VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES

Apotei Kusi Gabriel

BIOMASS AS AN ALTERNATIVE SOURCE OF ENERGY IN GHANA

School of Technology
2019

VAASAN AMMATTIKORKEAKOULU

UNIVERSITY OF APPLIED SCIENCES
Energy and Environmental Engineering

ABSTRACT

Author	Apotei Kusi Gabriel
Title	Biomass as an Alternative Source of Energy in Ghana A Case Study for Biogas Production
Year	2019
Language	English
Pages	88
Name of Supervisor	Riitta Niemela (Senior Lecturer)

Among the renewable energy sources, biomass continues to remain one of the dominant renewable energy sources across the globe. Biomass is already making a substantial contribution to meet the global energy demand. The contribution can be expanded very significantly in the future, providing greenhouse gas savings and other environmental benefits, further as causative to energy security, promoting trade balances, providing opportunities for social and economic development in our rural communities, and enhancement to the management of resource and wastes in our surroundings.

The aim of this thesis is to find out how best biomass (biogas production) can serve as an alternative energy source in Ghana to help minimize the current energy crises in the country. Ghana has experienced a serious energy crises for the past five to six years which has resulted in frequent power outages. An alternative solution to this problem is to introduce the country to most reliable and efficient source of renewable energy supply that is environmentally friendly with the concept of generating energy from biomass. In addition, this thesis assesses the environmental and socio-economic impact of various biomass technologies with appropriates safety measures regarding various biomass plant technologies. This thesis also evaluates the various biomass feedstock and their potentials for biogas production in Ghana.

Biomass for energy may be obtained from a diverse range of sources, the most important of which are energy crops, agricultural and forestry residues, municipal solid waste, industrial waste of all kinds and existing forestry.

Keywords Biomass to Energy, biogas, biomass plant, biomass resources

CONTENTS

LIST OF FIGURES AND TABLES

ABBREVIATIONS

LPG	-	Liquefied Petroleum Gas
MSW	-	Municipal Solid Waste
kW	-	kilowatt
COCOBOD	-	Ghana Cocoa Board
CPH	-	Cocoa Pod Husks
CPC	-	Tema Cocoa Processing
CHP	-	Combined Heat and Power
CO	-	Carbon Monoxide
CO_2	-	Carbon dioxide
CH_4	-	Methane
ECG	-	Electricity Company of Ghana
PURC	-	Public Utilities Regulatory Commission
MoFEP	-	Ministry of Finance and Economic Planning
UASB	-	Upflow Anaerobic Sludge Blanket
PJ	-	Peta Joules
OECD	-	Organization for Economic Co-operation and Development
IEA	-	International Energy Agency
Ktoe	-	kilotonnes of oil equivalent
H_2O	-	Water
AD	-	Anaerobic Digestion
SO_2	-	Sulphur dioxide1 ` 234
GDP	-	Gross Domestic Product
RDF	-	Refuse Derived Fuel
LFGR	-	LandFill Gasoline Recuperation
USD	-	US Dollar
GWh	-	Gigawatt hours

EC	-	Energy Commission
VALCO	-	Volta Aluminum Company
GSA	-	Ghana Standard Authority
HHV	-	High Heating Value
LHV	-	Lower Heating Value
MJ	-	Megajoule
VM	-	Volatile Matter
FC	-	Fixed carbons
GSS	-	Ghana Statistical Service

1 INTRODUCTION

Energy supplied across the globe is gained from both renewable and non-renewable sources. The non-renewable energy source commonly known as fossil fuel contributes to about 80 percent of the total energy consumed globally. Fossil fuels are relatively cheap and are easily identified and transported. The increase in energy demand in recent times has caused a rapid scarce in fossil fuel since it is non-renewable and cannot be replaced over time. However, the non-renewability of these sources of energy at a point in the future can cause an increase in energy prices where they are not economically feasible. Some environmental scientist have predicted that, coal, oil and natural gas will be scarce in the future. The scarcity will cause a rise in energy prices which will eventually lead to a shift to the use of renewable energy sources. The major downside of using fossil fuel is the cause of environmental pollution. Burning fossil fuel releases carbon dioxide (CO_2) into the atmosphere, which causes a greenhouse effect. The emissions that are released has been a major factor behind global warming. The burning of coal also releases sulphur dioxide (SO_2) into the atmosphere which creates harmful acid rain. Crude oil on the other hand contains toxic chemicals that pollute the air when combusted and are dangerous to human health. The fumes from vehicles and industries using heavy machinery also release carbon monoxide, which replaces the oxygen in the blood when inhaled. The uneven distribution of some fossil fuel energy has contributed to political tensions and other national problems regarding its availability. (Kartha S. et al. 2000)

