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Waste to Energy: an alternate energy source for Ghana

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Abstract: For the past three to four years, Ghana has experienced an energy crisis which has resulted in frequent power outages. Although water levels in the main Akosombo dam has been low, electricity generation from hydro has not declined but steadily increasing pointing to efficiency in generation. However inefficiencies in grid transmission coupled with decline in thermal generation of electricity from natural gas has led to the state the country currently finds itself. An alternative way to solve these problems and introduce the country to a more sustainable renewable energy that is environmentally friendly and encourages decentralized electrification is generating energy from waste. About 8.7 million households in urban areas or 12 million rural households can have their monthly consumption of electricity covered with the use of an estimated 2,975.6 million m^3CH4 biogas that can be technically produced from municipal solid and liquid waste, forestry residues, animal manure and crop residues. If the total estimated energy potential is channeled to the industrial sector, it can cover twice their annual electricity consumption. Given the current waste to energy profile, there is the need to put up a framework that will encourage the generation of energy from waste.

Key words: Waste, energy, anaerobic digestion, electricity, biogas, Ghana

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Glossary

Biogas - a methane-rich fuel produced from the anaerobic digestion or fermentation of organic material, such as animal waste, dung and crop residues in the absence of oxygen.

Biomass- biofuels derived from wood fuels, animal and crop residues, vegetable oils, energy crops and other byproducts with potential for energy production

Biofuel- consist of biodiesel and bioethanol

Bioenergy- all energy from renewable sources and includes biomass, biogas and biofuel.

Digestate - the residue after the biogas process

Incinerate – to burn something until it is completely destroyed

Fossil fuel- comprises coal, oil, petroleum, and natural gas products.

Flared- to burn with an unsteady, swaying flame like a candle in the wind

Combustion - a chemical process in which substances combine with the oxygen in the air to produce heat and light

Load sharing- a system sharing limited power to consumers by way of rationing

Abbreviations

CHP- Combined Heat and Power

GNESD-Global Network on Energy for Sustainable Development

IEA- International Energy Agency

IRENA- International Renewable Energy Agency

PURC-Public Utilities Regulatory Commission

MLW- Municipal Liquid Waste

MSW-Municipal Solid Waste

SEA-Swedish Energy Agency

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1.0. Introduction

The use of waste to generate energy has been implemented in many countries in the world but Ghana is yet to implement and fully enjoy the benefits that arise from this process especially with regards to energy generation from Municipal Solid Waste (MSW). The nation relies mainly on landfills for its MSW management which has implications for the environment and also health of citizens[1].However, there has been a growing need for industries to generate and use energy from the waste they produce in the face of the constant grid instabilities in the supply of electricity for production. As an economy that has been dependent on petroleum as a major share in the final energy consumption, Ghana has not yet been able to vary its energy mix to include sustainable renewable energy. Certainly, biomass is renewable source of energy making up on average 47% of the total energy supplied since 2005 but its sustainability in the long term raises causes for concern.

Another issue has been the ability to get the entire nation on the national grid. With the current grid instabilities that the nation is facing coupled with transmission losses over long distances, a decentralized energy system in rural areas offers an economically productive way to provide access to electricity. The dependence on imported petroleum to fuel generators can be reduced with a switch to biomass use (Mohammed et al, 2013). Since the seemingly failure of the first renewable energy project commissioned in 1991, the government has derailed in its interest in biogas as a source of energy offering little to no support to the industry.

Several studies have shown that Ghana has a great potential for generating energy from waste (Kemausuor et al., 2014; Mohammed et al., 2013; Duku et al 2011a, Ofori Boateng, 2013; Ulrike et al., 2014). Duku et al (2011a), Kemausuor et al., 2014 and Ulrike et al (2014) provide a comprehensive assessment of the different sources and amounts of biomass that are available in the country that can be used for bioenergy production. Ofori-Boateng et al (2013) showed waste to energy to be a sustainable option to managing MSW by generating electricity. The paper only considered cost assessment of different options of landfill facilities. Not only is waste to energy beneficial as a waste management strategy but it can also serve to reduce greenhouse emissions while opening up opportunities in the transport sector through the use of biogas as vehicle fuel and reducing national grid peak load.

The current study differs from previous ones in that it considers not only electricity as the end product of waste to energy but also biogas as vehicle fuel, for use in CHP plants and for cooking as well. It considers different sources of biomass: MSW, livestock and crop residues, sewage sludge (MLW), and forestry residues. Specifically the research question for the paper is:

How can generating energy from waste help in the energy situation in Ghana?

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[1] Aside the obvious emission of green house gases associate with landfills, most landfill sites in Ghana are located very close to residential areas and this has raised concern about the health implications of landfills on residents over the years.

The results of this study can serve as a guide to a better understanding of the energy situation in the country and the potential of waste to help in the energy sector especially in rural areas. It is a call to the government and stakeholders to rekindle interest in the renewable energy sector by putting up a framework that will support the generation of waste to energy by individuals as well as institutions.

1.1. Aim and scope of the study

The aim of the paper is to provide a better understanding of the current energy situation in Ghana and to explore additional ways of generating sustainable renewable energy in Ghana. Energy generation from waste that produces electricity and heat through Combined Heat and Power (CHP) sources that are fueled by biogas from waste for use in the transport, industrial and residential sectors are analyzed .

A discussion of the various forms of waste to energy technologies will be given making reference to one developed country-Sweden and one developing country-Thailand. Knowledge from these two countries that have advanced in the use of waste to energy technologies will be applied to the situation in Ghana setting the way for an analysis to see if the Ghanaian case will be feasible and profitable. Different sources of waste will be considered to give a broad view of the waste to energy potential in the country as against the narrow view of considering only MSW or just livestock and crop residues.

The next sections in this first chapter give some historical background of the country Ghana to help understand the subsequent discussions that concern the country. Chapter 2 reviews some literature about waste to energy generation in general and also on the individual country level. The third chapter presents an empirical analysis of waste to energy generation as applied to Ghana. Discussion of the results follows with a conclusion in chapter 4.

Figure 1: Map and location of Ghana

Source: http://www.sciencekids.co.nz/pictures/maps/ghana.html http://ghanamap.facts.co/ghanamapof/ghanamap.php

1.2. History of Ghana

Ghana is a country located in the sub-Saharan region of Africa precisely in West Africa (see Figure 1). The country occupies a total land area of 238,535 km^2 having 55.9% of this land area being cultivated. It is bordered on the east by Togo, on the west by Cote d'Ivoire, the north by Burkina Faso and the south by the ocean Gulf of Guinea. Originally called Gold Coast before its independence from the British, the country like many other African countries had huge amounts of mineral resources that attracted the Europeans to the country to trade. The first Europeans to come to Ghana were the Portuguese in 1471 and they started to trade gold, ivory and later slaves. In the middle of the seventeenth century, the British, Danes and Swedes also started to trade in the Gold Coast. The British gaining full control of the country colonized the then Gold Coast until March 1957 when the country gained independence.

1.3. Economic History

Ghana is one of the few Sub-Saharan countries that has enjoyed continued positive growth over the past fifty years. Having recorded increasing positive growth from 1985 and seen as the fastest growing economy in Sub-Saharan Africa for 2011, the country saw an upgrade from a lower income status to a lower middle income status from July 1, 2011[2].

[2] http://www.worldbank.org/en/news/feature/2011/07/18/ghana-looks-to-retool-its-economy-as-it-reaches-middle-income-status

A turn in the economic performance of the country started in 1983 when the country had to turn to the IMF and World Bank for help (Aryetey et al., 2000) after a series of misfortune that had taken a toll on the country. The oil price increases in the 1970s did not leave Ghana out. Additionally there was severe droughts from1981-1983. So after 25 years of independence as Hug (1989) put it the country was inflicted by declining growth. At the time of independence from the Brits in March 1957, Ghana's per capita income was comparable to South Africa, Korea, and Malaysia and even greater than Thailand, India and most other countries.

In 2014, the service sector was the main driver of growth in the nation contributing 50.2% of the economy. Industry share was 28.4% and agriculture contributed 19.9% however, since 2012, the growth rate in the economy has slowed down: from a growth rate of 7.3% in 2013, to 4.2% in 2014 and 3.9% in 2015 (Okudzeto et al., 2015). The energy crisis in the country according to Okudzeto et al., (2015) has contributed in part to the declining growth rate as well as increasing balance of payment deficits and depreciating currency. As a gold exporting country, low gold prices affected the economy reducing exports by nearly 26% in 2014.

1.4. Energy History[3]

Hydro power has been the number one way of electricity generation in Ghana for some time now but this hasn't always been the case. The potential for hydro power was conceived in 1915 but it wasn't until 1961 that the Volta River Authority[4] was established and commissioned with the task of building a dam on the Volta River at Akosombo and to also generate power by other means. In the 1920s direct current started being used as electricity then it switched to alternating current with the introduction of diesel generating power plants. In 1949 the first transmission network of 11kV was built from Tema to Nsawam (about 26.3 miles or 42 km). Following increasing use of electricity, the country's first major power station in Tema was commissioned in 1956 which soon became Africa's largest diesel power plant in 1964 when it increased its capacity from the initial 2MW to 35MW. At the completion of the Akosombo dam in 1966 with an installed capacity of 588MW and later to 912 MW in 1972 there was no need for the diesel plants. This is because hydro power was more reliable and cheaper compared to the diesel power plants.

The Electricity Company of Ghana (ECG) was established in 1969 to oversee the national distribution of electricity. Ghana had become so rich in power generation by 1972 that it started to

[3] http://www.gsb.uct.ac.za/files/Ghana.pdf

[4] The main power generation company in Ghana.

export power to Benin and Togo via a 161kV transmission line. By 1983 transmission was to be made to Cote d'Ivoire via a 220kV transmission line. Another hydroelectric power plant was established at Kpong in 1982 with an installed capacity of 160MW. The problem with power generation started in the early 1980s when the country experienced drought.

The current load-sharing[5] has its history from the first that started in the 1980s as an option for the decreased capacity due to the adverse effects of drought. As a consequence of the adverse impact of drought, government in 1985 took the decision that the nation's hydropower would be complemented by thermal generation and even before these plans were implemented a second drought struck the country from 1993 to 1995 (Malgas 2008) and then another in 1998. The effects of the 1998 drought were not so adverse because of the installed thermal capacity and also some emergency diesel generation that was used until 2000. In the same year the country opened up for private sector participation in the energy sector thus seeing the first IPP the Takoradi International Company (TICO) commissioned. The years 2006, 2007 saw the country experiencing drought again in the face of growing electricity demand because of the robust economic growth (Malgas 2008) and lack of private sector participation in the sector. The current energy crisis has been attributed also to the low levels of water in hydro dams, erratic supply of natural gas from Nigeria and also due to expansion and maintenance works (Ministry of Energy & Petroleum, 2014).

