© 2018 The Authors
932

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

Biogas technology diffusion and shortfalls in the central and greater Accra regions of Ghana

M. Osei-Marfo[a,c,*], E. Awuah[b] and N. K. de Vries[c]

[a] Water and Sanitation Unit, Department of Chemistry, University of Cape Coast, Cape Coast, Ghana

[b] Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

[c] Department of Health Promotion, CAPHRI, University of Maastricht, Maastricht, The Netherlands

*Corresponding author. E-mail: mosei-marfo@ucc.edu.gh

Abstract

The current status of biogas technology in Ghana, a developing country, was explored focusing on factors affecting dissemination of the technology 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-up, 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.

Key words: 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 to 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 one of the oldest of applications. Dahiya & Joseph (2015) reported that biogas technology is generally used for waste management, and that all

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

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 *et 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; Amigun & Blottnitz 2010; Bensah & Brew-Hamond 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). However, many projects have been unsuccessful or faced challenges soon after diffusion. 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-up 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 the 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

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[a]	1,209
Burundi	50	2002[a]	18,000
Ghana	20	1996[a]	750
Ghana	100	1999[a]	39,120
Ghana	20	2000[a]	7,974
Ghana	6	2004[a]	1,358
Ghana	300	2006[c]	191,792
Ghana	50	2009[c]	31,663
Ghana	6	2011[b]	2,189
Ghana	10	2011[b]	3,169
Ghana	2400	2012[c]	25 M
Ghana	200	2014[c]	77,778
Ghana	6	2015[c]	851
Kenya	8	2004[a]	2,973
Rwanda	1000	2004[a]	220,000
Uganda	6	2004[a]	1,005

[a]Adapted from Amigun & Blottnitz (2010).
[b]Retrieved from Bensah & Brew-Hamond (2010).
[c]data from this study (2017).

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

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.

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 *et 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; Arthur *et al.* 2011; Bensah *et al.* 2011), especially for cattle-owning households. Three digesters were dysfunctional and 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 *et al.* 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 of biogas technology 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 described as balloon, fixed dome and floating drum (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 (Figure 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 Figure 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).

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

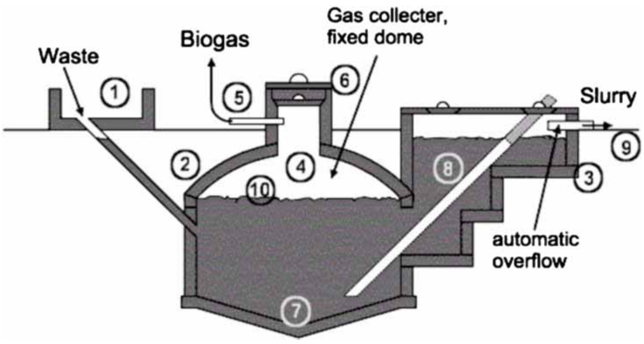

Figure 1 | Fixed dome digester 1. Mixing tank with inlet pipe. 2. Gasholder. 3. Digester. 4. Compensation tank. 5. Gas pipe. (adapted from Kossmann *et al.* (1999)).

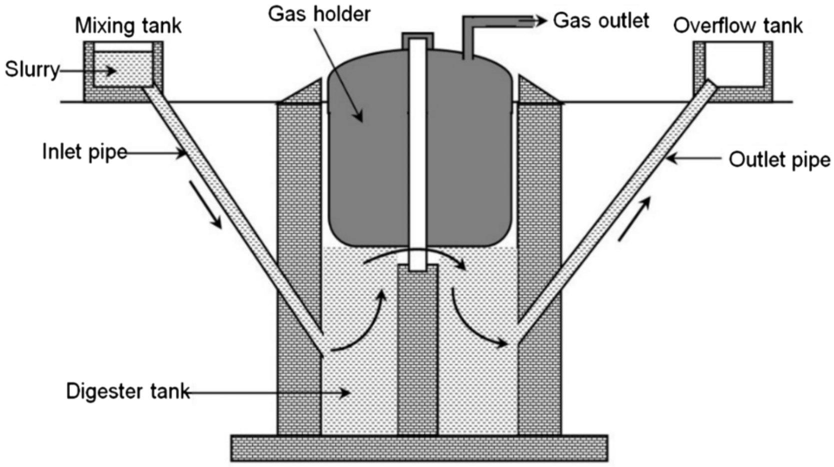

Figure 2 | Floating drum digester 1. Mixing tank with inlet pipe. 2. Digester. 3. Compensation tank. 4. Gasholder. 5. Water jacket. 6. Gas pipe. (adapted from Arthur *et al.* (2011)).

