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Development of biogas resources and technologies in Ghana, a survey

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Abstract
Due to rapid global population growth and urbanization, there is corresponding increasing demand for energy. This increasing demand has necessitated the need to explore alternative sources of energy. Besides the growing energy demand, issues of environmental protection and climate change have risen to the top of global politics, leading to increased interests in renewable energy sources. One of these renewable energy sources with very diverse applications is biogas. Biogas, like natural gas, can serve as cooking fuel, transportation fuel, and as source for electricity generation, making it a very versatile fuel. Biogas is produced from several organic feedstocks, using anaerobic digestion technology. The technology has not developed as expected in Ghana despite reported enormous feedstock potential mainly due to, lack of data on specific areas where feedstocks can be assessed and the corresponding specific biogas potential, among other reasons. This paper surveys specific areas across Ghana where the diverse biogas raw materials are concentrated. The paper also studies existing biogas technologies and their potential utilization in various economic sectors of Ghana where their application will have the highest socio-economic impact. Technical expertise and technology transfer options for the biogas technologies needed in Ghana were also assessed. The survey showed that the most common feedstock types, readily available in Ghana for anaerobic digestion are agricultural residues and food-processing residues, livestock manures, slaughterhouse wastes, municipal solid waste (organic fraction) and municipal sewage sludge. Agro-industries that process cassava waste, rice residues, palm oil residue, fruit processing waste and shea cake are the key agro-industries with very high biomass feedstock potential in Ghana. Each of the different feedstock surveyed showed methane potential in excess of 10,000,000 m^3CH_4 in each of the regions. The survey also showed that biogas plants in use in Ghana are either the small to medium scale (10 m^3 to 100 m^3) fixed-dome digester or the floating drum digesters and two functional industrial scale Upflow Anaerobic Sludge Blanket (UASB) plants and the Ccontinuous Stirred Tank Reactor (CSTR). Some economic sectors that will be impacted from the dissemination of biogas technology are agriculture, waste management, energy and climate change, health and social benefits such as job creation and improved well-being. The paper concludes that there are skills and expertise in Ghana to manage small to medium scale biogas digesters, but on the industrial scale, there exists limited expertise in the design, installation, operation and maintenance of the plants.

Keywords: Biogas resources; Biogas technologies; Anaerobic digestion; Industrial biogas; Biogas survey.

1. Introduction

The increasing energy demand due to population growth and industrialization along with the issues of environmental pollution and climate change has necessitated a move towards alternative sources of energy [1]. The rise of climate change to the top of global politics has also led to increased investments into renewable energy sources [2]. Renewable energy sources consist of energy sources that are constantly replenished by nature and as such will continue to be available even long after fossil fuels run out. Renewable sources such as solar, wind, geothermal, and biomass have gained popularity in recent years. Biogas is a renewable energy source with diverse applications and for this reason it has been widely adopted. Biogas, like natural gas serves as fuel for cooking, transportation, electricity generation, etc., making it a versatile energy source. Biogas can be produced from several biological feedstocks through anaerobic digestion – a process by which biodegradable materials are broken down by microorganisms in the absence of oxygen. Biological feedstocks such as sewage sludge, crop and agricultural residues, municipal and industrial waste can provide biogas when they undergo anaerobic digestion and the digester residues (digestate) recycled for use as fertilizer.

Anaerobic digestion of large quantities of municipal, industrial and agricultural wastes can provide biogas that can be used for heat and electricity production and the digester residue recycled for agricultural use as a secondary fertilizer. Biogas technology is seen as one of the renewable technologies in Africa capable of easing the energy and environmental problems of the continent. Several sub-Saharan African countries are utilizing a variety of waste resources ranging from slaughterhouse waste, municipal wastes, industrial waste, animal dung and human excreta for the production of biogas. The development of large-scale biogas production technology in Africa isn't at an advanced stage after several years of promotion, but a large potential still exists for its development, both at the industrial and small-scale levels. In Ghana, biogas from organic and municipal (liquid) waste is still gaining popularity but yet to reach an advanced stage in spite of reported large feedstock potentials [3, 4]. The major challenges to the development of this technology include lack of data on specific areas of feedstock and their potentials, lack of technical expertise and maintenance problem of existing systems [5].

The objective of this study was to conduct a detailed review on biogas, focusing on resources, technologies and their potential productive utilization in various economic sectors of Ghana where their application will have the highest socio-economic impact. The study was also aimed at assessing technical know-how and technology transfer options for the technologies and their applications, especially at the subnational level. To achieve this goal, a nationwide survey of feedstock was conducted to assess biogas feedstock quantities and locations in selected sectors as well as biogas plant installations. The selection of sectors was based on sectors with high potential for biogas production particularly institutions (e.g.: Metropolitan, Municipal and District Assemblies (MMDAs), hospitals, schools, etc.) and industries (mainly agriculture-related, processing, etc.).

2. Biogas technology in Ghana

2.1 Developments and perspectives

The development of biogas technology in Ghana dates back to the late 1960s, with the focus of providing energy for cooking in rural households [5]. However, the Ministry of Energy constructed the first biogas demonstration plant (a 10 m^3 Chinese fixed-dome digester) later in 1986 with Chinese Government's support at a cattle ranch owned by the Bank of Ghana (BOG) at Shai Hills [6]. Following that, the United Nations Children Fund (UNICEF) in 1987 supported the construction of a couple of domestic biogas demonstration plants at Jisonayilli and Kurugu in the Northern region of Ghana [6]. In June 1992, the Ministry of Energy (MoE) commissioned the first large scale community-based biogas plant which powered a 12.5 kVA generator in Appolonia, in the Greater Accra region to provide street lighting and electricity for small load appliances for households in the community [5]. Other institutions, organizations and churches including the Catholic Secretariat and the German Agency for International Cooperation (GIZ) have immensely supported the dissemination of biogas technology in Ghana.