Looking at the water levels in the Akosombo dam (Figure 4), the water levels have been declining from 2011 to 2014. In 2014, the level throughout the year was skewed towards the minimum operating level. In comparison to the 2011 whole year level (the highest water level since 2005) that was a very big difference. Also for the year 2014, the water level in the main Akosombo dam was very low. However, electricity generation by sources in figure 3 shows that hydro production of electricity has been increasing over the years from 2007. Perhaps efficiency in electricity generation could be the reason why even at low water levels electricity generation has increased over the years. Hence the low water levels or drought cannot be contributing to the crisis as Malgas (2008) claimed for the crisis from 1993 to 1995.

Thus the reason for the current energy crisis can be attributed to inefficiencies in transmission, grid instabilities and a lack of proper administration from VALCO, GRIDCO and ECG. The decline in thermal generation since 2013 (See Figure 3) supports the erratic supply of natural gas the ministry mentioned as being a cause. Considering the amount of transmission losses, a system of generating

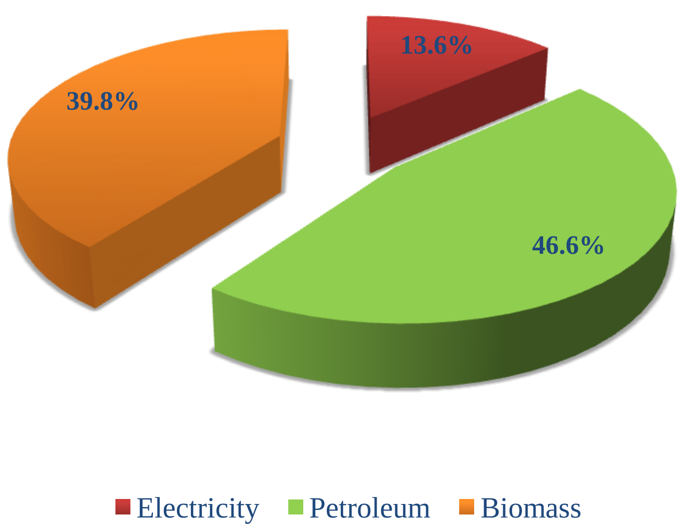
[5] Load sharing is a way of rationing limited power between users. Each geographical area has a day and time that it can have access to electricity.

energy that will minimize such losses is in order. Be it roof top solar panels that will supply electricity directly to households without the need to transmit through long distances or Combined Heat and Power plants that make use of biogas.

As at 2014, electricity that was used by final users and not for transformation into other energy sources accounted for 14% of the country's final energy consumption (See Figure 2). The use of biomass and petroleum by final users accounted for 40% and 47% respectively of the final energy consumption. Per capita energy consumption in the same year was 0.26 TOE/capita. As a secondary energy carrier, electricity depends on primary energy carriers such as hydro, biomass, coal, natural gas and petroleum. In Ghana however, electricity generation is mainly from hydro and thermal (Figure 3). It should be noted however that combustion in thermal plants is done using light crude oil, natural gas and petroleum diesel as fuels or primary energy carriers. The discharge greenhouse gases have been inevitable with the use of these fuels.

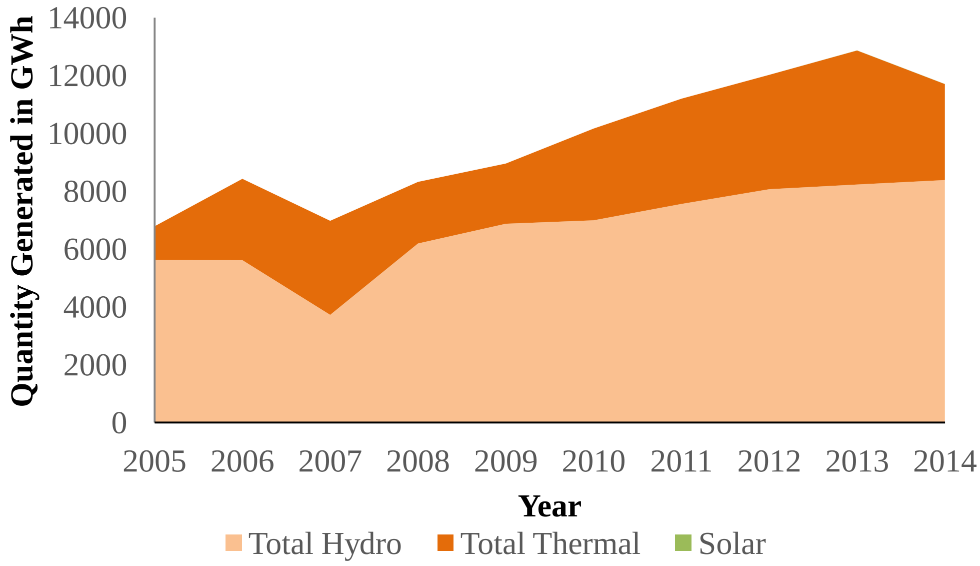
As at the end of 2014, hydro accounted for 55.8% of electricity generation capacity; 44.1% from thermal and only 0.1% for solar. As can be seen in Figure 3 below, hydro makes up a huge portion of the electricity generated in the country. The period from 2006 to 2007 shows a decline in hydro electricity generation because of the drought that the country experienced.

Figure 2: Final Energy Consumption in 2014 in Percentage



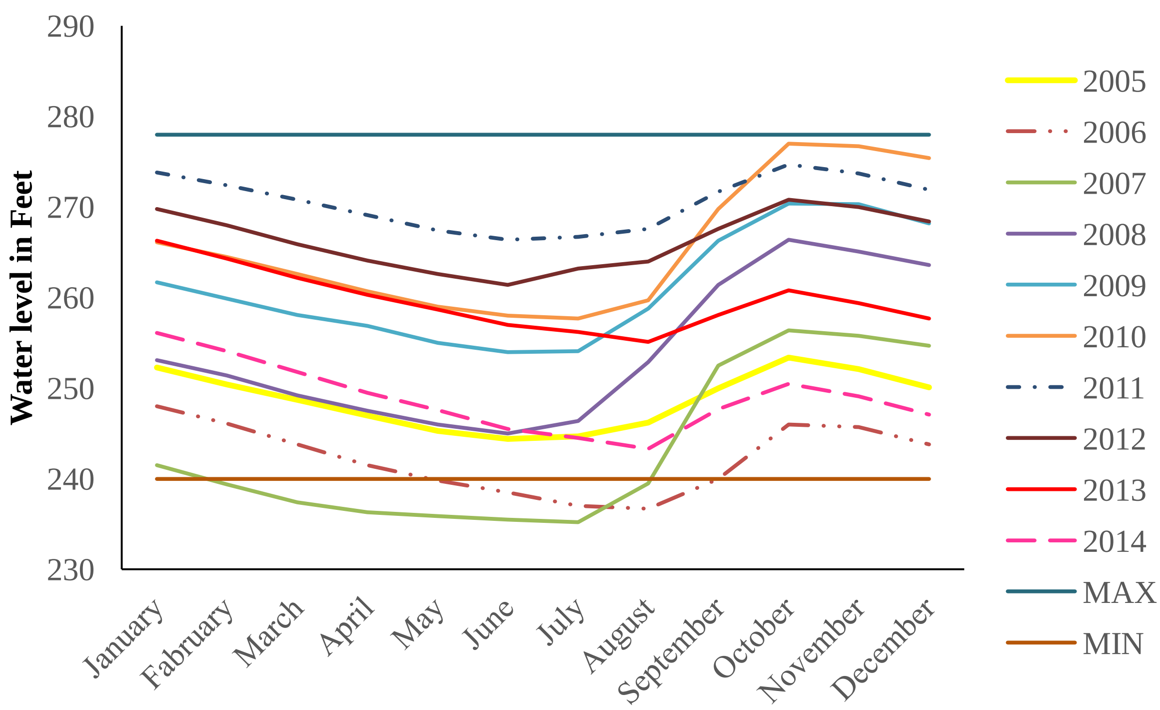
Source: Own calculations based on data from Energy Commission (2015)

Figure 3: Electricity Generation in Ghana by sources from 2005 to 2014



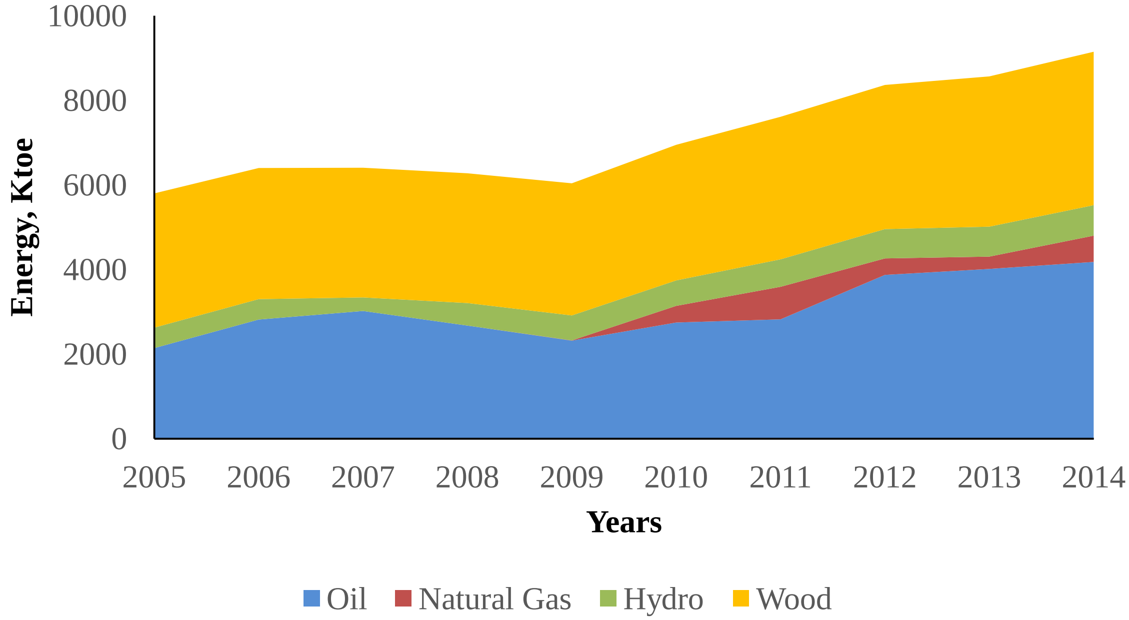
Source: Data from Energy Commission (2015)

Figure 4: Trend in Akosombo Dam water levels from 2005 to 2014



Source: Data from Energy Commission (2015)

Figure 5: Primary Energy Supply in Ghana from 2005-2014 in ktoe



Source: Data from Energy Commission (2015)

The primary energy supply in Ghana has been for a long time predominantly biomass from wood making about 47% of the total energy supplied on average. Though its portion in the mix shows a declining trend from 55% in 2005 to 42% in 2014, it is still a significant part of the energy supply. Although it is a renewable source of energy, it is not used sustainably. Since most of the wood comes from cutting trees and burning whole forests, this has led to the problem of deforestation and its subsequent implications for the environment.

