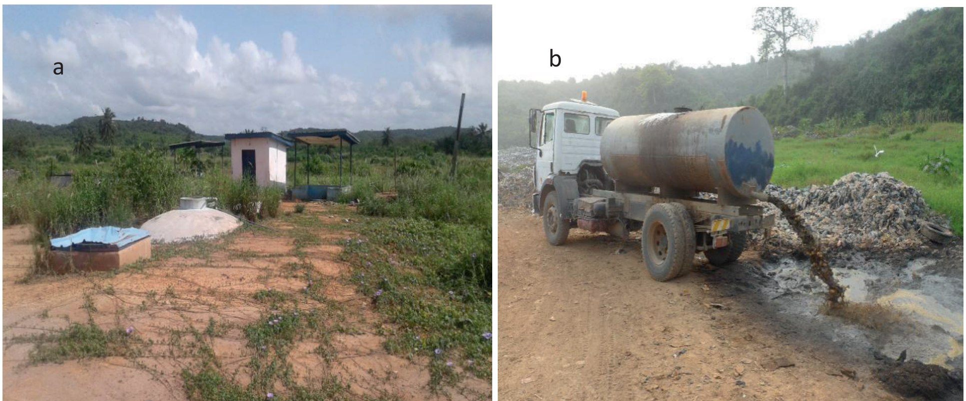

Fig. 6 (a) Abandoned 200 m^3/d biogas plant at KEEA, Central region, October 2017.
(a) Cesspit emptier disposing raw sludge on the ground at a dump site in Nkanfoa, Central region, October 2017

The Safisana plant at Ashaiman is a complete multi-purpose system, treating both liquid and some form of municipal solid waste (MSW) from some areas in and around the municipality. It generates biogas for electricity and also organic fertiliser for agriculture using a cast concrete fixed-dome with reinforced PVC. Its capacity is 2,800 m^3 and it can generate about 2.2 MW of electricity for the national grid. The biogas is converted to electricity by a combined heat and power (CHP) plant on the site. The feedstock sources include waste from Ashaiman and Tema markets, Accra and Madina abattoirs, Ashaiman public toilets, and Unilever (spent effluent) and Olam biscuit factories. Waste collection from the markets has improved their sanitation and consequently, public health. Waste collections from Unilever and Olam with transfer to the Safisana plant are beneficial, too, saving time and fuel because the landfill at Kpone is considerably further. Fig. 7 shows the Safisana plant. This plant works efficiently because, there is an assigned operator who do regular plant checks, there is consistent maintenance, regular feeding of the plant, drying beds for the digestate where it is co-composed with market waste (fruits and vegetables) for bio-fertiliser, and waste stabilisation pond with baffles for the treatment of liquid waste from the drying beds. It operates at 37^{o}C (mesophilic temperature).

Fig. 7 (a) The Safisana fixed-dome biogas plant, Ashaiman, Accra, September 2017, (b) The CHP at the Safisana Ashaiman site, September 2017; (c) Waste stabilisation pond with baffles at the Ashaiman site for treatment of liquid waste from the drying beds, September 2017

Biogas technology user satisfaction

The survey results show that the motivation for adopting the technology included generating biogas; science laboratory fuel for experimental sessions; fuel for cooking; generating electricity to light common areas during power outages, improving sanitation, providing bio-fertiliser for farmers, and creating job opportunities. During the survey, biogas users were asked whether their needs and expectations were met but it became clear from the answers that that was not the case. In fact, for 11 respondents (29%) the outcome was complete disappointment.

Most users blamed the service providers' inability to build an efficient system to meet their needs. The majority, who were partially satisfied (n = 19, 50%), were of the view that even though their needs (generating biogas) were not fully met, sanitation had improved and there were also no desludging charges, which has been a problem. Those who were dissatisfied noted that failure to achieve the objective of building the digester meant that the technology was a complete failure. A few users (n = 7, 21%) were satisfied because their needs and expectations had been met. The failure of most biogas digesters/plants; little or no gas; leakages; broken down of some units of the digester/plant (gas storage, pipes, and gas meter) after working for about one year or less or not at all. In most cases, when these occur, the plants remain in that state for years before they are fixed or the plants are abandoned. These seem to reduce or remove the interest of potential users in the technology. Most potential users do not see the successes of users of the technology in spite of the high investment cost and some reasons that demotivate them include; failure of digester to produce continuous gas after a short while of operating, space for siting of plant, attitude of service providers in fixing plant problems, and unsanitary plant surrounding and discharge points due to leakages. Nonetheless, some biogas service providers accuse other providers of collapsing the biogas business because of lack of qualification. They feel that those without qualification build digesters/plants that are unsustainable, affecting negatively those with qualification (sustainable digesters/plants) in securing contracts.

Costing biogas digesters/plants

Although biogas technology could be a partial solution to Ghana's energy and sanitation needs, digester design and construction has high initial cost. This is one of the major hindrances to the technology's adoption in Ghana. In Nepal, on the other hand a vital element for biogas promotion is subsidy, which reduces investment costs so that potential adopters see it as attractive (Bajgain & Shakya 2005). There is no subsidy policy in Ghana and for instance, the investment for a household digester appears to be between USD 889 and 1333 for 6 $m^3$and for 100 m^3 institutional digesters USD 15,556 to 20,000 by different service providers— the initial costs depending on the site characteristics. The survey also shows that, with the exception of Safisana, which has a routine maintenance plan (monthly and yearly), the other digesters/plants (household, institutional, community-based) have no routine maintenance plan. Maintenance is carried out when needed only – i.e., when the plant breaks down. However, the inlet may need maintenance monthly depending on the feedstock use, gas pipes is monthly to check for water trap, gas pressure meter should be checked annually, gas storage once each month (SNV/BSU 2016). The frequency of maintenance of a digester/plant may depend on its capacity or volume. For example, the maintenance of a 100 m^3 digester is completely different from a 2,800 m^3 digester. The general maintenance cost is between USD 67 and 111 for households, and USD 222 and 333 for institutional/community-based plant, depending on the service provider contracted. The combined investment and maintenance costs seem to deter potential users from adopting the technology.

Background of biogas service providers in Ghana

As part of the survey, the professional background of biogas service providers was investigated. The results indicated that 5 (21%) of biogas service providers are engineers. Of the other disciplines, 14 (58%) are artisans (plumbers, masons, carpenters) and 5 (21%) are graduates in arts, social sciences, business and other studies. In other words, the majority of biogas service providers in Ghana are trained artisans, which is confirmed by Smith (2011), that biogas technology creates jobs for local people (including artisans who can be trained to construct digesters) and improves livelihoods. Bensah *et al.* (2011) reported that the first period of biogas technology development in Ghana involved the training of local engineers and technicians in the design, construction and management of biogas plants, in a government sponsored project. An important constraint to the diffusion of the technology in Africa is inadequate expertise concerning the construction and maintenance of biogas plants (Surenda *et al.* 2014). In Ghana, artisans seem to have taken over the technology and this may be one reason why many biogas plants have failed to perform as expected.

Challenges with the different digester designs

Tables 5 and 6 are lists of some household and institutional/community-based biogas digesters/plants. The survey sought to identify the challenges common to the various designs and the results show that, for the household digesters, majority had challenges with gas production at a point in time.

As shown in Table 5, all household digesters surveyed are the fixed-dome type. Though a few were still producing gas, most of them did not after being operated for some period. This might be attributed to poor digester design, user attitude and inadequate knowledge of the technology, and/or lack of maintenance. Most users think that once a digester is installed, it should produce continuous gas irrespective of what goes into it, and no need for additional cost for maintenance. Almost all the household digesters visited had been connected to toilet facility (water closet (WC)), so it is fed any time the facility is used. In some cases due to water shortage at certain periods, users flush their excreta with grey water (mostly wastewater generated after laundry), which could inhibit the performance of microbes involved in the anaerobic processes. If a digester is not completely air tight, a key requirement for fixed-dome type, and the feedstock contains substances toxic to the microorganisms, producing biogas will be a challenge. The examples of selected household digesters presented in Table 5, shows that though the digesters are relatively new, there are challenges with gas production, except few which are in full operation.

Table 5: Examples of household biogas digesters

Location	Design type	Volume/ m^3	Year installed	Status	Water usage	Feedstock	Challenge
WO1 Bansah, Pokuase, Accra	Fixed-dome	6	2015	Operational	Regular	Human excreta	No gas, hence not connected to the kitchen
Mr Alhassan Appolonia, Accra	Fixed-dome	10	1986	Non functional	No	Cow dung	Abandoned due to lack of maintenance and feedstock
Mr Opuni Kasoa, Central	Fixed-dome	10	2017	Under construction	Not yet	Human excreta	Not yet
Nana Addo, Accra	Fixed-dome	6	2013	Functional	Regular	Human excreta	Gas flows
Mr Rockson Cape Coast	Fixed-dome	6	2017	Operational	Regular	Human excreta	Small amount of gas production, not connected to the kitchen
Former president House of Chiefs Cape Coast	Fixed-dome	10	2015	Functional	Regular	Human excreta	Gas flows

For the institutional/community-based biogas plants (see Table 6), most are fixed-dome type and are directly connected to toilet facilities (WC), but some of them were not completely air tight, so could not produce gas. Effluent joins nearby water bodies, yet due to poor design, certain discharge points flood and produces foul smell. Additionally, broken down gas storage and gas pipelines were common to some plants. For the Puxin type, it is as well connected to flush toilet facilities. Though gas is produced, it is not being used because of broken down gas storage (balloon). Effluent which was to be re-used for flushing toilet has failed because of broken down pump to lift the treated water into an overhead tank for gravity flow. The floating drum worked well initially with well-functioning balloon storage. It, however failed due to balloon leakage, rusted drum, and digester leakage that flooded the immediate environs. Finally, the ABR, being relatively new in the system did produce some gas but no storage.

Table 6: Examples of institutional/community biogas plants

Location	Design type	Status	Water usage	Challenge
Superannuation Hostel, UCC Central	Fixed-dome	Operational	Regular	No gas production, flooding and stench at effluent discharge point
Ankaful Maximum Prison, Central	Fixed-dome	Operational	Regular	Gas production, but broken down gas pipelines
KEEA Biomethanation plant, Central	Fixed-dome	Non functional	No, raw sludge from public toilets and households	No gas production, plant abandoned
Mfantsipim SHS, Central	Puxin	Operational	Regular	Gas production, non-functional gas meter and broken down balloon
Central University College, Accra	Fixed-dome	Operational	Regular	Broken down balloon, no gas
Accra Academy SHS, Accra	Fixed-dome	Operational	Regular	Balloon removed due to lack of gas
GIMPA, Accra	Floating drum	Operational	Regular	Plant leakage, broken down balloon, no gas
IIR, Accra	Anaerobic Baffled Reactor (ABR)	Operational	Regular	Gas production but no storage or connection, valve closed
Valley View University, Accra	Fixed-dome	Operational	Regular	Gas production but not enough for use
Atadeka, Accra	ABR	Operational	Regular	Gas production but no storage or connection for use

The challenges can be fixed, however, due to lack of follow-ups and regular maintenance by service providers, almost all institutional plants have become wastewater treatment plants. The function of the plant has shifted, in other words, from providing energy to sanitation purposes only. Majority of users get disappointed, especially, when there is little or no gas production based on service providers promise that users would have gas for use between 21 days and 1 year.

The shortfalls

The dissemination of biogas technology that will support sustainable development remains a challenge in developing countries. Based on this study some of the major shortfalls to the development and diffusion of biogas technology are:

Lack of subsidy: some individuals who know about the technology through friends, family or the media find the initial investment cost to be extremely high. Government could intervene by giving subsidies to such people who are willing to adopt, but cannot afford to acquire it. This avenue will certainly facilitate the diffusion rate.

Financial barrier: large-scale plants (institutional/community-based) require high capital investment. Since the government does not have enough financial resources to invest in such projects, other financial institutions should support. However, such institutions are not readily motivated to do so because of some reservations about the technology; the risk of failure and/or no trust in the success of the technology.

Lack of institutional collaboration: MoE and IIR, have been the main government institutions involved in the dissemination of biogas technology. There are, however, other institutions (ministries of Sanitation and Water Resources, Food and Agriculture, Environment, Science, Technology and Innovation, and Information) that could collaborate with these two institutions to effectively promote the technology to increase the rate of adoption.

Lack of regulatory body: There are several biogas service providers in Ghana, both individuals and group/company. They carry out their activities with little or no monitoring because some are registered and other are not. Apart from this, there is/are no standardised digester design for use by these service providers so they are not under any obligation to install a specific design. There is no regulatory body exclusively in-charge of biogas service providers for strict monitoring (adhering to standardised design). MoE, being in charge of renewable energy is yet to establish that.

Negative social perception: Biogas technology uses all kinds of biodegradable feedstock for gas production. The feedstock ranges from human excreta, animal dung and food waste etc. Some categories of people have a negative perception on the quality of the gas produced. They see the gas as contaminated, especially, if human excreta are the main feedstock. This kind of negative perception inhibits the dissemination of the technology.

Market value for bio-fertiliser: The digestate is thoroughly dried on drying beds to stabilise, free of pathogen, and is either used directly or co-composed with organic solid waste (fruits, vegetables, etc.) and used as bio-fertiliser or organic fertiliser. Although bio-fertiliser is a good soil conditioner rich in plant nutrients, that improves soil structure and increase harvest, most farmer prefer to use inorganic fertiliser which has diverse consequences on the environment. Farmers can save money meant for inorganic fertiliser and by that imports are reduced, however, patronage for bio-fertiliser is low.

Conclusions and way forward

Biogas technology is a sustainable and environmentally friendly technology. It should be intensively promoted to help solve energy and sanitation challenges, especially in developing countries where wood fuel and charcoal, and the management of waste (both liquid and solid), are major challenges. The problems relating to the adoption of biogas technology in Ghana are linked to issues such as the high initial investment cost that makes it impossible for potential users to adopt, satisfaction, digester design by unsuitably qualified biogas service providers, failures of follow-up and maintenance services, and monitoring. Also people have subjective perceptions about the technology that inhibit its diffusion.

The study outcomes lead to a number of recommendations:

- a subsidy policy by the government to individuals who cannot afford the full investment cost;
- financial institutions to support individuals and institutions with soft loans to aid the construction of biogas digesters/plants;
- the Ministry of Energy to institute a standardised design for service providers to ensure sustainability of the technology at both household and institutional levels;
- a regulatory body to be formed covering all biogas service providers to monitor their activities and document digesters constructed; and
- the ministries of Energy, Sanitation and Water Resources, Environment, Science, Technology and Innovation, Food and Agriculture, and Information collaborate to promote and disseminate biogas technology and encourage farmers patronise bio-fertiliser.

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Chapter 3

Characterisation of Wastewater and Treatment Efficiency of Biogas Plants: Effluent Discharge Quality

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Abstract

This study aims to characterise wastewater, assess effluent quality and treatment efficiency of 3 existing biogas plants in 3 distinct institutions in Ghana and to provide relevant data necessary to policy makers to inform decision and influence policy. Laboratory analyses were conducted on wastewater samples from the University of Cape Coast (UCC), Mfantsipim Senior High School (Mfantsipim) and Ankaful Maximum Security Prisons (Ankaful), between January and April 2018.

In all, 192 wastewater samples were collected from UCC, Mfantsipim and Ankaful for analyses. Physical, chemical and biological parameters were analysed on raw wastewater and on the effluent. Quality parameters were determined using the protocol outlined in the Standard Methods.

The results showed significant differences between effluent quality from UCC, Mfantsipim and Ankaful with most of the quality parameters falling within the Ghana Environmental Protection Agency (EPA) guidelines. However, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), dissolved oxygen (DO), biological oxygen demand (BOD_5), chemical oxygen demand (COD), ammonia-nitrogen (NH_3-N), total coliforms (T. coli), Escherichia coli (E. coli) and salmonella spp. (salmonella) exceeded the guideline values. The ratio between BOD_5/COD was .5 and .3 for UCC and Ankaful respectively, indicating high biodegradability while Mfantsipim recorded .06, indicating low biodegradability. The parameters which had high treatment efficiency for the biogas plants was UCC (TSS 72.22%, total volatile solids (TVS) 78.41%, BOD_5 64.22%, COD 63.56%, PO_4 61.29%, T. coli 1.9 log reduction, E. coli less than 1 log reduction, salmonella 1.5 log reduction and vibrio cholerae (V. cholera) 1 log reduction) followed by Mfantsipim (BOD_5 70.45%, COD 83.84%, NO_3 79.17%, T. coli 1.6 log reduction, E. coli 5 log reduction, Salmonella *spp.* 1.8 log reduction and V. cholerae complete removal), while Ankaful was (TDS 57.7%, TSS 68.17%, TVS 56.33%, BOD_5 82.4%, COD 81.13%, T. coli less than 1 log reduction, E. coli less than 1 log reduction, Salmonella less than 1 log reduction and V. cholerae .96 log reduction). The rest of the parameters exhibited negative and/or low values. The performance analysis of the three biogas plants showed that UCC performs a little better than Ankaful and far better than Mfantsipim in term of treatment efficiency.

The performance analysis indicated that the biogas plants were under-performing which could be attributed to poor maintenance, design deficiencies, poor environmental conditions and voluminous in-put loads. These factors impact the treatment efficiency resulting in relatively poor effluent quality which could put the health of the public at great risk.

It is therefore recommended that authorities and policy makers formulate appropriate regulations aimed at addressing the potential impact of poor effluent quality discharged into the environment.

Keywords: biogas plant; characterisation; treatment efficiency; effluent quality; UCC, Mfantsipim, Ankaful

INTRODUCTION

The Ghana Environmental Protection Agency Act, 1994 (Act 490) established the basis for effluent quality regulation to control and prevent discharge of waste into the environment and the protection and improvement of the quality of the environment, especially receiving waters (EPA Act 1994). Discharge requirements vary from one plant to the other, however, there is a general guidelines defined by the Ghana Environmental Protection Agency (EPA) on allowable average concentrations.

Waste generation is inevitable in everyday human activities. A greater part of waste generated is wastewater, knowing that most activities are water dependent (Lier et al., 2008) and discharging into the environment is a common phenomenon. Wastewater is water with physical, chemical or biological characteristics that have been altered due to the introduction of certain substances, which renders it unsafe for certain purposes such as drinking (Modi, 2011). Due to this, it requires a technology for treatment in order to prevent or reduce environmental pollution and potential health risk. With regards to the products in wastewater, some are generated directly by humans (faeces and urine), others are needed in functioning of the technology (flush water to move the excreta) and some are generated as a function of storage or treatment (sludge). This study adopts the definition of Tilley et al. (2014) who defines wastewater as a mixture of urine, faeces and flush water along with anal cleansing water and/or dry cleansing material. Wastewater is characterised as containing high pathogens due to the faeces and the nutrients of urine that are diluted in the flush water (Tilley et al., 2014), and other waste substances (Modi, 2011). Due to these characteristics, treatment of wastewater and continuous monitoring of effluent quality are very important to ensure sound environment, good public health and socio-economic soundness (Metcalf & Eddy, 2003). Nonetheless, according to Gross (2004), it is worth noting that the source of wastewater influences its characteristics, thus wastewater characteristics depend on the activity of the generating establishment. The generating establishment for this study include a second cycle educational institution (Mfantsipim School), a tertiary educational institution (University of Cape Coast) and a judiciary correctional institution (Ankaful Maximum Prison). The characteristics of wastewater from these distinct institutions may not be the same due to their varied lifestyle. Additionally, this wastewater is being used in biogas plants; hence, it is worthwhile to know what remains as pollution after treatment so as to inform both institutional authorities and EPA on the measures needed to improve effluent quality and to reduce potential short term and long term health risks. Hubbe et al (2016) indicated in their study that a biological wastewater treatment facility targets easily biodegradable organic matter, because it may not treat non-biodegradable organic matter properly. Previous studies have shown that a number of available methods have been established for the estimation of biodegradability, however, the traditional or well-adopted method mostly employed is a ratio of Biological Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) (Choi et al., 2017; Zhang et al., 2020). According to Lai et al (2011), biodegradability is the portion of the organic matter in the wastewater that can be easily removed by microorganisms. Its determination is important to understanding their consequence and the effects they have on the environment (Tusseau-Vuillemin et al., 2003).

Biogas plants apply the principle of biotechnology and microbiology, and are now widely used for wastewater treatment due to high efficiency, low energy use, green energy generation, rich bio-fertilizer production, reduction in the prevalence of chronic diseases associated with the use of wood fuel and job creation (Abdelgadir et al., 2014; Paraira, 2009; Mwirigi et al., 2014). Thus, using biogas plant for wastewater treatment is not limited only to pollution control but also results in beneficial end products as well.

Several studies have evaluated the performance of treatment plants by comparing the removal efficiency of parameters such as Biological Oxygen Demand (BOD_5), Total Kedjhal Nitrogen (TKN), Total Suspended Solids (TSS), Total Phosphorus (TP), Total Coliform (TC), Faecal Coliform (FC) and Salmonella with design standards which usually assume steady-state conditions. Nonetheless, only few studies have compared the removal efficiency of wastewater quality parameters to standards set by the local regulatory body as well as evaluating the performance of treatment plants (Mara, 1996; Oliveira & Sperling, 2006; Owusu-Ansah et al., 2015).

In order to evaluate the treatment efficiency of biogas plants, it is important to know the characteristics of the influent and the quality of the effluent in relation to regulatory effluent guidelines. That would reveal the performance of plant and also give an indication as to whether further treatment would be required before discharge so as to control environmental pollution. This is vital because according to Barzallo-Bravo et al. (2019), effluent from biogas plants are generally not good enough. The aim of this research is to characterise wastewater and to assess effluent quality and the treatment efficiency of 3 existing biogas plants in 3 distinct institutions in Ghana and to provide the relevant data necessary to policy makers to inform decision and influence policy.

MATERIALS AND METHODS

Description of study area

This study was conducted in Cape Coast Metropolitan Assembly (CCMA) and Komenda Edina Eguafo Abirem (KEEA) municipality in the Central region of Ghana (Fig.1) from January to April 2018. CCMA is located on longitude 1^{o} 15'W and latitude 5^{o} 06'N covering an area approximately122 square kilometres while KEEA lies between longitude 1^{o} 20' W and latitude 5^{o} 050' N also covering an area of 452.5 square kilometres.

The major economic activities are fishing, trading and farming. Located within the study area are two historical sites, Cape Coast and Elmina Castles, which serve as major tourists' sites that generate enormous revenue for the Government of Ghana due to the important role they played in the trans-African Slave Trade. Within the study area are Mfantsipim Senior High School (Mfantsipim) and University of Cape Coast (UCC) (CCMA), and Ankaful Maximum Prisons (Ankaful) (KEEA) where the study took place. Potable water supply to the study areas is mainly by Ghana Water Company Limited (GWCL) while those without piping resort to alternative water sources such as hand dug wells, streams, rainwater and water vendors. There are no sewer systems in the entire study area, however, on-site sanitation systems such as septic tanks, ventilated improved pit latrines, biofils and biogas plants are used for excreta management whereas others depend on public toilet facilities or practice open defecation. The choice of the study sites was based on their unique characteristics, Mfantsipim being a second cycle institution, UCC being a tertiary institution and Ankaful being a correctional centre and one of the biggest and well-resourced maximum prisons in West Africa. Most importantly, these three institutions use biogas plants for their wastewater management and these are the main functional biogas plants in the area.

Sources of wastewater samples

Wastewater samples were collected from three biogas plants; UCC, Mfantsipim and Ankaful. UCC biogas plant, a $100m^3$ fixed dome plant, is located on the northern campus of the university. It treats the waste of about 1400 people and the effluent is discharged into the environment. There is a connection to a biogas generator for subsequent electricity generation. The Mfantsipim biogas plant, a 50 m^3 Puxin type, is located near the classrooms and offices. It treats the waste of 2000 students. The plant has a separate biogas storage balloon to serve the Science laboratory while the effluent is re-circulated for the flushing of toilet.

The Ankaful plant, also a fixed dome type, is situated outside of the Prison yard. It has a 200 m^3 capacity which is designed to serve 4000 people. The plant has various units including a clarifier, an ultraviolet disinfection tank and drying beds. The effluent is stored for irrigation while the gas is stored for use in the kitchen.

Samples of influent and effluent were drawn from the inlet and outlet of the biogas plants for a 6 hour period to make a time composite sample. Some physical parameters were measured on-site while other quality parameters were determined using the protocol outlined in the Standard Methods (APHA, 2005).

Sampling and analysis

Wastewater samples (n = 192), 96 influent and 96 effluent, were collected and stored in sterilized 1.5L sample bottles for analysis. These samples were stored in laboratory ice-chest with ice packs and transported to the laboratory for analysis. The following physical parameters; pH, temperature, Dissolved Oxygen (DO), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured on-site using a HORIBA U-50 multipurpose water quality meter. Furthermore, the concentrations of Total Suspended Solids (TSS), Phosphates (PO_4), Total Phosphates (TPO_4), Nitrates (NO_3) and Ammonia Nitrogen (NH_3-N) were determined using a HACH DR6000 spectrophotometer. The concentration of Chemical Oxygen Demand (COD) was measured using the closed tube colorimetric method. The five-day Biological Oxygen Demand (BOD_5) concentration was determined using the Lovibond BD 606 BOD system. The concentration of Total Kjedahl Nitrogen was determined using the Macro-Kjedahl method as stated in (APHA) 4500 B. Total Volatile Solids (TVS) were determined using method as stated in (APHA) 2540 G. The bacteriological parameters (Total coliforms, E.coli, Salmonella *spp.* and Vibrio *cholera* were determined with chromocult agar using the spread plate method as stated in (APHA) 9215 C.

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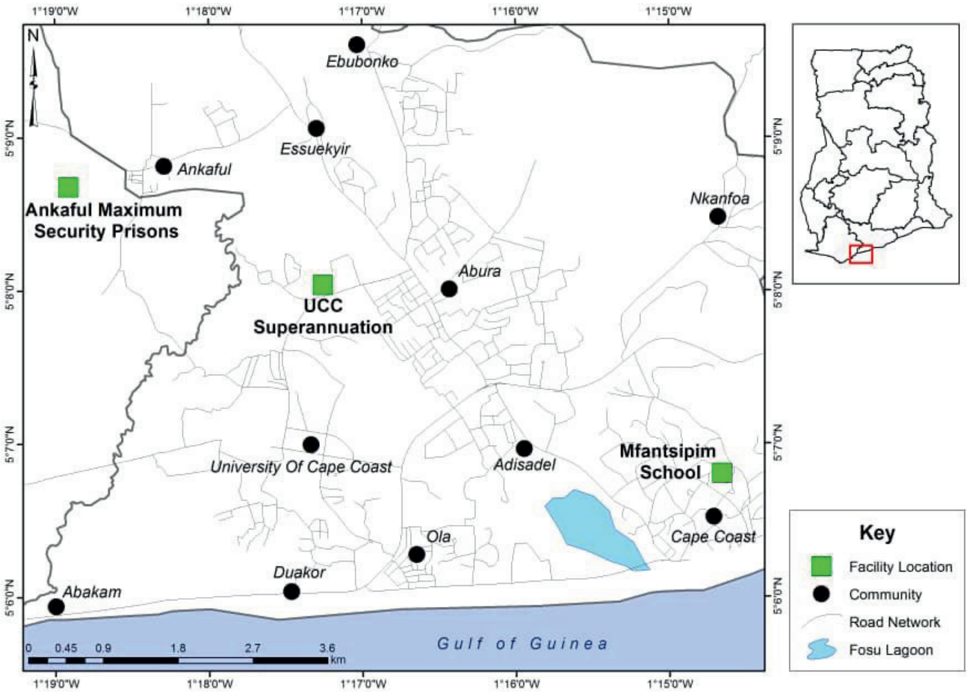

Fig.1 Map of study area with location of biogas plants

Statistical analysis

The data obtained after laboratory procedures were subjected to statistical analysis using the Statistical Package for Social Sciences (SPSS), version 21 and Microsoft Excel. Analysis of variance (ANOVA)/Kruskal-Wallis test was employed to obtain the descriptive statistics of the data as well as to determine any significant differences in the parameters between UCC, Mfantsipim and Ankaful biogas plants due to their unique source characteristics. Furthermore, the removal or treatment efficiencies of the various parameters were calculated by using equation 1.

$$\rho = \frac{Ci - Ce}{Ci} x100 \quad (1)$$

Where: ρ is removal or reduction efficiency in %, Ci is the concentration in the influent, Ce is the concentration in the effluent.