In an attempt to ascertain the true state of biogas technology in Ghana prior to the planning and development of a nationwide biogas programme in 2007, Kumasi Institute of Technology and Environment (KITE) conducted a survey which revealed that out of 50 sampled biogas plants, 22 (44%) were in good condition, 10 (20%) were functioning with some defects observed (such as: deteriorated gasholders, gas pipelines and appliance), 14 (28%) were off-line 2 (4% were abandoned and the remaining 2 (4%) were under construction. These conditions were due to owners' reluctance to bear extra cost maintaining the system and some service providers not spending time to take users through the rudiments and the functions

of the biogas systems [5, 6]. Majority of the biogas plants installed were for bio-sanitation interventions such as waste/effluent treatment plants and bio-latrines, which were located predominantly in educational and health institutions in urban areas.
Given the ability of biogas plants to improve sanitation while generating energy, several companies, public and private institutions as well as individuals have marketed the technology purely on business grounds over the years. This has facilitated the uptake of biogas technology in Ghana, but without a consolidated database of installations.

2.2 Biogas Feedstock and Resources in Ghana

Ghana has a wide variety of organic materials that can serve as feedstock for anaerobic digestion to produce biogas. The economy of Ghana is inclined towards the agricultural sector, which is made up of food crops (59.9 %), livestock (7.1 %), fisheries (7.6 %), cocoa (14.3 %) and forestry (11.1%) as its major sectors [7]. Two main classes of biomass feedstock for use in a biogas plant exist in Ghana. The first is farm-based products such as waste from farmlands, animal manure and agricultural residue. The second is made up of organic waste from food and feed industries and municipal solid wastes. The most common feedstock types, readily available in Ghana for anaerobic digestion include; agricultural residues and food-processing residues, livestock manures, slaughterhouse wastes, municipal solid waste (organic fraction) and municipal sewage sludge. Agro-industries that process cassava waste, rice residues, palm oil residue, fruit processing waste and shea cake are the key agro-industries with very high biomass feedstock potential in Ghana.

2.2.1 Cassava as feedstock for anaerobic digestion

Cassava is a root-tuber crop produced on relatively large scale in Ghana. It is a major food crop in the farming system of Ghana. It serves as a source of carbohydrate; one of the important food nutrients required in a balanced diet and it is also a source of income for most rural settlers. Cassava is also used for starch production for industrial applications in pharmaceuticals, brewery, glue, animal feed, etc .
Ghana is the sixth largest cassava producing country in the world and the third in Africa, with an estimated 70% of local farmers engaged in cassava production producing over 15 million metric tonnes (Mt) of cassava annually [8]. Cassava does well on marginal lands and represents approximately 50 % of the total roots and tubers produced in Ghana [9].
Cassava is grown in all regions of Ghana but is particularly abundant in Central, Eastern, Brong Ahafo (now split into Bono, Ahafo and Bono East) Volta, and Ashanti regions (see Table 1). The Eastern Region has the highest cassava production in Ghana followed by Brong Ahafo Region, Central Region, Ashanti Region and Volta Region in decreasing production order. The Eastern and Brong Ahafo regions have an average of 4,466,906.01 and 3,747,940.65 Mt per year respectively for cassava production. A study conducted by [10] revealed that about 93% of cassava peels generated annually are not utilized and eventually burnt. These unused residues are the actual quantity of feedstock available for biogas production. The report revealed that the percentage of these available (unused) peels from the Brong Ahafo Region was 87%, Central Region 9.5%, Ashanti Region 3% and Northern Region 0.5%. Residues in the Ashanti and Northern regions are mainly used for feeding livestock in the regions hence, the low percentages of available residues. The quantity of unused peels/residue available has a potential of about 1 million m^3 CH_4 [10].

2.2.2 Rice as feedstock for anaerobic digestion

Rice as a cereal is the most widely distributed staple food for a large part of the world’s population including Ghana. In Ghana, rice is grown in all 10 regions but mainly in the mountainous areas of the Volta region, Eastern region and the Northern region. The Volta region and Northern regions have an average 184,279.32 and 168,407.25 Mt of rice production respectively [11]. After harvesting rice, milling takes place principally to remove the husk and brans from paddy grains to produce edible rice kernel that is free from scums.
Rice like most plants consist mainly of the root, stem and the crown (pinnacle), collectively called, the rice straw. Rice paddy is the main component of interest in its harvest. The straws are left on the field after harvest and studies indicate that, for every ton of rice produced about 2.5-3.5 tons of straw is generated [3, 4]. This is undoubtedly a very huge amount of waste generated, however little to no use has been associated with rice straw. Huge piles of rice husk are left after processing the rice (by milling which is done to separate the edible grain from the husk) at the processing sites, which are usually in habited communities.

About 90% of the waste is left on site, which is either burnt in open air or compressed and dumped at landfill sites. However, these residues are readily available for biogas production.
In Ghana, since rice is usually cultivated along the northern and middle belts of the country, i.e. the Northern, Eastern, Volta and Ashanti regions, menacing amounts of rice husks can be seen in these areas.