Approximately 64% of the entire population had access to electricity as at 2012 with the urban population accounting for the most usage and only 40.1% of the rural population had access to electricity (WDI 2016). The low access to electricity by the population can be a reason for the predominant use of wood (Mohammed et al, 2013) since people depend on wood for both lighting, heating and cooking. Resource availability, cultural preference and economic factors are other factors that influence the use of wood as a source of primary energy supply (Sanchez, 2010).

It was not until 2009 that the use of natural gas became prevalent with the completion of the West African gas pipeline that transports natural gas from Nigeria to Benin, Togo and Ghana. The surge in use may be attributed partly to most drivers preferring gas to fill their cars instead of diesel oil or petroleum because of the price differences (Biscoff et al., 2012; Tettehfio et al., 2014). It is estimated that 58% of all LPG supplied is used by automobiles[6]. Drivers do not need new engines as gas cylinders are connected to the engine from the trunk of the car. This makes it possible to switch between gas and petrol or diesel whenever possible. The idea of gas using cars sets the stage for the exploitation of biogas as an alternative transport fuel if it is possible and feasible.

[6] https://www.newsghana.com.gh/ghana-gas-lead-us-on-a-path-to-lpg-sufficiency/

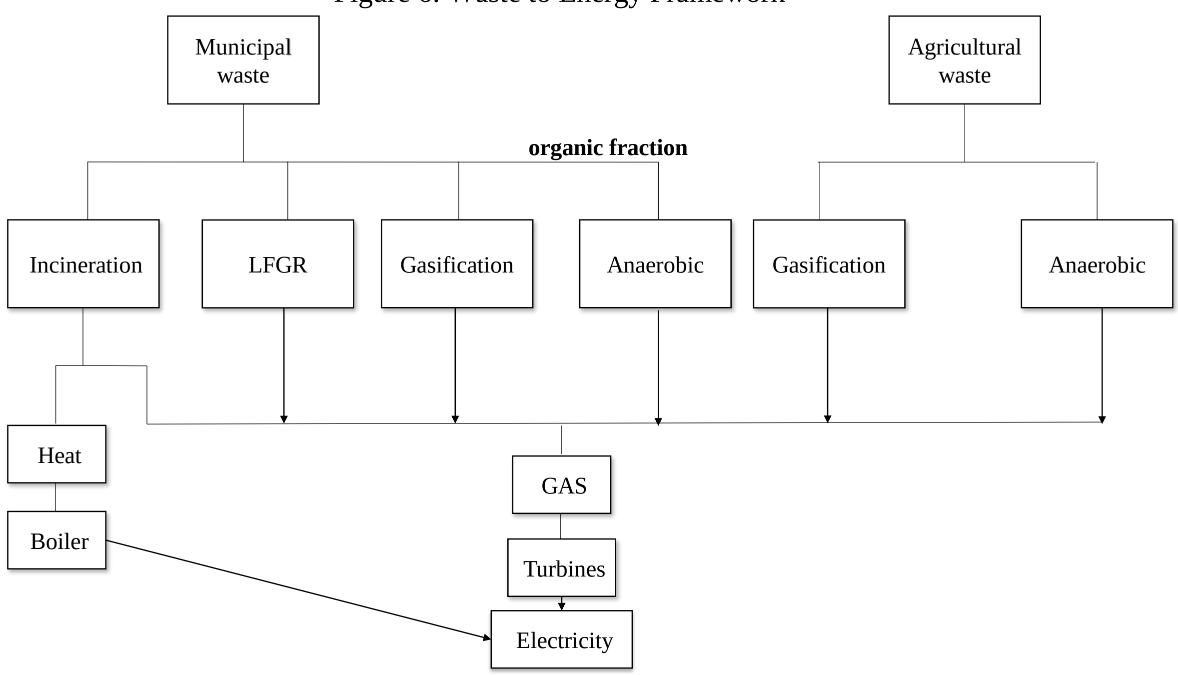
2.0. Literature Review

2.1. Theoretical Background

The circular economy offers an integrated perspective of the economy where economic waste is treated as a useful economic resource that can be used for production and consumption in order to achieve sustainable growth (George et al, 2015). As against the conventional market economy where production and consumption of goods are valued without considering the impacts on the environment like the depletion of natural resources and accumulation of waste, the circular economy considers these factors. Countries especially in Europe in order to incorporate the circular economy price externalities (Andersen 2007). Ayres and Kneese (1969) have pointed out that despite the fact that residues from production may be viewed as externalities, their economic significance tends to increase with economic development and so countries ability to make use of them will be as though they have discovered new natural resources.

2.2. Waste To Energy, What Is It?

Figure 6: Waste to Energy Framework



Source: Own Interpretation from ESWET handbook; Ofori-Boateng et al., 2013 & Duku et al., 2011b

In its simplest way waste to energy is simply generating energy from non-recyclable Municipal Solid Waste, animal manure, agricultural by-products and farm based wastes as well as some industrial and commercial waste. Waste to energy also provides a way to manage waste by avoiding methane emissions that is common with landfilling. It offers a good way to offset greenhouse emissions by generating energy from waste by reducing the use of fossil fuels since the by-products biogas, biocharcoal, Refuse Derived fuel (RDF) and pellets can be used for heating, cooling and electricity. The basic forms of waste to energy generation are through incineration/combustion, gasification, anaerobic digestion and landfill gas recovery (LFGR) (See figure 6).

Incineration/Combustion is a thermal process used in generating energy from waste through complete oxidation by converting solid waste into gaseous, liquid, and solid products under high pressure through burning. The energy that is recovered from the incineration plants can be used as electricity and or heat (see figure 6) since heat energy is released at the end of the process. About half of the energy that is produced in this manner is renewable since it is generated from waste that is carbon neutral (ESWET Handbook, p7). According to IEA (2006, 2007) 90% of energy produced from biomass is done through the use of combustion/incineration. It is a highly developed and market proven biomass technology compared to gasification (Demirbas 2005; Obemberger 2009) with a modern combustion plant and boiler having 90% efficiency (Leskens et al 2005) and a very little environmental impact.

Anaerobic Digestion is suitable for generating biogas from organic waste which is used as a feedstock in a digester. The biogas is produced when the microorganisms in the organic waste decompose in the absence of air in a biogas digester at temperatures between 55 and 66 degrees Celsius. It usually takes 3-5 weeks for methane to be produced and this amount is 2-5 times what is available from landfills. Since the amount of energy generated depends on the methane content of the waste, correct analysis of waste has to be analyzed (Ulrike et al., 2014). The organic waste can come from the organic fraction of the MSW, animal manure, crop residue such as maize stalks, rice husks etc, sewage sludge and industrial waste. The digestate that remains after anaerobic digestion contains high levels of nitrogen that makes it suitable for use as fertilizers compared to the ordinary use of fresh animal dung (Nwachuku 1986; Ramachandra 2008).

The process of gas recovery from decomposed organic waste at a landfill site is synonymous with what takes place in a digester during anaerobic digestion. The difference is that in a digester, the decomposition of the organic matter is controlled. When the micro organisms in the organic wastes decompose, they release two gases methane and carbon dioxide. These gases (biogas) are trapped, scrubbed and combusted in order to produce electricity. It takes a couple of weeks for these gases to be released in large quantities. Pipes are used as drilled wells within the landfill to trap the gas that is released. The gas is then fed in to combustion turbines to produce electricity.

2.3. Benefits of Waste to Energy

Waste is not waste but a misplaced resource that has the potential to be converted into reusable new materials, energy and other products with value. This means that if waste is managed well it can end up being a resource with beneficial uses in a circular economy.

Not only does waste to energy serve as a way of managing waste (Ofori-Boateng et al., 2013; Menikpura et al, 2016) but it can have other economic and social benefits such as providing employment and making it possible for women to spend more time with family (IRENA 2015). Waste to energy generation and for that matter bioenergy offers so many opportunities with its use. The resources (waste) are localized and come with little or no cost at all. In most cases it is the collection or transporting that requires some cost otherwise, as per its non good property, it has no cost. The localized nature of waste to energy offers a way to overcome the problem of limited access to electricity in remote rural communities (Ackom, 2013; Mohammed et al. 2013, IEA 2006, 2007). Not only does it solve the problem of energy scarcity in rural areas but it also opens up economic possibilities for rural folks.

The GNESD recounts in its 2011 report that communities have seen expansion and investments upon the introduction of biomass gasifier plants in India. Over 7 years, a 4.5 MW capacity grid connected biomass based power plant in Mysore India using 70% biomass as fuel created 450 new jobs in the crop residue supply chain and an additional 200 jobs at the biomass power plant. The contribution of the entire project to the rural economy is approximately 1 million USD. Also it has been evaluated that the use of biogas in a group of villages, Pichhaura, Dudapar, Ranipar and Asthuala Block Gagha in India has saved women the time used to collect fuelwood for cooking by three to four hours a day. Furthermore, they get to save almost the entire amount of money they spend on fuel wood which is approximately 80-110USD per annum. In Ghana, Ofori Boateng et al. (2013) have shown that for every megawatt of energy that is generated in an existing engineered landfill site, the average employment is 185 people.

The bioenergy generated can also be used for irrigation purposes thus increasing production and crop yield on farms. Farms will not have to be dependent on rain in order to grow crops. All these are ways through which poverty among rural dwellers can be reduced.

Biogas can be used with or without scrubbing for space heating, process heating, water heating and electricity generation. However if it is to be used as a vehicle fuel, it needs to be scrubbed of all impurities. This makes it easy to compress into cylinders and able to replace natural gas use in vehicles (as it can fuel an internal combustion engine and fuel cells) and LPG for cooking(Murphy et al., 2004; Afrane &Ntiamoah, 2011; Ofori-Boateng et al, 2013).

Murphy and McKeogh (2006) have recounted that in any MSW incineration system, nearly 15% of the waste can be used for electricity. Also MSW from 1,000,000 people will allow 12,400 cars to be powered, 30,900 houses have access to electricity and 15,100 houses heated in the United States and Europe. The use of energy from waste can be used as a substitute for wood and fossil fuels while supplying energy for cooking, heating, lighting and electricity.