Furthermore, in order to better describe the reduction in microbial load, a logarithmic scale or log scale is used. Therefore, the log reduction is given by equation 2.

$$Log\ reduction = log\ 10\ (A) - log\ 10\ (B) \quad (2)$$

Where: A is the viable microorganisms in the influent, B is the viable microorganisms in the effluent.

Log reduction is a mathematical notation that is used to express or describe reduction in numbers of microbes as a result of treatment.

RESULTS AND DISCUSSION

Characteristics of wastewater

ANOVA was conducted to compare the effluent quality of the three biogas plants. Summary results are presented in Table 1 and compared with EPA standards (EPA, 2012). Results of the analysis indicate that some of the physicochemical and biological parameters measured exceeded the allowable levels set by EPA and are displayed in red colour. There was no basis for comparison for TVS, and vibrio cholera. The pH of 6.08, 6.74 and 6.24 for UCC, Mfantsipim and Ankaful respectively were within the permissible limits of 6 - 9 ($p = .00$). This pH range is consistent with similar work (Ahmed et al., 2018). The pH of a treatment plant which employs an anaerobic digestion (AD) process has significant influence on the treatment process and according to Jayaraj et al. (2014), the optimum pH range of 6.8 - 7.2 is required, though the process can tolerate a range of 6.5 - 8.0. The results show that UCC and Mfantsipim recorded the lowest and highest pH values respectively. It is clear from the results that all three biogas plants were not operating at optimum pH and the effluent could consequently affect the quality of the receiving environment.

The average temperature range recorded was 27.34^{o}C, 28.82^{o}C and 29.38^{o}C indicative of effluent from UCC, Mfantsipim and Ankaful respectively, the differences being statistically significant ($p = .00$). Temperature setting is one of the most critical parameters for viable process and operation for biogas plants (Ramaraj &Unpaprom, 2016). Wang et al. (2019) argue that at optimum temperature range of 25^{o}C to 35^{o}C, biogas production is high as well as microbial activity, which results in improved effluent quality. The temperature range is an indication that all the three biogas plants were operating at optimum temperature and the values were also within the EPA standard values for effluent discharge. However, studies show that high water temperature decreases gas solubility in water bodies which could result in increased growth of aquatic plants (Usharani et al., 2010) and consequent eutrophication.

The electrical conductivity values ranged from 533.69 - 2618.98 µs/cm for effluent from all three biogas plants with Mfanstipim recording the highest value to fall above the EPA set standard of 1500 µs/cm. The difference in concentrations of UCC, Mfantsipim and Ankaful are statistically significant ($p = .00$). High electrical conductivity level may be an indication of the presence of other dissolved compounds or total salt content (Oluyemi et al., 2010). Similarly, according to Mitsch and Gosselink (2000), cations such as sodium, iron, calcium and magnesium, and anions such as nitrate, phosphate, chloride and sulphate contribute to the overall electrical conductivity of wastewater effluent.

The average total dissolved solids (TDS) range of 365.25 - 1624.21mg/L was recorded for the effluent from the three biogas plants, the difference being statistically significant ($p = .00$). The lowest TDS concentration was recorded at Ankaful while Mfantsipim recorded the highest concentration. The TDS concentrations for UCC and Ankaful were within the threshold for effluent discharge but Mfantsipim recorded TDS value that was above the EPA guideline value of 1000mg/L. This high TDS is an indication confirming the high electrical conductivity recorded for Mfantsipim. According to Oluyemi et al. (2010), the TDS of water, like electrical conductivity is an indicator of total salt content of the water. High levels of TDS may be attributed to the presence of anions, cations or salts and other dissolved substances present in the wastewater.

The concentration of dissolved oxygen (DO) for all three biogas plants ranged from 4.12 - 5.24mg/L for all three biogas plants. The difference is statistically significant at $p = .00$. The results indicate that the effluent quality of UCC falls within the threshold set by EPA, an indication of relatively quality effluent while that of Mfantsipim and Ankaful could not meet the EPA permissible limit of 5mg/L. Low DO levels could be attributed to high microbial load of the wastewater that has utilized maximum amount of the oxygen. Low DO could affect the survival of certain life forms of the receiving water.

The average concentrations of total suspended solids (TSS) of 66.53 – 543.19mg/L recorded for all three plants were statistically significant ($p = .00$) and above the allowable limit of 50mg/L set by EPA. High levels of TSS in effluent could result in reduced dissolved oxygen and build-up of sediments in the receiving water body.

The average total volatile solids (TVS) concentration rage of 41.5 – 346.55mg/L was recorded for the three biogas plants. There is a statistically significant difference between the three biogas plants ($p = .00$), even though there is no set standard by the regulating body. TVS are the organic solids that volatize during combustion. They contribute to the total solids present in wastewater, which when in high levels could cause cloudiness of the receiving water.

The average values recorded for biological oxygen demand (BOD) ranged from 31.5 – 125.46mg/L. ANOVA test indicated significant difference ($p = .00$) in the average BOD load. UCC and Mfantsipim had concentrations above the permissible level of 50mg/L set by EPA. High levels may be due to high organic loads which could not be completely degraded by microorganisms present in the biogas plant. The consequences of discharging excess amount of organics into receiving water bodies could be significant depletion of dissolved oxygen and

subsequent mortality of other oxygen dependent aquatic organisms (DeBusk, 1999). Also, the average chemical oxygen demand (COD) levels ranged from 123 – 1154.37mg/L which had statistically significant variation (p = .00) in the effluent discharge. It can be seen that UCC and Ankaful fell within the guideline values while Mfantsipim was above the threshold (250mg/L) set by EPA. The high concentrations may be attributed to other substances such as sulphides, sulphates and thiosulphates that are contained in the waste water (Russell, 2006).
With regards to the nutrients (NH_3-N, NO_3, TKN, PO_4 and TPO_4), the average concentrations recorded were: NH_3-N ranged between 8.61 – 13.52 mg/L, NO_3 ranged from .05 – .07 mg/L, TKN was in the range of 115.80 – 23.72 mg/L, PO_4 was 1.61 -3.40mg/L while TPO_4 was 3.17 – 6.62mg/L for UCC, Mfantsipim and Ankaful. Comparing the average concentrations, there exist significant variations between all three plants (p = .00). In the case of NH_3-N all three plants had effluent concentrations above the EPA guideline limit of 1.0mg/L with the highest NH_3-N concentration being recorded at Mfantsipim. These high levels could be attributed to some form of nitrification in the process of treatment. However, NO_3 and TKN had effluent concentrations within the set standard of 50mg/L for UCC, Mfantsipim and Ankaful. Furthermore, PO_4 and TPO_4 were also within the EPA guideline values of 10mg/L and 20mg/L for UCC, Mfantsipim and Ankaful. Concentrations of nutrients in effluent are essential to the receiving water bodies because the consequences could be eutrophication, odour nuisance and extinction of some aquatic life forms which depend on dissolved oxygen.

Biodegradability

The potential biodegradability of wastewater basically depends on the ratio of BOD_5 and COD. Monitoring the biodegradability of wastewater could provide important indication for pre-evaluation of the efficiency of treatment processes, as well as for assessing the extent of potential environmental pollution (Choi et al., 2017). It will further give an indication as to whether the treatment facility can comply with regulations for biodegradable organic matter such as BOD (Yang et al., 2015). Asano et al. (2007) established that a BOD_5/COD ratio of untreated wastewater is in the range of .3 – .8. A ratio of .5 or greater is an indication that the wastewater can be easily treated by biological means while a ratio below .3 indicates that the wastewater contain some form of toxic components or non-biodegradable organic matter. In this study, the BOD_5/COD ratio was .5, .06 and .3 for UCC, Mfantsipim and Ankaful respectively. These values signify that UCC and Ankaful have relatively high potential for biodegradability and fall within the recommended range of .3 - .8 as reported by Asano et al. (2007), therefore, the resulting effluent could have relatively reduced environmental pollution such as the deterioration of water quality in natural waters. However, Mfantsipim fell below the recommended range of .3 – .8 (Asano et al., 2007), hence, has low biodegradability potential. Consequently, the effluent from Mfantsipim could result in rapid growth of bacteria as well as high public risk and environmental deterioration (Escobar et al., 2001). Pre-treatment of the influent may be needed to improve its biodegradability.

Microbial load

The microbial analyses revealed significant loads of total coliforms, E. coli, salmonella *spp.* and vibrio cholerae. The average total coliforms load ranged from $4x10^5$ – $602.69x10^5$ cfu/100ml with Mfantsipim recording the highest load. These loads were above the permissible limit of 400 (cfu/100ml) for UCC, Mfantsipim and Akaful. The difference between the total coliforms load is statistically significant at p = .00. Similarly, the E. coli loads ranged from $.04x10^5$ - 46.5 $x10^5$ cfu/100ml with significant difference at p = .00. The E. coli load for all three biogas plants were above the EPA threshold of 10 (cfu/100ml). The use of faecal organisms as indicator of water quality has been widely used by many researchers. According to Belhaj et al. (2014), public health protection concepts originated from such studies. High loads could be attributed to unfavorable internal conditions which inhibit the treatment process. The high loads of total colifoms and E. coli suggest that further treatment may be needed prior to discharge into water bodies, since this could pose public health risk. It has been reported by Feachem et al. (1983) that faecal coliforms are able to survive in the environment for close to 50 days.

Also, the effluent loads for salmonella *spp.* ranged from 3.03 $x10^5$ – 36.5 $x10^5$ cfu/100ml with significant difference at p = .00 for all three biogas plants. The average salmonella *spp*. load for UCC, Mfantsipim and Ankaful were all above the EPA guideline value of 10 (cfu/100ml). Internal inhibitions or unfavorable conditions might have led to the high effluent loads. This has potential public health risk or could lead to outbreak of disease since salmonella *spp.* is able to survive in the environment for about 30 days (Feachem et al., 1983). Finally, vibrio cholera loads recorded ranged from 0 – 43.53 $x10^5$. There was a significant variation in vibrio cholerae loads between UCC, Mfantsipim and Ankaful biogas plants. Even though there is no standard for vibrio cholera, UCC recorded the highest load with Mfantsipim having all vibrio loads removed in the effluent. According to Feachem et al. (1983), at 20 – 30^{o}C, the survival of vibrio cholera in the environment is less than 5 days.

Treatment efficiency

The influent and effluent analysis of wastewater quality parameters for UCC, Mfantsipim and Ankaful biogas plants showing treatment efficiencies are presented in Table 2. The DO of all three biogas plants saw continuous reduction in the effluent concentrations which is expected due to the anaerobic processes these plants use.

The treatment efficiencies for UCC in terms of physical characteristics are as follows: pH (5.74%), temperature (-1.37%), EC (7.61%), TDS (3%), TSS (72.22%) and TVS (78.41%). The removal efficiencies of the physical parameters were all positive except for temperature which recorded a negative percentage indicating a rise in temperature. The temperature rise is, however, negligible and may not affect the receiving water body as the discharged effluent flows through drain before joining the receiving water. On the chemical parameters BOD_5 and COD had removal efficiencies of 64.22% and 63.56% respectively, indicating significant treatment, even though the effluent BOD_5 did not meet the permissible limit. For NH_3-N, NO_3 and TKN the treatment efficiency was 35.45%, 79.17% and 8.3% respectively with NO_3 receiving high treatment for UCC biogas plant while TKN received low treatment. With regards to PO_4 and TPO_4 the treatment level was 61.29% and 44.48% respectively. The level of TPO_4 treatment was low even though the effluent concentration was within the threshold limit. On the biological parameters percentage efficiency removal or log reduction, total coliforms had 1.9 log reductions (98.6%), E.coli had less than 1 log reduction (84.39%), salmonella *spp.* had 1.5 log reductions (97.13%) and vibrio cholera had 1 log reduction (91.1%) respectively. The removal efficiencies or log reductions are relatively low and this gives an indication that the biogas plant is not so effective in reducing these pathogenic microbes, thus, has a potential public health risk.

In the Mfantsipim biogas plant there was negative treatment removal for pH (-1.66%) and temperature (-7.5%) which indicate an increase from influent to effluent. The treatment efficiencies for EC (11.89%) and TDS (6.7%) were low, which could negatively impact the quality of the receiving environment. For TSS and TVS, there was relatively low removal efficiency of 42.7% and 44.02% respectively. The BOD_5 and COD had high treatment efficiencies of 70.45% and 83.84% respectively. In spite of this high removal percentage, the effluent discharge concentrations were above the permissible limit. This shows how strong the waste stream is. On nutrient treatments, the removal percentages were NH_3-N (39.8%), NO_3 (79.17%), TKN (26.43%), PO_4 (32.0%) and TPO_4 (18.87%). The treatment efficiency of the nutrient characteristics was low except for NO_3 which recorded high percentage. Though removal efficiency was low, all except NH_3-N fell within the recommended discharge

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standard set by EPA. With regards to microbial characteristics, treatment efficiency or log reduction was 1.6 log reductions (97.72%) for total coliforms, 5 log reductions (99.99%) for E. coli, 1.8 log reductions (98.26%) for salmonella *spp.* and complete removal of vibrio cholera. The log reductions show that the Mfantsipim biogas plant is relatively effective at microbial removal as compared to the other two biogas plants, even though the microbial loads in the effluent were still above the EPA standards.

The Ankaful biogas plant has the following removal efficiencies for the physical parameters: pH (18.54%), temperature (-11.46%), EC (47.6%), TDS (57.7%), TSS (68.17%) and TVS (56.38%). A rise in temperature resulted in the negative percentage removal while pH and EC recorded low treatment removal. For the chemical characteristics high treatment efficiency was recorded for BOD_5 (82.4%) and COD (81.13%) respectively. The high efficiency is evident in the effluent discharge concentrations falling within the EPA guideline values. Furthermore, the treatment efficiencies for NH_3-N (23.54%), NO_3 (22.22%), TKN (11.49), PO_4 (39.25%0) and TPO_4 (38.44%) were all low. The analysis show that even though the removal efficiencies were low, effluent concentrations were within the permissible limit except for NH_3-N. The microbial characteristics saw reduction in the effluent quality though the concentrations were above the recommended EPA values. The removal efficiencies or log reduction for total coliforms was less than 1 log reduction (58.51%), E. coli had less than 1 log reduction (73.28%), salmonella *spp.* had less than 1 log reduction (61.78%) and vibrio cholera had .96 log reduction (89.02%). It is evident that the Ankaful biogas plant is not effective with pathogenic microbial removal and therefore has a high public health risk.

Performance analysis

Physiochemical and biological qualities of treated effluent are important not only in the assessment of the degree of pollution but also in the choice of the best treatment technology needed and its performance. Pollution is one of the greatest abuses of our natural resources, particularly our water bodies. Overloading a water body beyond its recuperative capacities with improperly treated wastewater is of serious concern. Comparing the discharge qualities to the standards of EPA (Table 1) and the treatment efficiencies (Table 2) it is evident that UCC biogas plant performs a little better than Ankaful and far better than Mfantsipim biogas plants in terms of wastewater treatment. The performance analysis of the three biogas plants is presented in Fig. 2. It is worth noting that both UCC and Ankaful have the fixed dome biogas design while the Mfantsipim has the Puxin design. Moreover, UCC biogas plant was constructed in 2017, which is quite new, hence better performance is expected, while both

Ankaful and Mfantsipim plants were constructed in 2011. However, observations at the various biogas plant sites point to poor maintenance culture, some design deficiencies and poor environmental conditions. This is consistent with similar work by Owusu-Ansah et al. (2015). Additionally, it was also observed that the high volume of water that comes with the in-put load might have consequently affected the treatment process and this is comparable to similar study by Nuku et al. (1979). From the performance analysis, it is obvious that the above factors are contributing to the under-performance of these three biogas plants, hence affecting the effluent quality and this is supported in similar study (Barzallo-Bravo et al., 2019).

Table 1 Summary of physicochemical and microbiological characteristics, and discharge requirements of effluents from UCC, Mfanstipim and Ankaful biogas plants N= 96

Parameter	UCC			Mfantsipim			Ankaful			EPA Ghana (2012)	Robust test of equality of means	
	Effluent	Max	Min	Effluent	Max	Min	Effluent	Max	Min		p	F
pH	6.08(±.02)	6.31	5.84	6.74(±.03)	7.09	6.34	6.24(±.03)	6.78	6.01	6.0-9.0	0.00	176.34
Temp(°C)	27.34(±.08)	28.2	26.7	28.82(±.23)	31.00	25.65	29.38(±.09)	29.96	28.49	< 3 °C above ambient	0.00	150.15
Electrical Conductivity (µs/cm)	883.44(±1.28)	896.00	871.00	2618.98(±13.07)	2732.40	2349.60	533.69(±.56)	538.22	525.89	1500	0.00	42780.15
DO(mg/L)	5.24(±.05)	5.90	4.80	4.12(±.13)	5.25	2.63	4.79(±.02)	4.98	4.61	5	0.00	56.41
TDS(mg/L)	610.63(±.76)	621.00	602.00	1624.21(±7.90)	1697.37	1459.57	365.25(±2.46)	388.00	345.00	1000	0.00	12856.67
TSS(mg/L)	66.53(±.27)	69.00	63.00	543.19(±1.66)	567.00	532.98	102(±.23)	104.00	100.00	50	0.00	42082.72
TVS(mg/L)	41.5(±.58)	48.00	36.00	346.55(±.59)	354.00	339.00	93.47(±.29)	96.00	91.00	NS	0.00	86287.60
BOD_5(mg/L)	54.03(±.74)	61.00	47.00	125.46(±.51)	133.00	120.00	31.5(±.19)	33.00	30.00	50	0.00	14759.51
COD(mg/L)	119.53(.42)	125.00	114.00	1154.37(±2.13)	1192.00	1128.40	123(±.25)	125.00	121.00	250	0.00	115101.11
NH_3-N(mg/L)	8.61(±.08)	9.80	7.80	13.52(±.17)	16.39	11.32	9.29(±.04)	9.59	8.89	1	0.00	319.97
NO_3(mg/L)	0.05(±.00)	.06	.04	0.05(±.00)	.07	.04	0.07(±.00)	.07	.07	50	0.00	279.81
TKN(mg/L)	15.80(±.09)	16.70	14.60	23.72(±.15)	25.91	22.29	16.24(±.03)	16.50	15.98	50	0.00	1227.39
PO_4(mg/L)	2.69(±.03)	3.01	2.41	3.40(±.05)	3.94	2.54	1.61(±.00)	1.63	1.59	10	0.00	1495.42
TPO_4(mg/L)	5.63(±.06)	6.30	5.10	6.62(±.07)	7.70	5.90	3.17(±.01)	3.25	3.10	20	0.00	1822.98
Total coliform(cfu/100ml)	$4x10^5$ (±.22)	8.00	2.00	602.69 $x10^5$ (±6.09)	656.33	534.00	108.5 $x10^5$ (±.09)	109.00	108.00	400	0.00	98813.35
E coli (cfu/100ml)	16 $x10^5$ (±.36)	21.00	12.00	0.04 $x10^5$ (±.00)	.08	.02	46.5 $x10^5$ (±.31)	49.00	44.00	10	0.00	12407.48
Salmonella(cfu/100ml)	3.03 $x10^5$ (±.16)	5.00	1.00	802.16 $x10^5$ (±3.67)	860.00	765.00	36.5 $x10^5$ (±.19)	38.00	35.00	10.0	0.00	31569.90
Vibro cholerae(cfu/100ml)	43.53 $x10^3$ (±.43)	49.00	40.00	0(±.00)	0.00	0.00	33.5 $x10^3$ (±.33)	36.00	31.00	-	-	-

Table 2 Treatment efficiency of physicochemical and microbiological characteristics of UCC, Mfanstipim and Ankaful biogas plants N= 192

Parameter	UCC			Mfantsipim			Ankaful		
	Mean			Mean			Mean		
	Influent	Effluent	Treatment (%)	Influent	Effluent	Treatment (%)	Influent	Effluent	Treatment (%)
pH	6.45(±.04)	6.08(±.02)	5.74	6.63(±.30)	6.74(±.03)	-1.66	7.66(±.03)	6.24(±.03)	18.54
Temp(°C)	26.97(±.11)	27.34(±.08)	-1.37	26.81(±.21)	28.82(±.23)	-7.5	26.36(±.03)	29.38(±.09)	-11.46
Electrical Conductivity (µs/cm)	956.19(±.74)	883.44(±1.28)	7.61	2972.38(±15.20)	2618.98(±13.07)	11.89	1018.48(±1.18)	533.69(±.56)	47.6
DO(mg/L)	5.69(±.09)	5.24(±.05)	7.91	4.75(±.15)	4.12(±.13)	13.26	6.65(±.01)	4.79(±.02)	27.97
TDS(mg/L)	629.53(±.53)	610.63(±.76)	3	1740.79(±8.90)	1624.21(±7.90)	6.7	863.52(±.38)	365.25(±2.46)	57.7
TSS(mg/L)	239.53(±.37)	66.53(±.27)	72.22	947.91(±1.22)	543.19(±1.66)	42.7	320.47(±.18)	102(±.23)	68.17
TVS(mg/L)	192.19(±.75)	41.5(±.58)	78.41	619.09(±.93)	346.55(±.59)	44.02	214.03(±.50)	93.47(±.29)	56.33
BOD(mg/L)	151(±.81)	54.03(±.74)	64.22	424.53(±1.57)	125.46(±.51)	70.45	179(±.15)	31.5(±.19)	82.4
COD(mg/L)	328.03(±.81)	119.53(.42)	63.56	7145.38(±13.21)	1154.37(±2.13)	83.84	652(±.23)	123(±.25)	81.13
NH_3-N(mg/L)	13.34(±.05)	8.61(±.08)	35.45	22.46(±.28)	13.52(±.17)	39.8	12.15(±.03)	9.29(±.04)	23.54
NO3(mg/L)	0.24(±.00)	0.05(±.00)	79.17	0.24(±.00)	0.05(±.00)	79.17	0.09(±.00)	0.07(±.00)	22.22
TKN(mg/L)	17.23(±.12)	15.80(±.09)	8.3	32.24(±.25)	23.72(±.15)	26.43	18.35(±.03)	16.24(±.03)	11.49
PO4(mg/L)	6.95(±.03)	2.69(±.03)	61.29	5.00(±.07)	3.40(±.05)	32	2.65(±.00)	1.61(±.00)	39.25
TPO4(mg/L)	10.14(±.10)	5.63(±.06)	44.48	8.16(±.15)	6.62(±.07)	18.87	5.15(±.00)	3.17(±.01)	38.44
Total coliform(cfu/100ml)	285.5x10^5(±1.21)	4x10^5 (±.22)	98.6	26400.94 x10^5 (±270.29)	602.69 x10^5 (±6.09)	97.72	261.5 x10^5 (±.19)	108.5 x10^5 (±.09)	58.51
E coli (cfu/100ml)	102.5 x10^5 (±.54)	16 x10^5 (±.36)	84.39	10402.19 x10^5 (±55.02)	0.04 x10^5 (±.00)	99.99	174 x10^5 (±.26)	46.5 x10^5 (±.31)	73.28
Salmonella(cfu/100 ml)	105.47 x10^5 (±.44)	3.03 x10^5 (±.16)	97.13	46017.19 x10^5 (±298.13)	802.16 x10^5 (±3.67)	98.26	95.5 x10^5 (±.19)	36.5 x10^5 (±.19)	61.78
Vibro cholerae(cfu/100ml)	489.13 x10^5 (±.170)	43.53 x10^3 (±.43)	91.1	282.06 x10^5 (±1.93)	0(±.00)	100	305 x10^5 (±.67)	33.5 x10^3 (±.33)	89.02

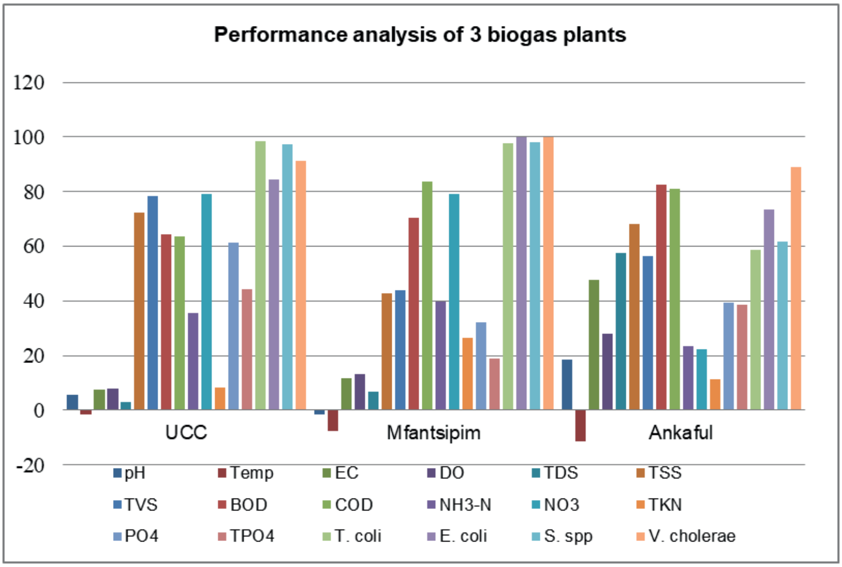

Fig. 2 Performance analysis of UCC, Mfantsipim and Ankaful biogas plants

CONCLUSION

This study observed that there exist significant differences in the effluent quality between UCC, Mfantsipim and Ankaful biogas plants. This is mainly attributable to poor maintenance, design deficiencies, poor environmental conditions and voluminous in-put loads. These factors impact the treatment efficiency resulting in relatively poor effluent quality which could put the health of the public at great risk.

This is a call on authorities and policy makers to formulate appropriate regulations aimed at addressing the potential impact of poor effluent quality discharged into the environment.

It is recommended that the effluent be further treated with sand filter bed embedded with activated charcoal and coconut fibre to improve the effluent quality before discharged into the environment so as to minimize the potential public health risk. Policy makers could also set-up a task force to periodically monitor the effluent discharge to ensure they meet the EPA standards. Furthermore, a database of all biogas plants built in the various regions of Ghana should be created to facilitate the work of the task force.