2.2.3 Oil Palm residue as feedstock for anaerobic digestion
Ghana currently has over 300,000 hectares of oil palm of which more than 80% is cultivated by private small-scale farmers [12]. An estimated 243,852 tons of palm oil is produced each year [13]. This quantity is undoubtedly a huge amount, which leaves behind several tonnes of residue. During the processing of the fresh fruit bunch (FFB), a significant amount of wastewater with high organic loads, known as Palm Oil Mill Effluent (POME) is produced. The ratio of POME produced is approximately 0.6 tons per ton FFB and has a methane potential estimate of up to 15 m^3 CH_4 per ton FFB processed [4]. Empty fruit bunches (EFB) and palm kernel shell (PKS) are waste generated by the milling process at the rate of 23% and 7% respectively from processed FFB. A fermentation test conducted on EFB and PKS generated indicated a methane yield of 155 m^3 CH_4 per Mt EFB and 254.2 m^3 CH_4 per Mt PKS.

2.2.4 Fruit process waste as feedstock for anaerobic digestion
Ghana, a major fruit and vegetables producer produces up to 15,000 Mt of mango and 525,000 Mt of pineapple a year [14]. In Ghana, as with many other agricultural products, fruit and vegetables are cultivated mainly by private small-scale farmers with the major commercial production areas located in the southern part of the country where they can easily be exported via the ports. While most Ghanaian fruits are exported unprocessed, there are some companies processing mango, pineapple, papaya and oranges locally. Although fruit processing has been very profitable to the country, it has also over the years created the huge challenge of fruit waste (fruit pulp, peels, crowns etc.). The processing industries generate significant quantities of these waste products. These waste products can quickly rot, giving rise to decayed material with a bad odour, which therefore needs proper treatment and also qualifies as feedstock for biogas generation.
Major commercial fruit processing companies in Ghana include: Pinora, HPW fresh and dry fruits, Blue Skies Ltd. and Golden Exotics all in the Eastern Region and Peelco and Aquafresh Ltd. in the Greater Accra region.

2.2.5 Shea Cake as Feedstock for Anaerobic Digestion
The northern sector of Ghana is less developed with lower income levels as compared to the southern sector [15], with majority of the rural people depending on agriculture and petty trading for their livelihood. Shea butter production is one of the major occupations for the rural people in the northern regions of Ghana [16]. Shea collection, processing and subsequent sale of shea-based products generate income with about 600,000 women in the northern regions depending on the income generated from shea butter production [17]. The shea tree is an important commodity in the northern part of Ghana; the fruit is a source of food and the seed an important source of glycerol and fatty acid [18]. Over the years, shea butter extraction has been done traditionally [19], which gives lower yield per unit raw material resulting in high waste generation.
In spite of the economic and nutritional benefits of shea, its processing generates a lot of by-product, capable of being used as a feedstock for biogas production. The wastes generated during shea butter processing are mainly wastewater, waste sludge, seed husks and seed shells. These wastes are indiscriminately disposed off thereby becoming menace to the environment and health threats to dwellers. However, some farmers do use some of the waste sludge from shea butter on their farms as a form of fertilizer. Waste from shea is biodegradable with a high level of volatile solids and is capable of producing biogas with a high percentage of methane [20]. Biogas production from the waste of shea butter if harnessed is capable of reducing the overdependence on wood as a source of fuel and thereby reducing deforestation in shea butter production areas.

2.2.6 Livestock manure as feedstock for anaerobic digestion
Livestock are traditionally reared in most Ghanaian homes. However, cattle, pigs and poultry rearing present the most potentially accessible feedstock for biogas production due to the availability of housing systems for these livestock, with pigs and poultry having higher potential.

Among the livestock types in Ghana, poultry is assumed to be the most commercially produced. Poultry farming has become foremost subsidiary occupation of farmers to supplement their incomes because it assures quick returns, requires minimum space and investment, and can be carried out by ordinary farmers. Poultry also has greater efficiency in converting feed into egg and meat compared to other livestock enterprises. Poultry production continues to grow and commercialize due to population growth, urbanization and ready market. The droppings or litter from poultry farms are rich biogas feedstock [21].

Poultry production in Ghana has a large component of village poultry involving local chickens, guinea fowls and ducks kept in an extensive system by almost all households in rural areas. Currently, there are quite a number of farms engaged in commercial poultry production in Ghana specifically in the Greater Accra, Ashanti and Brong Ahafo regions. According to [10], the Brong Ahafo Region is the leading commercial poultry production region in Ghana and most of the farms are located within the Dormaa District. In Dormaa District, there exist a total of about 213 farms out of which about 40 are large-scale production farms (with a minimum of 10,000 birds), 33 medium scale (5,000-10,000 birds) and the remaining small scale (less than 5,000 birds) [10].

Local consumption of pork in Ghana is growing and has the potential to grow to international standards [22]. The growth of this industry is directly linked to the generation of tonnes of pig droppings, which can constitute a nuisance and lead to serious waste management challenges. Pig production enterprise like all livestock activities, generates various regimes of biodegradable waste resources, which are suitable for conversion into bioenergy or specifically biogas and bio-fertilizer using the anaerobic digestion process. Pig manure has a relatively high gas production of between 0.040 – 0.059 m^3/kg [23].