Considering the numerous shortcomings of the use of fossil fuel energy, it has become necessary to find an alternative source of fuel that is free from CO_2, Carbon Monoxide (CO) and Sulphur dioxide for a safe and cleaner environment and the promotion of quality health for the people as well. (Murphy et al. 2006)

Biomass can be considered as a reliable and renewable source of energy to replace conventional fossil fuels in local industries and it can be expected to minimize the dependency of the overloaded national electricity grids. Solid biomass such as fuel fire (fire-wood), charcoal, agricultural and forest residues and animal dung have traditionally been utilized as a source of energy in the rural areas in most developing countries. In view of this, many medium - to - large agricultural, food processing or wood processing local industries in most developing countries and emerging economies are well placed to benefit from successful development of biomass to energy. Not ending there both agricultural and forest-based industries in developing and emerging economies also generate a substantial amount of biomass residue and waste that could, in principle, be used for energy production. (Murphy et al. 2006)

These few factors are some reasons for the strong call for the development of most renewable energy source such as solar energy system which is most common and the back bone of all source of energy system and the another source of energy system is the biomass energy system which is the main focus in this thesis.

1.1 Aim and Scope of the Thesis

The main motive behind this thesis is to find out the energy potential from biomass resources in Ghana, with the aim of this biomass energy potential to serve as an alternative source of energy which can provide a potential benefit to the country's energy sector and the development of both environmental and economic growth. The energy from biomass production can help reduce the unstable power supply on the national grid to the people of Ghana. Another reason is to also look at how biomass energy can be developed in Ghana with references to one developed country- Finland and one developing country- Thailand.

Biomass is the dominant energy sources contributing over 50% of the total energy consumed in the country in 2011. Ghana has vast arable and degraded land that could be used for the cultivation of energy crops for the production of solid and liquid biofuels'. (Energy Commission, 2012).

From the start of civilization, biomass fuel was unquestionably being utilized for the generation of energy. However, in the past few decades, debates have raged over whether biomass energy is really useful and sustainable. This fierce debate triggered researchers to study the feasibility of using biomass energy. The outcome of these researches were great. Studies show that biomass has many benefits over fossil fuels and helps to minimize the emission of greenhouse gas. This has been a motivation to carry out a case study for the production of biomass into energy in Ghana since the availability of biomass materials and other organic waste in Ghana are guaranteed.

(World Bank, 2012)

1.2 Identification of Need

Ghana can boast of numerous resources of energy such as hydrocarbons, hydropower, biomass, solar and wind. However, for the past few years Ghana's energy sector has lost some amount of credibility with the inability of power producers to meet the energy demand of the people. Currently the spate of control blackouts in Ghana has made outrage, dissatisfactions and inconvenience among the citizenry. Insufficient and untrustworthy control supply has in this way gotten to be one of the major imperatives to long-standing time financial development of the country. (Energy Commission, 2012)

This draws more attention to the need to strengthen the energy sector and create an alternative measure to curb Ghana's energy crises. The advancement of bioenergy in Ghana as an elective and economical source of energy will be one of the solution to help to resolve this power situation. This study specifically gives more insight on how biogas can be produced from the appropriate feedstock from biomass potential in the country to help minimize the current energy crises. Ghana has a considerable biomass asset that can give for the larger part of residential power utilization. With the various types of renewable energy sources and technologies, bioenergy can be considered as the most efficient and the promising type. The expansion of biofuels will improve energy security in Ghana. It will also help to reduce the exportation of oil from the foreign countries and stabilize Ghana's currency. This will also provide employment opportunity to the citizens and serve as a source of revenue to alleviate poverty. Critically, having access to clean advanced and feasible energy source is a way to move forward and contribute to the wellbeing and employment of the Ghanaian citizenry. (Energy Commission, 2010)