The by-products from fermentation of sugary and starchy crops produce ethanol that can be used as fuel for electricity generation in boilers or gasifiers. When mixed with petrol, ethanol can reduce greenhouse emissions from the use of vehicles as it increases its oxygen content and enables effective combustion in gasoline (Malca &Freire, 2006).

Previous research has also pointed out the environmental benefits that accrue to the use of energy from waste sources (Otoma et al, 1997; Weitz et al 2002; Zsigraiova et al, 2009). Emissions of greenhouse gases have seen declining trends with the introduction of the waste to energy technologies (See 2.6.).

2.4. Factors that affect waste to energy generation

The choice of waste to energy technologies depend on the waste characteristics, purpose of energy generation, resource availability and local conditions of plant location. The purposes could be for heating, cooling, electricity, biogas for transport and biofertilizers. Local conditions include economic conditions, availability of substrate, and proximity of biomass or substrate source to plants.

The humidity and composition of the waste also affects the choice of technology. High moisture content of waste affects its calorific value when used in an incinerator but in anaerobic digester, this will not be a problem because usually water is added to the digestion process (Tan et al, 2015). Whereas an incinerator can treat all types of waste together without the need for separation, an anaerobic digester will require separation of waste before use since it can only make use of organic waste. According to Lantz (2010) the production of combined heat and power from manure based biogas was not profitable under current conditions of the time in Sweden.

Resource availability and a clearly defined chain of production and supply are required for continual increase in the use of biogas (Lönnquist et al 2015). It should however be noted that certain factors influence the composition of waste namely seasons, income and location of the source of waste (World Bank, 2012; Deublein & Steinhauser 2008). Low income countries tend to have a high composition of organic waste whereas high income countries have higher portions of paper, plastics and other inorganic materials.

Murphy and McKeogh (2004) found that gasification of MSW produces more electricity than incineration; has lower gate fee and less green house emissions per kWh produced if a thermal product is not used. Having made a 3E (Energy, economic, environment) assessment of Malaysian MSW, Tan et al (2015) found out that incineration was a better option if both the production of electricity and heat are the objectives of the energy generation. However, if only electricity production is required, then anaerobic digestion becomes a favorable option.

2.5. Review of Thailand's Waste to Energy System

As a country that has moved from a low middle income country to an upper middle income status with a waste to energy concentration sector, Thailand offers a pathway that Ghana can follow being a lower middle income country.

In 2012 Thailand's Department of pollution control stated that less than 25% of the annual waste is properly managed. Just like Ghana, electricity shortage is a major problem in the country importing around 70% of its power requirements. In view of the above, Thailand's government has been keen on giving tax incentives to promote investments in the waste to energy sector.

Between 1995 and 2004 the government financed 15 biomass and 21 biogas projects. By 2009, the installed capacity of biogas for electricity generation was around 10.6MW (GNESD, 2011). The existence of a fund that subsidizes any additional electricity prices above the usual buy/back tariff has encouraged private firms to make investments in the sector especially small power producers. The subsidies also enable these companies to access loans from banks. In terms of legislation and infrastructures for supporting and promoting renewable energy use, the Thai government has laid a strong foundation especially the promotion of biomass energy (Prasertsan & Sajjakulnukit, 2006). There exists a renewable portfolio standard which requires power producers' production of 5% of installed energy-generating capacity from renewable sources.

In addition to MSW to generate energy, Thailand also uses biomass from agricultural residues such as rice husks, bagasse from sugarcane, rubber wood and palm oil (Prasertsan & Sajjakulnukit 2006) for energy generation. These residues are used for electricity generation by Small Power Producers (SPP) and Very Small Power Producers (VSPP) having an installed capacity of 1,457MW of which nearly half was sold to the national grid in 2011 (GNESD 2011). In addition, biodiesel and ethanol are generated from palm oil, jatropha and cassava, sugarcane respectively. As of March 2010, 5.9 million litres of biodiesel was produced daily from 14 biodiesel production plants largely from palm oil (Nimmanterdwong et al., 2014) used in the transportation sector. In the first quarter of 2014, 274.94 MW of biogas was used to produce electricity and 120.45ktoe of biogas used to generate heat. The country also produced 2.9million litres of ethanol daily (Thai Ministry of Energy, 2014).

Partnership between the private sector and local government has been the underlying factor in most of the waste to energy projects in Thailand in addition to favorable incentives and policies that encourage investment in the sector.

2.6. Review of Sweden's Waste to Energy System

Almost 50% of waste generated in Sweden is incinerated. According to the Swedish Waste Management authority, only four percent of the 500kg of waste produced by each person annually in Sweden is landfilled since the majority of the waste is recovered or reused. Landfill of organic waste has been forbidden since 2005 and companies are required to pay a tax of SEK 500/ton of household waste used for incineration if the plant does not generate electricity. On the other hand, with production of electricity, this tax is reduced to SEK100/ton. Around 20% of district heating is being supplied through heat from waste incineration plants while supplying electricity to almost 250,000 households. Waste incineration as the authority points out generates 1.1 million cubic meters of oil reducing 2.2 million tons of $CO2$ emissions annually. According to Dahlquist et al (2011) the biogas from landfills is also used for district heating, vehicle fuel and to power plants.

The waste to energy industry in Sweden is well advanced with the biogas produced used for transport as well. The achievement of this has been mainly through tax exemptions and investment support (Swedish Tax Agency, 2016; Hansson& Grahn, 2013; SweGov, 2013). The share of renewables in domestic transport was 12% in 2013 above what was to be attained by 2020 according to the European Union's Renewable Energy Directive (EU, 2009). Despite these impressive results, the sector is still operating below its potential since the use of agricultural residues and energy crops to produce biofuel has been minimal with much reliance on urban waste (Lönnquist et al 2013).

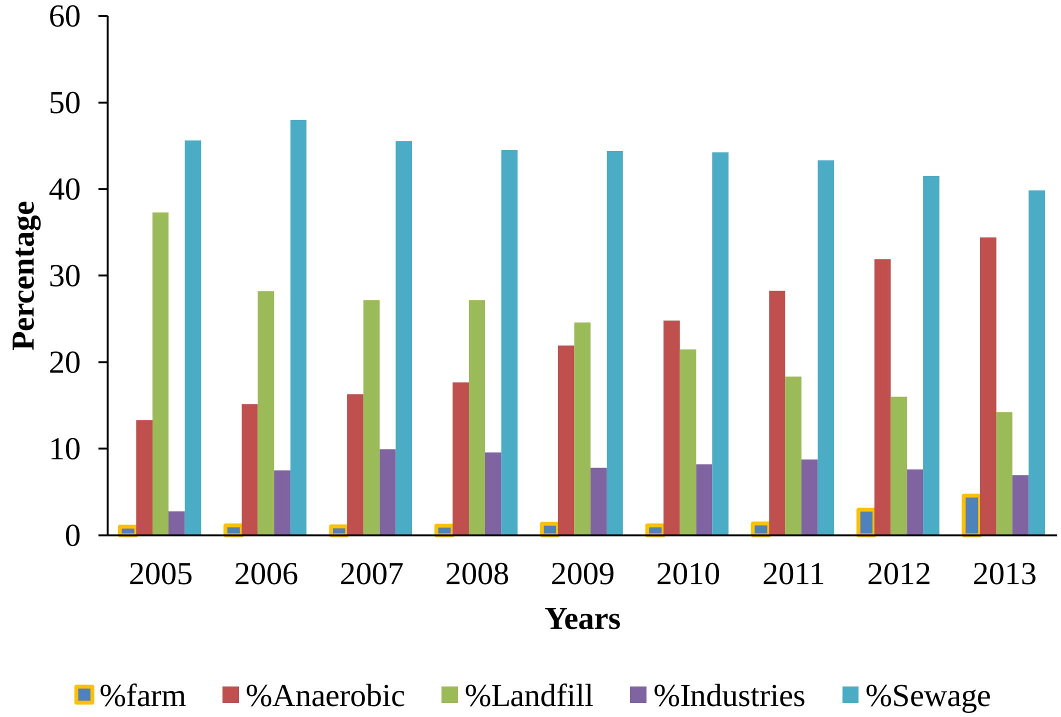
Municipalities (as local actors) involvement in the waste management process guided by national policy has been said to be the reason for the effective development of the waste to energy industry (Fallde & Eklund, 2015; SwedWaste). Sorting of MSW is a common practice in Sweden however findings show a low level of food waste sorting exists in some regions like Stockholm (Linne et al., 2008; SwedWaste, 2013).

In Sweden biogas is produced from sewage treatment works, anaerobic digestion facilities, farm biogas facilities, landfill sites and industrial facilities. Although the percentage of biogas produced from Landfill sites and sewage treatment works has been declining since 2005, they still have higher levels than what is being produced by industrial and farm facilities (See Figure 6). Industrial waste due to its alternative uses limits its use for biogas (Lönnqvist et al 2013). For instance it can be used as fodder and other energy generation like electricity, heating and cooling. This multiple usage of industrial waste is reflected in its use of biomass as depicted in Figure 7. The industrial sector has been the largest user of biomass over the years while the transport sector uses the least even though its use has been increasing in recent years.

It can also be seen from Figure 6 that the use of anaerobic digestion to convert waste to energy has been on the rise: increasing its percentage share of biogas production by more than double its 2005 share. Sewage treatment plants have been the highest contributors to the production of biogas.