2.2.7 Slaughterhouse and Abattoir Waste

Majority of the animals slaughtered in Ghana are done in individual homes, however, some patronise abattoirs in the regional capitals. The Accra and Kumasi Abattoirs are the largest in Ghana and have been equipped with modern facilities. Both have the capacity to slaughter 450 - 480 cattle per day, 450 - 480 sheep and goats per day and 200 pigs per day [10]. Abattoir operations are meant to recover the edible portions of slaughtered animals for human consumption. In the process, significant quantities of secondary waste materials not suitable for further consumption are generated and need to be effectively treated. Technically, slaughterhouse or abattoir waste is the solid waste and wastewater from an abattoir, which could consist of pollutants such as animal faeces, blood, fat, animal trimmings, paunch contents and urine. The average biogas yields are 60 m^3 per Mt paunch content with 55% methane and 37 m^3 per Mt blood with 60% methane [12].

2.2.8 Municipal Solid and Liquid Waste as Feedstock for Anaerobic Digestion

Solid waste management is an issue of concern to most governments of developing countries especially in Africa due to its effect on the environment. Rapid population growth rate has led to the generation of large amount of solid waste and a lack of technical and financial resources to address the related challenge by the municipal authorities. Organic material constitutes the largest portion of municipal solid waste (MSW). It is estimated by [4] that the municipal waste in the regional capitals of Ghana is about 0.56 Mt, which corresponds to a biogas potential of about 17 million m^3 CH_4/yr.

Although anaerobic digestion of sewage sludge in wastewater treatment facilities is a common practice worldwide, in Ghana currently, raw faecal and sewage sludge is hardly treated at sewage treatment plants but rather dumped at landfills or poured into the ocean [12]. Few institutions and individual homes have installed biogas digesters for the treatment of liquid waste.

2.3 Quantities and locations of biogas feedstock in Ghana

Biogas feedstocks such as agricultural residues, agro-industrial waste, livestock manure, slaughterhouse and abattoir waste etc. constitute the major resource or biomass feedstock available in Ghana. These resources are spread widely across the country in varying quantities. Several studies have been conducted to assess the quantities of these resources and their corresponding methane potential at the national and regional levels [3, 4]. Table 1 summarizes research finding and data collected during a biogas resource assessment [10] carried out at the district level across the country. It captures the biogas resources available at some surveyed sites within some districts across the country along with the quantities and corresponding methane potential. A geographical map showing areas/locations with most concentration of biogas resources and their methane potential is shown in Figure 1.

Table 1. Biogas Feedstock Availability and Methane Potential across Ghana.

Region	District	Community	Company/ Institution/ Organization	Resource Type	Resource Quantity	Unit	Residue Quantity	Methane Potential (M^3Ch4)
Greater Accra	ALL			MSW	1,126,755	t/yr		
	Accra	Bubuashie	Accra Academy	MLW	22,667	t/yr		272
	Ga West	Obeyeyie	Private individual	Cow dung	657	t/yr		17,498
	Ga West	Afuama	BLUE BLUE Pig Farm Ltd	Pig manure	1,183	t/yr	473	11,549
	Ga South	Honi	GULDREST Farms	Pig manure	394	t/yr		9,624
Ashanti	ALL			MSW	960,425	t/yr		
	Mampong	Mampong	Mampong Govt. Hosp.`	MLW	24,638	kg/y		296
	Ejura Sekyedumasi	Ejura	Several Private Individuals	Cow dung	1,138	t/yr		30,330
	Sekyere South District	Agona	Ideas Pig Farm	Pig manure	263	t/yr	263	6,416
	Mampong	Sekruwa	Josma Agro - Processing Ltd.	Cassava peels	187	t/yr	168	28,665
Eastern	ALL			MSW	544,233	t/yr		
	Lower Manya Krobo	Ayipong	Asutsuare farms	Cow dung	657	t/yr		17,498
	Lower Manya Krobo	Ayipong		Poultry manure	1,095	t/yr	1,095	60,757
	Lower Manya	Asutsuare	Apradu rice mill	Husk & bran	72	t/yr	65	12,046
	Lower Manya	Asutsuare	Ocean baby Ent.	Husk & bran	311	t/yr	311	57,821
	Lower Manya	Akuse	Lartey farms	Husk & bran	1,037	t/yr	1,037	192,738
	Lower Manya	Akuse	K-line farms	Husk & bran	1,037	t/yr	1,037	192,738
	Lower Manya	Akuse	Kpong Farms	Husk & bran	57	t/yr	57	10,567
	Lower Manya	Akuse	Abians Rice Mills and Agrochemicals	Husk & bran	855	t/yr	770	143,108
	Lower Manya	Akuse	Madam Katherine Enterprise	Husk & bran	1,037	t/yr	933	173,464
	West Akim	Asamankese	Pinora	Fruit waste	83,520	t/yr	83,520	14,536,890
	Kwaebibirem	Otumi Nkwantananso	31st Dec. Womens Movement Krama & Agyei Krama	POME	1,866	t/yr		
	Kwaebibirem	Kwae	Ghana Oil Palm Development Company	POME	313,170	t/yr		
	Denkyembo	Akwatia	Christian Mothers Association Krama	POME	518	t/yr		
Brong Ahafo	ALL			MSW	515,161	t/yr		
	Techiman	Techiman	Techiman Municipal Assembly	MSW	51,100	t/yr	51,100	5,690,496
	Techiman	Techiman	Holy Family Hospital	MLW	79,497	kg/y		954
	Techiman	Anwora	Aworowa Cassava Processing Society	Cassava peels	1,050	t/yr	997	169,711
	Techiman	Akrofrom	Yesu Adom Gari Factory	Cassava peels	900	t/yr	810	137,810
	Techiman	Krobo	Nnipa Hia Moa Gari Processing	Cassava peels	900	t/yr	855	145,466
	Techiman	Asueyi	Asuogya Agro-Processing	Cassava peels	1,166	t/yr	1,108	188,524
	Techiman	Mesidan	Nana Yeboah Gari Processing	Cassava peels	1,500	t/yr	1,425	242,444
	Sunyani	Sunyani	Sunyani Municipal Assembly	MSW	74,095	t/yr	74,095	8,251,219
	Sunyani	Sunyani	B/A Regional Hospital-Sunyani	MLW	204,491	kg/y	2,454	
	Sunyani	Sunyani	Sunyani Abattoir Company Ltd	Rumen, blood & bones	728	t/yr	728	26,765
	Dormaa	Dormaa Ahenkuro	Boris B's Farms & Veterinary Supplies Gh. Ltd	Poultry manure	131	t/yr	24	1,312
	Dormaa	Koraso	Kwadwo Amadu Unity Farms	Poultry manure	1,460	t/yr	117	6,481
	Dormaa	Masu	A M Unity Farms	Poultry manure	730	t/yr	132	7,291
	Dormaa	Suromani	I M Unity Farms	Poultry manure	876	t/yr	158	8,749
	Dormaa	Adomasi	M M Unity farms	Poultry manure	949	t/yr	171	9,478
	Dormaa	Atesikrom	G. I Nyame Aye Awie	Poultry manure	876	t/yr	158	8,749
	Dormaa	Masu	Adom Farms	Poultry manure	219	t/yr	40	2,187
Central	ALL			MSW	465,266	t/yr		
	Kommenda-Edina-Eguafo-Abirem(KEEA)	Elmina	KEEA Municipal Assembly	MSW	26,864	t/yr		2,991,575
	Kommenda-Edina-Eguafo-Abirem(KEEA)	Essaman	TEX Farms	Pig manure	184	t/yr	92	2,246
	Cape Coast	Ankaful	Ankaful Maximum Security Prisons	MLW	160,965	kg/y		1,932
	Cape Coast	Kramotawiah	TOPP Farms	Pig manure	329	t/yr		8,020
	Ewutu-Senya East	Otopiase	GERAL Farms	Pig manure	158	t/yr		3,850
	Ewutu-Senya East	Fianko	FREECO Farms Ltd	Pig manure	263	t/yr		6,416
	Assin South	Assin Kyinso	Central Regional Development Commission	Pig manure	13	t/yr		321
	Assin South	Assin Nsuaem	National Service Secretariat	Pig manure	250	t/yr		6,095
	Assin South	Assin Adubiase	FAUSBEN Farms	Pig manure	131	t/yr		2,887
	Mfantsiman	Akatekyiwa	AKATEKYIWA Farms	Pig manure	329	t/yr		8,020
	Assin South	Assin Dominase	Dannes Annointed Enterprise	Cassava peels	495	t/yr	495	84,217
	Abura Asebu Kwamankese	Abura Dunkwah	Tropical Starch Company Ltd	Cassava peels	72	t/yr	72	12,250
Volta	ALL			MSW	210,262	t/yr		