4

Chapter 4

Re-designed Biogas Plant for Sustainable Sanitation

EMBARGOED

Submitted as:
M. Osei-Marfo, A. E. Duncan, E. Awuah, N. de Vries
Re-designed Biogas Plant for Sustainable Sanitation

5

Chapter 5

People's Perceptions on the use of Human Excreta for Biogas generation in Ghana

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Abstract

This paper explored people's perceptions on the use of human excreta for biogas generation in Ghana using the theory of planned behavior (TPB). It sought to assess the effect of attitude, subjective norms and perceived behavioral control on people's behavioral intention to use human excreta (HEx) for biogas. Data collection was by questionnaire designed with the TPB constructs and other demographic information, and the analysis was done by structural equation modelling (SEM). The analysis produced two structural models: the standard TPB model and the adjusted model. Based on SEM, this study revealed that the adjusted model provides a useful and effective framework for analysing the interrelationships between socio-demographic variables and the standard TPB constructs than the standard TPB. Therefore the results show that the effect of attitude, subjective norms and perceived behavioral control are all significant and positive. Though all the constructs were significant and positive, participants showed low perceived behavioral control or they perceived low ability of using HEx for biogas.

Results revealed an adequate fit for people's behavioral intentions to use HEx for biogas. The adjusted model, generated by the inclusion of gender and education into the TPB model, provided a useful and effective framework for the interrelationships between socio-demographic variables and the TPB constructs than the standard TPB. Attitudes, subjective norms and perceived behavioral control significantly influenced intentions to use HEx for biogas. Though perceived behavioral control showed low controllability, subjective norm was a major factor with religion being key on intentions to use HEx for biogas generation. Gender and education had no direct significant influence on intentions, but their effects were mediated through the TPB factors. It was further revealed that knowledge on the benefits of biogas as well as the perceived effect of using human excreta was strong and positive. Interventions aimed at promoting the use of HEx for biogas should address low controllability and that should include government subsidy and financial support as well as education to address stigma and HEx knowledge. The intervention should also bring on board important persons such as religious leaders and persons from relevant institutions to lead more open discussions on HEx use for biogas.

Keywords: people's perception; human excreta; biogas; Ghana; theory of planned behaviour

Introduction

Over the past decades, the ever-growing human population with its attendant increase in waste generation, coupled with unsustainable waste management practices, has had serious implications on public health and the environmental sanitation. The United Nations in its sustainable development goals report, Goal 6, indicates the need for adequate sanitation, wastewater treatment and an end to open defecation by 2030 (UN, 2015). As such, treatment of wastewater, particularly human excreta using several waste treatment technologies, including biogas, becomes essential in efforts made by countries across the globe towards improvement in public health and environmental sanitation. According to Abbasi et al. (2012), biogas technology has been used to efficiently treat wastewater and sewage sludge since 1895. This indicates that the efficacy of this technology in treating human waste is not in dispute.

Biogas is a renewable energy source that employs anaerobic digestion process (i.e., in the absence of oxygen) in treating biodegradable matter. Research indicates that biogas is mainly composed of methane (40-70%), 30-40% carbon dioxide and other gases, which can further be improved to a natural quality of 75-99% methane (Mittal et al. 2018). Several studies have shown that anaerobic digestion is one of the oldest forms of sewage sludge treatment as well as a simple tool for managing waste (Dahiya and Joseph 2015; Mata-Alverez et al. 2014). Sewage sludge contains mostly excreta and water in combination with other substances (Tilley et al. 2014). Furthermore, humans generate about .5 to 1.5 kg excreta per day (Regattieri et al. 2018), and thus requires that wastewater is well managed to avoid or reduce environmental pollution to the barest minimum. In Ghana, off-site and on-site excreta management options such as sewerage system, septic tank systems, ventilated improved pit (VIP) latrine systems and open defecation are the predominant waste management practices used, but these are either energy intensive or environmentally unfriendly. Currently, the human excreta (HEx) management mix in Ghana stands at 21% basic sanitation (sewerage, septic tank system and VIP latrine system), 45% limited sanitation (improved facilities shared with other households), 13% unimproved (pit latrine) and 22% open defecation (GSS, 2018; Appiah-Effah et al, 2019). It is however important to note that in the urban areas, basic sanitation level is 25%, limited sanitation is 56% (mostly peri-urban settlements), unimproved is 8% while open defecation stands at 11% (GSS, 2018; Appiah-Effah et al, 2019).

The main legislation framework governing human excreta (HEx) management practices is the Local Government Act (Act 462), with the responsibility of providing sanitation services assigned to Metropolitan, Municipal and District Assemblies. Other policy documents which support the implementation of HEx management include Environmental Sanitation Policy (MLGRD 2010), which covers all aspects of environmental sanitation, including HEx management, acknowledging the challenges with HEx management especially urban/peri-urban and making households responsible for financing their own household facilities; Strategic Environmental Sanitation Investment Plan (adapted from WSUP (2017)) which proposes the establishment of a national revolving fund for household sanitation to be managed by microfinance institutions.

Unlike the others, research has established that the utility of a biogas system goes beyond only management of human excreta, to treating it and even generating renewable energy out of the excreta (Rupf et al. 2015; Arthur et al. 2011; Amigun and Blottnitz 2010). Thus, this has the potential to decrease over-reliance on other sources of energy such as fossil fuel and wood fuel, the use of which have varied adverse effects on the environment. Besides, biogas technology provides a by-product of bio-fertilizer that is rich in plant nutrients, which can partly or fully offset chemical fertilizers (Mariwah and Drangert 2011; Arthur et al. 2011). Other benefits of biogas systems include improvement of community livelihood (employment), sanitation, reduction in emission of greenhouse gas and finally improved life and health (DFID NET-RC, 2011; Bensah and Brew-Hamond 2010).

Presently, few households and institutions use biogas technology as HEx management practice (Osei-Marfo et al, 2018), with less than 2% biogas technology penetration target set by Strategic National Energy Plan (SNEP) (2006/2020).

The United Nations has encouraged the development and use of sustainable energy, and by extension renewable energy, by developing nations to meet their increasing energy demands in order to minimise environmental impacts (United Nations, 2011). This is necessary because in developing countries where energy is limited in supply and relatively expensive, biogas becomes the most reliable alternative source of renewable energy, and thus has greater relevance than it would in developed countries. This accounts for the reason why countries like China, India, Nepal, Bangladesh, Ethiopia and Tanzania have developed keen interest in using excreta to generate biogas (Abbasi et al. 2011).

However, the same cannot be said about Ghana where human excreta is perceived as an absolute waste, and for that matter local authorities spend between 50-75% of their annual budget to dispose of it (Cofie et al. 2005). Despite the numerous benefits associated with the use of biogas technology, there still exists a gap between behavioral attitudes/perceptions towards using human excreta for biogas production and the actual behaviour of using human excreta for biogas in Ghana. Oteng-Peprah et al. (2019) have argued that the perceptions that the public hold on an issue is very crucial, as it forms an integral part of any successful project implementation. This suggests that for a given population to accept any emerging technology, it is important to look into the perceptions they hold about the core components of that technology. This is in line with Gibson’s, 1979 (as cited by Mariwah and Drangert, 2011) assertion that “perceptions determine our behavior and what we perceive determines what we do next” (p. 2).

It is documented that factors such as tradition, religion and culture are perceived to be potential barriers to the adoption of biogas technology (DFID NET-RC 2011). Similarly, Shane et al (2015) found that traditional beliefs made it difficult for people to adopt biogas technology in Lusaka and Copperbelt, thus attributing this to the fact that the gas was generated from animal dung and human excreta. This reveals that whereas some people do not see anything wrong with the use of human excreta for biogas generation, others attach some level of stigma to it.

Previous research has shown that behavior change interventions based on behavior-oriented theories are usually more effective in changing behavior (Bartholomew et al. 2011). In this vein, Glanz and Bishop (2010) have suggested that one of the determinants of behavior change is the individual human choice and preference, while other determinants such as cultural, political or organisational, are assumed to have effects that are mediated through these two factors. Against this background, this study sought to assess people’s perceptions regarding the use of human excreta for biogas generation in Ghana using the theory of planned behavior, by exploring their opinions on the use of human excreta for biogas generation from religious, economic, educational and environmental points of view as the literature is silent on this aspect.

Theory of planned behaviour is a useful theory for this study because it states that a person’s behavior can be predicted by their intentions, and formation of intention is influenced by a person’s attitudes, subjective norms and perceived behavioural control. In line with this, it is hypothesised that peoples’ perceptions of the use of human excreta (HEx) for biogas is influenced by behavioral attitudes, subjective norms, and perceived behavioral control, as these may be formed without prior experience or knowledge of the biogas technology. Unlike factual knowledge, perception is known to be a subjective process of obtaining, understanding, and constructing sensory information so as to form a belief about what is happening in one's environment.

The main objective of the study is to assess the effect of people's perception on the use of human excreta for biogas generation in Ghana. Specifically, the study addresses the following objectives:

1. Examine the effects of behavioural attitudes on the use of HEx for biogas generation
2. Assess the relationship between subjective norms and the use of HEx for biogas generation
3. Test effect of perceived behavioral control on the use of HEx for biogas generation.

Insights from this study will be essential for developing interventions to promote the use of HEx for biogas generation to increase the acceptance and the uptake rates in Ghana and other developing countries.

Theory of Planned Behaviour

This study is guided by Ajzen's (1991) theory of planned behavior (TPB) (Fig. 1) which provides a framework for examining peoples behavioral intentions to use HEx for biogas production. According to Armitage and Conner (2001), the TPB is a well-validated social cognitive model used to predict people's intentions and behavior. The theory postulates that one's behavior can be predicted by one's intentions, which in turn is dependent on three aspects: attitude towards the behavior, which is the degree of one's favorable or unfavorable evaluation of the behavior in question (Fishbein and Ajzen, 1975); the subjective norm, that is the perceived social pressure to perform or not to perform the behavior (Ajzen, 1991); and perceived behavioral control, that is a person's perception of ease or difficulty in performing the behavior of interest (Ajzen, 2002). Therefore, in line with the TPB, the target behavior of interest is the individual perception towards the use of human excreta for biogas. Operationally stated, attitude is defined as the degree to which the individual expects positive/good or negative/bad outcomes from the performance of such behavior. Subjective norm refers to the level of approval from family, neighbours, religious leaders and government institutions to use HEx for biogas. Perceived behavioral control focuses on the individual's management of beliefs about easy or difficulty in using HEx for biogas. Hence, individuals who have positive attitude towards using HEx for biogas and believe there is normative support or approval for using HEx for biogas, and feel it is easy for them to use HEx for biogas should have strong intentions to carry out the behavior.

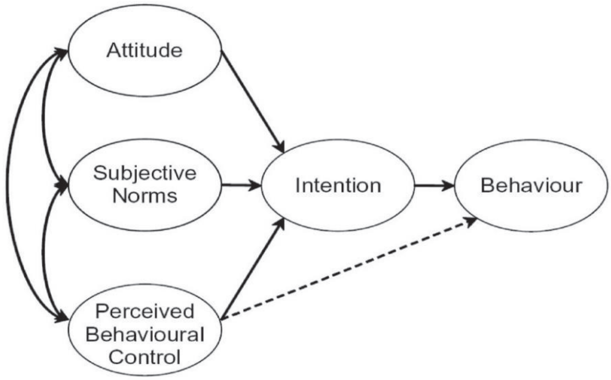

Fig 1 Theory of Planned Behavior (Ajzen 1991)

Hypotheses development

It can be explaind from Ajzen's (1991) TPB that people's perceptions on the use of HEx for biogas can be understood in terms of an individuals' attitude towards the use of HEx for biogas, subjective norms towards the use of HEx for biogas, and their perceived behavioral control over the use of HEx for biogas.

Three hypotheses were developed to bring into focus the coherence of the TPB model as follows:

Hypothesis 1: attitudes (health risk, environmental protection, bio-fertiliser and energy for cooking) have significant effect on the use of HEx for biogas generation (Oteng-Peprah et al, 2019).

Hypothesis 2: subjective norms (family, neighbours, religion and institutions) have positive relationship on the use of HEx for biogas generation (Osei-Marfo et al, 2020).

Hypothesis 3: perceived behavioral control (HEx knowledge, stigma, subsidy and cost) have positive influence on the use of HEx for biogas generation (Shane et al, 2015).

Methodology

Background and study area: Two study areas were selected in Ghana: Cape Coast Metropolitan Assembly (CCMA), located in the Central region and Ablekuma North Municipal Assembly, located in the Greater Accra region both in the Republic of Ghana (Fig. 2). Cape Coast is located on longitude 1^{o} 15’W and latitude 5^{o} 06’N covering an area approximately 122 square kilometres while Ablekuma North lies between latitude 5^{o} 33’ N and on longitude 0^{o} 12’ W also covering 60 square kilometres. The CCMA was selected because residents of the sub-urban coastal communities around the Cape Coast Castle have turned the shoreline into an open defecation ground. Meanwhile, Cape Coast Castle is a major tourists’ site that generates enormous income for the Government of Ghana due to the unique role it played in the era of the trans-African Slave Trade. Apart from that, about 45 tonnes of wastewater that is generated daily within the Metropolis is improperly disposed of on bare land at a dumpsite located some five kilometres away from the central business area, thus posing a potential serious health threat to residents of the metropolis (CCMA, 2014). In essence, despite the huge amounts of wastewater generated within the metropolis, the Cape Coast Metropolitan Assembly does not have any wastewater treatment plant or sewage system to hygienically dispose of this waste, thus the need to promote the use of biogas technology to avoid the harmful practice of discharging wastewater onto bare grounds at the dumpsite. The choice of Ablekuma North, being part of the Accra Metropolitan Area and within the capital city of Ghana, was based on reports of increased open defecation in the area which does not only affect public health but also puts Ghana’s position on open defecation at seventh (7th) globally and second (2nd) in Africa respectively (Osumanu, Kosoe and Ategeeng, 2019). Besides, it is known that one of the key causes of perennial flooding in Accra that often claims many lives is the illegal disposal of waste into waterways, thus choking the drainage systems (Asumadu-Sarkodie et al., 2015). Most household waste thrown into drains in the city contain human excreta tied in colored polythene bags, largely coming from unscrupulous people living in housing units without toilet facilities. Additionally, there is no sewage system in the Ablekuma North Municipal Assembly. Moreover, both Cape Coast and Ablekuma North are metropolitan areas that have residents with vast differences in their cultures, traditions, religions, educational levels, and socioeconomic status.

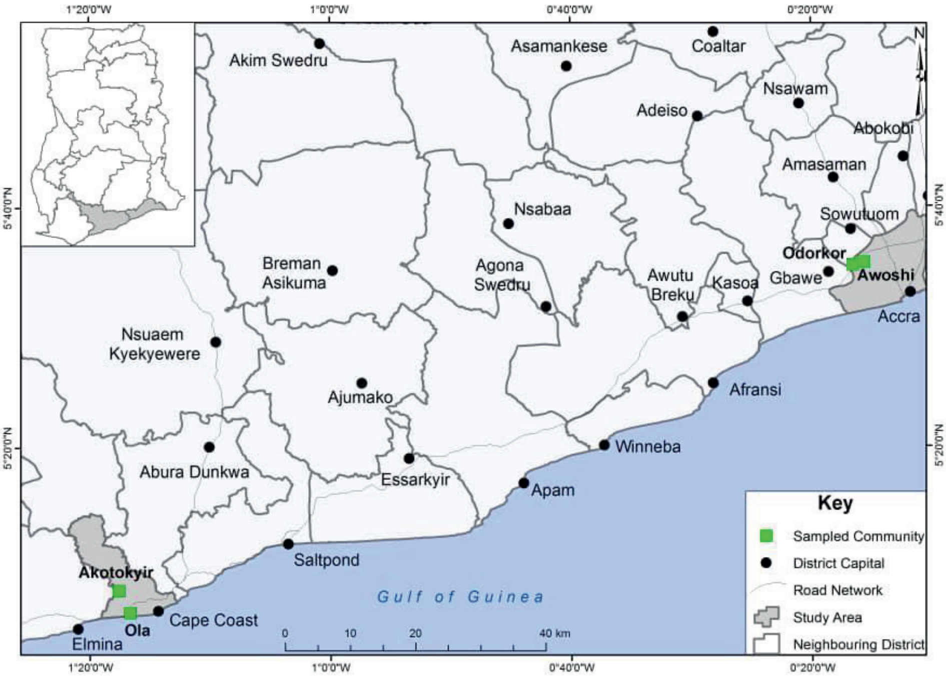

Fig. 2 Map of study area

Elicitation study: The study began with an elicitation survey, following suggestion by Fishbein and Ajzen (2010) within four communities in Greater Accra and Central regions using convenience sampling. This survey was conducted to identify salient beliefs underlying peoples' perceptions on the use of HEx for biogas generation. An open-ended questionnaire was administered, and the likely outcomes summarised in Table 1. The participants were asked to indicate: (a) the advantages/benefits and disadvantages/challenges of using HEx for biogas for domestic purposes, (b) persons or groups of people who would approve or disapprove of their actions with respect to using HEx for biogas, and (c) the factors that could facilitate or discourage them in using HEx for biogas for domestic purposes. A total of 120 respondents participated. A content analysis was then carried out and the most frequent beliefs and knowledge underlying peoples' perceptions were included in the formulation of TPB questionnaire. The TPB questionnaire was administered to 130 participants as a pre-test to test for consistency, ambiguity, understandability and psychometric properties prior to the main study. Modification and correction were made based on the responses to improve clarity and easy comprehension. A Cronbach's alpha of .709 was obtained, indicating that the scale was adequate.

Main study: The main study was conducted over a period of three months from July to September 2017. The total population of the study areas was 366,918, which composed of a combination of all residents of Cape Coast Metropolitan Assembly (169,893) and of Ablekuma North Municipal Assembly (197,024) (GSS-PHC, 2012). The researchers targeted all adult residents of Cape Coast Metropolis and Ablekuma North in Accra Metropolis who did not own or use biogas technology but depended on other excreta management technologies such as septic tank system, ventilated improved pit latrine or open defecation. Though the respondents had not received any biogas training, they indicated that they had heared of it through friends, family members or neighbours who own or have received training or campaign on biogas.

A two-stage stratified sampling design was adopted for the representative survey. The sampling frame used for the study is the frame of the Ghana 2010 Population and Housing Census (PHC) provided by the Ghana Statistical Service (GSS), which is a complete list of all census enumeration areas (EAs). An EA refers to a geographic area covering an average of 145 households. Two residence strata (urban and peri-urban: Urban refers to settlement with high population density, concentration of administrative bodies and infrastructure, and a diverse set of livelihood and income levels while peri-urban refers to settlement mostly concentrated in low-income urban areas usually located on the outskirts of cities (CEUP, 2016)) were created, and we selected equal numbers of EAs in each of our two residence strata. This design was chosen since it allowed us to evenly distribute the sample across the strata, thus ensuring that there is sufficient sample size in each strata type. The stratification was done for the two areas, which when multiplied by the two stratum types gave four strata. Within each of the four strata, we randomly selected two EAs, thus giving us an initial sample of eight EAs.

After having generated the first-stage sample of EAs, our research assistants listed all the households in the eight identified EAs. Then 40 households were randomly selected from each EA. Thus, the target sample was 320 representative households, of which 308 households were interviewed due to expression of unwillingness to participate by some households. At least two persons were interviewed in each household, which included the household head and any other male or female resident in the house. Any adult aged 20 years and above who has spent not less than twelve months in the household was eligible to participate in the survey. In total, 610 respondents consented to participate in the study, which included 282 from CCMA and 328 from Ablekuma North respectively.

Questionnaires:

The instrument for the collection of data was a questionnaire comprising three sections. The first concerned demomographic characteristics including age, gender, education, monthly income of an individual, ethicity and religion. The second focused on knowledge on benefits of biogas and perceptions of HEx for biogas, and the third dealt with TPB constructs on using HEx for biogas. The second and third sections had items measured on 7-point Likert scale. Six trained research assistants supported the administeration of the questionnaires.

Knowledge on the benefits of biogas- knowledge on the benefits of biogas was measured with seven items. Knowledge on the benefits of biogas is explained in terms of the perceptions of fuel, electricity, bio-fertiliser, sanitation improvement, job opportunities, public health improvement and environmental identity. The questionnaire assessed participants knowledge on the benefits of biogas (e.g. "Biogas can be an alternative fuel for cooking". 1 = strongly disagree, 7 = strongly agree).

Perception on human excreta for biogas- perception on using human excreta for biogas was measured with three items. Perceptions on human excreta for biogas is explained in terms of subjective beliefs of being negative practice, dangerous and safe use. The questionnaire assessed participants understanding or belief concerning the use of human excreta for biogas (e.g. "Using human excreta for biogas is negative". 1 = strongly disagree, 7 = strongly agree).

Attitude (A)- attitude was measured with four items using behavioral beliefs and their corresponding outcome evaluations. These items include health risk: the possibility that an individual can fall sick, environmental protection: maintaing the quality of the natural environment, bio-fertiliser: digested excreta, and energy for cooking: biogas obtained from the use of HEx. Participants rated the likelihood that using HEx for biogas would produce each of the outcomes, and rated the importance of each outcome (e.g. "Using human excreta for biogas will expose me to health risk". 1 = strongly disagree, 7 = strongly agree). The overall attitude score was obtained according to an expectancy-value model (Fishbein and Ajzen, 2010), Equation (1), in which the score for the likelihood of an outcome is multiplied by its corresponding score of importance. This is expressed as follows:

$$A = \Sigma b_i e_i \qquad (1)$$

Where A is the attitude towards the use of HEx for biogas behavior under consideration, b_i is the strenght of belief i that performing the behavior will produce outcome i, and e_i is the evaluation of outcome i. The same expectancy-value model was applied to obtain the overall score for each belief-based measures indicated below.

Subjective norms (SN) – subjective norm was measured using four items to assess participants normative beliefs and their motivation to comply. These items are family: members of both nuclear (spouse and children) and extented family (siblings and parents), neighbours: people living next door or in the same vicinity, religion: influence of religious leaders and institutions: government agencies. Participants rated the approval of important refernts or people and whether their opinions have any influence on their decision to use or not to use HEx for biogas (e.g. “My family would…..me making use of human excreta for biogas”. 1 = strongly disapprove, 7 = strongly approve).

Perceived behavioral control (PBC) – perceived behavioral control was measured with four items using control beliefs and power of control factors. These items are HEx knowledge: an individual’s information about human excreta, stigma: the shame associated with using human excreta, subsidy: money granted by government and cost: price of biogas construction. Participants assessed factors that would facilitate or hinder their ability to use HEx for biogas (e.g. “I need to acquire special knowledge on how to use human excreta for biogas”. 1 = strongly disagree, 7 = strongly agree).

Intention- behavioral intention was measured with three items. They include make effort, intends and have plans. Participants assessed their intentions to use HEx for biogas (e.g. “I will make effort to use human excreta for biogas”, “I intend to use human excreta for biogas”, “I have plans to use human excreta for biogas”. 1 = strongly disagree, 7 = strongly agree).

Table 1: Summary of salient beliefs

Behavioural beliefs	Normative beliefs	Control beliefs
Health risk	Institutions	Cost
Environmental protection	Religion	Subsidy
Bio-fertiliser	Neighbours	Stigma
Energy for cooking	Family	HEx knowledge

Data analysis and descriptive analysis of variables

Although 610 participants agreed to participate in the study, 408 responses (67% response rate) were received with all items completed. This study used Statistical Package for Social Sciences (SPSS), version 21 and Analysis of MOment Structures version 23 (AMOS 23) to analyse the collected data, and descriptive statistics as well as correlation were used. The analyses were conducted in two stages (Anderson and Gerbing, 1988). First, confirmatory factor analysis (CFA) using maximum likelihood was used to assess the underlying structure of the variables in the model as well as the adequacy of the model. Secondly, structural equation modelling (SEM) was used to find the best-fitting model and to test the causal relationships within the model. SEM is a general statistical modelling technique which uses the combination of factor analysis and regression or path analysis to analyse the structural relationship between measured variables and latent constructs (Hox and Bechger 1999). This technique is preferred for this study because it estimates the multiple and the interrelated dependence in a single analysis. Furthermore, to know the extent or effect of education and sex (Wolters 2014; Olli et al. 2001) on intentions, these background factors were introduced into the model (adjusted TPB model).

The study framework has three exogenous and one endogenous variables for using HEx for biogas generation. Almost all the variables of the TPB constructs had Cronbach's alpha values above .60 as recommended by Hair et al. 2010. The model was assessed using normed fit index (NFI), Tucker-Lewis index (TLI), comparative fit index (CFI) and root mean square error of approximation (RMSEA). Both Cangur and Ercan (2015), and Hox and Bechger (1999) stated that NFI, TLI and CFI values of at least .9, and RMSEA of < .6 to .8 are required to accept a model respectively.

Results

Demographic profile of respondents

The demographic characteristics of the respondents are presented in Table 2. It can be observed from the descriptive statistics of the respondents profile that majority of the respondents are male (58.3%), and about 32% of the respondents are young adults, in the 20 to 30 age category. About 45% of the respondents have tertiary education, an indication of their comprehension of the questionnaire and their ability to appreciate the benefits associated with biogas technology, especially, improvement in the environment. This high percentage of tertiary education may be due to the establishment of tertiary institutions in the study locations. Additionally, majority of the respondents earn a monthly income below GH¢ 500, equivalent to US$ 114 (34.3%) which is below the low income group level (GSS-DHS, 2018). Majority of the respondents, 68.6% and 85.8% are Akans and Christians respectively, a reflection of the predominant ethnic and religious groups in Ghana (GSS-PHC, 2012).

Futhermore, an attempt was made to find out if there is a relationship between the study locations on the use of HEx for biogas. Table 3 presents the results of the study locations by their demographic profile. The results revealed that there was significant association between Cape Coast Metropolitan Assembly and Ablekuma North Municipal Assembly (Table 3).

It emerged that for gender, the proportions of 52.2% (male) and 47.3% (female) in CCMA are significantly different from 63.3% (male) and 35.7% (female) proportions in Ablekuma North Municipal Assembly (ANMA) on HEx use for biogas. This means that more male intend to use HEx for biogas in ANMA than their counterparts in CCMA, but it is the vice versa for females in ANMA and CCMA. For age categories 20-30 and 51-60, 43.3% and 10.2% are significantly different from 18.1% and 28.6% in ANMA and CCMA respectively while the rest (31-40, 41-50 and above 60) do not differ significantly from each other. Thus more young adults in ANMA intend to use HEx for biogas while in CCMA, adults in the 51-60 category anticipate to use HEx for biogas. For education, 9.8% (none), 36.3% (basic) and 31.9% (tertiary) in CCMA are significantly different from 2.2% (none), 19.5% (basic) and 55.3% (tertiary) in ANMA while secondary do not differ significantly from each other. It is clear that respondents in ANMA have more formal education hence, they may have more positive intention to use HEx for biogas than respondents in CCMA.