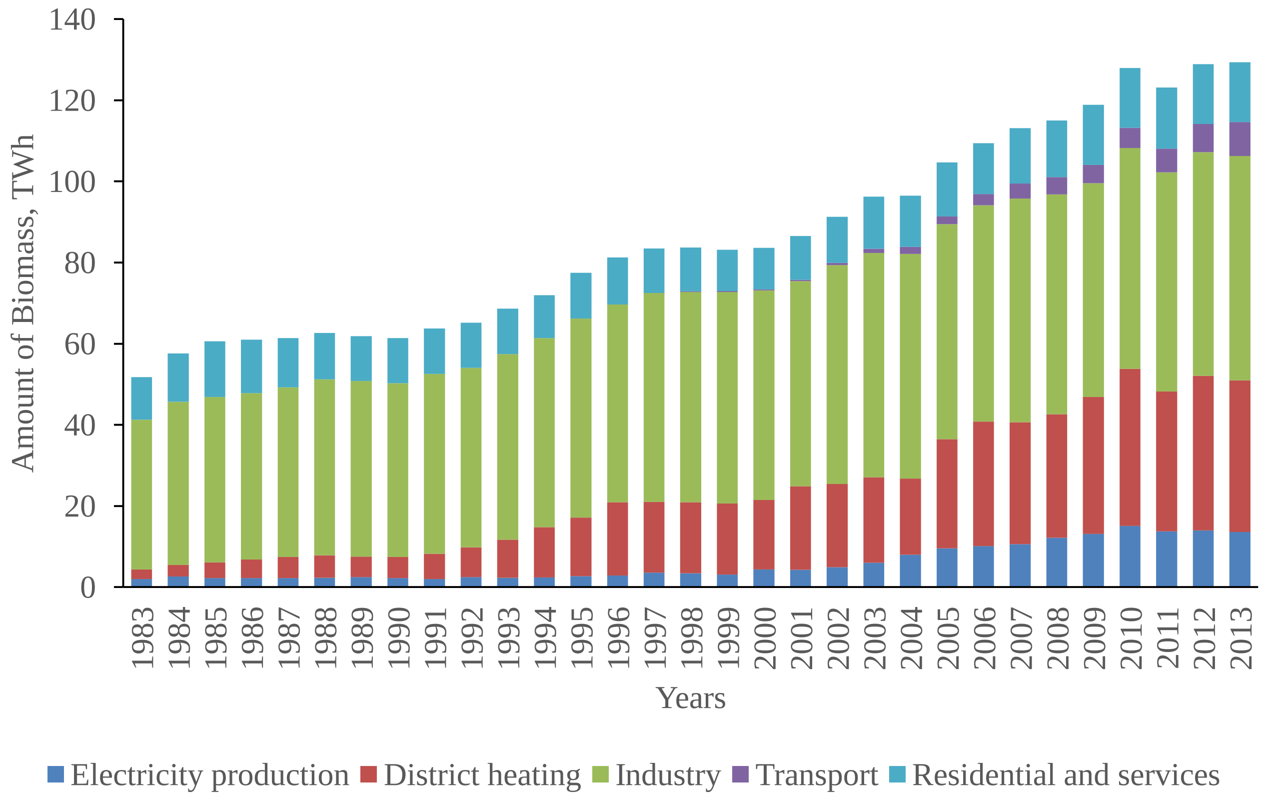
Production of biogas from farm based plants has been very low basically because of the relatively higher investment cost as compared to investments in co-digestion plants (Lönnqvist et al 2013). In order to promote the production of electricity from renewable sources and reduction of transmission losses a number of incentives and policies have been implemented. Facilities that are connected to the low voltage grid are given a compensation for reducing transmission losses in the regional and national electricity grid. The compensation is set at 5 Euros/MWh although it varies among regions (Lantz 2010). Also, for every MWh of electricity produced from renewable source in an approved plant, the producer is entitled to one renewable electricity certificate which can be sold at highest bidding rate on the market (SEA 2009).

Figure 7: Percentage Share of biogas production in Sweden, by facility 2005–2013



Source: Data from Swedish Energy Agency

Figure 8: Use of biomass, per sector in Sweden from
1983 to 2013 in TWh



Source: Data from Swedish Energy Agency and Statistics Sweden.

2.7. The Case of Ghana

2.7.1. Current Waste to Energy Profile

About 100 biogas plants are currently installed. However, most of these plants are just bio-sanitation interventions such as waste treatment plants and biolatrines for health and educational institutions that are usually located in urban areas (KITE 2008; Bensah & Brew-Hammond 2010; Arthur 2009). Firms and individuals who make use of these energy sources only do so because they want uninterrupted supply of power which is not assured with grid connection and only a few may be concerned about the environment. The number of biogas digesters installed in households is limited and where they exist, it is used for biosanitation purposes only. There are at least four biomass cogeneration plants used in palm oil mills with an average annual power generation of 7 GWh. However, they are not captured in the country's electricity balance because of lack of data (Energy Commission, 2006).

Municipal Solid Waste generated in the country is managed only through landfills and uncontrolled incineration from which no energy is captured for use. Engineered landfill sites to generate energy from waste have been commissioned for a long time but have not yet realized completely their goal.

The Energy Commission has as part of its strategic national energy plan to promote and achieve a 2% penetration in the use of biogas for heating and cooking in institutional kitchens, laboratories, hotels and restaurants by 2020. In 2013, the first feed-in tariff for producers of electricity from renewable sources was published by the Public Utilities Regulatory Commission (PURC) which was revised in 2014. This points to some effort to encourage the renewable energy market however, more attention is given to solar and wind than to waste to energy generation.

Though the notion that bioenergy for rural development and poverty alleviation exists, there are no comprehensive approaches and policies specifically targeting the use of bioenergy to bring about rural development and poverty alleviation (GNESD 2011; Bensah &Brew-Hammond 2010). The use of biogas to generate electricity for rural communities has been done experimentally by the Ministry of Mines and Energy but the unsuccessful nature of the experiment in Apollonia which produced biogas from human waste and cow dung for cooking and electricity has not encouraged further promotion of biogas use (Mensah, 2000; Ofori-Boateng & Kwofie, 2009).

An alternative fuel that has been in use for many years now especially in the northern part of the country (where wood is scarce) is animal waste but only for cooking (KITE 2008). The use of animal waste for biogas production is not common in Ghana. The common use is for cooking when it has been burnt up. However, according to Ramachandra (2008), this way of generating energy has low energy efficiency compared to if the animal waste had been used for biogas. See Table.1 below.

Table 1: Comparative analysis of energy obtained direct burning of animal dung and biogas production from 25 kg of fresh dung.

Parameters	Direct burning	Biogas production
Gross energy	10,460 kcal	4,713 kcal
Device efficiency	10%	55%
Useful energy	1046 kcal (10%*10460 kcal)	2592 kcal (55%*4713 kcal)
Manure	None	10 kg of air dried

(Source: Ramachandra 2008)

A 25 kg of fresh dung when used for direct burning (cooking) has a gross energy of 10,460 kcal but because of the device efficiency of 10%, only 1046 kcal (10% × 10,460 kcal) of energy becomes useful. Since all the dung is burnt up, none is left for manure. However the same 25 kg when used directly to produce $1m^3$ of biogas results in an additional 10kg of air dried manure. Gross energy represents the total energy emitted in the burning process or in the process of producing the biogas. Given the device efficiency, the useful energy is the actual energy that gets to be used in the burning process or biogas production process since energy losses occur without 100% device efficiency.

2.7.2. Previous research

Although the use of wood fuel has been declining in recent years, the shift towards LPG as cooking fuel that is much advocated for as a substitute has other environmental impacts such as human toxicity potential, and terrestrial ecotoxicity potential. Afrane and Ntiamoah (2011) showed based on a life cycle assessment that the use of charcoal and LPG had the most adverse effects on global warming and human toxicity respectively. Biogas compared to LPG and charcoal had overall the least impact on the environment.

Since biogas is needed to replace fuel for cooking, a cost effective way is to store it in cylinders for use instead of connecting underground pipes to all houses. However, for storage of the raw biogas to be possible, it will need to be scrubbed or purified from its 33-45% CO_2 content that makes it impossible to compress into cylinders (Ofori-Boateng & Kwofie, 2009). Given operational conditions in Ghana, a water scrubbing method of purification is recommended by Ofori-Boateng & Kwofie (2009) after considering capital, maintenance, operational and environmental costs of the other methods. Purification of biogas also enhances the efficiency of generators that are used for producing electricity. Although some have argued that usage of biogas for cooking does not require any further purification from trace gases except if it is to be used in an internal combustion engine (Salomon & Lora, 2009), purification in the Ghanaian case is required in order to store the biogas and also cut down on cost.

Using 2006 figures on animal waste, Arthur et al., (2011) showed that 350 million m^3 of biogas could have been produced and an equivalent of 2100 GWh or 7875,000 GJ if calorific value of 22.5 MJ/m^3 is used. Bensah and Brew-Hammond (2008) also showed that an amount of 360,000 tonnes of liquid organic fertilizer could be produced yearly, which would be capable of fertilizing about 70, 000 hectares of irrigated farmland or 140, 000 hectares of dry farmland.

According to Mohammed et al (2013) gasification used in Combined Heat and Power (CHP) plants to generate energy is one of the most promising technologies for rural communities. This could be because the use of gas turbines in the gasifiers makes the production of electricity effective at a cheaper cost compared to fossil fuel derived electricity (Williams & Larson 1992; Baykara & Bilgen 1982). There is also the benefit of getting biocharcoal as a result of gasification which Duku et al., (2011b) also indicated can increase soil quality, crop productivity, reduction in greenhouse gas emissions, can capture and store carbon preventing its release into the atmosphere when applied to the soil.

Ramachandra (2008) based on estimates made on India, reports that a 2 m^3 biogas plant can replace 26 kg of LPG, 37 Liters of kerosene, 88 kg of charcoal, 210 kg of fuel wood and 740 kg of animal dung that is used to generate heat through direct burning. The $2m^3$ biogas plant only requires 50 kg of dung to produce a minimum of 150 Litres of biogas and maximum of 200 Litres depending on the thermal efficiency.

A comprehensive assessment of the different sources and amounts of biomass that are available in the country that can be used for bioenergy production has been made by Duku et al., (2011), Kemausuor et al., (2014), Thomsen et al., (2014) and Ulrike et al (2014). Thomsen et al., (2014) focused on agricultural residues but Kemausuor et al., (2014) and Ulrike et al (2014) provide broader sources of waste including, animal wastes, forest residues, fruit processing, municipal solid and liquid wastes. Thomsen et al., (2014) recommends anaerobic digestion that uses manure and municipal liquid waste as the first bioenergy option in Ghana because it is a flexible technology and the substrates are suitable for low-tech systems.

Aside estimating the biomass potential, Kemausuor et al., (2014) and Ulrike et al (2014) estimate the heat energy potential and electricity potential respectively. Kemausuor et al., (2014) estimate the technical potential of bioenergy from different sources of waste to be 96 PJ in 2700 Mm3of biogas. This amount they say can replace a quarter of the woodfuel used in the country. The paper also estimates the potential of replacing petroleum based fuel with bioethanol but does not consider the use of biogas either for electricity generation or as a transport fuel as is done in this present paper. Although Ulrike et al (2014) estimates electricity generation from biogas, no further analysis on how much will be made available for households and industries is made.

2.7.3. The way forward: Lessons from Sweden and Thailand

Since 1990, the population has experienced a growth of 77.1% whereas the total primary energy supply has only increased by 69.9% with wood fuel being the predominant fuel for cooking in Ghana. These points to the need for an expansion and diversity in the total primary energy supply to include a sustainable renewable energy like biogas. Government needs to focus on supporting and promoting biogas production and use.