	Ketu North	Avalavi	New Jerusalem Mills	Husk & bran	97	t/yr	97	18,117
	Ketu North	Avalavi	Edenic Mills	Husk & bran	35	t/yr	31	5,782
	Ketu North	Gagodope	Danyo Farms Company Limited	Husk & bran	116	t/yr	116	21,587
	Hohoe	Ahado	Dodzi Rice Mills	Husk & bran	415	t/yr	415	77,095
	Hohoe	Hohoe	Grimpex Rice Mill - John Miller	Husk & bran	1,106	t/yr	995	185,028
	South Tongu	Fievie	GADCO Ghana Limited	Husk & bran	67,200	t/yr	60,480	11,243,038
	South Tongu	Kpenu - Dabala	Brazil Agro-Business Group Ltd.	Husk & bran	3,538	t/yr	3,538	657,718
	Biakoye	Worawora	GN Worawora rice mill	Husk & bran	19,200	t/yr	17,280	3,212,297
Western	ALL			MSW	202,502	t/yr		
	Nzema East	Bi-zonal: Nsiem & Bamiamkor; Axim Urban Council	Nzema East Municipal Assembly	MSW	158,206	t/yr		17,617,776
	STMA	Sekondi	Ghana Police Services	MLW	138,134	t/yr		1,658
	STMA	Kansaworodo	ANIMA Farms	Pig manure	1,577	t/yr	1,577	38,496
	STMA	Ghana Air Force Base	Ghana Air Force	Pig manure	394	t/yr	394	9,624
	Ahanta West	Kanfakrom	PREMIER Western	Pig manure	5,256	t/yr	5,256	128,319
	Ahanta West	Ewusiejoe	NORPALM Gh Ltd	POME	25,000	t/yr	25,000	5,139,774
	Ahanta West	Prestia Nkwanta	B-BOVID Ltd	POME	9,900	t/yr	5,148	1,058,382
	Mpohor	Adum-Banso	Benso Oil Palm Plantation-BOPP	POME	27,700	t/yr	5,540	1,138,974
Northern	ALL			MSW	173,229	t/yr		
	Tamale	Tamale	Zoomlion Company Ghana Ltd	MSW	547,500	t/yr		60,969,600
	Tamale	Tamale	Tamale Slaughter house	Rumen, blood & bones	274	t/yr	164	6,039
	Tamale	Tamale	Teishisuma	Shea cake	58	t/yr	6	673
	Savelugu-Nanton	Gushie	Intergrated Tamale Fruit Company	Fruit waste	180	t/yr	180	31,330
	Tolon	Changanayili	Avnash	Husk & bran	30,000	t/yr	30,000	5,576,904
	West Gonja	Damango	kanyitiwele cassava processing group	Cassava peels	119	t/yr	12	2,021
Upper East	ALL			MSW	95,101	t/yr		
	Bolgatanga	Bolgatanga	Zoomlion Company Ghana Ltd	MSW	9,490	t/yr		1,056,806
Upper West	ALL			MSW	93,385	t/yr		
	Wa	Wa	Wa Municipal Assembly	MSW	29,200	t/yr		3,251,712
	Wa	Wa	Zoomlion Company Ghana Ltd	MSW	63,145	t/yr		7,031,827