Table 2: Respondents profile

Variable	Frequecy	Percentage
Gender		
Male	238	58.3
Female	170	41.7
Age		
20-30	131	32.1
31-40	117	28.7
41-50	80	19.6
51-60	75	18.4
Above 60	5	1.2
Education		
None	23	5.6
Basic	110	27.0
Secondary	92	22.5
Tertiary	183	44.9
*Monthly Income		
Below GH¢ 500	140	34.3
GH¢ 500 – 1000	137	33.6
GH¢ 1000 – 2000	96	23.5
GH¢ 2000 – 3000	22	5.4
Over GH¢ 3000	13	3.2
Ethnicity		
Akan	280	68.6
Ewe	45	11.0
Ga-Adangbe	27	6.6
Northerner	56	13.7
Religion		
Christianity	350	85.8
Islam	53	13.0
Traditional	5	1.2

*US$1 = GH¢ 4.4 at the time of data collection

With regards to individual's monthly income, 45.1% (below GH¢ 500), 17.6% (GH¢ 1000-2000) and 0.5% (GH¢ 2000-3000) are significantly different from 25.7% (below GH¢ 500), 28.3% (GH¢ 1000-2000) and 9.3% (GH¢ 2000-3000) in CCMA and ANMA respectively. Monthly income groups GH¢ 500 – 1000 and Over GH¢ 3000 do not differ significantly from each other. The results show that majority of respondents in ANMA earn between GH¢ 1000 to over GH¢ 3000 monthly, hence are more likely to use HEx for biogas than respondents in CCMA. This is because, their monthly income afford them the ability to pay for biogas installation.

For ethnicity, 74.2% (Akans) and 3.3% (Ga-Adangbe) are significantly different from 64.2% and 9.3% in CCMA and ANMA respectively while 90.7% (Christians) and 8.2% (Islam) are significantly different from 81.9% and 16.8% in CCMA and ANMA respectively. The remaining demographic profile (Ewe, Northener and Traditional) do not differ significantly from each other.

Table 3 Respondents profile according to study locations

Variable	Study location				Pearson Chi-Square		
	Cape Coast		Ablekuma North		χ^2	p-value	df
	Count	Percentage Within location	Count	Percentage Within location			
Gender							
Male	95_a	52.2	143_b	63.3	5.089	.024	1
Female	87_a	47.8	83_b	35.7			
Age							
20-30	33_a	18.1	98_b	43.4	39.658	.000	4
31-40	57_a	31.3	60_a	26.5			
41-50	38_a	20.9	42_a	18.6			
51-60	52_a	28.6	23_b	10.2			
Above 60	2_a	1.1	3_a	1.3			
Education							
None	18_a	9.8	5_b	2.2	33.487	.000	3
Basic	66_a	36.3	44_b	19.5			
Secondary	40_a	22.0	52_a	23.0			
Tertiary	58_a	31.9	125_b	55.3			
Monthly Income							
BelowGH¢ 500	82_a	45.1	58_b	25.7	32.961	.000	4
GH¢500-1000	64_a	35.2	73_a	32.3			
GH¢1000-2000	32_a	17.6	64_b	28.3			
GH¢2000-3000	1_a	0.5	21_b	9.3			
OverGH¢3000	3_a	1.6	10_a	4.4			
Ethnicity							
Akan	135_a	74.2	145_b	64.2	10.562	.014	3
Ewe	14_a	7.7	31_a	13.7			
Ga-Adangbe	6_a	3.3	21_b	9.3			
Northerner	27_a	14.8	29_a	12.8			
Religion							
Christianity	165_a	90.7	185_b	81.9	6.656	.036	2
Islam	15_a	8.2	38_b	16.8			
Traditional	2_a	1.1	3_a	1.3			

Each subscript letter denotes a subset of location categories whose column proportions do not differ significantly from each other at the .05 level.

Respondents' knowledge on the benefits of biogas

Respondents' knowledge on the benefits of biogas is presented in Table 4. From the descriptive statistics of the respondents knowledge on biogas, it can be seen that respondents reported strong knowledge on the benefits of biogas (M = 6.08, SD = 1.42). Generally, respondents believe that biogas has numerous benefits. A majority of the respondents strongly agree: that biogas can be an alternative fuel for cooking (62%), that biogas can be used to generate electricity (54%), that the digested sludge from biogas production can be used as bio-fertiliser on farmlands (60%), that using biogas can result in improvement in environmental sanitation (61%) and consequently using biogas can improve public health (49%). Additionally, about 60% of the respondents strongly agree that using biogas can create job opportunities while 46% strongly agree that it gives one an environmentally friendly identity. These results suggest that the positive benefits of biogas as expressed by the respondents may influence their perceptions and decision to use it.

Table 4 Respondents' knowledge on the benefits of biogas

Cronbach's alpha = .859 GM (SD) = 6.08 (1.42)		Level of agreement (%)						
Statement	M[a]	SD	QD	[α]SD	N	*SA	QA	SA
Biogas can be an alternative fuel for cooking	6.17	3.4	2.2	1.5	.0	14.0	17.4	61.5
Biogas can be used to generate electricity	6.03	2.0	3.7	3.2	.0	16.7	20.6	53.9
Digested sludge from biogas production can be used as bio-fertilizer on farmlands	6.16	1.7	2.5	3.4	.2	14.7	17.2	60.3
Using biogas can improve environmental sanitation	6.21	2.7	1.2	2.5	.5	13.2	18.9	61.0
Using biogas can create job opportunities	6.17	2.9	.5	1.7	2.5	13.5	22.1	56.9
Using biogas can improve public health	5.94	3.7	1.5	2.9	2.7	17.2	22.8	49.3
Using biogas gives one an environmentally friendly identity	5.85	3.4	2.7	3.4	3.4	16.7	24.0	46.3

GM = grand mean; M = mean; [a]Theoretical range = 1-7; SD = strongly disagree; QD = quite disagree; [α]SD = slightly disagree; N = neither; *SA = slightly agree; QA = quite agree; SA = strongly agree

Respondents' perceptions concerning human excreta for biogas

A descriptive statistics of respondents' perception concerning human excreta for biogas is presented in Table 5. Respondents reported positive perceptions towards the use of human excreta for biogas (M = 5.71, SD = 1.62). On the average, respondents strongly disagree: that using HEx for biogas is negative (49.3%), and that using HEx for biogas is dangerous (43.6%). Finally, a majority of the respondents strongly agree that they are confident of safely using HEx for biogas (36.8%). This positive perception concerning the use of HEx for biogas may positively impact on their overall intention to use HEx for biogas.

5

Table 5 Respondents' perceptions concerning human excreta for biogas

Cronbach's alpha = 0.759 GM (SD) = 5.71(1.62)		Level of agreement (%)						
Statement	M[a]	SD	QD	[α]SD	N	*SA	QA	SA
Using human excreta for biogas is negative	5.92	49.3	23.3	14.7	5.1	2.2	1.5	3.9
Using human excreta for biogas is dangerous	5.65	43.6	21.3	16.7	7.7	2.7	1.7	6.4
I am confident that I can safely use human excreta for biogas	5.56	6.1	2.0	3.9	2.5	25.7	23.0	36.8

GM = grand mean; M = mean; [a]Theoretical range = 1-7; SD = strongly disagree; QD = quite disagree; [α]SD = slightly disagree; N = neither; *SA = slightly agree; QA = quite agree; SA = strongly agree

Descriptive statistics of TPB constructs

The descriptive statistics presented in Table 6 and indicating the overall mean score in comparison to the theoretical range showed that respondents exhibited strong intentions (M = 5.76, SD = 1.58), positive attitude (M = 10.36, SD = 8.58), high social pressure (M = 11.47, SD = 7.67), and low controllability (M = .44, SD = 11.10) towards the use of HEx for biogas. Additionally, the mean scores for attitudinal variables are high for environmental protection, bio-fertiliser and energy for cooking, and low for health risk. The mean scores for social pressure are high for family, religion and institutions, and moderate for neighbours whereas the mean scores for perceived behavioral control are low for knowledge and stigma, and negatively low for subsidy and cost.

The correlation matrix (see Table 6) indicates that almost all the variables have significant association with intentions. Furthermore, the results show that attitude and subjective norm are significant predictors of intentions to the use of HEx for biogas, while perceived behavioral control showed weak effect on intentions to use HEx for biogas.

Measurement model

The CFA results, as shown in Fig. 3 indicated that the model fits the data well (RMSEA = .075, NFI = .901, TLI = .911 and CFI = .933). All items loaded were significantly associated with their respective latent variables as shown in Table 7, except health risk (β = - .092, p = .085). Nonetheless, it was not excluded because, it was important to assess respondents beliefs as far the use of human excreta and health risk are concerned. Composite reliability of study constructs indicating the internal consistency of multiple indicators for each construct, ranged from .71 to .86, exceeding the recommended threshold suggested by Bagozzi and Yi (1988).

Table 7 Results of measurement model

Variable	Factor loading, β	Significance, p	Composite reliability
Attitudes			.709
Energy for cooking	.72	.000	
Bio-fertiliser	.88	.000	
Environmental protection	.66	.000	
Health risk	.09	.085	
Subjective norms			.727
Family	.50	000	
Neighbours	.61	.000	
Religion	.82	.000	
Institutions	.58	.045	
Perceived behavioral control			.83
HEx knowledge	.73	.000	
Stigma	.66	.032	
Subsidy	.88	.000	
Cost	.73	.040	
Intentions			.865
Make effort	.81	000	
Intends	.92	.000	
Have plans	.74	.000	

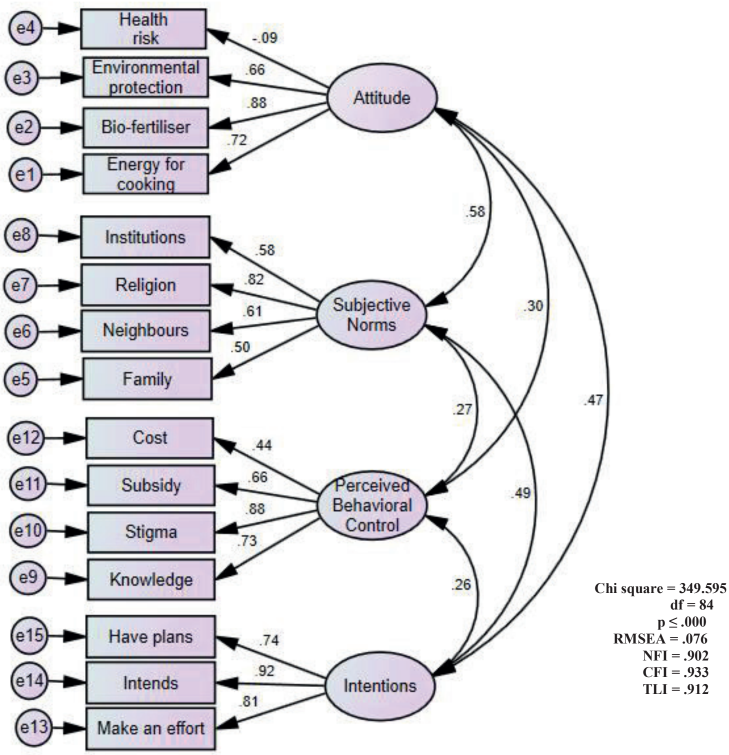

Fig. 3 Results of confirmatory factor analysis

The TPB model

The SEM results showed an adequate fit to the data (RMSEA = .075, NFI = .901, TLI = .911 and CFI = .933), presented in Fig. 4. The structural model explained 30% of the total variance in respondents' intentions to use human excreta for biogas and two constructs (attitude and subjective norms) were significantly related to intentions to use HEx for biogas based on their path coefficients. Furthermore, based on Cohen (2013) classification, it was revealed that attitude ($\beta = .256$, $p < .001$) had a significantly moderate effect on intentions to use HEx for biogas, subjective norm ($\beta = .315$, $p < .001$) had a strong and significant effect on intentions to use HEx for biogas whereas perceived behavioral control ($\beta = .100$, $p = .064$) had non-significantly small effect on intentions to use HEx for biogas. In comparing the path coefficients of the three latent variables, it can be observed that effect from social pressure including family, neighbours, religion and institutions was important factor to motivate people's intentions to use HEx for biogas generation.

Finally, the direct association between the three latent variables showed significant paths between attitude and subjective norms (β = .578, p < .001), attitude and perceived behavioral control (β = .302, p < .001), and subjective norms and perceived behavioral control (β = .269, p < .001).

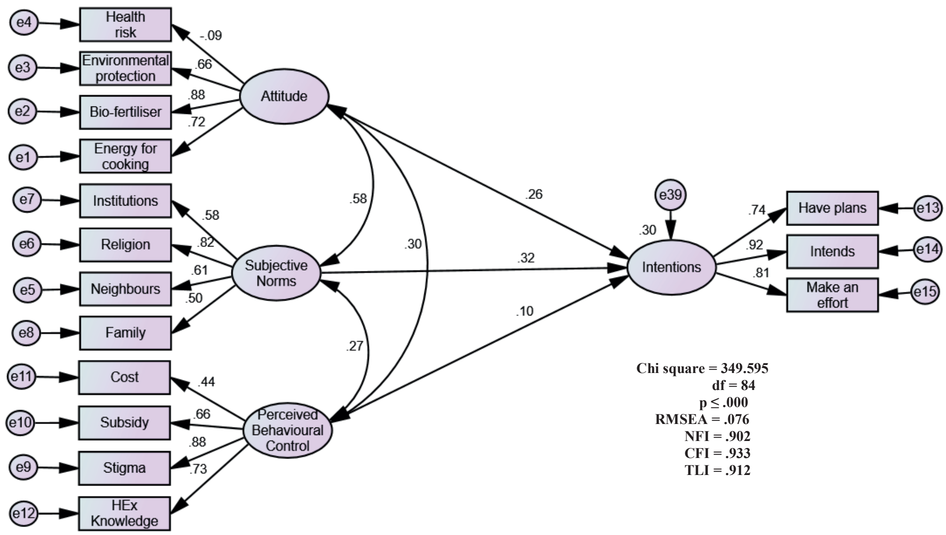

Fig. 4 Human excreta for biogas

Adjusted TPB model

An adjusted model was developed by introducing gender and education into the TPB model. This is consistent with previous studies (Lopez-Mosquera 2016; Botetzegias et al. 2015; Christian et al. 2007). Thus the TPB model was compared to the adjusted model. The SEM results (RMSEA = .072, NFI = .906, TLI = .902 and CFI = .942) showed adequate fit to the data (Fig.5). Compared to the TPB, the adjusted model showed similar explained variance of intentions to use HEx for biogas (adjusted TPB = 31% vs standard TPB = 30%), and marginally better fit (adjusted TPB: RMSEA =.072, NFI =.906, TLI = .902, CFI =.942 vs standard TPB: RMSEA = .075, NFI = .901, TLI = .911 and CFI = .933). However, with the adjusted model, all the three constructs (attitude: β = .261, $p < .001$, subjective norms: β = .318, $p < .001$, and perceived behavioral control: β = .107, p = .045) were significantly related to intentions to use HEx for biogas. This implies that the adjusted TPB model could well predict individuals' intentions to use HEx for biogas production.

Furthermore, the results indicated that both gender and education had no direct impact on intentions to use HEx for biogas. However, gender mediated through attitude (health risk and bio-fertilizer) and perceived behavioral (HEx knowledge and stigma) control, while education mediated through all three constructs (attitude: environmental protection and bio-fertilizer, subjective norms: family, religion and institution, and perceived behavioral control: stigma) displayed in Table 8. This implies that for gender, although bio-fertilizer could be obtained for agricultural purposes, health risk associated with the use of HEx cannot be overlooked. Furthermore, gender considers HEx knowledge and stigma important since they have not received any biogas technology training or campaign. For education, environmental protection and bio-fertilizer are key as far as HEx use for biogas is concerned. This is evident with high percentage of respondents (45%) reporting tertiary education. Moreover, education does not downplay important referents such as family, religion and institution, however, stigma is of concern irrespective of the level of education. Additionally, a cross tabulation of gender and education showed that more females as compared to males have no education as well as less tertiary education, as presented in Table 9.

Table 8: Results of background factors and constructs

Latent	Background factors	Education		Gender	
		β	p	β	p
Attitude	Health risk			.117	.017
	Environmental protection	.102	.037		
	Bio-fertiliser	.098	.046	-.103	.036
Subjective Norms	Family	.097	.049		
	Religion	.105	.032		
	Institution	.125	.011		
Perceived Behavioral Control	Knowledge			-.115	.019
	Stigma	.108	.027	-.102	.037

Table 9: Gender and education cross tabulation

		Education				
		None	Primary/JHS	Secondary	Tertiary	Total
Gender	Male	9	67	56	106	238
	Female	14	43	36	77	170
Total		23	110	92	183	408

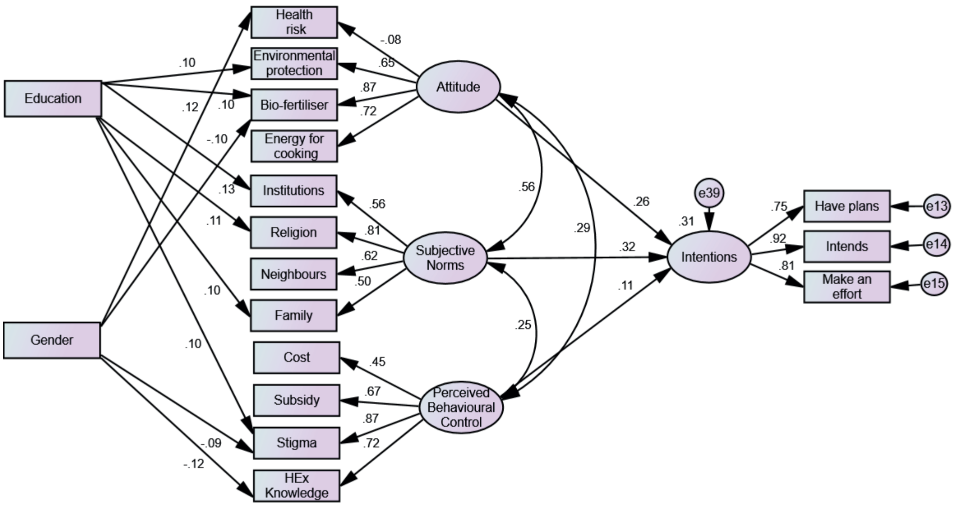

Fig. 5 Human excreta for biogas with background factors.

Note: to avoid overloading the figure, some arrows between the background factors and the predictor variables are not depicted. Only significant paths are displayed.

Hypotheses testing

Standardised coefficient estimates indicate that the association between attitude and behavioral intentions (attitude: $\beta = .261$, $p < .001$) supports hypothesis 1, association between subjective norms and behvioral intention ($\beta = .318$, $p < .001$) supports hypothesis 2, and association between perceived behavioral control and behavioral intentions ($\beta = .107$, $p = .045$) also supports hypothesis 3. Thus the SEM results indicate that all the paths were significant and positive. Therefore, hypotheses 1 – 3 are confirmed.

Furthermore, it can be observed in Fig. 4 that the standardised coefficients indicate that the direct effect of subjective norms on behavioral intentions was greater than behavioral attitude and perceived behavioral control. Also, subjective norms indirectly influenced behavioral intentions through attitude ($\beta = .564$, $p < .001$). This suggests that attitude plays a mediating role in the relationship between subjective norms and behavioral intentions to use HEx for biogas generation.

Discussion

The results of this study confirm to a large extent that TPB can be used in explaining people's perceptions on the use of HEx for biogas generation in Ghana. The TPB provided useful insight into the perceptions people have about the use of HEx for biogas, although not all the theory tenets were supported (Galaviz et al. 2015) in the standard TPB. The modelling comparison revealed that the adjusted model including gender and education had modestly better explained variance or explanatory power towards the use of HEx for biogas than the standard TPB. Thus the adjusted model provides a useful and effective framework for analysing the interrelationships between socio-demographic variables (education and gender) and TPB constructs than the standard TPB. Whiles the results revealed that for the standard TPB, attitude and subjective norms were the only factors that significantly influenced intentions to use HEx for biogas, the adjusted model showed that all the three constructs (attitude, subjective norms and perceived behavioral control) have significant effect on people's intentions to use HEx for biogas, and are valid predictors of intentions. In line with this, Ghana's Strategic National Energy Plan (SNEP) (2006/2020) seeks to achieve 2% penetration of biogas for cooking by 2020. However, this goal may not be achieved considering low or no implementation of policies such as Strategic Environmental Sanitation Investment Plan (SESIP) and SNEP.

Generally, people's attitudes are considered important determining factor to using HEx for biogas and its importance has been supported by previous studies (Zhang et al. 2013; Petts et al. 1998; Boehmer-Christiansen 1995). With reference to attitude, although four items were measured, three of them (energy for cooking, bio-fertiliser, environmental protection) significantly influenced intentions to use HEx for biogas while health risk had a negative and non-significant impact on intentions to use HEx for biogas. This suggests that individuals have perceived belief that the use of HEx for biogas has no significant health implications. This is supported by a study in Rwanda and Uganda where individuals with high benefit and low risk judgement will engage in HEx use regardless of the actual risks involved (Ekane et al, 2015). Additionally, this was confirmed by individuals' direct evaluation of perceptions concerning

HEx for biogas. Specifically, a minority of the people regarded HEx as dangerous and negative. These outcomes suggest that people have a positive attitude towards the use of HEx for biogas generation in Ghana and that interventions designed to promote HEx for biogas could highlight these four factors.

The results revealed that a subjective norm was a major factor to influence people's intentions to use HEx for biogas. For subjective norms, all four important referents (family, neighbours, religion and institution) had a significantly positive influence towards the use of HEx for biogas generation. This finding demonstrates that the judgement of significant others is important (Leeuw et al., 2015) with regards to the use of HEx for biogas generation. Of particular importance is religion (religious leaders), where a majority of people in Ghana consider their religious leaders as very important. For example, in Mthatha, in the Eastern Cape of South Africa, respondents were asked what they thought might work to change peoples' perception towards using HEx as fertilizer and soil conditioner in their gardens. The response was, leading by example by people with high standing seen using HEx and educational workshops by institutions, would be the best way to inform and change peoples' perception towards HEx use (Vuuren, 2008). For norm-based interventions to be effective, behavior of important others should be a focus, especially religious leaders.

The study revealed that all the four perceived behavioral control factors (cost, subsidy, stigma and HEx knowledge) significantly influenced HEx use intentions and this is consistent with previous study (Osei-Marfo et al, 2018). The mean score suggests that the participants perceive low controllability over HEx use. Thus an individual may be having positive attitude and normative disposition towards HEx use due to its significant benefits yet their volitional control would ultimately moderate their behavioral intentions and consequent behaviour. However, it appears that in spite of the significant benefits associated with HEx use, the high costs and maintenance coupled with lack of subsidy could contribute to low controllability to use HEx for biogas (Osei-Marfo et al, 2018). Per the Environmental Sanitation Policy (MLGRD 2010), households are responsible for financing their own household facilities, hence currently, there is no government subsidy on household biogas installations for HEx use. Nonetheless, the SESIP proposes the establishment of a national sanitation fund for addressing financing challenges. Furthermore, the SESIP encourages microfinance institutions to support government acquire more public financing for HEx management especially at the household level. For stigma and

HEx knowledge, it could be mitigated when people with high societal standing are seen using HEx coupled with HEx use campaigns by relevant institutions.

Therefore for perceived behavioural control to be effective, intervention designed in promoting the use of HEx for biogas generation should include financing and/or subsidies to reduce the cost implications, important persons in society leading HEx use campaigns to deal with stigma and relevant institutions educating the society on HEx use for biogas.

It was revealed that generally, there was a significant association between the study locations (CCMA and ANMA) which could be attributed to the unique demographic characteristics of these locations.

Additionally, it was shown that gender had no direct significant influence on intentions, but its effect is, however, significantly mediated through attitude (health risk and bio-fertiliser) and perceived behavioral control (stigma and HEx knowledge). This suggests that people believe that bio-fertiliser could be obtained for agricultural purposes, however, there appears to be some health concerns associated with using HEx for biogas. This is supported by previous study by Mariwah and Drangert (2011), that handling HEx is not a taboo but is rather perceived as an act of uncleanliness that may pose a health risk. Additionally, people were of the view that HEx knowledge and stigma could hinder individuals' intentions to use HEx for biogas. These results may provide indications for gender-specific intervention elements because, it was revealed that more female respondents had no education and few had tertiary education as compared to their male counterparts (see Table 5). This could influence their perceptions on the use of HEx for biogas generation and this is supported in previous studies (Jan and Akram 2018; Shane et al. 2015); higher education enhances one's ability to analyse and understand information.

For education, the results showed that there was no direct significant impact on intentions, rather, it was mediated through all the three predictors of intentions towards the use of HEx for biogas. In this study, effects of education on the positive outcomes of environmental protection and bio-fertilizer were significant. This suggests that ones' level of education is related to beliefs they form on HEx use for biogas, as it was observed that majority of the respondents had tertiary level of education. Again, the views of important others were key in the use of HEx for biogas and education had a significant effect on the perceived social pressure of the two most important referent, religion and institutions. It is worth noting that these two factors may play an important role in intervention designs. Furthermore, education had a significant link with stigma. This is an indication that stigma could prevent people from using HEx for biogas irrespective of their level of education.

Finally, the study revealed that participants showed strong positive perceptions about the use of HEx for biogas and as well, showed strong positive knowledge on the benefits that come with biogas in general. This might be due to advertisements on local radio stations and the display of posters about biogas technology.

These findings provide useful insight for designing appropriate interventions towards the use of HEx for biogas generation.

Conclusion

This study applied TPB in explaining people's perceptions on the use of HEx for biogas generation. Understanding people's perception on the use of HEx for biogas is important to promote the implementation of HEx use strategies. This study concludes that the adjusted model has better explanatory power and is a valid predictor of peoples' intentions to use HEx for biogas generation which is influenced by demographic profile (education and gender). This is an indication that there is the need for a critical look at the effect of socio-demographic characteristics in terms of promoting HEx use for biogas. Though attitude and subjective norms were positive, perceived behavioural control was low. This situation should inform authorities/policy-makers that interventions aimed at promoting HEx use for biogas should address low controllability and that should include government subsidy and financial support to deal with cost and subsidy, as well as education to address stigma and HEx knowledge. The intervention should also bring on board important persons such as religious leaders and persons from relevant institutions to lead more open discussions on HEx use for biogas.

Table 6: Cronbach's alpha, grand means, standard deviations, variable means and correlation between all variables.