Use of CHP systems in biogas production is proven to be resilient to adverse weather conditions that the normal electricity grid cannot stand (USDOE, 2013). This can help with the problem of transmission inefficiencies that contributes to the current energy crisis. Combined heat and power is better for farm based biogas because not much heat is needed on farms especially given the high temperatures. It will allow for the generation of electricity which has alternative uses and can be connected to the national grid if it is not needed on the farm. Lesson from the Swedish waste to energy framework however shows that farm based biogas facilities are however expensive compared to co-digestion facilities.

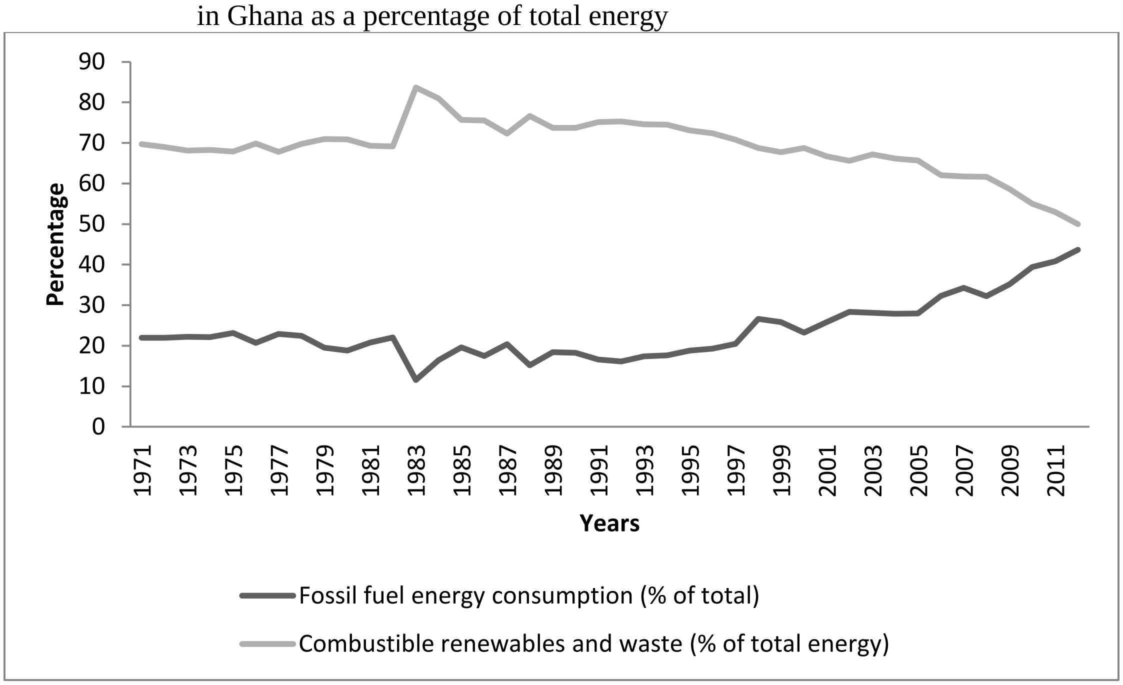
Unlike most countries who have made attempts to decrease their fossil fuel consumption, Ghana has been increasing hers as can be seen in Figure 9. Overall fossil fuel consumption has doubled since 1971 meaning that emissions have also increased as a consequence. Data from the IEA as shown in Figure 9 confirms this increase. From 1990 to 2013, the percentage change in CO2 emissions was 413.5% (See Figure 10). Between 1991 and 1995 fossil fuel consumption was at substantially low levels before it started its upsurge. Increasing campaign for LPG use instead of woodfuels by the government has also contributed to the increasing fossil fuel consumption (See Figure 9). In recent years, drivers' interest in using autogas (LPG) as fuel instead of gasoline has also increased and this has often led to shortages amidst the limited supply intended for households.

The fact that combustible renewable use is reducing in the face of increasing fossil fuel use calls for attention with regards to the nation's energy and environmental future in a circular economy. Any sustainable energy transition should be towards cleaner and sustainable renewable energy and not fossil fuels. Sweden through its waste to energy system has been able to reduce CO2 emissions from oil drastically pointing out a possibility for Ghana to use such a system to reduce its emissions from fossil fuel use.

There is the need to set up a waste management system which encourages sorting of waste so that organic waste can be utilized for energy generation. Uncontrolled incineration of waste without energy recovery can also be restricted by introducing a tax for those who do so.

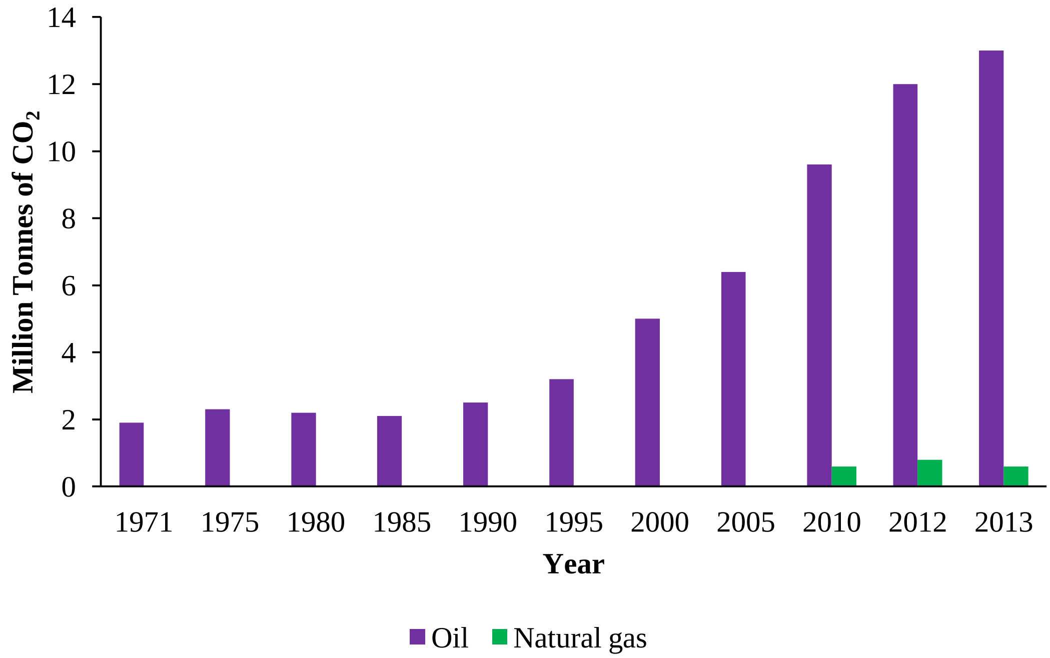
A legislative infrastructure on waste to energy that supports the participation of the private sector like in Thailand will ensure that the energy potential of animal manure and crop residues is realized. Economic incentives for producers of energy from waste can be done through subsidies, a compensation for reducing transmission losses and a renewable electricity certificate.

Figure 9: Fossil fuel consumption and combustible renewable consumption in Ghana as a percentage of total energy



Source: Data from World Development Indicators (2016)

Figure 10 : CO_2 emissions from fuel combustion in Ghana from 1971 to 2013



Source: Data from International Energy Agency (2015)

Instead of using expensive thermal production of electricity to supplement the hydro production, waste to energy offers a sustainable alternative in addition to wind and solar. Since 1998 end user tariff has increased by about 5.2-8.2 US cents per kWh and introduced a distribution service charge of about 3.4 US cents. The use of thermal generating plants that make use of imported fuels also place a burden on country's limited foreign exchange and it is part of the reasons for the constant depreciating value of the Ghanaian cedi. This over reliance on imported fuels can be reduced with a switch to bioenergy that is locally produced. With commercial drivers preferring LPG use, a biogas industry that will encourage biogas use as vehicle fuel is commendable.

3.0. Empirical Analysis

3.1. Data

The data used is basically secondary data from national and institutional statistical databases, academic publications and reports from stakeholders.

3.2. Potential feedstock for Waste to Energy technologies in Ghana

Due to the lack of data on MSW, Meiza et al (2015) estimated from a survey that the rate of waste generation in Ghana was 0.47 kg/person/day which translates into 12710tons of waste per day per the current population of 27,043,093. The high organic content of waste in Ghana offers a high potential for waste to energy industry to develop in Ghana especially in using anaerobic digestion but inhabitants must be made aware of the need to sort their solid waste in order for this to become a sustainable option. Compared to Thailand's organic waste component being 48% of MSW (World Bank, 2012) Ghana has an organic waste content ranging between 61% and 64% of MSW (Asase et al 2009; Meiza et al, 2015).

The large volumes of starchy crops such as cassava, yam, maize, potatoes, cowpea, groundnut and sugar crops such as sugar cane, sugar beet and sweet sorghum makes Ghana's potential for ethanol production huge. A large amount of animal waste, crop and forest residues are available that will be conducive for electricity generation through anaerobic digestion. The lignocellulosic nature of crop and forestry residues makes their biogas potential very high because of their high methane content.

3.3. Waste to Energy Potential from Anaerobic Digestion

The technical potential of waste takes into account several factors aside the amount of waste that is produced. These factors include the concentration of organic fraction of MSW(C_{OFMSW}), concentration of total solid (C_{TS}), biomethane potential of the waste (BMP), residue to product ratio (RPR), recoverability of manure(R_{Manure}) and the average efficiency of continuous biogas production compared with the biomethane potential for lignocellulose based wastes. In estimating the technical potential of biogas from the different waste sources, the following equations were used as per Kemausuor et al (2014):

$$Biogas_{MSW} = Q_{MSW} \times C_{OFMSW} \times C_{TS} \times BMP_{OFMSW} \quad (1)$$

$$Biogas_{MLW} = Q_{MLW} \times C_{TS} \times BMP_{MLW} \quad (2)$$

$$Biogas_{Manure} = Q_{Livestock} \times Q_{Manure} \times R_{Manure} \times C_{TS} \times BMP_{Manure} \quad (3)$$

$$Biogas_{Crop} = Q_{Crop} \times RPR \times (BMP_{Buswell\ Gluc} \times C_{Gluc} + BMP_{Buswell\ hemic} \times C_{Hemic}) \quad (4)$$

$$Biogas_{Forest\ residue} = Q_{Residue} \times RPR \times (BMP_{Buswell\ Gluc} \times C_{Gluc} + BMP_{Buswell\ Hemi} \times C_{Hemic}) \quad (5)$$

Biogas potential from municipal solid waste is estimated in equation (1) as the product of the amount of municipal solid waste, concentration of organic fraction, concentration of total solid and biomethane potential of the waste. An organic fraction concentration of MSW of 64% was used from Asase et al., (2009), and $BMP_{OFMSW} = 0.32m^3\ CH4/kgTS$ (Gunaseelan, 1997). The total solid concentration (541) used was calculated based on estimates from Kemausuor et al., (2014) however, data on the annual MSW was estimated from Meiza et al., (2015) giving an annual waste for the entire population to be 4,524,760 tonnes which is approximately 4.5Mt.