1.3 Research Questions

Every thesis has its own research questions that needs to be analyzed and resolved with the provision of concrete and satisfied solutions or answers to these research questions. Solutions to most of these questions are obtained from the aims and the findings of a particular thesis in question. This thesis has two main research questions which was analyzed and answered. These questions were:

- What is the energy potential from biomass resources in Ghana?
- How can biomass potential be developed in Ghana?

Detailed solutions to these questions has been discussed in the subsequent chapter.

1.4 Limitation of the Research

A thesis of this nature has its limitation. Although some data and other primary information were obtained from some friends and staffs at Ghana COCOBOD for a case study in chapter 7. All other information and other proofs collected for this study relied on secondary data and a literature review. The data collected for bio-waste and other relevant information regarding to this research are obtained from open sources and other related articles. A study of this nature requires a field survey and observation across the country in question. This is necessary to give a precise and concrete evidence and a great outcome for future reference. But due to key factors such as capital and time constraints, this thesis was undertaken and limited to an analysis and observations based on secondary data and other open sources to provide a better outcome.

1.5 Structure of Study

The next part in this thesis which is chapter 2 talks about the country's profile, pestle analysis and other relevant factors to help understand the subsequent discussion that concerns the country. Chapter 3 gives some information about the literature review relating to this thesis. Chapter 4 describes the various types of energy conversion methods of biomass. Theoretical frameworks of the evaluations of the various pestel analysis and their implications on biomass in Ghana has been detailed in chapter 5. Research methodology giving details on how data were collected for this thesis and other ethical issues in research for this thesis are also embedded in Chapter 6. Empirical analysis on data, potential feedstock for biomass energy in Ghana, energy potential for biomass from anaerobic digestion are in Chapter 7 Moreover, case study was conducted to investigate the quantity of cocoa pod husks generated in Ghana annually and evaluate energy potential from these cocoa pod husks. A dialog of the grouped styles of biomass to energy advances are given, making references to one developed country, Finland and one developing country, Thailand are also in the same Chapter. Reflection on these two nations have progressed in the utilization of biomass to energy technologies. This can also be connected to the circumstances in Ghana. This will set a way for the examination to work out since Ghana's case is conceivable additionally beneficial. A very diverse sources of biomass are thought of to allow a wide view of biomass to energy potentials. Final discussion and conclusion are presented in Chapter 8.

2 COUNTRY'S PROFILE

2.1 Ghana's Profile and Population

Ghana officially called the republic of Ghana, is an independent state. It is located on the Atlantic Ocean towards the West side of Africa. In May 2012 the Statistical Service of Ghana released the 2010 population and housing census. The result indicated that Ghana has a population of 24millon as against 18 million in 2000. The population growth was estimated to be around 2.2%. The urban population is 51% of total population with an estimated growth rate change of 3.4%. The national total population density was around 126.72 per square kelometers in 2017 (World Bank, 2018). The current population of Ghana in 2019 is estimated to be around 30,011,304 million.

Accra is the capital and largest city of Ghana, which has an urban population of 2.27 million. The Greater Accra Metropolitan Area (GAMA) has about 4 million inhabitants which makes it the 11th largest metro area in Africa. The 2nd largest city in Ghana is Kumasi with a total of 1.4 million inhabitants. Tamale is third with total inhabitants of 360,579 (GSS, 2013).

Agriculture is the key sector of Ghana's economy accounting for 23 percent of national GDP in 2102. 53.6 percent of the total population of Ghana gain their livelihood from the agricultural sector while the remaining 46.4 percent of the population gain their livelihood from the industry and the service sector. Ghana's GDP and GDP Per Capita in 2013 stood at 48.1 billion and 1,858 US Dollars respectively. The figure below illustrates the seven ecological regions of Ghana. (GSS, 2013) Figure 1 below illustrates the seven ecological regions of Ghana on the regional map.