Latent	Cronbach's alpha	Mean (SD)	Variables	Mean	Correlation matrix																
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Attitude	0.564	10.36^b (8.58)	1. Health risk	2.71	1																
			2. Environmental protection	12.01	-.020	1															
			3. Bio-fertiliser	12.88	-.085	.596**	1														
			4. Energy for cooking	13.82	-.067	.412**	.639**	1													
Subjective norms	0.706	11.47^b (7.67)	5. Family	11.04	.096	.198**	.237**	.256**	1												
			6. Neighbours	9.52	.036	.168**	.158**	.182**	.357**	1											
			7. Religion	10.67	.007	.339**	.374**	.314**	.397**	.546**	1										
			8. Institutions	14.65	-.130**	.390**	.505**	.447**	.249**	.270**	.449**	1									
Perceived behavioural control	0.771	0.44^b (11.10)	9. Knowledge	4.88	-.142**	.253**	.318**	.276**	.082	.122*	.186**	.322**	1								
			10. Stigma	1.70	-.103*	.199**	.228**	.187**	.142**	.083	.148**	.259**	.661**	1							
			11. Subsidy	-2.6	-.177**	.051	.056	.129**	.079	.148**	.089	.139**	.404**	.581**	1						
			12. Cost	-2.23	-.017	-.040	-.080	-.046	.041	.097*	.037	.020	.299**	.351**	.485**	1					
Intentions	0.863	5.76^a (1.58)	13. Make an effort	5.89	-.149**	.191**	.324**	.411**	.206**	.259**	.293**	.197**	.237**	.186**	.291**	.028	1				
			14. Intends	5.91	-.128**	.322**	.351**	.366**	.239**	.256**	.392**	.262**	.215**	.158**	.271**	.068	.744**	1			
			15. Have plans	5.85	-.053	.214**	.231**	.311**	.217**	.227**	.262**	.196**	.140**	.095	.232**	.045	.613**	.687**	1		
Background factors	-	-	16. Gender		.118*	-.064	-.105*	-.037	.010	-.027	-.095	-.034	-.117*	-.095	-.012	-.027	-.075	-.047	.039	1	
			17. Education		-.042	.104*	.101*	.057	.097	-.001	.108*	.126*	.072	.102*	-.015	-.043	.035	-.018	-.047	-.027	1

** Significant at $p < 0.01$; * Significant at $p < 0.05$; [a]Theoretical range = 1-7; [b]Theoretical range = -21 to 21

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Chapter 6

Dynamics of Household Heads' Intentions to Adopt Biogas Technology in Ghana

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Abstract

Evidence abounds that biogas technology has enormous health and environmental benefits, including improvement of community livelihood and health, sanitation, sustainable energy and reduced emissions. In spite of these benefits, intentions to adopt biogas technology are low among household heads in developing countries, notably Ghana. This study aimed to investigate the dynamics of household heads' intentions to adopt biogas technology, based on the theory of planned behavior. The study adopted an exploratory design and collected data from 394 household heads' using questionnaires. It was discovered that attitude, subjective norms and perceived behavioral control are significant predictors and independently contributed to predicting household heads' intentions to adopt biogas technology. Additionally, the study found that, the dynamics of ethnicity and education have a significantly direct effect on household heads' intentions to adopt biogas technology. The study recommends that respected persons in local communities, using different ethnic dialects, lead public education and awareness creation on the benefits of the use of biogas technology. Besides, government should subsidize the cost of biogas plants installation so as to promote its adoption rate.

Keywords: Biogas technology; Ghana; theory of planned behavior; household heads; ethnicity; education.

Introduction

Globally, energy is one of the key requirements needed to improve all aspects of human life. Many empirical studies have shown that energy drives the economic growth and development of societies (Energy Commission, 2006; Mengistu et al., 2016). The energy demand increase with increase in population that emanates from urbanization and industrialization, which is characteristic of most developing countries. However, most developing countries have to deal with limited access to energy often resulting from energy crises, reliance on unsustainable sources of energy such as fossils and firewood, and their attending effect on the environment (Amigun & Blottnitz, 2007).

Owing to this, experts in energy resources have suggested that exploring renewable energy resources and technologies will result in sustainable energy management (Brew-Hammond, 2010). Furthermore, the Advisory Group on Energy and Climate Change (AGECC) (2010) have proposed that the global community should be concerned with providing access to modern energy services by 2030. This places a clarion call on individuals, groups, academics, communities, non-governmental organizations (NGOs), civil society organizations (CSOs) as well as state and regional governments to make conscious efforts towards promotion of the use of renewable energy resources.

Biogas is a renewable energy that belongs to the biofuels category, which is obtained by the biological breakdown or decomposition of biodegradable matter in the absence of oxygen under controlled conditions. Its composition is largely methane (60-70%), carbon dioxide (30-40%) and other trace gases. Thus, biogas technology (BT) is a modern technique for processing organic waste from municipalities and industries into biogas and also, generating highly effective bio-fertilizer in the production process (Suslov & Kushchev, 2010). According to Amigun and Blottnitz (2010), biogas technology provides an attractive route for partially meeting energy needs, and consequently overcoming energy poverty and its attendant effects on economic development in Africa. Research shows that although the technology has been in existence for many decades, its adoption is either still at the infant stage or the dissemination rate is very low in most developing countries (Mengistu et al., 2015). Many experts and researchers consider BT as an excellent tool for improving human well-being, environmental quality, and macroeconomic benefits to societies. These benefits include improved sanitation, improved water quality, reduced indoor smoke, better lighting, reduced drudgery for women, generation of bio-fertilizer, conservation of resources (trees), reduced greenhouse gas emissions and creation of employment opportunities (Amigun & Blottnitz, 2010; Arthur et al., 2011; Bensah & Brew-Hammond, 2010; Rupf et al., 2015). As such, of the seventeen sustainable development goals (SDGs), nine of them have a direct relation to renewable energy (i.e. SDG's 1, 2, 3, 5, 6, 7, 8, 13, and 15), thus underscoring the importance of renewable energy for the growth and development of nations. In Ghana, it is pertinent to explore and tap into the enormous benefits of BT to help mitigate the intermittent energy crises and sanitation challenges that face the country, considering the fact that the waste stream in Ghana is mainly biodegradable. Excrement management including collection, transportation, disposal and treatment is a big challenge in Ghana. Studies have shown that even though collection and transportation have been consistent and seen improvement over the years, disposal and treatment are distressingly lagging behind (Ahmed et al., 2019; Boot & Scott, 2008) due to woefully inadequate treatment facilities. In extreme cases, excrement is discharged directly unto bare lands at dumpsites. According to Osei-Marfo et al. (2018), BT is gradually gaining popularity for excrement treatment at the household, institutional and industrial levels in Ghana. However, the authors further noted that the thrust has been low in spite of the known benefits of the technology. Just like implementation of any project, acceptance by the beneficiaries is vital to the success of the project. Accordingly, Michalisin et al. (1997) have noted that understanding the cognitive and motivational barriers, and dynamics of individuals who are unwilling to use a new technology could lead to improvement of efficiency and effectiveness. This emphasizes the extent to which intent affects adoption of a new technology by both individuals and communities. Several works have been conducted to assess factors that influence the adoption of BT using different approaches such as questionnaires, interviews, focus group discussions and other equally good methodologies (Mengistu et al., 2015; Gifford & Nilsson, 2014; Zheng & Yoshino, 2003). Most of the findings of these studies show a clear support for BT as an environmentally friendly technology that improves well-being, livelihood, provides bio-energy and reduces emissions. However, Gifford and Nilson (2014) argue that lifestyle and behavior pattern cannot change by simply transmitting knowledge. This implies that acceptance of a new technology by members in a community requires the involvement of influential personalities in the society, such as household heads. Therefore, Ajzen (2011) has noted that there is the need to identify the beliefs people hold towards an issue and how these beliefs affect their intentions and behavior rather than making sure people have accurate information. Although some studies have researched on what influences the behavior of households to adopt BT (Berhe et al., 2017; Jan & Akram, 2018; Mwirigi et al., 2018; Uhunamure et al., 2019), little is known about the dynamics of how Ghanaian household heads' intentions influence their decisions to either adopt or reject BT. Adoption and utilization of BT by households seem suitable for Ghana's waste characteristics, and considering the fact that the country has an average temperature of 30°C (Ghana Metrological Agency, 2019), which is suitable for facilitating anaerobic decomposition. However, for households to adopt BT depends largely on the decisions of the household heads. Using the Theory of Planned Behavior (TPB) model, this study aims at improving an understanding of the dynamics of the intentions, and in effect decisions of household heads in Ghana to adopt BT as an alternative method for managing biodegradable waste and also obtaining bio-energy and bio-fertilizer for domestic use and agricultural purposes. The study examines the reasons why household heads will want to adopt BT from religious, cultural, resource availability, family (important persons) and environmental quality points of view. The outcome of this study would be crucial for developing interventions aimed at promoting the adoption of BT and develop a model, which could be used by policymakers in Ghana and other developing countries.

Conceptual framework

The Theory of Planned Behavior (TPB) is a psychological theory used in predicting and explaining human behavior (Fig. 1). According to the TPB, an individual's behavior is guided by three considerations: Beliefs about the likely consequences of the behavior (behavioral beliefs), beliefs about the normative expectations of others (normative beliefs) and beliefs about the presence of factors that may facilitate or hinder the performance of the behavior (control beliefs). Behavioral beliefs produce a favorable or unfavorable attitude towards the behavior; normative beliefs produce perceived social pressure or subjective norms; and control beliefs end in perceived behavioral control (Fishbein & Ajzen, 1980). These three constructs, attitude towards the behavior, subjective norm and perceived behavioral control result in the formation of behavioral intention which may then lead into the actual action. The direct path linking perceived behavioral control to behavior, models the actual behavioral control. Thus the extent to which one has the skills, resources and other conditions suitable for the performance of a particular behavior. Hence, the successful performance of a behavior does not only depend on favorable intention, but also on a reasonable level of behavioral control (Ajzen & Fishbein, 2005). The model posits that people's attitudes towards behaviors are determined by their accessible beliefs about the behavior. In this case, belief is defined as the subjective probability that the behavior will produce a given outcome or experience. The expected outcome is assessed with the subjective evaluation of the outcome (Leeuw et al., 2015). Attitude, subjective norm and perceived behavioral control are obtained by the product of behavioral beliefs and outcome evaluations; normative beliefs and motivation to comply;

and control beliefs and perceived power to control respectively. The behavior of interest in this study is household heads intention to adopt BT, which is the willingness to accept BT as an alternative method for managing domestic waste. Based on the considerations of TPB, the household head's consideration to adopt BT looks at waste reduction, emission reduction and energy source. Thus, when household heads believe that adopting BT produces positive outcomes, they will have favorable behavior. On the other hand if they think otherwise, the behavior will be unfavorable. The household head's social norms refers the pressure of influencing or level of acceptance to adopt BT from important referents such as family, friends, neighbors, experts and fire personnel. The household head's perceived behavioral control refers to the ability to adopt BT, thus whether it will facilitate or impede the behavior Leeuw et al., 2015; Ajzen, 1991; Ajzen, 2006). Ajzen (2006) argued that an individual's intention to adopt BT becomes stronger if attitude and subjective norm are favorable with regard to the behavior (BT adoption) and perceived behavioral control is greater. Structural equation modeling (SEM) was used to analyze the predictive strength of these variables and to examine the relationship between the variables and the intentions of the household heads to adopt BT. There are many behavioral theories that have been successfully used to address human behavior, however, since accepting and adopting BT as an alternative method for waste management appears to be a reasoned act, TPB seems to be useful and best option (Lee et al., 2010).

Methodology

This study was cross-sectional conducted in two peri-urban and urban communities in Cape Coast Metropolitan Area, Central and Accra Metropolitan Area, Greater Accra regions of Ghana. Central and Greater Accra regions were selected due to their cosmopolitan nature. These areas have a blend of rural, peri-urban and urban settlements with different cultural and ethnic groupings. Data for the study was gathered using a random sampling technique. The study used the TPB to assess the predictive power of the theory's constructs on household heads' intentions to adopt BT as an alternative method for waste management.

Pilot study

The study began with an elicitation for accessible beliefs from a sample of respondents prior to designing the TPB questionnaires. A pilot study was conducted among local residents in the study areas involving 108 respondents (40 females, 68 males). This involved an open ended questionnaires administered to capture their readily accessible beliefs about adopting biogas technology. It was explained that their opinions about adopting biogas technology were being sought so they should write whatever comes to mind. They were specifically asked to write their opinion on: (a) the advantages and disadvantages of adopting biogas technology as an alternative method for waste management, (b) to state the persons or groups of people who would approve or disapprove of their actions of adopting biogas technology as an alternative for waste management, (c) the factors that could either facilitate or prevent them from adopting biogas technology. Subsequently, a content analysis of the responses was conducted to ascertain frequencies of responses. The most frequent responses were included in the development of the TPB questionnaires. This was done by tallying the number of a particular response given (Fishbein & Ajzen, 1980; Leeuw et al., 2015). A pre-test of the questionnaire was conducted among 118 local residents in the study area prior to the main study. The pre-test was conducted to test the consistency, clarity, understandability and psychometric properties of the questionnaires.

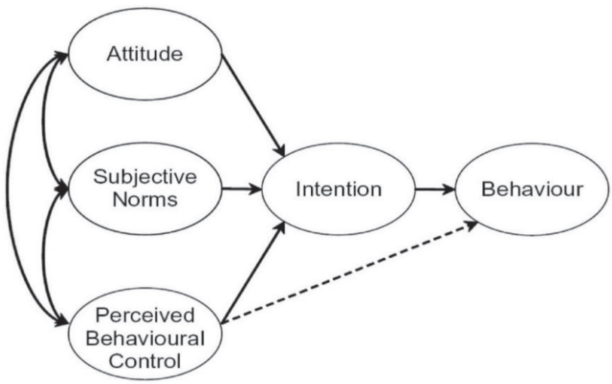

Fig. 1 The Theory of Planned Behavior model (Ajzen, 2006)

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The questions were then modified to correct any ambiguous wordings. A Cronbach’s alpha of .685 was obtained, indicating that the scales were adequate.

Main study

The study was conducted in July-September 2017 and members within the study area were approached by the researcher to inquire for their consent to participate in the study. Before administering the questionnaire, the aim of the study was explained to the participants. The questionnaire had two sections: demographics for the first section and the TPB constructs for the second section. The items in the second section were measured on a 7-point Likert scale.

Six trained research assistants supported respondents who had difficulty in answering the questionnaires. The questionnaires were administered in an ordinary house setting.

Questionnaires

Attitude (A)

Attitude was measured with three items using behavioral beliefs and their outcome evaluations. The questions in the questionnaire assessed the advantages and disadvantages of adopting BT. The salient beliefs identified include emission reduction, waste reduction and energy source.

Subjective norms (SN)

Subjective norm was measured using normative beliefs and their motivation to comply. A total of five items were used to assess respondent's normative beliefs and their motivation to comply. Respondents were asked to rate particular important people in their lives who would approve or disapprove of their adoption of BT and whether their opinion had any influence on their decision to either adopt or not to adopt BT.

Perceived behavioral control (PBC)

Perceived behavioral control was measured with three items using control beliefs and power of control factors. The questionnaire assessed the factors which may enable or prevent respondents' ability to adopt BT.

Intentions (I)

The intentions of participants were measured using three items. They were asked to indicate if they will make effort, if they intend and if they have plans to adopt BT.

Demographics

The demographic information of respondents was obtained with five items specified in Table 1, reporting gender, age, education, ethnicity and religion.

Background factors: ethnicity and education

According to Ajzen (2011b), background factors such as gender, age, ethnicity, education, income, nature of personality have the potential to influence the beliefs people hold. In order to further understand what could influence household heads' reasons for adopting BT, the potential impact of ethnicity and education were examined. It seems likely that ethnicity and education could influence the intentions of household heads in adopting BT hence these background factors were considered relevant in this study. Additionally, other studies have documented significant impacts of ethnicity and education on the adoption of BT (Mengistu et al., 2016; Berhe et al., 2017; Shane et al, 2015), therefore gaining further insight will be useful for this study.

Statistical analysis

During the study, 645 people were approached but responses were received from 438 people (68% response rate). The questionnaires that had any item vacant, was not included in the analysis, therefore 394 completed responses were coded and saved into IBM SPSS version 23. The TPB constructs were analyzed using factor analysis with SEM using SPSS Amos 23 with maximum likelihood estimation. The analyses were performed in two stages. First, the standard or original TPB model was tested for BT adoption. Second, to better understand the extent of influence ethnicity and education have on intentions, these background variables were introduced into the model (Mengistu et al., 2016; Berhe et al., 2017; Shane et al, 2015).

Descriptive analysis of variables

The study framework contains three exogenous and one endogenous variables. Each variable had Cronbach alpha value above .60 as recommended by Hair et al. (2010) and Samuels (2015). A composite variable of each belief was obtained by multiplying each belief statement by its corresponding belief evaluation. Assessment of the model was done by using sample size independent fit indices such as normed fit index (NFI), Tucker-Lewis index (TLI), comparative fit index (CFI) and root mean square error of approximation (RMSEA) (Hooper et al., 2008; McDonald & Ho, 2002). Cangur & Ecran (2015), and Hox & Bechger (1999) have suggested that acceptable values for NFI, TLI and CFI should be at least .90 while values above .95 are classified as excellent, and RMSEA values smaller than .08 classified as acceptable while values less than .06 classified as excellent.

Results

Demographic characteristics

The demographic profile of the respondents is presented in Table 1. The respondents’ ages ranged between 20 to above 60, with 31 - 40 (39.1%) being the majority. The descriptive statistics indicate that the respondents were dominated by males (76.6% male), which is a representation of household heads in the study area. The majority of the respondents had tertiary education (33.5%), implying their understanding of the questionnaire, and this is slightly above basic education (32.0%), which might pose a challenge of understanding the questionnaire. The majority of respondents were Akans (58.9%) and Christians (84.8%), reflecting the predominant ethnic group and religion in Ghana respectively (GSS, 2012).

Descriptive statistics of variables

Participants (n = 394) showed relatively strong behavioral intentions (M = 5.86, SD = 1.57), favorable attitude (M = 12.70, SD = 8.57), moderately high social pressure (M = 11.31, SD = 7.30) and negative controllability (M = -9.50, SD = 8.38) to adopting biogas technology. Additionally, Pearson's correlation matrix displayed in Table 2 indicates that just about all the TPB variables are significantly associated with intentions. The inter-item correlation varies from .135 to .392. From the results, it is clear that the significant predictors of household heads BT adoption intentions were attitude and social pressure. Perceived behavioral control, however, showed a negatively weak effect on intentions to adopt BT by household heads.

Table 1: The demographic profile of respondents (N = 394)

Demographics	Frequency	Valid percentage
Gender:		
Male	302	76.6
Female	92	23.4
Age:		
20-30	25	6.3
31-40	154	39.1
41-50	114	28.9
51-60	94	23.9
Above 60	7	1.8
Education:		
No formal education	58	14.7
Basic	126	32.0
Secondary	78	19.8
Tertiary	132	33.5
Ethnicity:		
Akan	232	58.9
Ewe	56	14.2
Northern	71	18.0
Ga-Adangbe	35	8.9
Religion:		
Christianity	334	84.8
Islam	49	12.4
Traditional	11	2.8

The standard TPB model

The standard TPB model for BT adoption by household heads is shown in Fig. 2. According to the test, this model accounted for 32% of the total variance in household heads' behavioral intentions to adopt BT. The model's fit indices (RMSEA=.080; NFI=.878; CFI=.908; TLI=.883) indicated a mediocre fit to the data. Following the classification suggested by

Cohen (2013) classification, the standardized estimates showed that attitude (A) ($\beta = .265$, SE = .016, $p < .001$) had a moderate but significant influence on intentions, subjective norm (SN) ($\beta = .478$, SE = .032, $p < .001$) had a strong and significant influence on intentions while perceived behavioral control (PBC) ($\beta = .246$, SE = .019, $p = .005$) had a moderate but significant effect on intentions to adopt BT. Furthermore, the direct relationships between the composite beliefs and the TPB latent variables were all high (βs range from .687 to .865, $p < .001$). This is an indication of high influence on respondents' latent variables on BT adoption. With regards to the effects between the latent variables, attitude and subjective norm showed significantly positive effect ($\beta = .627$, SE = 2.447, $p < .001$), whereas both subjective norm and perceived behavioral control, and attitude and perceived behavioral control showed significantly negative effects ($\beta = -.589$, SE = 2.061, $p < .001$) and ($\beta = -.469$, SE = 2.302, $p < .001$) respectively. The positive value indicates that as social pressure increases, a positive attitude toward intention to perform the behavior also increases. On the other hand, the negative values indicate that when household heads perceive that controllability is difficult, social pressure may be of no importance and consequently a negative attitude may be developed towards adoption of BT.

Effects of beliefs

The beliefs were examined to determine their effects. The three behavioral beliefs explained 59.7% of variance in attitude towards BT adoption by household heads. These beliefs were "adopting biogas technology will help me reduce pollution/emission", "adopting biogas technology will help me reduce the volume of waste to the landfill/dumpsite/treatment plant" and "adopting biogas technology will provide me with energy source". The effect of these include: emission reduction ($\beta = .66$, $p < .001$); waste volume reduction ($\beta = .89$, $p < .001$); and energy source ($\beta = .71$, $p < .001$).

The five normative beliefs explained 73.4% of the variance in subjective norms towards intention to adopt BT. These normative beliefs were "my family will approve of me adopting biogas technology", "my neighbors will approve of me adopting biogas technology", "my friends will approve of me adopting biogas technology", "environmental experts will approve of me adopting biogas technology" and "fire personnel will approve of me adopting biogas technology". The effects of these beliefs on intentions to adopt BT is family ($\beta = .47$, $p < .001$).

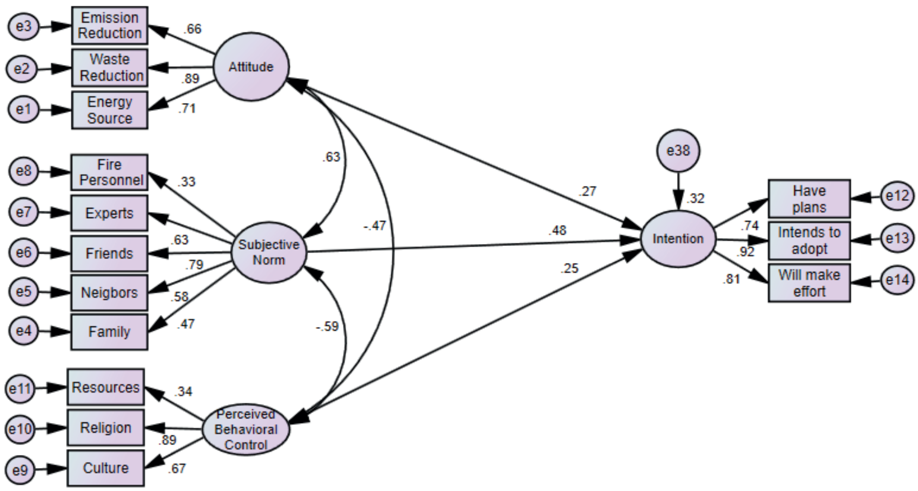

Fig. 2 Intention to adopt biogas technology

Modified TPB model: effects of ethnicity and level of education

In the modified TPB model, ethnicity and level of education were introduced as background factors (Fig. 3). Results indicated an acceptable model fit for intentions to adopt BT (RMSEA=.071; NFI=.946; CFI=.965 TLI=.952) and explained 33% of the variance towards adoption intentions. Level of education had both direct (β = .130, SE = .060, p = .013) and indirect significant positive effect on intentions to adopt BT; thus level of education had direct effect on all three factors of attitude: emission reduction (β = .206, SE = .389, p < .001), waste reduction (β = .190, SE = .382, p < .001), and energy source (β = .118, SE = .343, p = .013), all five factors of subjective norms: family (β = .130, SE = .385, p = .007), neighbors (β = .137, SE = .327, p = .004), friends (β = .135, SE = .322, p = .003), experts (β = .223, SE = .292, p < .001) and fire personnel (β = .133, SE = .252, p = .007) and one factor for perceived behavioral control: resources (β = -.111, SE = .453, p = .020). For ethnicity, it had only a direct significantly negative effect on intentions to adopt BT (β = -.115, SE = .056, p=.014). Only significant paths have been shown to avoid overloading the figure.

Discussion

This study tested the suitability of the use of the TPB framework to understand the dynamics of the intentions of household heads to adopt BT in Ghana. The results of this study confirm that all the constructs of the model, attitudes, subjective norms and perceived behavioral controls accounted for the proportion of variance in the dynamics of intentions to adopt BT. In terms of model comparison, the use of SEM revealed a mediocre fit for the standard TPB and an acceptable fit upon introduction of background factors (ethnicity and education) to the standard TPB model. The introduction of ethnicity and education improved the model by an insignificant difference in the variance towards the dynamics of intentions to adopt BT. It was realized that ethnicity had a direct significantly negative influence towards intentions and this is supported by previous research (Shane et al., 2015). This demonstrates that an individuals' ethnic background do matter when it comes to decisions relating to BT adoption, and this may negatively influence intentions towards the technology. However, education had both direct and indirect significant effect towards dynamics of intensions to adopt BT. This finding is consistent with (Jan & Akram, 2018). Education influences intentions indirectly by mediating through all factors of attitude, subjective norms, and perceived control through only resources. This suggests that one's level of education plays a key role towards intentions to adopt BT. Studies have shown that analytical capability of information and understanding of a technology are all linked to a person's level of education (Jan & Akram, 2018; Shane et al., 2015). Therefore, the level of education will inform the level of comprehension of biogas technology and consequently its adoption. The dynamics of household heads intentions to adopt BT appears to be influenced to a large extent by ethnicity and the educational level. Highlights of the specific beliefs and factors that impacted largely respondents' dynamics of intentions to adopt BT are worth noting. It was revealed that intentions to adopt BT was affected by three behavioral beliefs (emission reduction, waste reduction and energy source), five normative beliefs (family, neighbors, friends, environmental experts and fire personnel) and one control beliefs (resources).

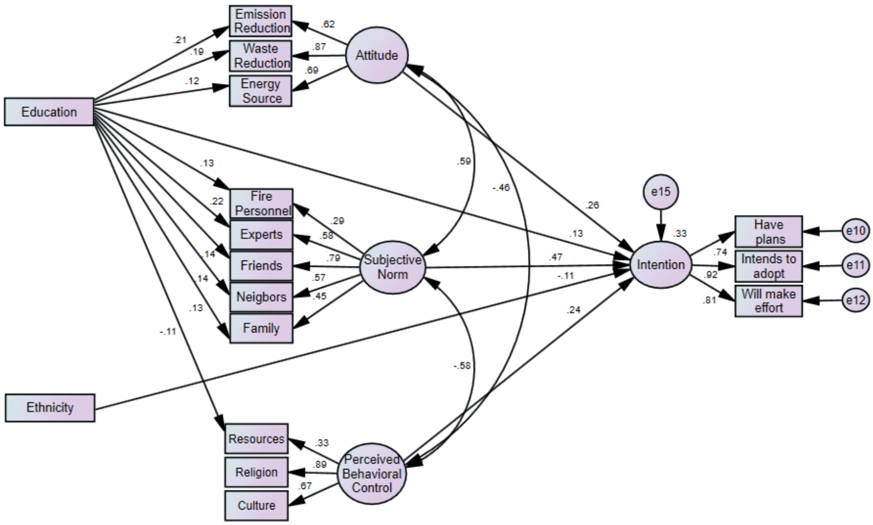

Fig. 3 Modified TPB model depicting effect of education and ethnicity on intentions to adopt biogas technology
Note: to avoid overloading the figure, only significant paths are displayed

For behavioral beliefs, it was observed that emission reduction, waste reduction and energy source played a role in significantly influencing intentions to adopt BT which is supported by previous studies (Berhe et al., 2017; Jan & Akram, 2018; Shane et al., 2015). The use of BT and its associated benefits cannot be over emphasized. It was realized that respondents had a positive attitude, considering the fact that the use of a technology will consequently reduce emissions into the atmosphere, reduce waste volumes to landfill/dump sites and above all provide renewable energy for domestic purposes, which in effect will reduce the cost for buying energy. Thus respondents were interested in the quality or improvement of the environment. This suggests that interventions targeted at encouraging household heads to adopt BT would be highly effective if these benefits (emission reduction, waste reduction and energy source) are emphasized. With regards to subjective norms, it was revealed that family, neighbors, friends, environmental experts and fire personnel were all having significant effect on intentions to adopt BT and this is consistent with similar study by Leeuw et al. (2015). It was revealed that respondents have reverence for people they consider important in their lives and that the opinions of these important people could influence their intentions of adopting BT. These findings suggest that when designing interventions aimed at encouraging household heads to adopt BT, family members, neighbors, friends, experts and fire personnel add up to the dynamics and they could be involved to facilitate or play key role in the campaign for BT adoption. Nonetheless, for perceived behavioral control, only resources had a significant influence on intention dynamics to adopt BT and this is supported by a similar study (Osei-Marfo et al., 2018). It was revealed that respondents showed moderately negative control towards intentions to adopt BT. The initial investment cost for the installation of a biogas plant, periodic maintenance cost, the capacity of service providers (human resource) are examples of perceived control factors which negatively influence household heads intentions to adopt BT as reported by Osei-Marfo et al. (2018). The outcome suggests that even if the respondents have a positive attitude towards BT adoption, but the required resources that will enable adoption are lacking or inadequate, behavioral intentions could be negatively influenced as revealed in this study. This is an indication that interventions designed to motivate household heads to adopt BT may have to outline and address the required resources that are perceived to be lacking or inadequate.