2.4 Biogas technologies, projects and their applications

There are several technologies of biogas plants, but most plants in Ghana are either the fixed-dome digester or the floating drum digester and on a small to medium scale (10 m^3 to 100 m^3), except for a few Upflow Anaerobic Sludge Blanket (UASB) plants and the Continuous Stirred Tank Reactor (CSTR) constructed on an industrial scale (e.g. UASB plant at Guinness Ghana Breweries Limited in Kumasi).

The floating-drum plants consist of an underground digester and a moving gasholder. The gasholder floats either directly on the fermentation slurry or in a water jacket of its own. The gas is collected in the gas drum, which rises or moves down, according to the amount of gas stored. The gas drum is prevented from tilting by a guide frame. Most of the floating-drum digesters are of the water-jacket type with a spherical digester (BORDA model) while the gasholders are fabricated from mild steel, glass-fibre or a high-density polythene gasholder.

The fixed-dome plant consists of a digester with a fixed, non-movable gasholder, which sits on top of the digester. When gas production starts, the slurry is displaced into the compensation tank. Gas pressure increases with the volume of gas stored and the height difference between the slurry level in the digester and the slurry level in the compensation tank. The costs of a fixed-dome biogas plant are relatively low. It is simple and has no rusting steel parts hence, a long life of the plant (20 years or more) can be expected. The plant is constructed underground, protecting it from physical damage and saving space.

A survey conducted by [5] indicated that, about 80% of biogas plants disseminated in Ghana are based on the fixed-dome design which makes them the most popular as they are less expensive compared to floating-drum digesters. Fixed-dome models disseminated by the various companies are the CAMARTEC (Centre for Agricultural Mechanization and Rural Technology) model, the Deenbandhu model, the Chinese dome model, and lately the Puxin digester.

Industrial biogas plants consist of digesters with very large volumes or capacity and are usually made of steel or concrete. They are equipped with stirring and heating mechanisms to aid the anaerobic digestion process due to large substrate quantity or non-homogeneous conditions inside the digester. The feedstocks for industrial biogas digesters are usually on site industrial waste from agro industrial processes or municipal waste. Several types of industrial biogas digesters exist in different sizes. Ghana has benefited from a few industrial biogas plants and the most common industrial biogas plant installed is the Upflow

Anaerobic Sludge Blanket (UASB) digester, the Continuous Stirred Tank Reactor (CSTR) and the Horizontal Plug Flow. The biogas plants installed at Guinness Ghana Breweries Limited in Kumasi and Zoomlion Faecal Treatment Plant at Lavender Hills both feature an UASB technology and the Kumasi Abattoir biogas plant features the Horizontal Plug Flow (HPF) technology. A summary of some biogas projects and applications of the gas and other by-products in Ghana are shown in Table 2.

These three industrial biogas technologies deployed in Ghana are adopted from other developed countries and there still exist prospects of transferring other advanced technologies for use and application in Ghana. However, very little information about the performance and efficiency (in relation to feedstock and atmospheric conditions) of these technologies in Ghana is available. The authors are conducting separate studies to investigate the technical performance and economics of these technologies and explore the possibility of improving or transferring other advanced technologies, where necessary.