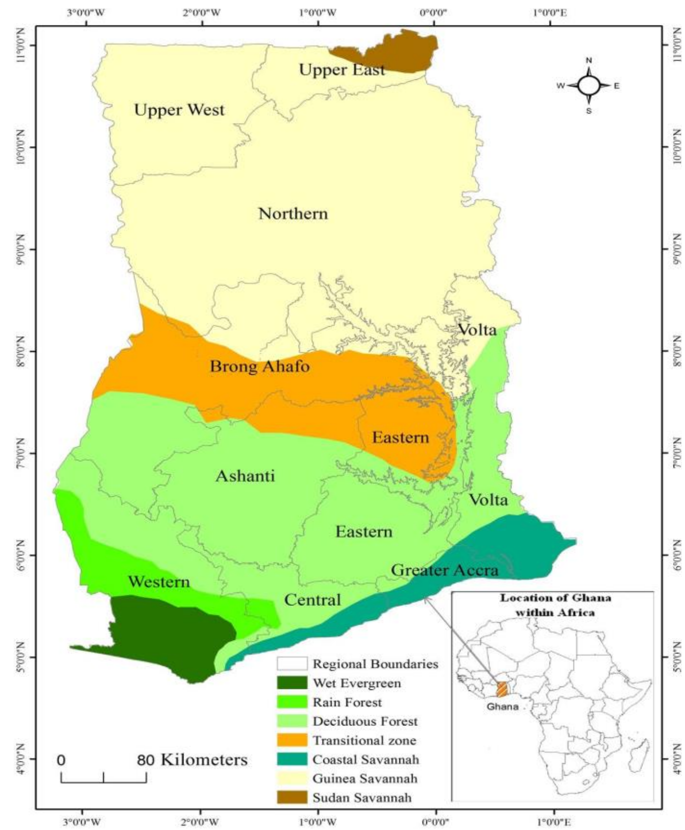


Figure 1. Seven Ecological Regions of Ghana on a regional map.

Climatic conditions differ in each of the different agro-ecological zones. The Tropical Eastern Coastal Belt is warm and comparatively dry, the southwest is hot and humid and the north is relatively hot and dry, compared with the other parts of the country. The mean annual temperature in Ghana rarely falls below 25°C.
(MoFA, 2011).

2.2 Economic History

Ghana has been concern altogether phases of Africa's economic development throughout the last decades. Because the economic fortunes of African societies have waxed and waned, so too have Ghana's going away that country within the early 1990s during a state of abnormal condition, unable to create the "leap" to Africa's next, yet unsure section of economic evolution (Arthur,2009)

When the slave trade ended in the early years of the 19th century, the neighborhood economic system grew to become the focused on so-called legit trade, which the emerging industrial powers of Europe stimulated as a supply of substances and markets as a useful resource to their very own manufacturing and sales. The British, in particular received growing manipulate over the vicinity for the duration of the 19th century and promoted the manufacturing of palm oil and trees as well as the continuation of gold production. In return, Africans have been inundated with imports of purchaser goods that, unlike the luxuries or domestically unavailable imports of the trans-Saharan trade, shortly displaced African products, in particular textures. In 1878 cacao trees had been added from the Americas. Cocoa shortly grew to be the colony's main export; Ghana produced more than half the international yield by the 1920s. African farmers used kinship networks like commercial enterprise firms to unfold cocoa cultivation for the duration of giant areas of southern Ghana. Legitimate change restored the usual productivity of Ghana's economy; however, the inflow of European items began to displace indigenous industries, and farmers targeted greater on cash vegetation than on critical meals plants for neighborhood consumption. (U.S library of congress)