Limitations

Theoretically, this study examined the dynamics of household heads intentions to adopt BT. It is possible that the respondents may have been biased with their responses since motivational factors on the actual behavior were excluded. Secondly, the research was conducted in only Central and Greater Accra regions of Ghana, hence the model should be tested in the other regions of Ghana to allow for generalizations. Lastly, the sample size and the sampling technique is another limitation. Selection biases may have been introduced.

Conclusions

This paper concludes that the use of belief-based TPB model supports the prediction of intentions to adopt BT by household heads in Ghana. Attitude, subjective norms and perceived behavioral control were identified to be the determinants that influence household heads intentions to adopt BT, hence, designing interventions should be based on the dynamics indicated in this study. Furthermore, perceived behavioral control had significantly negative effect on intentions, hence, it is important to outline suitable measures to correct or control the beliefs of people. These findings could serve as a guide for policymakers to help increase the rate of the adoption of biogas technology in Ghana and other developing countries.

The study outcomes lead to the following interventions:

- Respected persons in local communities, using different ethnic dialects, should lead public education and awareness creation, highlighting the benefits of biogas technology;

- Government should subsidize the cost of biogas plant installations, especially for those who cannot bear the full investment cost so as to promote its adoption rate, and consequently deal with lack of or inadequate resources.

Table 2: Cronbach's alpha, grand means, standard deviations, variable means and correlation between all variables

Latent	Cronbach's Alpha	Mean (SD)	Variables	Mean	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Attitude	.782	12.70 [a] (8.57)	1 Emission reduction	11.78 [b]	1													
			2 Waste volume reduction	12.67 [b]	.598**	1												
			3 Reliable energy source	13.66 [b]	.411**	.628**	1											
Subjective Norm	.692	11.31 [a] (7.30)	4 Family	10.93 [b]	.197**	.238**	.259**	1										
			5 Neighbors	9.53 [b]	.172**	.167**	.192**	.375**	1									
			6 Friends	10.52 [b]	.338**	.376**	.314**	.401**	.541**	1								
			7 Environmental experts	14.44 [b]	.378**	.497**	.441**	.243**	.279**	.444**	1							
			8 Fire personnel	11.14 [b]	.220**	.315**	.251**	.116*	.129*	.204**	.312**	1						
Perceived Behavioral Control	.641	-9.50 [a] (8.38)	9 Culture	-12.86 [b]	-.155**	-.257**	-.206**	-.019	-.138**	-.256**	-.321**	-.074	1					
			10 Religion	-13.00 [b]	-.256**	-.367**	-.272**	-.139**	-.283**	-.430**	-.430**	.105*	.606**	1				
			11 Resources	-2.64 [b]	-.227**	-.351**	-.236**	-.208**	-.129*	-.203**	-.307**	-.176**	.239**	.274**	1			
Intentions	.863	5.86 [b] (1.57)	12 I will	5.87 [a]	.193**	.308**	.392**	.215**	.270**	.298**	.194**	.135*	-.055	-.135**	-.255**	1		
			13 I intend	5.89 [a]	.319**	.341**	.355**	.238**	.259**	.388**	.252**	.201**	-.011	-.151*	-.231**	.746**	1	
			14 I have plans	5.82 [a]	.206**	.218**	.298**	.213**	.234**	.256**	.183**	.175**	.036	-.047	-.144**	.612**	.683**	1

*=p<0.05 level, **=p<0.01 level

[a] *Theoretical range = -21 - 21*

[b] *Theoretical range = 1 -7*

7

Chapter 7

Institutional involvement and collaboration in disseminating biogas technology in Ghana

Submitted as:
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Institutional involvement and collaboration in disseminating biogas technology in Ghana

Abstract

Globally, biogas technology has been touted by academics, international organizations, United Nations, pressure groups among others, as an effective tool for protecting the planet against degradation. As such, stakeholders in the biogas technology sector have made some policy recommendations to that goal. These include a global campaign in support of energy for sustainable development, climate financing by the international community, all countries adopting appropriate national strategies, innovative financial mechanisms, and encouraging private-sector participation in achieving the goal. Obviously, for countries to promote the accessibility and create favorable perception on the adoption of biogas technology requires institutional involvement and collaboration. That is, institutions need to participate and contribute in terms of ideas and expertise as well as work together to ensure the dissemination and uptake of biogas technology in Ghana.

The aim of this study is to assess the level of institutional involvement and collaboration, and barriers to biogas technology dissemination in Ghana. A qualitative method was employed and data collected from 101 respondents through interviewing. The results indicated that involvement of government and financial institutions in disseminating biogas technology was low whiles biogas service providers showed moderate involvement. With regards to collaboration, it was revealed that institutions moderately collaborate in awareness creation but had low collaborations for promotion, monitoring and evaluation. Furthermore, the lack of a national biogas policy, low government commitment towards biogas technology and low financial support were key barriers to effective institutional involvement and collaboration in disseminating biogas technology in Ghana. It is recommended that government shows a high commitment by providing the needed resources for dissemination activities and also task the Ghana Energy Commission to formulate a national biogas policy to facilitate dissemination and adoption. Finally, a national biogas steering committee composed of all relevant stakeholders, including the Finance Minister or a representative from the Finance Ministry would create a good platform to help champion the dissemination of biogas technology in Ghana.

Key words: institutional involvement; collaboration; government institutions; biogas service providers; financial institutions; biogas technology

Introduction

The use of biogas technology for the production of clean energy has been touted by academics, international non-governmental organizations (NGOs), United Nations, pressure groups among others all around the world. In the United Nations (UN) sustainable agenda for 2030, the UN has expressed strong determination to protect the planet from degradation through sustainable consumption and production, sustainable management of natural resources, and taking urgent actions in response to climate change with the ultimate goal of supporting the needs of the present and future generations (UN, 2015). According to UNDP & WHO (2009) about 3 billion people worldwide rely on traditional biomass for cooking and heating, which is alarming to the sustainability of the planet.

In Sub-Saharan Africa, extant research indicates that a very high proportion of the population relies on traditional biomass (firewood) for domestic energy, citing Burkina Faso, Liberia and Tanzania where over 95% of the populations rely on firewood for cooking and heating (Brew-Hammond, 2010). The felling of trees for firewood without corresponding tree-planting projects does not only degrade the planet but also, it has great implications for climate change. For example, the use of firewood is a significant source of greenhouse gas emissions with its attendant health problems as a result of the exposure to smoke (Bhattacharya & Salam, 2002).

In Ghana, almost 50% of the nation's energy consumption is for residential purposes, with about 76% of residents using firewood for cooking and related purposes (Energy Commission, 2006). This high use of biomass has been associated with the country's rising levels in atmospheric carbon dioxide. For instance, studies show that carbon dioxide emissions rose from 7.7 million tonnes in 2000 to 16.8 million tonnes in 2019 due to biomass energy usage (World Data Atlas) (Energy Commission, 2006). These statistics suggests that a considerable proportion of the Ghanaians population does not use sustainable energy, and thus clearly indicates how unregulated means of energy consumption could have adverse consequences on the economy as well as the environment.

In view of this, the Advisory Group on Energy and Climate Change (AGECC) has proposed that the global community should focus on providing access to modern energy services by 2030 (AGECC, 2010). Accordingly, some actions have been recommended to help achieve this goal including a global campaign in support of energy for sustainable development. All countries prioritize this goal through the adoption of appropriate national strategies, providing innovative financial mechanisms, climate financing by the international community and encouraging private-sector participation in achieving the goal etc. (AGECC, 2010).

To address energy and related socio-economic and environmental challenges, the development and dissemination of biogas technology (BT) offer a promising intervention. Nonetheless, the use of BT is still at its infant stage in Ghana despite the fact that the technology was introduced some three decades ago (Bensah et al, 2011). According to Bensah et al (2011) there is a market potential for the installation of 16,207 household biogas plants in Ghana, meanwhile, Hanekamp & Ahiekpor (2015) have noted that at least 400 biogas installations have been constructed throughout Ghana, thus calling on the government to establish a national biogas programme. Evidence from the above empirical studies clearly indicates that biogas technology has been underutilized in Ghana.

Additionally, Arthur et al. (2011) have stated that about 815,109 m^3 of biogas from sewages of four public universities in Ghana annually, which is equivalent to 4,891MWh of energy can replace 4,532 tonnes of firewood. While the government of Ghana sought to achieve 2% penetration of biogas for cooking in hotels, restaurants and institutional kitchens by 2020 (Energy Commission, 2006), Brew-Hammond (2010) argues that to get near that target, a significant increase in the number of stakeholders, together with more effective institutions in the renewable energy sector will be required. Other empirical studies have indicated that government incentives, long term financing and capital grant contribute to the growth/dissemination of BT, especially when government recognizes BT as a tool for reducing greenhouse gas emissions and a means of using less fossil fuels (Sok, 2012; Ministerie van LNV et al, 2007; Mittal et al. 2018).

Specific to Ghana, biogas technology related research has focused mainly on biogas dissemination in Ghana (Bensah & Brew-Hammond, 2010); biogas as a potential renewable energy source (Arthur et al., 2011); prospects for household biogas plants (Bensah et al., 2011); biogas generation from sewage (Arthur et al., 2011); and feasibility study to establish institutional biogas system (Hanekamp & Ahiekpor, 2015). There is, however, no empirical study focusing on institutional involvement and collaboration in disseminating BT in Ghana during the period of this work. This study therefore explores the level of institutional involvement and collaboration, and barriers to the dissemination of biogas technology in Ghana.

Institutional arrangement

The term institutional arrangement has been widely defined and used by several researchers in different fields, yet there has not been a full consensus on its definition among scholars. For some researchers, institutional arrangement is comparable to markets, states, corporate hierarchies, networks, associations and communities (Hollingsworth et al., 1994; Hollingsworth and Boyer, 1997). Similarly, Eaton et al. (2008) refer to institutional arrangement as a set of rules or agreements governing the activities of a specific group of people pursuing a certain objective. In the view of the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM), institutional arrangement refers to the formal government organizational structures as well as informal norms which a country put in place for arranging and undertaking its policy work (UN-GGIM, 2017).

This organizational structure makes use of informal institutions such as the general public, non-government organizations and private sector groups. According to Hodgson (2006), such institutions are characterized by: their own established criteria to define their boundaries of influence, as well as differentiate their members from non-members; specific lines of command with clear accountability; defined members responsibilities, rules and regulations to be followed by all members and a clear set objectives to be achieved (Mengistu et al., 2016).

This study, therefore defines institutional arrangement as organizational structures, both formal government institutions and private sector groups (biogas service providers and financial institutions) which are in place to facilitate the dissemination of BT in Ghana.

Government institutions

Government institutions refer to the relevant government bodies that have been tasked by law to collaboratively see to the development, promotion, management and utilization of renewable energy (PRGH, 2011) in Ghana. These relevant institutions include but are not limited to the Energy Commission (EC), Environmental Protection Agency, Ghana (EPA), Ministry of Food and Agriculture, Ministry of Environment, Science, Technology and Innovation (MESTI), Metropolitan, Municipal and District Assemblies (MMDAs) of Local Government, Ministry of Sanitation and Water Resources (MSWR) and Ghana National Cleaner Production Centre (GNCPC).

According to the Renewable Energy (RE) Act 2011, these relevant institutions shall collaborate with the Energy Commission in the exercise of its powers and performance of its functions, dissemination of renewable energy.

Biogas service providers

Biogas service providers refer to individuals and institutions that have registered with Biogas Association of Ghana (BAG). The formation of BAG was initiated by Energy Commission of

Ghana, Environmental Protection Agency, Ghana, and Ghana National Cleaner Production Centre (GNCPC) in 2017. The objective is to carry out, encourage and support research into BT and to ensure the development of quality standards by training actors in the industry based on modern approved practices (Daily Graphic, 2017). The association is also to ensure creating awareness of the benefits of BT in Ghana. Membership of BAG stood at 66 (38 registered individual members and 28 company members). BAG, which is supposed to be coordinating the activities of its members is a non-for-profit institution and solely depends on the support of donor agencies to run its activities. However, biogas service providers operate purely on business grounds and are important stakeholders in the dissemination of BT in Ghana.

Financial institutions

Research has shown that financial institutions are key stakeholders in the promotion of BT (Arthur et al., 2011; Bensah et al., 2011; Berhe et al., 2017; Osei-Marfo et al, 2018), and for that matter, are considered to be relevant in assisting in the articulation and functioning of institutions mandated for the deployment of BT. In India, for example, the Ministry of Finance, banks and other financial institutions form part of the committees responsible for biomass energy policies and strategies for deployment and execution (Singh & Setiawan, 2013). Similarly, in Burkina Faso, the Ministry of Finance and Economy is an active member of the steering committee for the National Biodigester Programme, which sees to the promotion and construction of biogas plants (World Bank, 2019). The formulation of such committees brings about better collaboration between financial institutions and all BT stakeholders.

However, Ghana is yet to have such a committee on national biogas programme. It is high time Ghana adopted either Burkina Faso or India’s model of involving the Ministry of Finance in BT steering committee, so as to get the financial institutions on board to support BT development. List of some of the financial institutions that participated in this study include: GCB Bank, National Investment Bank (NIB), Zenith Bank, Fidelity Bank, ADB Bank, Prudential Bank, etc.

Institutional involvement and collaboration

Extensive research conducted over the years highlights the value of institutional involvement and collaboration (Osei-Marfo et al, 2018; Bensah and Brew-Hammond, 2010). This study defines institutional involvement as the participation and contribution by both government and private organizations in terms of ideas and expertise to facilitate the diffusion or dissemination of BT in Ghana while collaboration is the process by which government and private organizations work together to ensure the dissemination and uptake of BT in Ghana.

Benefits of institutional involvement and collaboration are numerous including subsidies and credit arrangements, manuals and guidelines, training and supplies of spare parts (Mengistu et al, 2016). Other benefits involve maintenance services, monitoring and evaluation services (Osei-Marfo et al, 2018), supervision services, and research and development (Mengistu et al, 2016).

Strategies to foster significant institutional involvement and collaboration include establishing a biogas programme with full government support, ensuring financial flow mechanism, encouraging and facilitating private sector coordination (World Bank, 2019) and establishing a regulatory body for biogas service providers (Osei-Marfo et al, 2018).

Nonetheless, institutional involvement and collaboration is almost non-functional despite the mandate or task assigned to relevant government institutions by the Renewable Energy Act 2011, especially for biogas technology development. Additionally, due to size and quality of human resources, an institutional structure on renewable energy seems to be established mainly at the national level (Mengistu et al, 2016), making the activities at the regional and district level more challenging. Furthermore, one other barrier to institutional involvement and collaboration is dissemination tools (Bensah et al, 2011; Bensah & Brew-Hammond, 2010). Thus little or no resources are available for undertaking their activities.

Feasibility of biogas technology

Globally, about 50 million biogas plants have been installed with the majority of these plants located in Asia, with concentrations in China, Nepal, India, Bangladesh, Vietnam and Cambodia (Clemens et al, 2018). In sub-Saharan Africa, the dissemination, to date, has been more limited, even though East Africa has made good progress (Ethiopia and Kenya have almost 21,000 units each), and in West Africa, Burkina Faso has over 12,000 units installed (Hivos-ABPP 2018 production data). Yet according to Heegde and Sonder (2007), a study conducted by Netherlands Development Organization (SNV) and International Institute for Agriculture revealed that, cooking with biogas is technically feasible for 18.5 million households and consequently, benefiting about 150 million people in sub-Saharan Africa. Nonetheless, various barriers hinder the dissemination and scale up of biogas technology across the African continent (World Bank, 2019). In Ghana, at least 400 known biogas plants have been installed (Hanekamp & Ahiekpor, 2015), with the predominant design being fixed-dome, floating drum and the Puxin type. Improvement to sanitation challenges and search for alternative energy sources have been the main motivation for building biogas plants (Osei-Marfo et al., 2018). Studies have shown that a majority of the existing biogas plants, especially those meant for energy source, did not meet the expectations of its users (Ahiataku-Togobo & Owusu-Obeng, 2016; Bensah & Brew-Hammond, 2010; Osei-Marfo et al., 2018). On the other hand, biogas plants built for sanitation improvement are functioning well (Hanekamp & Ahiekpor, 2015; Osei-Marfo et al., 2018). Both Hanekamp & Ahiekpor (2015) and Osei-Marfo et al. (2018) have indicated that biogas technology is technically feasible in Ghana, citing unstandardized digester design and quality control of digester design, lack of monitoring during construction, lack of maintenance, lack of follow-up by relevant institutions as key setbacks to the technology. It is imperative to note that, key to ensuring the sustainability of a biogas plant largely depends on the financial commitment on the part of users towards undertaking periodic maintenance of the system throughout the plant's lifetime. Osei-Marfo et al. (2018) found that most plants are left to the mercies of the weather once constructed, yet users expect optimum yield.

Policies and institutional framework on renewable energy

Renewable energy policies in Ghana were initially developed in response to energy crises in the early 1980s, when there was a major drought, resulting in reduced inflows to the Volta hydropower reservoir (Energy Commission, 2006). This crisis adversely affected the overall performance of the economy, hence, it became government's priority to develop policy and to set up a working group to address the energy issues. Apparently, there was the need to explore other renewable energy sources to augment the hydropower due to the crises. Since the 1980s to present, successive governments as well as development partners have supported to promote renewable energy technologies in Ghana through policies, plans and strategy documents. A list of major policies, plans and strategy documents that have been developed since 1986 include Issues and Options in the Energy Sector (1986); National Electrification Scheme (1989); Vision 2020 (1995); Ghana Poverty Reduction Strategy (GPRS) (2003); National Renewable Energy Strategy (NRES) (2003); Growth and Poverty Reduction Strategy (2006); ECOWAS White Paper on Access to Energy Services (2006); Strategic National Energy Plan (SNEP) (2006/2020); Ghana Shared Growth and Development Agenda (GSGDA) I & II (2009/2014); National Energy Policy (2010); Energy Sector Strategy and Development Plan (2010); Renewable Energy Act, 2011 (Act 832); Sustainable Energy for

All Action Plan/Agenda of Ghana (2012/2016); Mini-grid Electrification Policy (2016), Bioenergy Policy (Draft) (Government of Ghana, 2018) and Renewable Energy Master Plan (2019).

In spite of all these policies, the main goal of the renewable energy sub-sector, which was to increase the proportion of renewable energy supply mix by 10% by 2020 and to contribute to the mitigation of climate change, is yet to be achieved.

With regards to all the policy documents, Vision 2020 (1995) sets strategic targets to encourage pursuing a vigorous programme in BT by setting up models at the rural areas to reduce pressure on forest for wood fuel, and also to expand electricity supply using natural gas, solar energy, biogas, domestic and industrial waste; SNEP (2006) sets a target of 2% biogas technology by 2020; while RE Act (2011) makes provision for feed- in –tarrif for renewable energy sources.

Methodology

This study adopted a descriptive design (Berhe, 2017) to analyse and assess the extent of institutional involvement and collaboration in BT dissemination in Ghana. The study was conducted from January to May 2019 in the Central and Greater Accra regions of Ghana. These regions do not have the same number of installed biogas plants. The Greater Accra has higher biogas installations than the Central region; Greater Accra is the capital city of Ghana and it is believed that businesses thrive there as compared to the other regions, hence there is inattention for the other regions (Osei-Marfo et al, 2018). The respondents for this study are heads of relevant governmnent institutions, project managers of financial instituions, biogas service providers and biogas experts/consultants. These respondents were selected based on their involvement directly or indirectly in renewable energy (biogas, solar, wind).

Sample size was determined using Godden (2004) as seen in Equation (1). Non-probabilistic sampling tecnique was used in this study. Respondents were approached by the researcher to request for their consent to participate in the study, after the aim of the study was explained to them. Six interviewers conducted the interview with two people (the interviewer and the interviewee) present during each interview session. The interview was structured into sections: background information (government, financial, biogas expert, biogas service provider), institutional involvement, collaboration with relevant institutions and barriers to BT dissemination. One-on-one face-to-face interviews were conducted with all government institutional heads, biogas experts, project managers of financial institutions and 15 biogas service providers while 26 of them granted telephone interview due to their busy schedules and location. Interviews were recorded and transcribed into written form for descriptive analysis. The results presented are those reflecting the respondents perspective, and are presented in frequencies, percentages, charts and direct quotations.

$$n = \frac{Z^2 * P(1-P)}{C^2} \quad (1)$$

Where n = sample size
Z = confidence level (95%)
P = total number of respondents
C = confidence interval (5%)
By substitution, the sample size for respondents is 80, however, the total population of 101 was used - see table 1.

Table 1: Respondents status and sample size distribution

Respondent category	Population size	Percentage of total	Sample size
Government institutions	16	16	13
Biogas service providers	41	41	33
Financial institutions	37	36	29
Biogas experts/ consultants	7	7	5
Total	101	100	80

Results and discussion

Institutional involvement

Respondents were inquired to indicate their level of institutional involvement in promoting BT by rating them as low, moderate or high (see Fig. 1). The levels of involvement are described as follows:

Government institutions: The response from respondents revealed that the involvement by mandated government institutions in BT dissemination could generally be described as low *(n = 11, 69%),* though few indicated moderate *(n = 4, 25%)* and high *(n = 1, 6%)* respectively. This according to respondents could be attributed to differences in services, roles and expectations. These differences may cause role overlap or confusion, especially during decision-making. Though respective institutions have their respective services, respondents had an expectation that all relevant government institutions would come together to draw program of activities to guide and facilitate their involvement in BT activities. They appear to be independent, hence carry out their independent activities. Nonetheless, the Energy Commission, EPA and GNCPC, do collaborate and work together mostly when there is a major activity to be undertaken (workshop/seminar with biogas service providers) or when experts' contributions are needed on a major project. The majority acknowledged that their involvement with biogas service providers and financial institutions in undertaking activities is relatively low, even though these institutions are relevant stakeholders and are key in BT dissemination.

Biogas service providers: biogas service providers indicated that there exists moderate *(n = 31, 76%),* low *(n = 8, 19%) and* high *(n = 2, 5%)* involvement among them, as an association with the government institutions with a majority of the involvement being moderate. Thus they participate in activities that are organized by government institutions, especially the Energy Commission, EPA, GNCPC and the MMDAs. Although their activities are mostly undertaken in the MMDAs, BT adoption and use by many communities and households in Ghana can be described as low. This could be attributed to low commitment by the MMDAs towards the dissemination of BT. Additionally, it was discovered that very low or no collaboration exists between service providers and financial institutions. Thus, biogas service providers do not receive any financial support from financial institutions. Their projects are funded by themselves or donor agencies. The Executives of BAG also revealed that they were in consultation with the Energy Commission in securing license for BAG members to enable proper monitoring of their activities by the association. That became necessary due to the frustration members go through in obtaining license for operation and the need to keep records of biogas installations.

Financial institutions: it was revealed that low *(n = 35, 95%)* institutional involvement exist between financial institutions, biogas service providers and the government institutions. Though these financial institutions indicated that they have at once supported RE projects (solar and hydro power), BT does not appear to be promising and that the risk of failure is quite high. These factors might have contributed to their low involvement in supporting dissemination of BT in Ghana. They however indicated that they were prepared to support relevant stakeholders in which ever capacity they could.

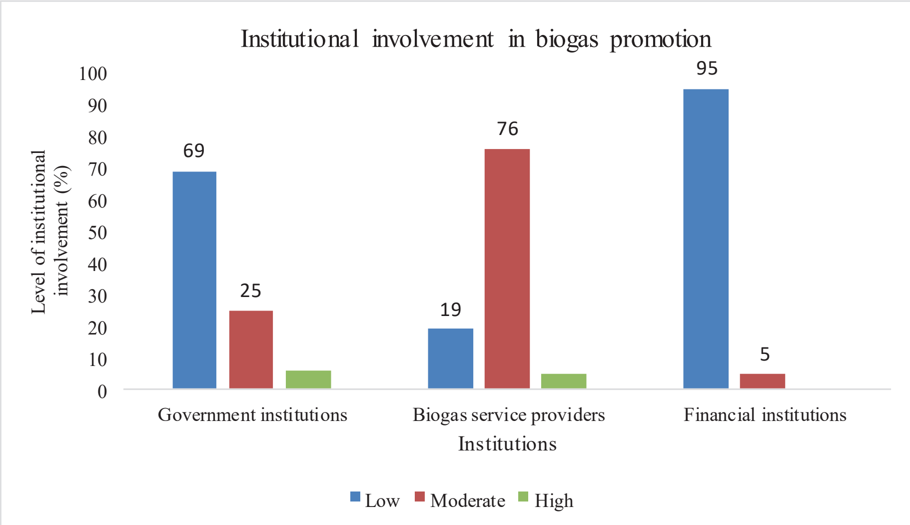

Fig. 1 Institutional involvement in biogas promotion

Collaboration with relevant institutions

Respondents, composed of biogas service providers, government and financial institutions, were asked to indicate the level of collaboration between their institution and other relevant institutions as low, moderate or high, in terms of awareness creation, promotion, monitoring, and evaluation (see Fig. 2). The answers or responses of the assessment are:

Awareness creation: it is meant to let people know that BT exists and that it can contribute to improved community livelihood, environment and economy, thereby alleviating poverty. A majority of the respondents indicated that collaboration in terms of awareness creation was moderate *(n = 48, 51%)* with the others indicating high *(n = 4, 4%)* and low *(n = 42, 45%)* collaborations respectively. BAG on behalf of biogas service providers has been up to the task of creating awareness occasionally. They engage with the media houses (television and radio) to discuss BT and its associated benefits whenever they receive funding from donor agencies. The government institutions, also through sanitation challenge workshops create awareness. BT is usually presented as a sustainable alternative for solving sanitation challenges. Outcome of such workshops are mostly aired on radio or television as news item to the Ghanaian populace, hence, creating awareness.