The Puxin digester is made of concrete with a carbon fibre gasholder (Bensah *et al.* 2011) (Figure 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 wastewaters. A new version, known as the Lavender Hill faecal treatment plant (LHFTP) and a rehabilitated Mudor waste water plant (MWWP, also UASB), were commissioned in November 2016, in Korle Gonno, Accra. The maximum capacity of

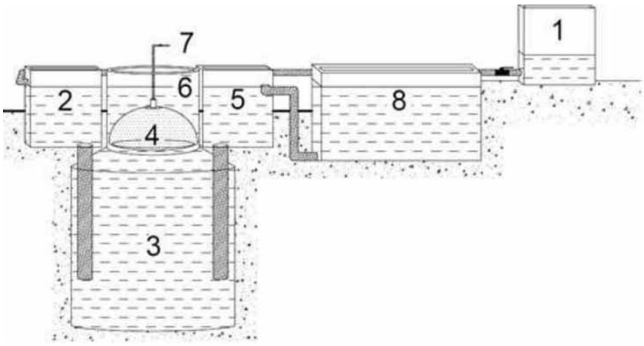

Figure 3 | Puxin digester 1. Mixing tank with inlet pipe. 2. Digester. 3. Compensation tank. 4. Gasholder. 5. Gas pipe. (adapted from Arthur *et al.* (2011)).

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

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. 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 Accra. The ABR looks like a traditional septic tank system (Figure 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.

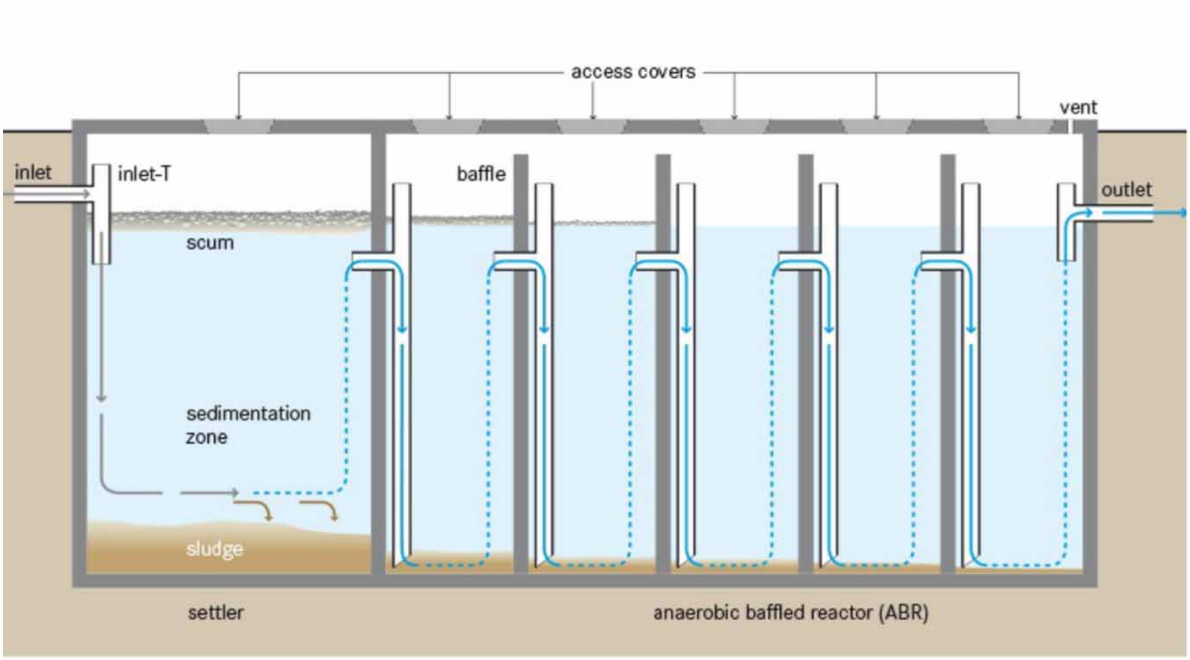

Figure 4 | ABR (adapted from Tilley *et al.* (2014)).

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).

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

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 two and three MMDAs in the respective 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):

$$\text{Sample size} = Z^2 * \text{P}(1 - \text{P})/\text{C}^2 \tag{1}$$

where $\text{Z} =$ confidence level
$P =$ total number of digesters/respondents
$\text{C} =$ 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.

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

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 eight 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 the 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 the Central region. All but three of the household plants were in a good state and functioning, with respect to treating faecal matter; the other three 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 allowing 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 a 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. Figure 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 a waste water 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 environments could have direct or indirect effects 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

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

Figure 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.

outcome is considered a health risk. 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 was the 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, three 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. Figure 6 shows the state of the KEEA plant and how raw sludge is disposed of at the site.