When Ghana gained its independence from Britain in 1957, the financial system appeared secure and prosperous. Ghana used to be the world's leading producer of cocoa, and had a well-developed infrastructure to service trade, and a rather superior training system. At independence, President Kwame Nkrumah sought to use the obvious steadiness of the Ghanaian financial system as a springboard for economic diversification and expansion. He started the system of moving Ghana from in particular agricultural economy to a mixed agricultural-industrial one. Using cocoa revenues as security, Nkrumah took out loans to set up industries that would produce import substitutes to many of Ghana's exports. Nkrumah's plans have been formidable and grounded in the wish to limit Ghana's vulnerability to world trade. Unfortunately, the fee of cocoa collapsed in the mid-1960s, destroying the indispensable steadiness of the financial system and making it almost impossible for Nkrumah to proceed his plans. Pervasive corruption exacerbated these problems. In 1966 a team of army officers overthrew Nkrumah and inherited a nearly bankrupt country. Since from then, the stability of both the economic and political affairs of the country have been tremble. (George et al. 2015)

Ghana’s financial performance has been quite solid over the past three decades during which the Nation has sought after market-led economic arrangements and programs with negligible association of the government in direct financial activities. The recuperation of the country’s economy from recession in the early 1980s through financial change and auxiliary adjustment programs, and the sustained growth have earned the nation a part of commendations in terms of financial accomplishment. Ghana recorded approximately 5.2 percent yearly growth between 1984 and 2010. She became a lower income country after a rebase of her national accounts in 2010, with an alteration in the base year from 1993 to 2006. The rebase pushed the country’s annual growth to 8.3 percent between 2007 and 2012. In 2011, the country commenced commercial generation of oil. This advancement contributed about 5.4 percent (oil-GDP) to the 15.0 % GDP growth in that year. This gave Ghana an advantageous position as one of the six faster growing economies in the world that year. Ghana’s economy quickened to 8% in 2017, driven by the mining and oil segments, making it the second-fastest developing African economy. In 2018, Ghana’s economy proceeded to expand quickly, but at a slower pace than the rate in 2017. In spite of the fact that the government is executing a few of its promises, such as planting for food and jobs, and free secondary education programs, there should be more reforms to strengthen the country's economy.(George et al. 2015)

2.3 Energy History

In the past decade, Ghana has encountered severe power supply challenges costing the country about US $2.1 million averagely in loss of generation daily. This scenario has developed although set up generation capacity has more than doubled over the period, increasing from 1,730 MW in 2000 to 3,795 MW in 2016. The maximum electricity demand solely elevated by 50 percent during this same period, rising from 1,393 MW in 2006 to 2,087 MW in half a decade now (Energy Commission, 2016)

The energy supplied in the then Gold Coast was mainly from diesel generators owned by industrial enterprises, such as factories and mines. The sector was revolutionized with the completion of the Akosombo Hydroelectric Power Station which exported energy to neighboring countries Togo, Burkina Faso and Benin. The completion of the Akosombo Dam Project in 1972 supplied a total capacity of 912 MW of power. Although the most important goal of the project was to generate electricity for the Aluminum industry- VALCO, it also made it possible to switch from diesel generators to hydroelectricity. (Energypedia, 2015)

Ghana, in view of the expansion in production capacity, encountered its first energy crisis in 1984. This crisis was a result of an extreme drought that happened between 1982 and 1984, during which the whole inflow into the Akosombo Dam was less than 15 percent. The crisis led to the introduction of Thermal Power Plants into Ghana’s generation mix. The first of these Thermal Power Stations was a 550 MW facility at the Takoradi. The Volta River Authority (VRA) in Ghana manages Takoradi Thermal Plant. The potential of the installed thermal plants in Ghana has expanded to 2,053 MW as at the end of 2015 (Energy Commission, 2016a).

Energy crisis has ended up as a common household phenomenon in Ghana with the adoption of the word “Dumsor” to describe the situation. In December 2013, the 400 MW Bui Hydroelectric Power Station was commissioned to generate electrical energy to support the load on the country. (National Energy Statistics, 2017)

Electricity demand has increased significantly to the point where the supply is not enough to meet the demand, causing extreme energy crises over the last decade. In a bid to solve the crisis, the energy sector reform was carried out in the late 1990s to open up the electricity market for private sector participation to assist deal with the power crises. (National Energy Statistics, 2017) Electricity demand versus installed electricity in Ghana in 2016 is presented in the graph below as figure 2.