Promotion: it is about publicizing BT and its benefits, so as to increase adoption and uptake rate. This could be achieved through media advertisements, signpost and hand flyers (Osei-Marfo et al., 2018) as well as word of mouth by users. The majority of the respondents who indicated low collaboration *(n = 76, 81%)* of BT promotion were of the view that BT was not a priority project, hence, government's commitment towards its promotion is low. Furthermore, 15% *(n = 14)* and 4% *(n = 4)* of the respondents indicated moderate and high collaborations respectively. This is reflected in the low resources availability (finance and other logistics) for BT promotion activities. Resources that would facilitate the work of mandated government institutions are readily not available, making promotion activities and programs challenging. Few BAG members who can afford the cost of advertising their services do so in order to expand their business (Osei-Marfo et al, 2018), and by that BT receives some level of promotion.

The financial institutions indicated that they have no memorandum of understanding with the relevant institutions (both government and private) to support BT promotion activities; therefore, their annual budget does not make provision for that in a situation they are called upon for support. Furthermore, BAG revealed that there is no national biogas policy to aid BT promotion, which would consequently increase its uptake. These setbacks, coupled with others do not ensure the success and effectiveness of BT promotion in Ghana and this is supported by a similar study (Njoroge, 2002). As such BT dissemination has been very low in Ghana even though the technology was introduced over three decades ago (Bensah & Brew-Hammond, 2010).

Monitoring: is meant to be a regular gathering of information on the activities of BT in order to track the progress or dissemination rate (Bartle, 2007). Respondents revealed that there is low collaboration in terms of monitoring *(n = 77, 82%)* and that there is no monitoring team to even check quality standards of biogas installations. Additionally, the respondents showed few moderate *(n = 13, 14%)* and high *(n = 4, 4%)* monitoring collaborations respectively. The institutions mandated by law to collaborate and ensure the development of BT, which includes monitoring both government and private organizations are handicapped. Respondents, especially those in the government institutions indicated that this could be attributed to inadequate resources and lack of political will. Due to lack of monitoring, there is no record of total installed biogas digesters/plants in Ghana and this is supported by previous research (Bensah & Brew-Hammond, 2010; Osei-Marfo et al., 2018). Thus institutions and especially the biogas service providers are carrying out their activities without any form of monitoring to ensure that the right things are being done. Research has shown that proper monitoring yield positive results such as identifying gaps and challenges in activities, and revising how activities are conducted due to information gathered (Bartle, 2007). Effective monitoring will therefore go a long way to improve dissemination of BT and consequently, increase its uptake.

Evaluation: this involves gathering and analyzing information about BT activities so as to improve its effectiveness (Patton, 1987). Respondents indicated that collaboration, regarding evaluation of BT activities (e.g. awareness creation and promotion) is generally low *(n = 77, 82%)* with the rest showing moderate collaboration *(n = 18, 18%)*. There is no existing committee which evaluates BT activities in order to suggest measures to be taken to improve BT activities. As a result of low collaboration in terms of evaluation, there has not been much improvement in BT dissemination and adoption in Ghana. Additionally, the impact of BT and its numerous benefits are not experienced by the Ghanaian populace. Research has shown that evaluation brings about improvement in program design and implementation as well as demonstrates program impact on society. Lack of evaluation could lead to spending significant amount of money and time pursuing strategies that may cause no change to the issue being addressed (EMI, 2004). Furthermore, without evaluation, the society may not know about the great work that relevant institutions and stakeholders might be doing to solve existing sanitation challenges, which includes adoption of BT.

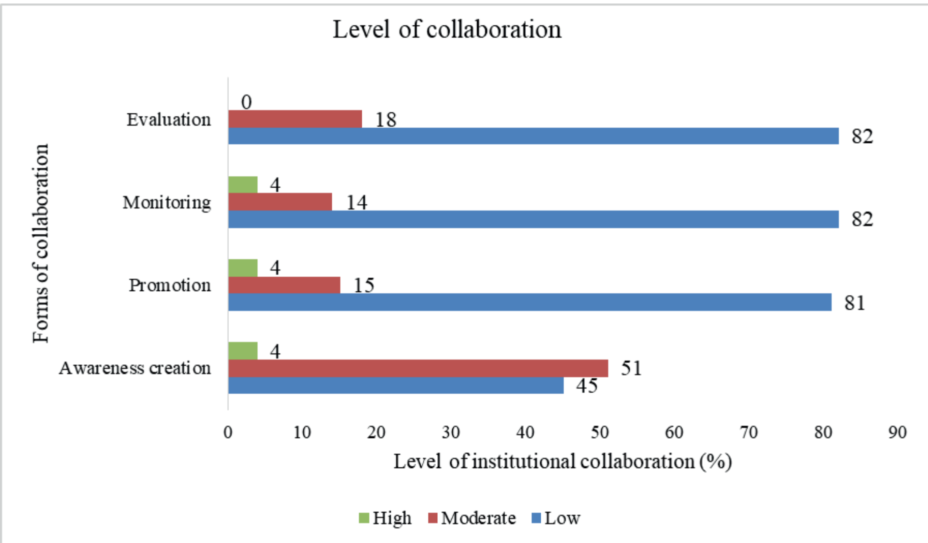

Fig. 2 Level of collaboration

Biogas experts'/consultants opinion

The opinion of biogas experts were sought as a way of assessing the level of institutional involvement and collaboration in dissemination of BT. These biogas experts have about 10 years' experience in BT. They were of the view that institutional involvement is either low or almost non-existent, stating that laws and regulations have inadequate implementation strategies, hence, there is no clear direction to be followed. With regards to collaboration, they indicated that that is relatively low, except on occasions where donor agencies sign memorandum of understanding to collaborate with government institutions that may also require the involvement of private institutions. In such situations, both government and private institutions (biogas service providers) collaborate for joint programs.

One expert remarked: "we have very good institutions but they do not see the urgency in collaborating to make BT attractive to people. BT has many benefits, but how will the people get to know if there is no intentional awareness creation or promotion? Government institutions should seriously collaborate with BAG to carry out this important task" This is an indication that collaboration has not been the best among relevant institutions.

Another expert expressed: "the Renewable Energy Act 2011 and other regulations and policies are not explicit on BT promotion strategies. Very little information had been given on BT, however, much is said about other renewable technologies. There should be a national biogas policy to guide BT dissemination and strategies for implementation". Thus existing policies/regulations do not emphasize or is somehow silent on BT as compared to other renewable resources.

Finally, another expert stated that: "it appears government has no interest in BT promotion, which consequently has led to the low dissemination by relevant institutions. If government should show interest and commitment, the end result will be increased BT adoption and uptake in Ghana". Thus it is clear that experts consider the commitment of government in BT dissemination as low and that it has in turn affected relevant government institutions in particular, in promoting BT.

The above comments imply that these biogas experts are not satisfied with the level of institutional involvement and collaboration in dissemination BT in Ghana.

Challenges/barriers to BT dissemination

During the study, some barriers were identified as hindering the effective dissemination of BT. Key among them include:

Lack of a national biogas policy: BT faces intense challenge as far as dissemination and uptake is concerned. It is in competition with other cheaper alternatives like wood fuel and sawmill residue, which are available locally for cooking applications (Arthur et al., 2011; Mittal et al., 2018) as well as other sanitation systems like septic tank, ventilated improved pit, pour flash and biofil, for excreta management. These alternatives, however, have negative health and environmental impacts associated with their use, i.e. indoor air pollution causing respiratory diseases, loss of forest resources, emission of greenhouse gases, and air pollution (Arthur et al., 2011; Mittal et al., 2018).

These negative impacts do not only affect health and the environment, but the economy as a whole. This therefore calls for a national BT policy to be formulated which will be a stand-alone document to support its dissemination. The policy, when formulated could detail the strategies to be employed to create awareness and promotion, thereby increasing BT uptake. Additionally, the policy may highlight the long term benefits associated with BT, i.e. improvement in community livelihood and health, sanitation, sustainable energy and reduced emissions (Osei-Marfo et al., 2020) during the promotion exercise. These could whip the interest of potential users to forego other energy and sanitation alternatives, however cheap they may be due to their associated negative impacts. Furthermore, when a national BT policy is formulated and enforced, all new building projects would be obliged to install biogas systems whiles old buildings replace other sanitation technology with biogas technology. This will consequently improve health, environment and the economy.

Low government commitment: one main barrier to effective BT dissemination is low government commitment. The commitment of government in the dissemination of BT is key to its success. Government's commitment may be in the form of financial resources for BT development, allocation of air time for awareness creation on national television and radio, provision of vehicles for BT promotion activities, human resource capacity development, developing a public private partnership BT business model, and instituting a national biogas program. It is worth noting that many BT projects have failed or faced challenges shortly after diffusion in Ghana due to low government commitment and this is supported by Bensah & Brew-Hammond (2010). However, BT diffusion has been successful in other countries due to high government commitment as well as government recognizing BT as a tool for reducing greenhouse gas emissions and a means of using less fossil fuel (Sok, 2012, as cited in Ministerie van LNV et al, 2007).

Thus high government commitment could motivate mandated institutions and other stakeholders to advance BT dissemination with much efficiency. There is no doubt that government's commitment towards BT dissemination plays a significant role in achieving success or failure.

Low financial support/Financial challenges: one of the important barriers to BT dissemination in Ghana is low financial support. It is known that the success or failure of a relatively new technology depends mostly on financing (Mengistu et al. 2016). It was revealed that many BT activities have been ineffective and or halted due to very low financial support. It is usually incumbent on government to make financial resources available for the dissemination of a technology (BT) which will have positive impact on peoples' health, sanitation and the whole economy, however, due to financial constraints, other financial institutions are expected to assist to ensure its success. Conversely, these financial institutions are not readily motivated to support BT promotion activities because of the risk of failure and/or no trust in the success of the technology (Osei-Marfo et al. 2018). This was confirmed during interview with project managers of financial institutions: it came to light that collaboration was almost non-existent and there is no memorandum of understanding between them (financial institutions) and relevant BT stakeholders (government institutions and biogas service providers).

Conclusions and recommendations

This study concludes that institutional involvement and collaboration in disseminating BT was generally low, although the technology was introduced about three decades ago. Thus institutional involvement was low for both government and financial institutions, whereas biogas service providers showed moderate involvement in disseminating BT in Ghana. Additionally, institutional collaboration in terms of awareness creation was moderate while collaboration regarding promotion, monitoring and evaluation were all low. The barriers relating to effective institutional involvement and collaboration in dissemination BT were associated to lack of a national biogas policy which makes the technology loose its importance, low government commitment and low financial support. However, the financial institutions indicated their interest and willingness to support the dissemination of BT in the near future.

Based on the study outcomes, the following recommendations are made:

- the government should task the Energy Commission to formulate a national biogas policy;
- that government should show high commitment by making needed resources available for use to improve BT dissemination and uptake;
- a national BT steering committee, composed of experts including the finance minister or their representative should be constituted to champion the cause of BT.

8

Chapter 8

General Discussion

Introduction

Sanitation is an important and basic need for any individual or group of people in any home, community or country as a whole. It generally encompasses: safe collection, storage, treatment and disposal/reuse of especially human excreta. In Ghana, several sanitation technologies are used for excreta management and sanitation improvement, of which a majority is not sustainable and consequently impacting on public health and the environment. There is therefore the need to promote a technology that could sustainably manage human excreta with almost no challenges, and in this respect biogas technology cannot be overlooked.

The aim of the research reported in this dissertation was to study the feasibility and acceptability of biogas solutions in sanitation (sustainable management of human excreta) in the Central and Greater Accra regions and to inform the development of interventions that gear towards sustainable sanitation in Ghana; with a particular focus on dissemination and shortfalls of biogas technology, performance of existing biogas plants, proposing an alternate model to the existing biogas plants, perceptions on human excreta use for biogas, willingness to adopt biogas technology, and institutional involvement in promoting biogas technology. This chapter summarises and discusses the main findings as well as the strengths, limitations and implications to inform future research. It then ends with a general conclusion. This chapter addresses the following questions: what factors are affecting the dissemination of biogas technology and what are the associated challenges? What is the quality of the effluent being discharged by existing biogas plants? How can the existing design be improved? What is the social perception on the use of human excreta for biogas generation? Are household heads willing to adopt biogas technology? What are the most prominent objections and advantages? What is the level of institutional involvement and collaboration in disseminating biogas technology?

Main findings

Biogas technology diffusion and shortfalls in the Central and Greater Accra regions of Ghana

Chapter 2 has, after interviewing stakeholders (biogas users, service providers and consultants), shown that the dissemination of biogas technology is higher in Greater Accra than in Central region. In the opinion of stakeholders, this could be attributed to the fact that Greater Accra is the capital city of Ghana and it is considered a booming city for businesses, hence there is inattention for the other regions. It was revealed that obtaining biogas for household/institutional use (cooking, fuel for science experiment sessions, electricity generation), improving sanitation, obtaining bio-fertiliser for agriculture and job opportunities were the motivation for using biogas technology. Nonetheless, a majority of household and institutional/communal biogas digesters/plants had challenges with gas production at some point in time or unsanitary environments due to leakage. Most of them failed to produce gas after being operated for some period. Such challenges were attributed to poor design, poor operational conditions (Dhoble & Pullammanappallil, 2014), user attitude, inadequate knowledge of the technology, and/or lack of maintenance. Most users think that the digester/plant should continue to function as expected irrespective of what goes into it or without maintenance.

Furthermore, some users were completely disappointed on the outcome of the technology (29%: *n = 11*), *50%* (*n = 19*) were partially satisfied since sanitation was improved but with failed biogas production, while 21% (*n = 7*) were satisfied because their needs and expectations had been met. Most users blamed the service providers for their inability to install an efficient system to meet their needs knowing that the initial investment cost was quite high. The findings confirmed the challenge of poor designs when it was revealed that *58%* (*n = 14*) of the service providers were artisans (plumbers, masons, carpenters), *21%* (*n = 5*) were graduates in arts, social sciences, business and others, with only *21%* (*n = 5*) being engineers. Some major shortfalls to the development and dissemination of biogas technology identified include: lack of subsidy; financial barriers; lack of institutional collaboration; lack of regulatory body; negative social perception and market value for bio-fertiliser. Based on the findings, it is recommended that: a subsidy policy be established by government to support individuals who cannot afford full investment cost; financial institutions support individuals and institutions with soft loans to aid the construction of biogas digesters/plants; Ministry of Energy should institute a standardised design for service providers to ensure sustainability of the technology at both household and institutional levels; a regulatory body should be established to monitor the activities of all service providers and document digesters constructed; and the ministries of Energy, Sanitation and Water Resources, Environment, Science, Technology and Innovation, Food and Agriculture, and Information should collaborate to promote and disseminate biogas technology and to encourage farmers to patronise bio-fertilisers.

Characterisation of Wastewater and Treatment Efficiency of Biogas Plants: Effluent Discharge Quality

Chapter 3 has revealed that there exist significant differences in the effluent quality from three institutional biogas plants, namely University of Cape Coast (UCC), Mfantsipim Senior High School (Mfantsipim) and Ankaful Maximum Security Prisons (Ankaful). The results indicated that most of the quality parameters were within the Ghana Environmental Protection Agency (EPA) guidelines. Nonetheless, quality parameters such as electrical conductivity (EC), total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD_5), chemical oxygen demand (COD), ammonia-nitrogen (NH_3-N), total coliforms, *Escherichia coli* (E. coli) and *Salmonella spp*. exceeded the EPA guideline values. The results showed that Mfantsipim had effluent values exceeding the recommended EPA (2012) guideline values for all the quality parameters listed above while UCC and Ankaful exceeded for TSS, BOD_5, NH_3-N and all the microbial characteristics. The high loads of microbes in the effluent discharged poses a public health risk, which could result in an outbreak, and they are of much concern since research has shown that faecal coliforms and *Salmonella spp.* could survive in the environment for 50 days and 30 days respectively (Feachem et. al., 1983). With regards to treatment efficiency, it was revealed that the physiochemical and biological characteristics of treated effluent indicated that UCC biogas plant is relatively better than Ankaful and Mfanstipim biogas plants in terms of wastewater treatment. UCC and Ankaful have a fixed dome biogas plant designs while Mfantsipim is a Puxin design (see Chapter 2 for details). It is worth noting that the UCC biogas plant was constructed in 2017 while Ankaful and Mfantsipim were both constructed in 2011 and so it was expected that the effluent quality from UCC would be far better than Ankaful and Mfantsipim, which however was not the case. The general low performance of the three biogas plants could be attributed to design deficiencies, poor maintenance culture and poor environmental conditions. These conclusions are supported by similar work by Owusu-Ansah et al. (2015). The effluent quality suggests that further treatment is required in order to minimise the degree of pollution of the environment.

Re-designed Biogas Plant for Sustainable Sanitation

Chapter 4 addressed the challenges associated with existing biogas plant designs. The study identified challenges such as failure of biogas production, leakage leading to unsanitary environment, absence of influent and effluent access, which are design deficiencies leading to poor effluent quality. The findings also revealed that some of these challenges can be attributed to lack/inadequate knowledge of the technology and/or user attitude and this is supported by a study conducted by Mukumba et al. (2016). Based on these challenges, a new design concept was proposed. This re-design concept combines a fixed dome with an expansion chamber, an anaerobic baffle reactor (ABR), a constructed wetland (CWL) and a disinfection chamber (DC). The additional components (CWL and DC) are to improve the effluent quality before finally discharging into the environment or for re-use such as irrigation or aquaculture. The modified design also provides access for influent and effluent sampling, therefore making effluent quality monitoring possible as well as co-digestion with kitchen waste. The cost for installing a re-designed household plant is approximately US$ 1,530 to US$ 5,950 for $4m^3$ to $12m^3$ and that of communal/institutional plants are US$ 10,900 to US$ 22,400 for $56m^3$ to 120 m^3 whereas that of an existing household design ranges from US$ 1,500 to US$ 5,900 for $4m^3$ to $12m^3$ and US$10,800 to US$22,300 for 62 m^3 to 110 m^3 for communal/institutional. These costs take into account the site characteristics, material and labour costs. A maintenance cost of about US$ 100 to US$ 350 (household and communal/institutional plants) per year could also be incurred for both re-design and existing plants. The re-designed plant may require an area between $9m^2$ to $16m^2$ for $4m^3$ to $12m^3$ and $10m^2$ to $20m^2$ for $56m^3$ to $120m^3$ for the construction of a household and communal/institutional plants respectively as compared to $8m^2$ to $16m^2$ for $4m^3$ to $12m^3$ and $10m^2$ to $20m^2$ for $62m^3$ to $110m^3$ for a household and communal/institutional plants respectively.

A sustainability analysis was done based on the following criteria (SuSanA, 2010): health and hygiene, environmental quality and natural resources, and technology and operation. It indicated that the re-designed concept has a strong strength in collection, treatment and re-use of excreta whereas finance and economic, and socio-cultural and institutional showed average strength. Thus the re-designed biogas plant concept is sustainable and meets the three sustainability pillars: environmental, economic and social (see Fig 1). It however remains to be realized and piloted.

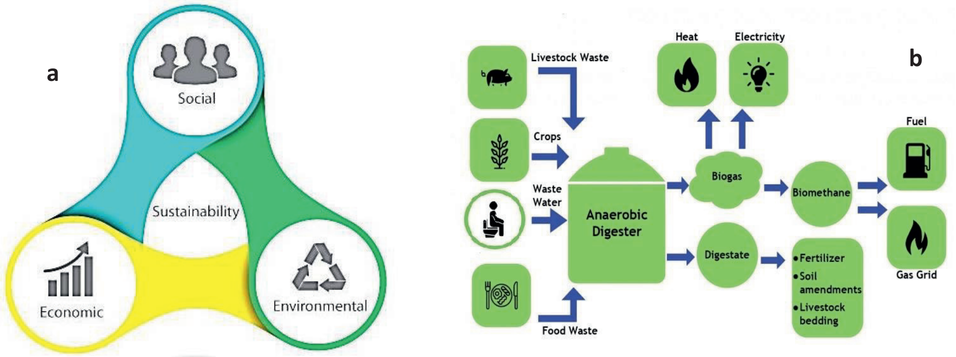

Fig. 1 (a) Sustainability pillars (adopted from Swish maintenance limited, 2021)
(b) Environmental and socio-economic benefits of biogas plant (anaerobic digester) (adopted from MV Technology, 2020 with slight modification)

People's Perceptions on the use of Human Excreta for Biogas generation in Ghana

Chapter 5 brought insight into the perceptions that people have on using human excreta for biogas generation. This study adopted the theory of planned behavior (TPB) to assess people's behavioral intentions to use biogas generated with human excreta (HEx) (Armitage and Conner, 2001). In this study, the target behavior was the individuals' intentions to use human excreta for biogas. A questionnaire was used to collect data from 408 respondents from Cape Coast Metropolitan Assembly, in the Central region and Ablekuma North Municipal Assembly, in the Greater Accra region. Analysis of MOment Structures version 23 (AMOS 23) was used, in which structural equation modelling (SEM) was used to find the best-fitting model and the causal relationships within the model. Furthermore, gender and education were introduced into the TPB model to know their effect on intentions (Olli et al., 2001; Wolters, 2014).

The findings confirmed that TPB could be used in explaining people's perceptions on the use HEx for biogas production in Ghana. Although not all the standard TPB tenets were supported (Galaviz et al. 2015) the analysis provided useful insights into the perceptions people have about the use of HEx for biogas. Two structural models were produced: the standard TPB model and an adjusted model.

The modelling comparison revealed that the adjusted model including gender and education had a modestly better explained variance towards the use of HEx for biogas than the standard TPB. Consequently, the adjusted model provided a useful and effective framework for analysing the interrelationships between socio-demographic variables (education and gender) and the TPB constructs than the standard TPB. While the results revealed that for the standard TPB, attitude and subjective norms were the only factors that significantly influenced intentions to use HEx for biogas, the adjusted model showed that all the three TPB constructs (attitude, subjective norms and perceived behavioral control) had significant effects on people's intentions to use HEx for biogas, and were valid predictors of intentions.

Within attitude, it was revealed that three items (provision of energy for cooking, bio-fertiliser, environmental protection) significantly influenced intentions while health risks had a non-significantly negative impact on intentions to use HEx for biogas. This finding confirms other works that people's attitudes are important determining factors to using HEx for biogas (Zhang et al. 2013; Petts et al. 1998; Boehmer-Christiansen 1995). A similar study in Rwanda and Uganda revealed that individuals with high benefit and low risk judgments would engage in HEx use regardless of the actual risks involved (Ekane et al, 2015). The findings suggest that people have a positive attitude towards HEx use for biogas generation in Ghana and so interventions designed to promote HEx for biogas could highlight these four factors.

The findings showed that for subjective norms, four items (family, neighbours, religion and institution) had a significantly positive influence towards the use of HEx for biogas generation. In concert with other studies, it was revealed that the judgment of significant others, especially religious leaders was important with regards to HEx use (cf. Leeuw et al., 2015). For example, in Mthatha, in the Eastern Cape of South Africa, respondents were asked what they thought might work to change peoples' perception towards using HEx as fertilizer and soil conditioner in their gardens and the response was, leading by example by people with high standing seen using HEx (Vuuren, 2008). This gives an indication that for norm-based interventions to be effective, behavior of important others should be a focus, especially, religious leaders.

Furthermore, it was revealed that all four perceived behavioral control factors (cost, subsidy, stigma and HEx knowledge) significantly influenced HEx use intentions. Respondents perceived low controllability over HEx use. Thus, high investment and maintenance costs, lack of subsidy, stigma associated with HEx use coupled with insufficient knowledge on HEx use contributed to low controllability to use HEx for biogas.

Mapped interventions could consist of the formulation of a policy that leads to subsidizing the high investment cost and/or giving of soft loans for the installation of a biogas plant by potential users, people with high reputation (especially religious leaders) in the society should be encouraged to adopt BT by using HEx for biogas and being part of the team (including relevant institutions) that promotes and educates on HEx use for BT, and highlighting the high benefits associated with HEx use such as obtaining energy for cooking, bio-fertiliser for farming and environmental protection from pollution. This way, cost, subsidy, stigma and HEx knowledge would have been addressed.

For gender and education, there were no direct significant influences on intentions but they mediated: for gender through attitude (health risk and bio-fertiliser) and perceived behavioural control (stigma and HEx knowledge), and for education through attitude (environmental protection and bio-fertiliser), subjective norms (institutions, religion and family) and perceived behavioural control (stigma) respectively. For gender, people were of the view that bio-fertiliser could be obtained, however, health risks, stigma and HEx knowledge were of concern to most women, and these could hinder their intentions to use HEx. This was highlighted in the results; more females had no form of education, with only a few having tertiary education. This might have influenced their opinions on HEx, since higher education enhances one’s ability to analyse and understand information. Therefore, gender-specific interventions could be designed for better education on HEx use. The impact of education brought to bear the positive outcomes of HEx use resulting in environmental protection and bio-fertiliser for farming, however, stigma was an issue of concern. Thus, stigma attached to the use of HEx could deter people from using HEx for biogas irrespective of the positive outcomes as well as the level of education. Therefore, these important people should facilitate education on HEx use thereby overcoming the stigma. These interventions, when implemented, could be useful in the future promotion of BT and HEx use in Ghana.

Dynamics of Household Heads’ Intentions to Adopt Biogas Technology in Ghana

Chapter 6 tested the suitability of the use of the theory of planned behavior (TPB) framework to understand the dynamics of household heads’ intentions to adopt biogas technology (BT) in Ghana. The dynamics of the intentions explain the willingness of household heads to adopt BT since they play key role in decisions-making in households in Ghana. Hence, an exploratory design, using questionnaire was developed and data was collected from 394 household heads from CCMA, Central and AMA, Greater Accra regions. Data analysis was by Analysis of MOment Structures version 23 (AMOS 23), in which SEM was used to find the best-fitting model and the causal relationships within the model. To know the extent of the effect of ethnicity and education (Ajzen, 2011) on their intentions to willingly adopt BT, these factors were introduced.

The analysis produced two models; the standard TPB model with a mediocre fit and an adjusted model (including ethnicity and education) with an acceptable fit. The results confirmed that all the TPB constructs; attitudes, subjective norms and perceived behavioral control accounted for a proportion of variance in the dynamics of intentions to adopt BT. It was also observed that the introduction of ethnicity and education improved the model with regards to their willingness to adopt BT.

Ethnicity had a direct significantly negative influence on intentions to adopt BT and this is supported by previous research (Shane et al., 2015), which demonstrated that an individuals' ethnic background matters in decisions making, especially, relating to BT adoption, which may consequently influence intentions negatively. Thus, their willingness to adopt BT could be influenced by their ethnicity, since in some ethnic groups, handling or using excreta/dung is considered a taboo. Similarly, a study by Shane et al (2015) indicated that in Zambia, due to traditional and cultural beliefs, people in the community may find it difficult to accept the use of biogas as fuel because it is produced from dung, manure or sometimes human excreta. Furthermore, women in some parts of Zambia and children from some royal families were not allowed to collect dung due to cultural beliefs and or were considered as dirt (Shane et al, 2015). It becomes even more unacceptable when HEx is being used to generate energy for cooking, and this has been a challenge in BT adoption and implementation in many developing countries (Shane et al, 2015).