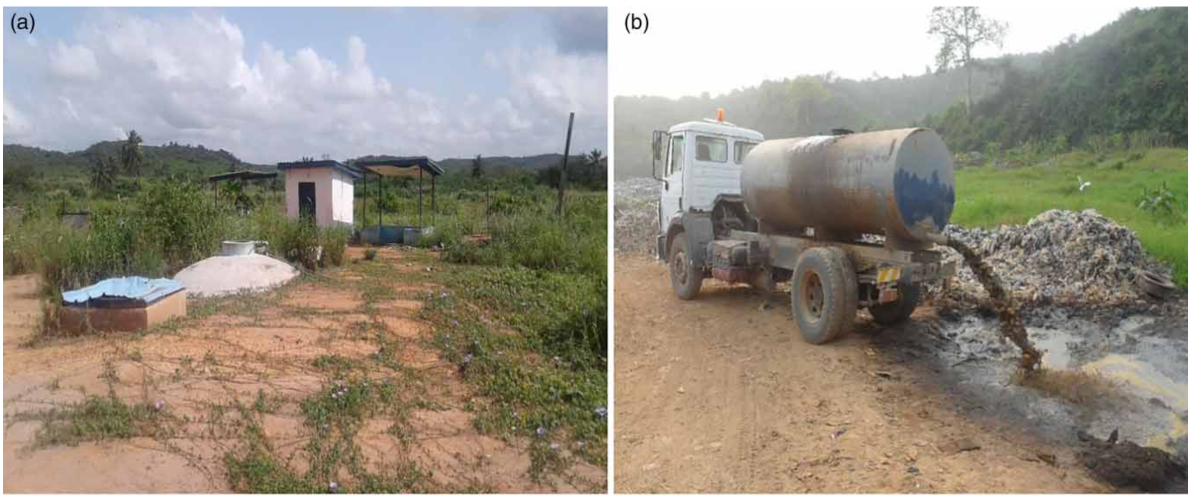

Figure 6 | (a) Abandoned 200 m^3/d biogas plant at KEEA, Central region, October 2017. (b) Cesspit emptier disposing raw sludge on the ground at a dump site in Nkanfoa, Central region, October 2017.

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

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.

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 away. Figure 7 shows the Safisana plant. This plant works efficiently because there is an assigned operator who does 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 a waste stabilisation pond with baffles for the treatment of liquid waste from the drying beds. It operates at 37 °C (mesophilic temperature).

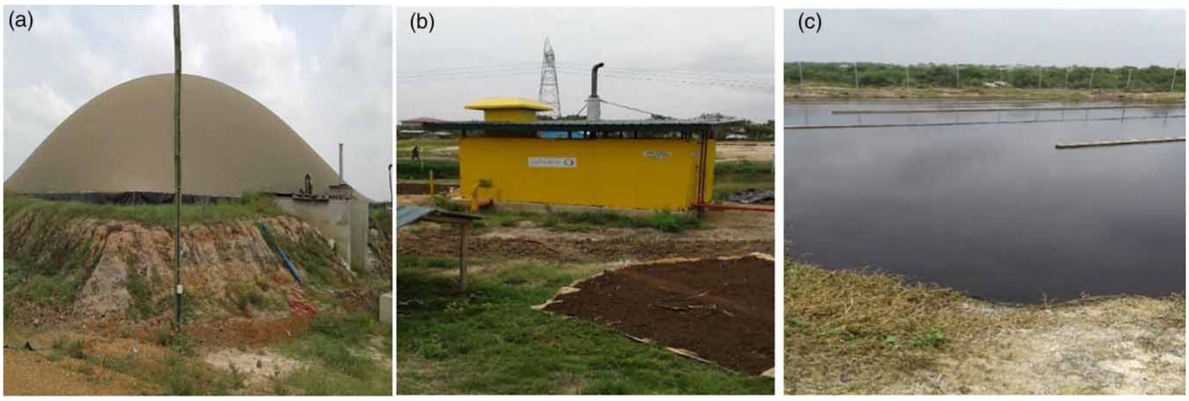

Figure 7 | (a) The Safisana fixed dome biogas plant, Ashaiman, Accra, September 2017, (b) the CHP at the Safisana Ashaiman site, September 2017; (c) Waste stabilisation pond with baffles at the Ashaiman site for treatment of liquid waste from the drying beds, September 2017.