Equation (2) shows the potential of biogas from Municipal Liquid waste to be a function of the quantity of waste, concentration of total solid and the biomethane potential. The concentration of total solid for municipal liquid waste (MLW) and the biomethane potential of MLW is assumed to be 8.9 g TS/100 g and 0.34 m^3 CH4/kg TS respectively from Arthur and Brew-Hammond (2010) for equation (2).

The potential from manure estimated from equation (3) is given as a product of number of livestock available in the country, the quantity of manure produced by the livestock, the recoverability of manure, total solid concentration and the biomethane potential. Data for the estimation of livestock population is from MoFA(2011) for; quantity of manure estimated from Kartha and Larson (2000), Milbrandt (2009), recoverability of manure (KITE 2008), total solid concentration from Randall et al (2006) and the BMP from Kemausuor et al. 2014.

Equation (4) and (5) states that the potential biogas from lignocellulose waste depends on the residue to product ratio, biomethane potential calculated with Buswell's formula for glucan and hemicellulose, concentration of glucan and hemicellulose in a specific residue. Estimation of equation (4) and (5) is from Kemausuor et al., (2014).

Crop residues estimated include stalks, husks, cobs, straw, shells, peelings(cassava) , trunks and leaves (plantain), bagasse (sugarcane), pods (cocoa, sorghum), fibre, kernel shells and empty fruit bunches(palm oil). Ethanol which is a liquid fuel that can produce energy can be derived from the crop residues such that it replaces the use petrol (Kemausuor et al., 2014). It can also be used in local industrial applications and to a large extent even exported for foreign exchange. Currently, the country imports most of its ethanol consumption. As the most used solvent next to water in the chemical industry, its use in industrial products such as paints, lacquers, dyes and oil, the demand for ethanol is increasing. It is even used in schools, universities and hospitals as reagents and sterilizers (Ayernor & Ocloo, 2003). The overall energy and biogas potential when anaerobic digestion is used is given in Table 4. Forestry residues are made up of slabs, wane, bark and sawdust whereas livestock included in the estimation are cattle, sheep, goats, pigs and poultry.

Table 2: Energy potential of crop residues in 2011

Crop Residue		**Biogas**	
	Technical potential of waste (Mt/yr)	Potential Biogas (M $m^3 CH4$/yr)	Energy potential (PJ/yr)
Maize	3.03	675	24.2
Rice	0.31	63	2.3
Millet	0.27	39	1.4
Sorghum	0.64	132	5
Groundnut	1	130	4.6
Cowpea	1.13	212	7.5
Cassava	0.72	250	9
Plantain	1.5	80	3
Soybean	0.46	110	3.9
Yam	2.5	340	12
Cocoyam	0.54	72	2.6
Sweet potato	0.017	2	0.1
Oil palm	0.74	129	4.6
Coconut	0.208	33.2	1.2
Sugarcane	0.025	4.5	0.2
Cotton	0.061	11	0.4
Cocoa beans pods	0.67	43	1.5
Total Crop Residue	**13.821**	**2325.7**	**83.73**

(Source: Author's calculation based on estimates from Kemausuor et al., 2014)

Table 3: Resource potential from residues for biogas and electricity generation in Ghana

Resource category	Quantity of waste (Mt/yr)	Potential Biogas (Mm^3 CH4/yr)	Energy potential (PJ/yr)	Potential* Electric Capacity PJ/yr	Potential* Thermal Capacity PJ/yr
Municipal Solid Waste *****	4.64	514	18.50	6.48	7.40
Municipal Liquid Waste	0.56	17	0.61	0.21	0.24
Forestry residues	0.35	18.3	0.67	0.23	0.27
Animal manure	2860	100.6	3.62	1.27	1.45
Crop residues	13.82	2325.7	83.73	29.31	33.49
Total		**2975.6**	**107.1**	**37.5**	**43.0**

(Source: Own calculation based on estimates from Kemausuor et al., 2014; *****: Own estimation)

Energy potential is calculated based on the assumption that 1 m^3 biogas=10 kWh=3.6×10^{-8} PJ so that if we consider the efficiencies in converting to electricity and thermal energy, it gives the potential Electric and Thermal capacity. From Murphy et al, (2004), the efficiency rate for conversion to electricity is 35% and 40% efficiency for thermal conversion. This implies that for energy potential of 18.5 PJ/yr for municipal solid waste, (35%×18.5 PJ/yr=6.48 PJ/yr) gives the electric capacity for municipal waste. 40%×18.5 PJ/yr= 7.40PJ/yr gives the thermal capacity. Even if only electricity from municipal solid waste is harnessed, this will contribute to about 17% (6.48 PJ÷37.5 PJ) of the electricity consumption in the country (See Table 3 and 5).

From Table 3, crop residues and municipal solid waste show the largest contribution to the biogas potential in the country with both accounting for 95.5% of the biogas potential (See Table 4). Forestry residues and municipal liquid waste have the least share with 0.6% share each. From Table 5, the national electricity consumption in 2014 was 11.08 TWh an equivalent of 40 PJ. Given the total potential electricity capacity of 37.5 PJ from Table 3, this represents 93.8% (37.5÷40) of the nation's electricity consumption in 2014.

In 2014, thermal production of electricity from natural gas was 16.46 PJ of electricity (Energy Commission, 2015). With the total estimated biogas potential, twice the amount of electricity could have been generated.

Table 4: Share of total biogas potential in Ghana

Resource category	Potential Biogas (M m^3CH4/yr)	Share of total biogas potential (%)
Municipal Solid Waste	514	17.3
Municipal Liquid Waste	17	0.6
Forestry residues	18.3	0.6
Animal manure	100.6	3.4
Crop residues	2325.7	78.2
Total	**2975.6**	100.0

(Source: Own calculation and estimates based on estimates from Kemausuor et al., 2014)

Table 5: Final Energy Consumption in Ghana in 2014

Energy source	Amount consumed (ktoe)	Twh	PJ	% of total Energy
Electricity	953	11.08	39.9	13.6
Petroleum	3271.7	38.05	136.98	46.6
Biomass	2791.7	32.46	116.88	39.8
Total	7016,4	81,6	293,76	

Source: Own calculation based on data from Energy Commission (2015)

The conversions used here is from the IEA's unit converter: 1TWh=3.6 PJ

Table 6: Analysis of Total Potential Electric Capacity from Biogas Usage

Consumers	Parameters	Units(kWh)
	Total Annual Potential Electric capacity	10,417 M
Urban	Average monthly Electricity consumption per household	100
	Annual(100×12)	1200
	No of households to be powered (10,417÷1200)	8.7 M
Rural	Average monthly Electricity consumption per household	73.3
	Annual(73.3×12)	879.6
	No of households to be powered(10,417÷879.6)	11.8 M

Source: Own Calculations based on data from Energy Commission (2015) ,M=million

Table 5 illustrates how the 37.5 PJ of potential electric capacity from waste can be used by both households in urban and rural areas. The equivalent of 37.5 PJ in kilowatt hours is what is given in the table where 1PJ=277,777,778 kWh. Approximately 8.7 million households in urban areas can benefit from the electricity generated from waste. Even more households (almost 12 million households) in rural areas stand to benefit from this potential electric power. The same amount of power generated (37.5 PJ=10.42 TWh) can provide twice (10.42 TWh÷5.055 TWh=2.06) the annual electrical consumption in the industrial sector (5.055 TWh) (Energy Commission 2015).

3.4.0. Cost Assessment and Substitution potential of biogas

The next section examines how the potential biogas can be better used either as a transport fuel or as to generate both electricity and heat. Data used is from Murphy et al.,(2004), Public Utilities Regulatory Commission (2015), International Renewable Energy Agency (2015), and Energy Commission of Ghana(2015).

3.4.1. Biogas as an alternate transport fuel

Table 7: Density and Energy Value of Fuels

Parameters	**Value**
Energy value of oil	47.89 GJ/T
Density of petrol	673 kg/m
Energy value of petrol	32.23 MJ/l
Density of diesel	850 kg/m
Energy value of diesel	40.7 MJ/l
Energy value of raw biogas	37.78 MJ/Nm^3
CH4-enriched biogas (95% CH4): Energy value	$0.95 \times (37.78\ MJ/Nm^3) = 35.9\ MJ/Nm^3$
$1m^3$ biogas produces $0.579m^3$ CH-4 enriched biogas	

Source: Murphy et al.,(2004)

Table 8: Efficiencies of fuel use in different Car Types

Fuel	Car Type	Efficiency of fuel in Car
Petrol	Volvo V70 bi-fuel	9.8 km/l= 0.3 km/MJ
CH4-enriched biogas	Volvo V70 bi-fuel	9.6 km/Nm^3 = 0.267 km/MJ
Diesel	Volvo S60	13.17 km/l= 0.32 km/MJ
CH4-enriched biogas	Volvo S60 bi-fuel	10 km/Nm^3= 0.29 km/MJ

Source: Volvo, 2002

It is assumed that these Volvo cars represent most cars that run on dual fuels in Ghana.

3.4.1.1. Asset value as petrol substitute

Petrol costs ¢3.39/l in Ghana. Dividing by the energy value of petrol to get the cost per energy used gives=¢3.39 ÷ 32.23 MJ/l =¢0.105/MJ but we have to also consider the efficiency of biogas to replace petrol so this gives:

Biogas has 90% efficiency of petrol: 0.9×¢0.105=¢0.0945/MJ

Now we have to consider the efficiency of $1m^3$ CH4- enriched biogas used in a Volvo V70 bi-fuel car. Every car has its own fuel efficiency as stated above so we use the corresponding value for this car bearing in mind that $1m^3$ biogas produces $0.579m^3$ CH-4 enriched biogas.

$1m^3$ CH4- enriched biogas: (¢0.0945/MJ ×9.6 km/Nm^3×0.579)/0.267 km/MJ = ¢1.967 m^3

Currently solar PV users in Ghana benefit from 30%-50% subsidy on project financing (IRENA 2015). The minimum is assumed for biogas use so the revenue to be earned from substituting petrol with biogas becomes:

Asset value of $1m^3$ biogas =¢1.38(¢1.967m^3 ×0.70) allowing for 30% subsidy.