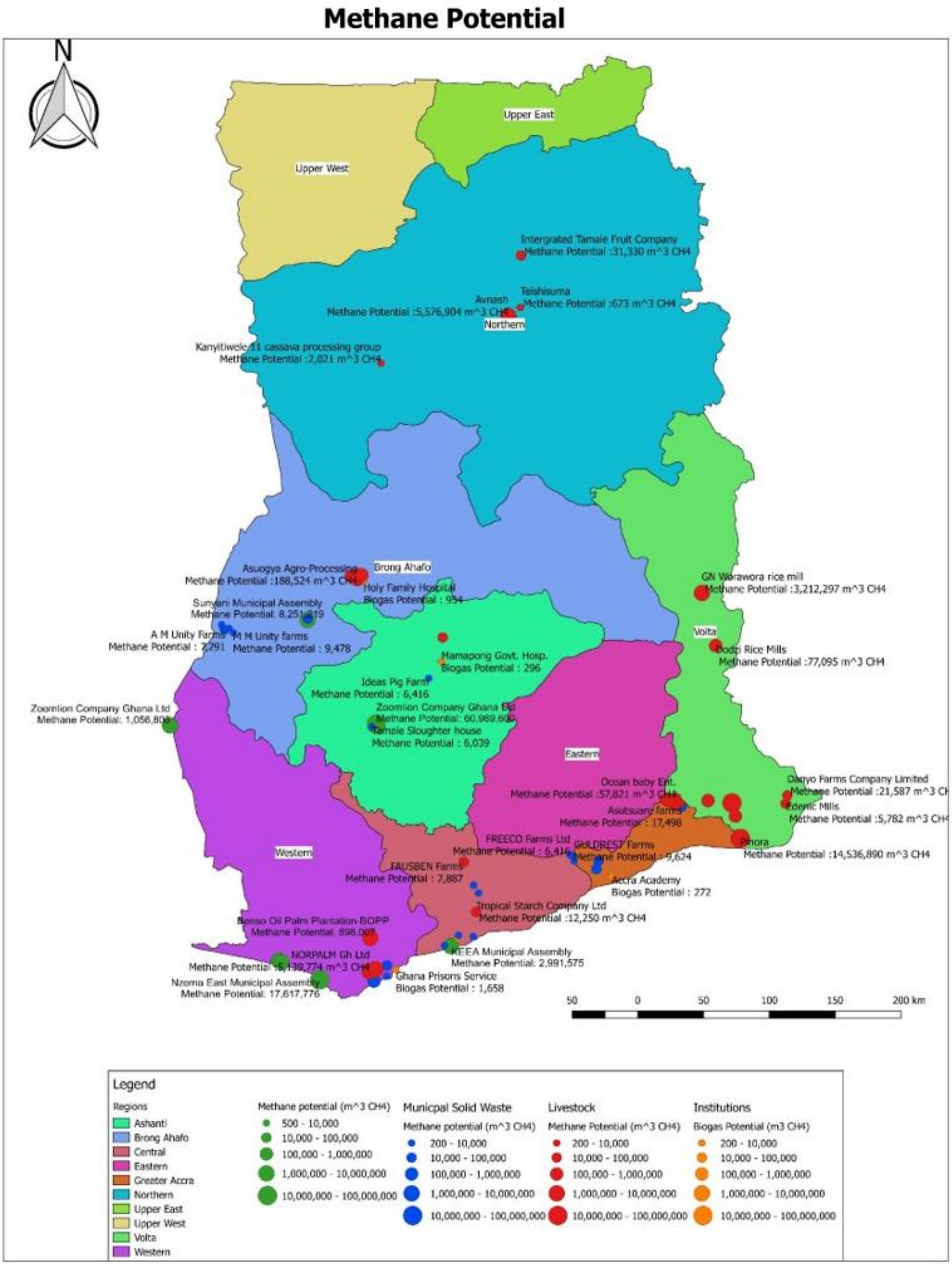

Figure 1. Map showing Methane potential and location of some biogas feedstock across the country.

Table 2. Biogas plants, technologies and their applications in Ghana.

Name of Plant	Location	Year Est.	Feedstock	Volume (M^3)	Techno-Logy	No. of Diges-Ters	Expected Output	Application & other Uses	Status
Kumasi Abattoir Biogas Plant	Kumasi, Ashanti Region	2015	Waste water, intestine contents, cow dung	430 m^3	Horizontal plug flow digester	1	150 m^{3}gas/day 32.5 kW 30 kVA generator	Singeing of cattle and livestock, lighting, compost and liquid fertilizer for fish pond	Ongoing
HPW Fresh & Dry Ltd Biogas Plant	Adeiso, Greater Accra	2011	Fruit waste and waste water	450 m^3 each, with 100 m^3 gasholder	Concrete biogas digester	2	500 m^{3}gas/day 120 kW generator & a 200kW boiler.	Heating and drying in fruits processing.	In use
Ayensu Starch Co. Ltd. Biogas Plant	Bawjiase, Central Region	2003	Wastewater, cassava pulp, cassava peels	545 m^3	Not Known	6	N/A	Heating	Not functional
Kumasi Institute of Tropical Agriculture (KITA) Biogas plant	Domeabra, Ashanti Region	2017	Faecal matter, pig dung, kitchen waste	40 m^3	Fixed dome digester	1	3.5 kW 15 kVA generator	Lighting and cooking	In use
Safi Sana Ghana Ltd biogas plant	Accra	2016	Solid waste, faecal substance & organic waste	2500 m^3	Reinforced PVC airproof reactor tank	1	100 kW	Electric power, Heating & bio fertilizer	In use
Apolonia Biogas Project	Accra	1987	Cow dung and human excreta	15 m^{3}each 30 m^{3}each 10 m^{3}each 25 m^{3}each	Fixed dome digesters	6 2 8 3	12.5 kVA	Street lighting. Electricity for low voltage appliances.	Not functional
Guinness Ghana Breweries Limited Biogas Plant	Kumasi, Ashanti Region	2008	Agro-industrial waste, waste water	800	Upflow Anaerobic Sludge Blanket (UASB)	1	360kW	Flared but possible use for thermal energy. Heat and steam generation	In use
Ghana Oil Palm Development Company (GOPDC) Biogas Plant	Kwae, Eastern Region	2014	Palm Oil Mill Effluent	10,000 m^3 each	Not Known	2	126 kW	Heat and steam for refinery plant processes Organic fertilizer	In use
Ejura slaughter house biogas plant	Ejura, Ashanti Region	2000	Waste water, intestine contents, cow dung	5 0m^3 each	Fixed dome digesters	2	N/A	Singeing of cattle and livestock. Cooking by farmers and caretakers	Not functional after gasholder explosion in 2005
Zoomlion Faecal Treatment plant	Lavender Hill	2016	Septic, faecal matter	2400 m^3/day	(UASB)	1	1 kW	Street lighting	In use

3. Economic sectors with high potential for biogas utilisation and impact

Biogas technology is very key to the sustainable development of Ghana's economy particularly in accelerating the country's quest to achieve the Sustainable Development Goals (SDGs). A successful biogas and biotechnology industry will facilitate Ghana's achievement of the SDGs with regards to Goal 7 (Affordable and Clean Energy), Goal 6 (Clean Water and Sanitation), Goal 13 (Climate Action), Goal 14 (Life below Water), and Goal 15 (Life on Land).