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 problem issues were: failure of most biogas digesters/plants; little or no gas; leakages; and breakdown of some units of the digester/plant (gas storage, pipes, and gas meter) after working for about one year or

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

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. This seems to reduce or remove the interest of potential users in the technology. Most potential users do not see the successful use of the technology in spite of the high investment cost and some reasons that demotivate them include failure of the digester to produce continuous gas after a short period of operation, lack of space to site the plant, the attitude of service providers towards 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 a lack of qualifications. They feel that those without training build digesters/plants that are unsustainable, affecting negatively those with qualifications (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 a 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 1,333 for 6 m^3 digesters, 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 require to be viewed monthly to check for trapped water, the gas pressure meter should be checked annually, and the gas storage checked 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 an 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 five (21%) of the biogas service providers surveyed are engineers. Of the other disciplines, 14 (58%) are artisans (plumbers, masons, carpenters) and five (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 shows (Smith 2011) that biogas technology creates jobs for local people (including artisans who can be trained to construct digesters) and they improve 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 (Surendra *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.

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

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,

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

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

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

for the household digesters, the majority had challenges with gas production at some point in time. As shown in Table 4, all household digesters surveyed are the fixed dome type. Though a few were still producing gas, most of them failed 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, with no need for additional cost for maintenance. Almost all the household digesters visited had been connected to a 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 waste water 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 digesters, and the feedstock contains substances toxic to the microorganisms, producing biogas will be a challenge. The examples of selected household digesters presented in Table 4 shows that though the digesters are relatively new, there are challenges with gas production, except a few of which are in full operation. 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 are 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 in some plants. For the Puxin type, they are 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 the toilet, has failed because of a 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, a rusted drum, and digester leakage that flooded the immediate environs. Finally, the ABR, being relatively new in the system, did produce some gas but there was no storage. The challenges can be fixed, however, due to lack of follow-up and regular maintenance by service providers, almost all institutional plants have become waste water treatment plants. The function of the plant has shifted, in other words, from providing energy to sanitation purposes only. The 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 a 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.

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

Lack of regulatory body: There are several biogas service providers in Ghana, both individuals and groups/companies. They carry out their activities with little or no monitoring because some are registered and other are not (Table 4). Apart from this, there is/are no standardised digester designs 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 a regulatory role.

Negative social perception: Biogas technology uses all kinds of biodegradable feedstock for gas production. The feedstock ranges from human excreta, animal dung, food waste etc. Some people have a negative perception of the quality of the gas produced. They see the gas as contaminated, especially if human excreta is 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, and is free of pathogens, 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 increases harvests, 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 should collaborate to promote and disseminate biogas technology and encourage farmers patronise bio-fertiliser.

ACKNOWLEDGEMENT

This research was supported by the Netherlands Government under the NUFFIC project NICHE 194-01 [grant number CF9419] and the Maastricht University, the Netherlands.

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

REFERENCES

Ahiataku-Togobo, W. & Owusu-Obeng, P. Y. 2016 *Biogas Technology-What Works for Ghana?* http://energycom.gov.gh/files/Biogas%20-%20What%20works%20for%20Ghana.pdf. (accessed 20 October 2016).

Amigun, B. & Blottnitz, v. H. 2010 Capacity-cost and location-cost analyses for biogas plants in Africa. *Resources, Conservation and Recycling* **55**, 63–73. http://doi.org/10.1016/j.resconrec.2010.07.004.

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

Bajgain, S. & Shakya, I. S. 2005 *The Nepal Biogas Support Program: A Successful Model of Public Private Partnership for Rural Household Energy Supply* (Mendis, S. M. ed.). SNV-Netherlands Development Organisation, Biogas Sector Partnership, Kathmandu, Nepal.

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

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

Berhe, T. G., Tesfahuney, R. G., Deata, G. A. & Mekonnen, L. S. 2017 Biogas plant distribution for rural household sustainable energy supply in Africa. *Energy and Policy Research* **4**, 10–20. http://doi.org/10.1080/23815639.2017.1280432.

Dahiya, S. & Joseph, J. 2015 High rate biomethanation technology for solid waste management and rapid biogas production: an emphasis on reactor design parameters. *Bioresources Technology* **188**, 73–78. http://doi.org/10.1016/j.biortech.2015.01.074.

Dhoble, S. A. & Pullammanappallil, C. P. 2014 Design and operation of an anaerobic digester for waste management and fuel generation during long term lunar mission. *Advances in Space Research* **54**, 1502–1512. http://doi.org/10.1016/j.asr.2014.06.029.

Garfi, M., Marti-Herrero, J., Garwood, A. & Ferrer, I. 2016 Household anaerobic digesters for biogas production in Latin America: a review. *Renewable and Sustainable Energy Reviews* **60**, 599–614. http://doi.org/10.1016/j.rser.2016.01.071.