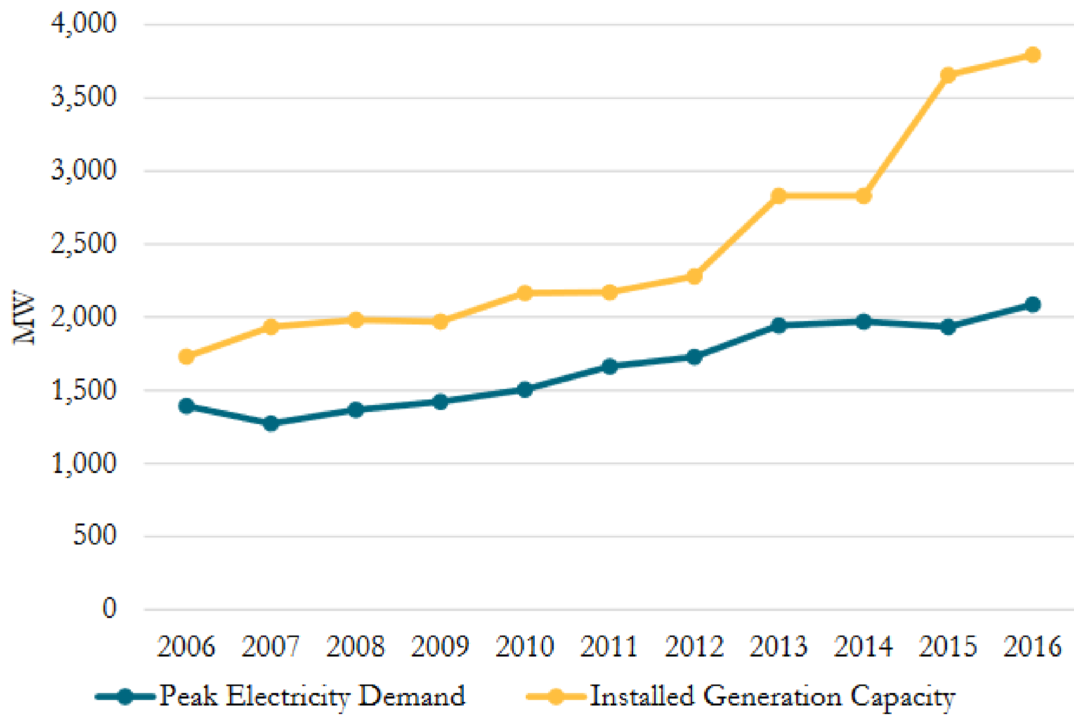


Figure 2. Electricity demand versus Installed Electricity in Ghana as at 2016. (Energy commission of Ghana 2016)

2.4 Energy Consumption in Ghana

Ghana is well endowed with both renewable and non-renewable energy resources. Energy consumed in Ghana is obtained from crude oil, natural gas, petroleum products, biomass, solar, hydro and Electricity.

Biomass is the dominant energy source contributing over 50% of the total energy consumed in the country in 2011. (Energy Commission, 2012). The total energy produced at the end of 2017 was 13,909.4 kilotonnes of oil equivalent (ktoe) with a final energy consumption of 6,984.2 ktoe. The final energy consumption was made up of 1,039.8 ktoe (14.9% of the total energy consumed) of electricity, 3,115.0 ktoe (44.6% of the total energy consumed) of petroleum and biomass of 2,829.4 ktoe (40.5% of total energy consumed). The annual growth in the demand for fuelwood and charcoal, which are the dominant sources of fuel, is estimated at 4%. A significant amount of the wood fuel consumed is wasted through the use of obsolete and inefficient biomass utilization technologies. Electricity demand, on the other hand, is growing on the average between 11% annually while consumption of petroleum products is estimated at about 6% per annum. These growth rates are high. (Energy Commission, 2016a) Figure 3 shows the total share of energy consumption in 2018.