3.4.1.2. Asset value as diesel substitute

The same analysis as above is done in this section only with diesel parameters.
Diesel is ¢3.30/l in Ghana=¢3.30 ÷40.7 MJ/l =¢0.081/MJ
Biogas has 90% efficiency of diesel =0.9 ×0.081= ¢0.073/MJ
1m CH4 enriched biogas: (¢0.073/MJ × 10km/Nm^3 × 0.579) / 0.29 km/MJ =¢1.457

Asset value of $1m^3$ biogas = ¢1.02 allowing for 30% subsidy

This means that one earns ¢1.02 if diesel is replaced with biogas.

3.4.2. Biogas producing Combined Heat and Power.

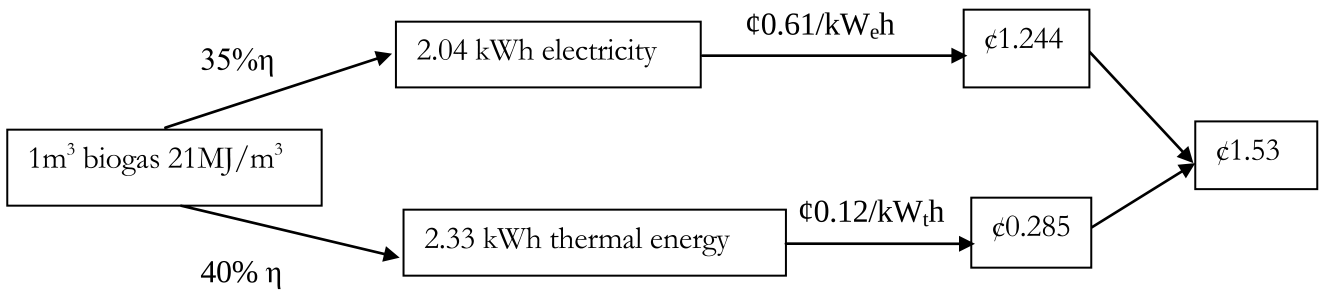


Figure 11: Asset value of $1m^3$ of biogas producing Combined Heat and Power.
(Source: Own Calculations adapted from Murphy et al, 2004)

Raw biogas has an energy value of 37.78 MJ/m^3 (see parameters above) but at 55.5% efficiency in a combined heat and power plant, the energy value of $1m^3$ of biogas becomes (55.5%×37.78 MJ/Nm^3=21 MJ/m^3). When this amount of energy is converted to thermal energy at 40% efficiency (40%×21 MJ/m^3 =8.31 MJ/m^3=2.33 kWh using the conversion that 1 MJ=0.278 kWh), 2.33 kWh of thermal energy is produced. If this is sold at ¢0.12/kW_th (the rate for the cheapest fossil fuel alternative, LPG), the revenue is ¢0.285 for every kWh of heat produced. When the $1m^3$ of biogas is used to produce electricity at 35% efficiency, 2.04 kWh of electricity is produced which can be sold for revenue of ¢1.244 at a rate of ¢0.61/kW_eh (PURC 2015).

3.4.3. Biogas as an alternate cooking fuel

With reference to Ramachandra (2008), a $2m^3$ biogas plant can replace the monthly LPG consumption of 4 households (26 kg÷7.3 kg), charcoal and firewood for 2 households (88 kg ÷36.2 kg) and kerosene for 11 households (210 kg÷88.7 kg) in Ghana given the average monthly consumption of LPG is 7.3 kg per household, 3.5 kg for kerosene, 88.7 kg for firewood and 36.2 kg for charcoal, (Energy Commission, 2015). This offers a promising project of household biogas digesters especially in the savannah and forest areas where animal waste and crop residues are more.

4.0. Discussion and Conclusion

Indeed Ghana has great opportunities to generate bioenergy from crop residues (Tables 2 and 3) and other wastes. There is a possibility to include biogas in the nation's energy consumption having an estimated potential of 3051 M m^3 annually. Electricity from municipal solid waste has the potential to cover 16% of the national electricity consumption annually (Table 3 and 5). Furthermore, about 8.7 million households in urban areas stand to benefit from the total waste to energy potential in the country of 107 PJ that translates to 37.5 PJ electric capacity. This is even more promising in rural areas where about 12 million households (Table 6) will benefit from electricity supply that is limited in these areas if all the potential was directed to rural areas. Transmission losses will be drastically reduced. The construction of small biogas plants ($2m^3$) for households has the potential to replace the monthly LPG consumption of 4 households, charcoal and firewood consumption for 2 households and kerosene consumption for 11 households (See 3.4.3.). Not only do households stand to benefit but also the industrial sector will benefit immensely due to the huge potential since twice the annual industrial power consumption can be covered.

As an alternate transport fuel, biogas has the potential of earning ¢1.38/Nm^3 as petrol substitute and ¢1.02/Nm^3 as diesel substitute. If used in a CHP plant ¢1.53/ Nm^3 can be earned if both electricity and heat are produced but ¢1.244/Nm^3 for electricity-only production (Figure 11). This suggests that biogas use in a CHP plant has an economic advantage over its use as a transport fuel. However when used as a substitute for petrol, earnings are more than its use for the production of only electricity.

Scrubbed biogas that contains 95-98% of methane can be used as vehicle fuel. In Ghana most drivers use dual fuel even for cars that were not manufactured as dual fuel cars. This is because all they need do is get a gas cylinder installed at the trunk of their cars that is connected to the engine in such a way that they can switch between fuels whenever it is convenient. In the long term, a national gas grid can be constructed so that the biogas can be made available in service stations. Otherwise from a centralized anaerobic digestion facility, tankers can carry biogas to service stations as is the usual way of transporting LPG, petrol and diesel in the country.

Looking at the way livestock farming is organized in Ghana, it does not seem lucrative to use manure from livestock as a sole feed in generating biogas. Farms are small and rather scattered which means that gathering of wastes into one big plant will be difficult. The small nature of herds on farms might also constrain substrate availability to be used on individual biogas based farms.. However this is a laudable venture for the government if the goal of poverty reduction in the three northern regions is to be sustained since these are the regions where most of the livestock are reared. Co-digesting manure with other wastes like municipal liquid waste or crop residues will help with the problem of substrate availability. Setting up a centralized plant that will receive these manure and feedstock for energy purposes can open up employment opportunities to collect manure from different locations. They can also service farms by offering cleaning of sites so that the manure is not too contaminated to be useful.

Farmers can earn additional money by producing biogas for themselves or selling to a bigger plant that will use it for vehicle gas. They can even sell their manure and other substrates to a centralized co-digestion plant where the biogas is to be produced. Used as an appropriate technology in rural areas, biogas technology can save time used by women to travel long distances to collect firewood and also improve health conditions that are mostly complicated with inhaling smoke from the use of firewood and charcoal. The absence of lung and throat infections will contribute to a long life expectancy.

The production and use of biogas will help the country become less dependent on events that happen in the rest of the world. The money earned will stay in the country thus reducing the burden on foreign exchange needed to pay for crude oil and natural gas imports. Revenue from ethanol production can also help. As a country that consumes a lot of petroleum and wood and heavily subsidizes LPG, the use of biogas will help reduce the dependence on fossil fuels and its consequent emissions.

However, there is the need for dedicated research towards finding conditions under which projects and facilities can be modeled to suit the local conditions in the country. Research and development is necessary to ensure the development of low scale technologies that will reduce cost and work perfectly under local conditions. This will tend to open up the market for alternative renewable energy sources. Given the high skills needed in waste to energy facilities, it will be appropriate for government to start making human capital investment in this direction. This will also lead to the exploitation of areas that may be country specific that can reduce costs as learning increases.

As a lesson from Sweden, there is the need to set up a waste management system which encourages sorting of waste so that organic waste can be utilized for energy generation. If landfilling of waste is to be continued as the only form of waste management, at least gas should be recovered in order to reduce its effects on the environment. In view of this uncontrolled incineration of waste should be prohibited and culprits taxed. Moreover, support for small power producers in the private sector should be encouraged as well a structured legislative framework put in place as it is in Thailand.

Although this paper has considered energy that can be gotten from only waste, it is worth mentioning that additional energy can be generated from energy crops that are also in abundance in

Ghana. Future analysis should be able to incorporate this when estimating the national potential of biofuels.

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Appendix

A. Calculation of biogas potential from Manure

Type of Livestock	Population (million)	Estimated manure (kg/head/day)	Recoverability Fraction(kg/g)	Manure available (Mt/yr)	C_{TS} gTS/100g	BMP_{Manur} m3/kg TS
Cattle	1.5	12	0.2	1300	12	0.22
Sheep	3.8	1.2	0.2	330	25	0.22
Goats	4.9	2	0.2	710	25	0.22
Pigs	0.54	3.6	0.5	350	11	0.22
Poultry	47	0.02	0.5	170	25	0.22

$$Biogas_{Manure} = (Q_{Livestock} \times Q_{Manure} \times R_{Manure}) \times C_{TS} \times BMP_{Manure}$$

$$Biogas_{Manure} = Manure\ Available \times C_{TS} \times BMP_{Manure}$$

$Biogas_{Cattle} = 1300 \times 12 \times 0.22 = 34 Mm^3 CH4/yr$
$Biogas_{Sheep} = 330 \times 25 \times 0.22 = 18 Mm^3 CH4/yr$
$Biogas_{Goats} = 710 \times 25 \times 0.22 = 30 Mm^3 CH4/yr$
$Biogas_{Pigs} = 350 \times 11 \times 0.22 = 8.6 Mm^3 CH4/yr$
$Biogas_{Poultry} = 170 \times 25 \times 0.22 = 10 Mm^3 CH4/yr$

$Biogas_{Manure} = 34+18+30+8.6+10 = 100.6 Mm^3 CH4/yr$

B. Energy potential from manure

1m^3 biogas=3.6×10^{-8}PJ

100.6Mm^{3}biogas=100,600,000×3.6×10^{-8} =3.62 PJ/yr

C. Potential electric capacity from manure

At an efficiency of 35%:

35%× 3.62 PJ/yr = 1.27PJ/yr

D. Calculation of biogas from MSW

The quantity of waste was calculated from Meiza et al., 2015: 12710 tonnes of waste daily × 365 days=4,639,150 tonnes/yr

$$Biogas_{MSW} = Q_{MSW} \times C_{OFMSW} \times C_{TS} \times BMP_{OFMSW}$$
$$Biogas_{MSW} = 4{,}639{,}150 \times 0.64 \times 541 \times 0.32$$
$$Biogas_{MSW} = 514\text{Mm}^3\text{CH4/yr}$$

E. Energy Potential from MSW

$1m^3$ biogas=3.6×10^{-8}PJ

$514Mm^3$biogas=$514{,}000{,}000\times3.6\times10^{-8}$ =18.5PJ/yr

F. Potential Electric Capacity from MSW

At an efficiency of 35%:

35%×18.5 PJ/yr = 6.48PJ/yr