The main strategic value for biogas technology is the production and use of the biogas. This has many environmental, economic and social benefits on the society or community and nation for which the technology is implemented. Some economic sectors that will be impacted from the dissemination of biogas technology are discussed in subsections 3.1 to 3.5.

3.1 Agriculture

Ghana's agricultural sector contributes immensely to the growth of the economy with about 18.3% GDP with an annual growth rate of 8.4% in 2017 with crop remaining the largest activity with a share of 14.2 % to GDP [24]. Majority of households in Ghana are reliant on agriculture with most of them using manure as their major source of fertilizer. The high annual growth rate of Ghana can be attributed to improved agriculture and agricultural practices.

With a very high demand for fertilizers in maintaining crop productivity, it is important to note that, the amount of technically available Nitrogen (N), potassium (K) and phosphorous (P) in the form of organic materials is around eight times as high as the quantity of chemical fertilizers actually consumed in developing countries [25]. The effluent from a biogas digester has been proven to be the best fertilizer for farms providing farmers with an improved organic and in addition it can be used on farms as an alternative to chemical fertilizers [26]. The use of biogas effluent as organic fertilizer has a cumulative effect of increased crop production yields and eventual reduction of imported chemical fertilizers hence an improved Ghanaian economy.

3.2 Waste Management

Metropolitan, Municipal and District Assemblies (MMDAs) can resort to the use of biogas technology in solving the problem of public waste disposal and wastewater treatment. This will immensely improve sanitation, reducing the amount of waste and the cost of its removal while saving the environment from potential greenhouse gas emission that would have resulted from improper waste disposal. Through the use of biogas as fuel, the harmful effect of methane on the environment is greatly reduced. Also, surface and ground water are significantly protected from pollutants, which would have resulted in contaminating the water resource available if disposed of indiscriminately and also expose consumers and users to toxins. The organic matter present in the digestate (slurry) used as high value fertilizer also helps protect the soil from depletion and erosion.

3.3 Health

The use of wood fuel in households exposes people to various acute respiratory, eye diseases and increases infant mortality rate as a result of incomplete combustion of the fuel [27]. Replacement of wood fuel with biogas as cooking fuel reduces smoke in the home resulting in reduced probability of contracting an acute respiratory or eye disease mainly by women and children. Also, excreta-related diseases are very common, and faecal sludge contain correspondingly high concentrations of excreted pathogens such as the bacteria, viruses, protozoa, and the helminthes (worms) that cause gastro-intestinal infections (GI) in men [28]. The treatment of these faecal matters through anaerobic digestion is a good way of improving sanitation and public health reducing sanitation induced ailments.

3.4 Energy and climate change

A biogas plant installed at a facility such as a food and fruit processing site, where the waste can be used as feedstock saves a lot on energy and cost through the conversion of the waste into energy and heat for regular operations. An example of this is the use of biogas produced at the Kumasi, which can be used for singeing of the slaughtered animals and the use of heat generated from biogas for drying of fruits at HPW Fresh and Dry Ltd.

According to [29], the use of biogas will help Ghana to contribute towards achieving the SDGs (see beginning of section 3) as well as her developments and climate goals like those contained in the nationally determined contributions (NDCs) – such as the adoption of alternate urban solid waste management, improved agriculture and food security through bio fertilizer use. In addition, the use of biogas technology for electricity generation and thermal applications both at the household and industrial levels will contribute immensely to the achievement of Ghana's development and RE target of 10 % RE penetration into the energy mix by 2020, but now extended to 2030.

3.5 Economic and social benefits

The installation, production or operation and use of a biogas plant has proven potential of creating jobs for indigenes or the community where the installations are located. The jobs can range from waste collectors, artisans and technician to skilled personnel and experts. Workers who gain employment at a biogas plant thereby have an improved social and economic status.

4. Capacity and technical know-how required for biogas technology uptake in Ghana

Biogas technology installations on a small-scale require artisanal skills and knowledge of construction to install the digester. Not much expertise is required on the installation of such systems. However, installation of large-scale biogas plants requires engineering know-how and technological advice and competence. Also, there are many potential clients looking for experts and experienced installers who will provide full service after installation to ensure long term use of the plant. Some capacity and technical know-how required include:

- Contractors who will be responsible for the engineering, procurement and construction works of the project.
- Technical and biological support services, which include regular onsite services and analysis of feedstock to ensure optimum efficiency in biogas production.
- Maintenance and service providers with expertise for preventive and corrective maintenance of the biogas plant.
- Logistics providers for biomass feedstock transportation and supply to ensure consistency in feedstock supply for optimal biogas production.
- Consultants for permit and licencing acquisition procedures
- Organic fertilizer manufacturing and supply. The knowledge on how to transform effluents into liquid and solid fertilizers for agricultural purposes is also required.

In conclusion, there are skills, resources and technical know-how in Ghana for the installation, operation and maintenance of small to medium scale biogas digesters. Several companies, organizations and institutions in the country have expertise in installing and maintaining small-scale biogas digesters throughout the country and even at the district levels. However, on the industrial scale, there exists limited expertise in the design, installation, operation and maintenance of the industrial biogas digesters. Some of the industrial biogas technologies being implemented in Ghana are being operated and maintained by local experts and engineers purposely trained to do so. There is therefore the need for capacity building on these technologies.

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