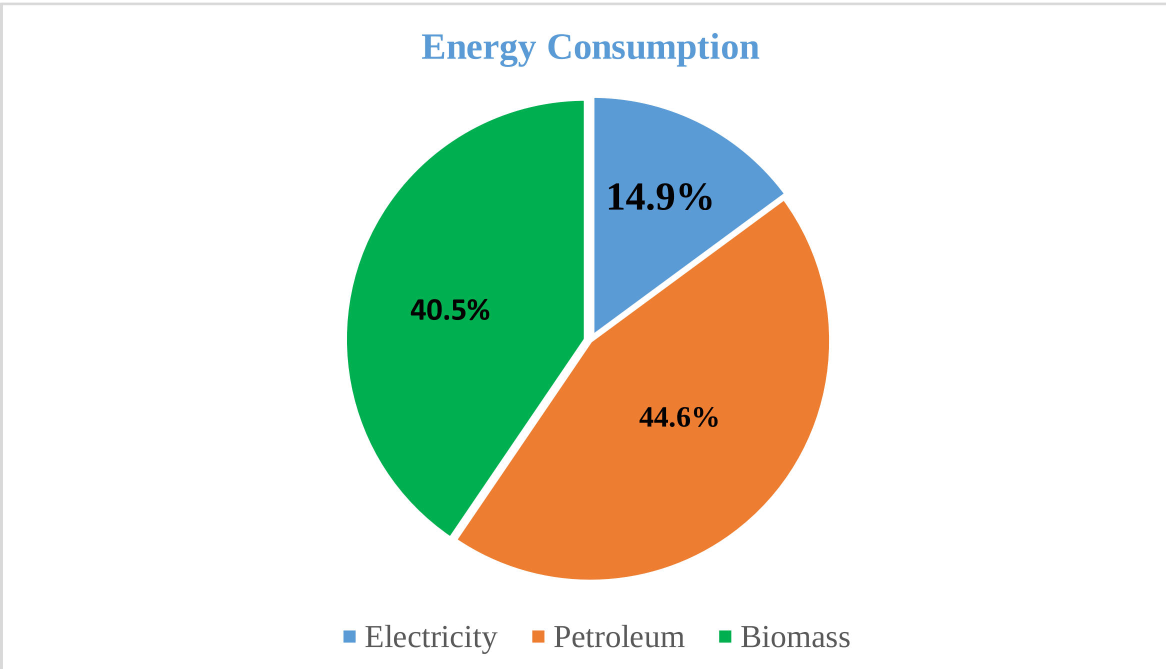


Figure 3. Energy Consumption. (Energy Commission 2018)

2.5 National Stakeholders in the Energy Sector

The Ministry of Energy is accountable for formulating, monitoring and evaluating policies programs and initiatives for the power sector in Ghana with monitory aid from the Ministry of Finance and Economic Planning (MOFEP). The Ministry is also at once responsible for implementation of the National Electrification Scheme in a variety of parts in the country. The Energy Commission (EC) and the public utility Regulation Commission (PURC) are responsible for regulating the activities of the power sector. The EC is accountable for technical rules of the power sector, including licensing of operators and advising the Ministry of Energy on the things relating to power coverage and planning. The PURC, on the different hand, is an unbiased regulatory agency accountable for economic laws of the energy sector, in particular approving costs for electricity sold by distribution utilities to the public. PURC is also accountable for monitoring the high quality electricity offerings delivered to their consumers. (Energy Commission, 2017) The schematic diagram below indicated as figure 4 shows the various stake holders in the energy sector of Ghana. Electricity consumption pattern from 2006 to 2016 is also given in figure 5.