Ghana Statistical Service 2012 *Population and Housing Census*. http://www.statsghana.gov.gh/docfiles/2010phc/Census2010_Summary_report_of_final_results.pdf (accessed 20 December 2016).

Godden, B. 2004 *Sample Size and Confidence Interval Tutorial*. http://williamgodden.com/tutorial.pdf/january-2004 (accessed 13 February 2017).

Karekezi, S. 2002 Renewables in Africa-meeting the energy needs of the poor. *Energy Policy* **30**, 1059–1069.

Khann, E. U. & Martin, A. R. 2016 Review of biogas digester technology in rural Bangladesh. *Renewable and Sustainable Energy Reviews* **62**, 247–259. http://doi.org/10.1016/j.rser.2016.04.044.

Kossmann, W., Pönitz, U., Habermehl, S., Hörz, T., Krämer, P., Klingler, B., Kellner, C., Wittur, T., von Klopotek, F., Krieg, A. & Euler, H. 1999 *Biogas Digest (Volume II) - Biogas - Application and Product Development*. https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/526. (accessed 6 November 2018).

Kumar, A., Mandal, B. & Sharma, A. 2015 Advancement in biogas digest. *Green Energy and Technology.* http://doi.org/10.1007/978-81-322-2337-5_14.

Kumasi Institute of Technology and Energy 2008 *Feasibility Study Report on Domestic Biogas in Ghana*. Submitted to Shell Foundation, Accra, Ghana.

Mata-Alvarez, J., Dosta, J., Romero-Güiza, M. S., Fonoll, X., Peces, M. & Astals, S. 2014 A critical review on anaerobic co-digestion achievements between 2010 and 2013. *Renewable and Sustainable Energy Reviews* **36**, 412–427. http://doi.org/10.1016/j.rser.2014.04.039.

Mulinda, C., Hu, Q. & Pan, K. 2013 Dissemination and problems of African biogas technology. *Energy and Power Engineering* (5), 506–512. http://doi.org/10.4236/epe.2013.58055.

Njoroge, D. K. 2002 *Evolution of Biogas Technology in South Sudan; Current and Future Challenges*. http://www.mekarn.org/procbiod/kuria.htm (accessed 19 January 2017).

Rupf, V. G., Bahri, A. P., Boer, d. K. & Mchenry, P. M. 2015 Barriers and opportunities of biogas dissemination in Sub-Saharan Africa and lessons learned from Rwanda, Tanzania, China, India, and Nepal. *Renewable and Sustainable Energy Reviews* **52**, 468–476. http://doi.org/10.1016/j.rser.2015.07.107.

Sasse, L. 1988 *Biogas Plants*. Federal Republic of Germany: Technische Zusammenarbeit GmbH, Eschborn, Germany.

Smith, J. U. 2011 *The Potential of Small-Scale Biogas Digesters to Alleviate Poverty and Improve Long Term Sustainability of Ecosystem Service in Sub-Saharan Africa*. Ethiopia.

SNV/Biogas Solution Uganda 2016 *Operation and Maintenance of Biogas Plants, Bio-Slurry Management and Use*. https://kenyabiogas.com/wp-content/uploads/2016/11/handbook_on_operation_and_maintenance_of_biogas_plants_bio-slurry_use_and_management.pdf (accessed 20 September 2018).

Spickett, J., Goh, Y., Katscherian, D. & Ellies, P. 2010 *Health Risk Assessment Scoping Guidelines*. https://ww2.health.wa.gov.au/~/media/Files/Corporate/general%20documents/Environmental%20health/Health%20risk%20assesment/HRA-Scoping.pdf (accessed 18 September 2018).

Surendra, K. C., Takara, D., Hashimoto, A. G. & Khanal, S. K. 2014 Biogas as a sustainable energy source for developing countries: opportunities and challenges. *Renewable and Sustainable Energy Reviews* **31**, 846–859. http://doi.org/10.1016/j.rser.2013.12.015.

Water Practice & Technology Vol 13 No 4
doi: 10.2166/wpt.2018.100

Tilley, E., Ulrich, L., Lüthi, C., Reymond, P., Schertenleib, R. & Zurbrügg, C. 2014 *Compendium of Sanitation Systems and Technologies*, 2nd ed. (Donahue, P. ed.). Eawag, Dübendorf, Switzerland.

United Nations 2011 *Promotion of New and Renewable Sources of Energy*. http://www.un.org/esa/dsd/resources/res_pdfs/ga-66/SG%20report_Promotion_new_renewable_energy.pdf (accessed 6 November 2018).