However, education had both direct and indirect significant effect on intentions to adopt BT and this finding is supported by a similar study (Jan and Akram, 2018). The findings revealed that one's level of education played a key role in intentions to willingly adopt BT. Analytical capability of information and understanding of a technology were all linked to a person's level of education (Jan and Akram, 2018; Shane et al., 2015). Therefore, the level of education informed the level of comprehension of biogas technology and consequently its willingness for adoption.

It was shown that the dynamics as well as the willingness of household heads to adopt BT appeared to be influenced to a large extent by ethnicity and the educational level. Interventions that could improve the rate of BT adoption include more education to correct the misconceptions about BT, by the use of the ethnic dialect by respected persons. In addition, more people should be encouraged to upgrade themselves from basic to at least secondary education with the advent of a social intervention programme (free senior high school) by the government. That will improve their understanding on issues and by extension, the need to willingly adopt BT in future.

Institutional involvement and collaboration in disseminating biogas technology in Ghana

Chapter 7 assessed the level of institutional involvement and collaboration, and barriers to biogas technology dissemination in Ghana. A qualitative technique was employed and data collected from 101 respondents through interviewing. These 101 respondents were composed of heads from relevant government institutions, project managers from financial institutions, and biogas service providers.

The findings revealed that the involvement of mandated government institutions in BT dissemination was low which was attributed to differences in services, roles and expectations as well as lack of financial resources. Thus, because they are independent in their way of activities, there appeared to be challenges in coming together to hold common program of activities. In spite of these challenges, three institutions (Energy Commission, EPA and GNCPC) do collaborate to undertake activities (seminar/workshop/project) occasionally.

Furthermore, biogas service providers indicated that their involvement in activities by government institutions was moderate, but their collaboration with them, most especially the MMDAs was low. In their opinion, there was lack of will on the part of the MMDAs in collaborating with them to embark on activities. Consequently, it resulted in low adoption of BT at the household and community/institutional levels in the various MMDAs.

Moreover, it was revealed that there was low involvement and collaboration between financial institutions and biogas service providers as well as government institutions. This was attributed to the high risk of BT failure perceived by financial institutions, though they had at once supported other renewable energy (solar and hydropower) projects. They however indicated that they were prepared to support relevant stakeholders should the need arise.

The study also identified lack of a national biogas policy, low government commitment and low financial support/challenges as barriers to effective BT dissemination in Ghana.

The outcomes of this study have been confirmed in chapters 5 and 6, that the leadership of important persons and cost implications for BT installation are important in the promotion of BT.

Mapped out interventions that could advance the dissemination of BT include the formulation of a national biogas policy by the Energy Commission; government commitment to funding BT promotion activities by relevant institutions, and a biogas technology steering committee composed of relevant stakeholders (including important persons), including the finance minister or their representative thereby creating the platform for the promotion of BT at all levels.

Finally, the most important conclusions drawn from this study are that: there is willingness on the part of stakeholders (government institutions, biogas service providers and financial institutions) to collaborate and get involved in disseminating BT, but interventions are needed for administration and the general public; there are obstructing factor (education and economic factors), but there is economic advantage to BT too; there are also technical possibilities to BT.

Methodological strengths and limitations

This section describes the methodological approaches of the studies in this dissertation. It focuses on the strengths and limitations of the study designs. This study looked at the challenges associated with the use of biogas technology to sustainably manage human excreta and consequently improve environmental sanitation, hence, different methodologies were employed. These include interviews, questionnaires, experimental or measurements and design model. In view of this, the conclusions drawn are not based on one methodology but the entire study. The methodologies used in this dissertation have implications for future research and practice.

A strength of the dissertation is the heterogeneous methods adopted for the studies. The studies in this dissertation used: 1) gathering of relevant data through interviewing, 2) performance of experimental analyses on effluent quality, 3) proposing a new design concept of a biogas plant and 4) gathering of relevant data with a well-defined and tested belief-based model (the theory of planned behavior) to predict intentions to adopt biogas technology (BT) as well as perceptions about using human excreta (HEx) for biogas via questionnaires. The focus was to examine BT diffusion and shortfalls as well as assess institutional involvement in BT promotion, characterize the quality of effluent being discharged into the environment, re-design an existing biogas model for improvement in treatment and to evaluate peoples' behavioral beliefs on BT and HEx use.

The interview approach with relevant stakeholders (biogas service providers, biogas users, biogas consultants, heads of government institutions and financial institutions) revealed factors which hinder the diffusion of BT and the involvement of institutions to promote BT as reported in chapters 2 and 7. This approach allowed, especially, the institutions to pinpoint their challenges that needed to be addressed. The outcomes give a clear picture on the way forward. The study in chapter 3 measured the quality of effluent, after treatment by biogas plants, which is being discharged into the environment or re-used for other purposes. This effluent is a direct contributor to environmental pollution as well as a risk to public health.

Having knowledge about the quality of the effluent is a way of mitigating any adverse potential impact. The challenges of existing biogas plants and the quality of effluent led to the re-design concept in chapter 4. This design concept introduces constructed wetland and a disinfection chamber to further improve the treatment efficiency of an existing design. These additional units have the potential of improving the effluent quality to meet the EPA standards for effluent discharge. The use of the belief-based model for the evaluation and the prediction of an individual's intentions brought to bear the effects of beliefs on one's behavior. Using the theory of planned behavior (TPB) constructs (attitude, subjective norms and perceived behavioral control) and socio-demographic variables (education, ethnicity and gender) were useful to some extent. Looking back, a Diffusion of Innovations Theory (DIT) approach would have been a better theoretical framework to assess household heads and institutional actors as far as biogas dissemination and adoption are concerned. The DIT describes the diffusion process in phases; dissemination, adoption, implementation and maintenance (Bartholomew et al, 2011). Nevertheless, the studies from chapters 5 and 6 showed that education, ethnicity and gender had influence on individual's behavior in terms of intentions to adopt BT and also use HEx for biogas generation. These findings provide useful insight for policy makers to design suitable interventions that would encourage people to use BT irrespective of the type of feedstock. Combining views of institutional stakeholders with those of end-user/consumer/household decision makers is an important strong point. However, better or more useful outcomes might have been revealed if DIT approach had been used.

The study had some limitations which include: 1) fatigue on the part of some respondents, especially for the interviewing and answering of questionnaires. Some of the respondents complained of always being interviewed or answering questionnaires, hence, that could influence their opinion on providing the right answers to the questions; 2) the study was conducted in only Central and Greater Accra regions of Ghana, therefore, the models for chapters 5 and 6 should be tested in the other regions of Ghana to allow for generalization; 3) the design concept of the biogas plant is yet to be piloted; 4) selection biases may have been introduced in the sample size and the sampling techniques. However, the use of randomization and characteristics that represents the population at large helped to minimise possible biases.

Implications and recommendations

Implications for policy

This research has a number of implications for policy due to the heterogeneous nature of approaches employed. In order to adopt biogas technology for sustainable sanitation, government should show some level of high commitment by making resources available to relevant institutions such as the Energy Commission, Environmental Protection Agency (EPA), Ghana National Cleaner Production Centre (GNCPC) and the Metropolitan, Municipal and District Assemblies (MMDAs) for effective performance of their tasks such as awareness creation, education, promotion or dissemination, monitoring and evaluation of BT and its related activities at all levels. These relevant institutions can also perform effectively when there is a policy guide. Therefore, the Energy Commission should be tasked by the government to formulate a national biogas policy to serve as a guide to all relevant stakeholders. Furthermore, a steering committee should be constituted at all levels, thus, national, regional and the MMDAs to champion the promotion and adoption of BT for sustainable sanitation, targeting both communities/institutional and household decision makers. The foci of such campaign should highlight the numerous benefits associated with BT such as environmental protection leading to reduction in pollution and public health risks, reduction in emissions, obtaining bio-fertiliser for farming, reduction in waste volume sent to treatment or dumped in the open and production of energy for cooking. Additionally, the positive attitudes that people have formed as a result of the benefits associated with BT, the normative aspect being the influence of important or respected persons (especially religious leaders) in local communities should be upheld and the control aspects being cost, stigma, subsidy and HEx knowledge should be well addressed during campaigning.

There should also be a subsidy policy set by the government to support individuals and communities/institutions that cannot afford the full investment cost for BT installation. In the absence of subsidy policy, financial institutions should support individuals and communities/institutions with soft loans for BT installation cost. High investment cost is one of the barriers to BT adoption, and so a subsidy policy and/or soft loans will serve as a means of promoting the technology and also increasing the adoption rate which will consequently result in improved environmental and sustainable sanitation.

Relevant stakeholders such as the ministries of Food and Agriculture, Environment, Science, Technology and Innovation, and Sanitation and Water Resources should collaborate, educate and encourage farmers to patronize and use more of bio-fertilizers (by-product obtained from biogas technology) instead of chemical fertilizers.

There is also the need for a standardized biogas plant design for dissemination and installation, therefore, the re-designed concept could be considered although it is yet to be piloted and tested. This will result in reducing and/or eliminating the challenges identified with the existing designs. A task force could be formed by EPA to periodically monitor the quality of effluent discharge for existing plants and the re-designed plants, when it becomes operational, to ensure the effluent quality meets EPA standards. To enhance the work of the task force, a database of all installed biogas plants should be created. Owners of plants with poor effluent quality could be fined and cautioned to put mitigation measures in place.

Recommendations for future research

There still remain some aspects for research continuity. These include piloting the re-designed concept to evaluate its treatment efficiency and the effluent quality, and quantifying the biogas generated. When piloted, the use of the new design can be studied. It is recommended that a budget and funding is allocated towards this cause. Financial support should be solicited from the government, non-governmental organizations, financial institutions and relevant institutions for this purpose. Consequently, it will result in economic, social and environmental improvements, which are the pillars of sustainability. Also, intervention development for public opinion should be supported by research. Finally, apart from using questionnaires and interviewing, participatory observation approach could be tested.

General conclusion

The objective of this dissertation was to highlight biogas technology as a sustainable sanitation system for managing human excreta, focusing on BT diffusion and performance, alternate plant model for performance improvement, peoples' perceptions and willingness to use HEx and adopt BT and the involvement of institutions in BT promotion. The findings of this dissertation gives insight on challenges with excreta management due to inadequate and or lack of waste treatment plants resulting in raw or partially treated human excreta being discharged into the environment with its attendant public health risks. It as well identified the challenges/failures associated with the existing biogas plants due to unstandardized plant design and lack of monitoring. Furthermore, the findings revealed that there was low uptake rate of BT due to perceived low controllability (including investment cost) and low collaboration and involvement of relevant institutions in promoting the technology.

These findings serve as a guide for policy-makers and contribute to a body of renewable energy research that gives insight into the failure and achievements of biogas technology in Ghana.

This study concludes that biogas technology is a sustainable and environmentally friendly technology that could be employed for the sustainable management of waste (both human excreta and solid organics) in the midst of inadequate and or lack of waste treatment plants; a standardized biogas plant design (re-designed concept) be developed; subsidy policy be formulated; to create a database for biogas plants installed; formulation of a national biogas policy; to create a platform for BT education and awareness by relevant institutions and important persons such as religious leaders; to create a market for bio-fertilizer.

The implementation of these interventions would increase BT uptake, improve environmental sanitation and drastically reduce public health risks.

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Impact Paragraph

This section discusses the relevance of this dissertation to social, economic and environmental development or sustainability. It discusses how the main findings can reach the target group and implications for future outcomes.

Relevance

Disposal of human excreta (HEx) is increasingly becoming a challenge in rural, urban and peri-urban areas. The mode for HEx disposal is mostly by open dumping, with its attendant public health implications, insanitary environment, and the pollution of both surface and ground water. While biogas technology (BT) could salvage this worrying situation by the treatment of HEx, resulting in the improvement in public health, environmental sanitation, fertiliser production, electricity generation and curbing climate change, attention on BT as solutions in sanitation is yet to be realized.

Whiles the developed countries have attained access to universal sanitation services, the developing countries are still lagging behind (WHO/UNICEF JMP, 2021), with Ghana having about 4.5% coverage (NESSAP, 2010-2015). Although proper waste management is an indicator of good governance (Whiteman et al, 2001), there is political neglect of sanitation, because it is not considered a high profile issue.

The findings of this dissertation give insight on the challenges with sustainable excreta management due to inadequate and or lack of waste treatment plants and its open disposal into the environment, the low performance and or failure of existing biogas plants, as well as shortfalls to the development and dissemination of biogas technology, belief issues on HEx use for biogas and adoption of BT, low institutional involvement in promoting BT, low government commitment and financial support for effective BT dissemination, lack of a national biogas policy, and lack of subsidy policy.

Addressing these challenges are essential and urgent; hence the need for:

a. the institution of a standardized biogas design and the documentation of constructed biogas plants, formulation of a subsidy policy, and the collaboration of relevant state institutions for the purpose of promoting BT (chapter 2).
b. further treatment needed for improvement in the performance of biogas plants (chapters 3 and 4).

c. the formation of a BT steering committee composed of relevant stakeholders (including important persons), as well as the finance minister or their representative, in order to create the platform for BT promotion at all levels (chapter 5 and 6).
d. formulation of a national biogas policy, government commitment to funding BT promotion activities by relevant institutions (chapter 7).
e. institution of a public campaign twice in a year to motivate the population, and take away misconceptions and fears (chapters 4 and 7).

These findings and their interventions could be a game-changer in Ghana, should decision-makers consider its implementation.

Environmental and socio-economic relevance

The consequences of environmental pollution and its effect on socio-economic development cannot be underrated. The continuous dumping of raw or partially treated HEx into the environment, as discussed in this dissertation, which is also a behavioral problem, causes pollution of our water bodies and the environment, leads to serious public health risks, and adverse economic development; the Ghana government losses GH¢ 420 million (US$ 290 million) annually, or the equivalent of 1.6% of annual gross domestic product (GDP) as a result of sanitation related diseases. Furthermore, environmental pollution also affects tourism, foreign investors, other businesses and climate change. The effectiveness of interventions to address these consequences are linked to the recommendations made in this dissertation. In view of this, Ghana’s Affordable Housing project, completed in June 2020, at Asokore Mampong in Kumasi, a gated community with 1,024 housing units has adopted biogas technology (a centralized biogas sewage treatment system) for the treatment of their HEx. This intervention will not only protect the environment, it will also improve public health thereby increasing productivity, and also generate green energy (reduced emissions) to the community members, hence, contributing to curb climate change. The cost of frequent desluding of feacal sludge will as well be avoided.

The construction of this community-based biogas plant is an indication that decision-makers are gradually beginning to appreciate the importance and sustainability of BT for the improvement of sanitation. The sustainability of this biogas plant will go a long way to change the behavioral beliefs of people who have formed misconceptions about BT.

It is expected that decision-makers would ensure the implementation of community-based and institutional as well as household biogas plants in Ghanaian communities, institutions and homes, with the end result being the general improvement in sanitation and environmental quality, and also bringing about socio-economic development.

Finally, one important impact of biogas technology as solutions in sanitation is to control climate change, which is a night mere to the global community.

Summary

The ever-growing human population with its attendant increasing waste generation, coupled with unsustainable waste management practices, has serious implications on public health and the environmental sanitation. Although the United Nations in its sustainable development goals report, Goal 6, indicates the need for adequate sanitation and wastewater treatment, and an end to open defecation by 2030, Ghana may miss this goal due to unsustainable technologies. This is a worrying situation, especially when about 80% of the Ghanaian population lack access to improved sanitation facilities/services.

Efforts made by some developed countries across the globe towards improvement in public health and environmental sanitation have been the use of biogas technology (BT) for the treatment of wastewater, particularly human excreta (HEx). This is an indication that the efficacy of using BT in treating HEx is not under dispute. In Ghana, the predominant HEx management practices used include septic tank systems, ventilated improved pit (VIP) latrine systems and open defecation, and a few sewerage systems, but these are either environmentally unfriendly or energy intensive. Biogas technology, a sustainable sanitation system, could salvage HEx management challenges. Undeniably, sanitation is linked to health and to socio-economic development, and affects many, but is championed by few. Furthermore, BT has additional advantage of producing biogas for electricity or heating, bio-fertilizer for agriculture and the ability to curb climate change.

In spite of the fact that the active development of BT started over three decades ago, Ghana is still struggling with its dissemination and adoption. This challenge could be attributed to the failure of existing biogas plants, belief issues on HEx use for biogas and adoption of BT, low institutional involvement in promoting BT, low government commitment and financial support for effective BT dissemination, lack of a national biogas policy, and lack of subsidy policy.

The main aim of the present research presented in this dissertation was to study the feasibility and the acceptability of biogas solutions in sanitation in Ghana.

Chapter 2 gives an overview of biogas technology dissemination in Ghana by highlighting the challenges and shortfalls, as well as comparing the level of uptake in Central and Greater Accra regions. This was achieved through interviewing stakeholders (biogas users, service providers and consultants) and by observation. The results showed that the motivation for using BT was to obtain fuel for cooking and for science experiment sessions, to generate

electricity, to improve sanitation, to obtain bio-fertiliser for agriculture, and to create job opportunities, however, this was not entirely achieved. Some users (29%: *n = 11*) were completely disappointed, others (*50%: n = 19*) were partially satisfied because their sanitation was improved but with no biogas, while a few (21%: *n = 7*) were satisfied because their expectations had been met.

A majority of biogas plants (household and institutional/communal) had challenges with gas production at some point in time and or unhygienic surroundings due to leakage, despite the high initial investment cost. These challenges were attributed to poor design by service providers, poor operational conditions, user attitude, inadequate knowledge of the technology, and or lack of maintenance. It was revealed that with the background of service providers, a majority were artisans (plumbers, masons, carpenters) (*58%: n = 14*), some were graduates in arts, social sciences, business and others *(21%: n = 5*), with a few being engineers *(21%: n = 5*).

The level of uptake of BT was higher in the Greater Accra region as compared to the Central region. This is because, business is considered to do well in the Greater Accra, the capital city of Ghana than the other regions. In spite of these challenges, the dissemination and uptake levels could be increased if a standardized biogas design and a subsidy policy are established.

Chapter 3 assesses the quality of effluent discharged from existing biogas plants (University of Cape Coast (UCC), Mfantsipim Senior High School (Mfantsipim) and Ankaful Maximum Security Prisons (Ankaful)). The levels of effluent quality were then used to evaluate the treatment efficiency or performance of these plants. The performances of these plants were compared to the quality standards set by the Ghana Environmental Protection Agency (EPA). In all, eighteen (18) parameters were assessed and out of these, eight (8) parameters, namely electrical conductivity (EC), total suspended solids (TSS), dissolved oxygen (DO), biological oxygen demand (BOD_5), chemical oxygen demand (COD), ammonia-nitrogen (NH_3-N), total coliforms, *Escherichia coli* (E. coli) and *Salmonella spp*. exceeded the EPA standard values, posing potential public health risks. The high load of microbes in the effluent discharged is of public health concern because they can remain in the environment for over 30 days.

In terms of treatment efficiency, though the UCC biogas plant is relatively new (constructed in 2017), and one was expecting that the effluent quality would be far better than Ankaful and Mfantsipim (both constructed in 2011), however, that was not the case. Factors that might have contributed to the general low performance of these biogas plants include design deficiencies, poor maintenance culture and poor environmental conditions. Further treatment is therefore necessary.

In chapter 4, an alternate biogas model (for both household and institutional/community-based) is proposed to address the challenges associated to the existing biogas plants. Some of the challenges identified include: failure of plant to produce biogas, leakage resulting in unsanitary environment, absence of influent and effluent access which are design deficiencies leading to poor effluent quality. A new design concept was proposed based on these challenges, which is expected to improve plant performance and effluent quality.

The re-designed concept combines a fixed dome with an expansion chamber, an anaerobic baffle reactor (ABR), a constructed wetland (CWL) and a disinfection chamber (DC), with CWL and DC being additional components to the existing design. The re-design provides access for influent and effluent sampling, hence it is possible to monitor effluent quality as well as inclusion of co-digestion with kitchen waste. With regards to installation cost and the area required, the difference between the re-design and the existing are almost the same. For instance, the cost for a re-designed household plant is about US$ 1,530 to US$ 5,950 for $4m^3$ to $12m^3$ (with area of $9m^2$ to $16m^2$) and US$ 10,900 to US$ 22,400 for communal/institutional plants with capacity of $56m^3$ to 120 m^3 (with area of $10m^2$ to $20m^2$) whiles an existing household design ranges from US$ 1,500 to US$ 5,900 for $4m^3$ to $12m^3$ (with area of $8m^2$ to $16m^2$) and US$10,800 to US$22,300 for 62 m^3 to 110 m^3 (with area of $10m^2$ to $20m^2$) for communal/institutional. Though the re-designed is yet to be realized and piloted, it is sustainable and meets the three sustainability pillars: environmental, economic and social.

Chapter 5 reports on people's perceptions on using HEx for biogas generation using TPB (attitude, subjective norm, and perceived behavioural control) framework to assess people's behavioral intentions. The outcomes showed that although not all the tenets for the standard TPB were supported, it could still explain people's perceptions on HEx use, after two structural models were produced: the standard TPB model and an adjusted model (including gender and education). The adjusted model had modestly better explained variance towards HEx use for biogas than the standard TPB, hence provided a useful and effective framework for analysing the interrelationships between socio-demographic variables (education and gender) and the TPB constructs than the standard TPB: thus attitude, subjective norm, and perceived behavioural control had significant effect on people's intentions to use HEx for biogas and were valid predictors of one's intentions.

The findings revealed that subjective norms (family, neighbours, religion and institution) played important role and had significantly positive influence on the use of HEx for biogas generation, though perceived behavioral control (cost, subsidy, stigma and HEx knowledge) was low. For people to increasingly embrace and use HEx for biogas, people with high reputation (especially religious leaders) in the society should be encouraged to adopt BT by using HEx for biogas and also to be part of the HEx promotion and education team, while policy on subsidy is formulated to take care of the high investment cost. Furthermore, gender-specific interventions could be designed for better HEx education.

In chapter 6, the willingness of household heads to adopt BT was assessed using TPB (attitude, subjective norm, and perceived behavioural control) framework. Here, the dynamics of household heads intentions towards BT explains their willingness to adopt BT. The analysis produced two structural models; the standard TPB model and an adjusted model (including ethnicity and education). The results showed that all the TPB constructs; attitudes, subjective norms and perceived behavioral control accounted for a proportion of variance in the dynamics of intentions to adopt BT. Furthermore the introduction of ethnicity and education improved the model with regards to household heads willingness to adopt BT. However, ethnicity (traditional and cultural belief, e.g. taboos) had a direct significantly negative influence on intentions to adopt BT whereas education had both direct and indirect significant effect on intentions to adopt BT.

The findings revealed that ethnicity and the educational level influenced to a large extent the dynamics as well as the willingness of household heads to adopt BT. More education, using ethnic dialect by respected persons would correct the misconceptions about BT. Additionally, people should take advantage of the government’s social intervention (free senior high school) to upgrade their level of education to bring about better comprehension of the technology, thereby increasing willingness to adopt BT in the near future.

Chapter 7 assesses the level of institutional involvement and collaboration, and barriers to biogas technology. The study revealed that due to differences in services, roles and expectations, and lack of financial resources, the involvement of mandated government institutions in BT dissemination was low, with the exception of three institutions (Energy Commission, EPA and GNCPC) that collaborate to undertake activities (seminar/workshop/project) occasionally. Moreover, though there was moderate involvement in activities by service providers, their collaboration with most especially, MMDAs was low,

and that has effect on the level of BT adoption at the household and community/institutional levels. Additionally, the high risk of BT failure perceived by financial institutions has resulted in low involvement and collaboration between them, and government institutions and biogas service providers. These challenges have been aggravated by the lack of a national biogas policy, low government commitment and low financial support/challenges. Suitable interventions could however improve institutional involvement in promoting biogas technology in Ghana.

Finally, **chapter 8** of this dissertation summarises the most important findings from the various studies conducted, as well as methodological strengths and limitations, and implications of this study on future research. Based on the main findings of this study, the most important challenges identified were those of sanitation systems for human excreta management due to inadequate and or lack of waste treatment plant, causing poor environmental sanitation and posing public health risks, and low uptake of BT for sustainable sanitation solution due to low dissemination of the technology.

Important conclusions drawn from the activities of this dissertation are that *biogas technology is a sustainable and environmentally friendly technology that could be employed for the sustainable management of waste (both human excreta and solid organics); a standardized biogas plant design (re-designed concept) be developed; subsidy policy be formulated; to create a database for biogas plants installed; formulation of a national biogas policy; to create a platform for BT education and awareness by relevant institutions (including research institutions) and important persons; to create a market for bio-fertilizer.*

The commitment by relevant stakeholders and the implementation of the appropriate interventions would increase BT uptake, improve environmental sanitation through sustainable sanitation system, and most importantly reduce public health risks.

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Now unto him who is able to keep you from falling, and to present you faultless before the presence of his glory with exceeding joy, to the only wise God our Saviour, be glory and majesty, dominion and power, both now and ever, Amen (Jude 1: 24-25 KJV).

Curriculum Vitae

Mrs. Martha Osei-Marfo was born on 1st January, 1980 in Cape Coast in the Central region of Ghana. After completing her Senior Secondary School education between 1997 and 1999 at Tema Secondary School, she was offered an admission to read Biological Sciences (2001-2005) at the University of Cape Coast (UCC) for her bachelor's degree. She graduated in 2005 with a major in Chemistry.

After her national service in 2006 as a Teaching Assistant at the Department of Chemistry, UCC, she was offered admission to the Kwame Nkrumah University of Science and Technology, Department of Civil Engineering to read Water Supply and Environmental Sanitation between 2006 and 2008. She graduated successfully and was awarded a Master of Science in Water Supply and Environmental Sanitation in 2008.

She started her professional career as an Assistant Researcher at the Institut International d'Ingénierie de l'Eau et de l'Environnement (2iE), Ouagadougou, Burkina Faso and was involved in research and analysis at the wastewater laboratory.

In 2009, Martha was employed as a Lecturer into the Department of Chemistry, Water and Sanitation Unit in UCC where she is involved with student teaching, research and supervision of student research. She was appointed the officer in charge of departmental seminars between 2010 and 2015, and in 2012 to 2013 she got appointed as academic adviser for first year students.

In January 2016, she started her PhD Studies in Maastricht University, the Netherlands on split-site as part of the staff development component of the NUFFIC Project.

In 2020, Martha got promoted from the rank of Lecturer to the rank of a Senior Lecturer. She is married to Michael Osei-Marfo with three children; Nana Ntiamoah Osei-Marfo, Naana Ntifua Tabuaa Osei-Marfo and Nana Acquah Asamoah Osei-Marfo. Martha can be contacted through +233244487447 and mosei-marfo@ucc.edu.gh.

Publications

Publications presented in this dissertation

Osei-Marfo, M., de Vries, N. & Awuah, E. (2021). Peoples's perception on the use of human excreta for biogas generation in Ghana. *Environment, Development and Sustainability,* doi: https://doi.org/10.1007/s10668-021-01439-4

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Re-designed Biogas Plant for Sustainable Sanitation

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Other publications

Bryant, I. M. & **Osei-Marfo, M.** (2021). Innovative designs in household biogas digester in built neighbourhoods. Chapter in Anaerobic digestion in natural and built environments. IntechOpen. doi: http://dx.doi.org/10.5772/intechopen.97210.

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