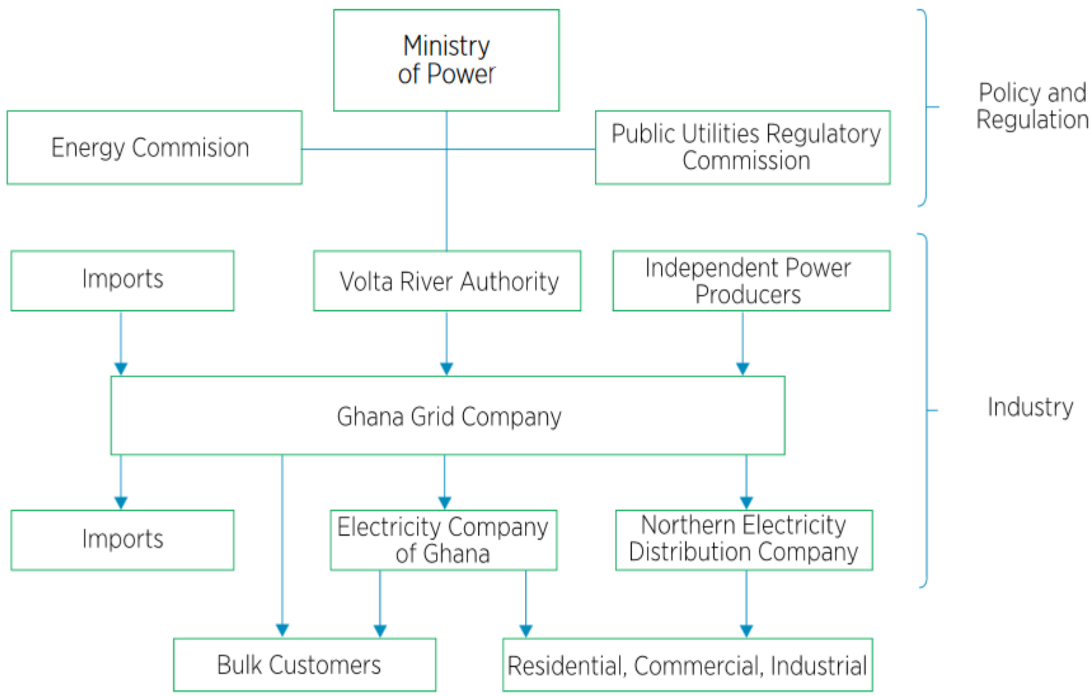


Figure 4. Structure of Ghana's energy sector. (Energy Commission, 2016a)

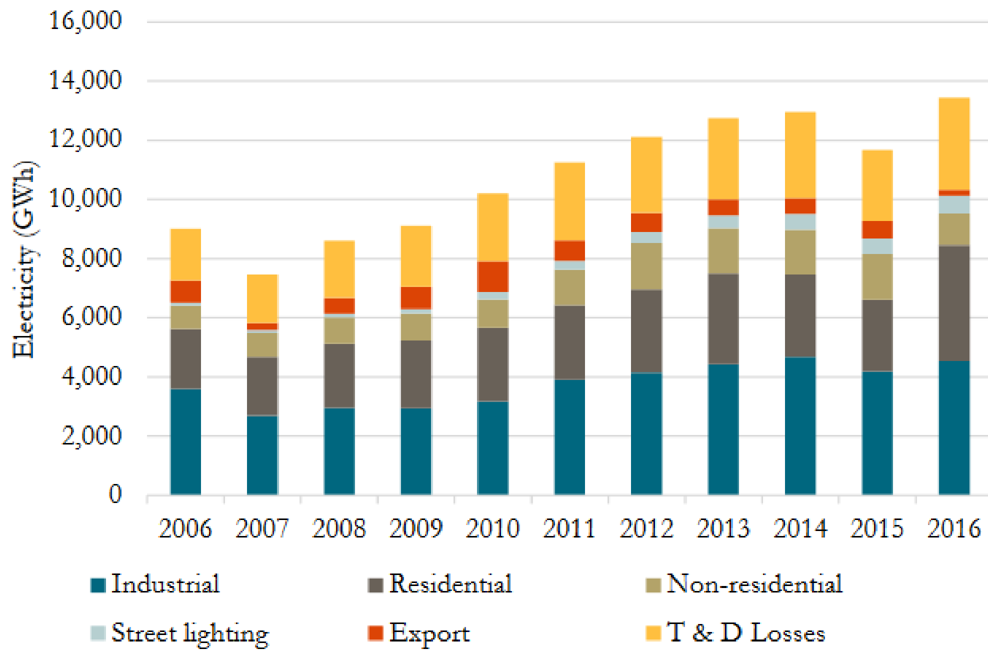


Figure 5. Current electricity consumption pattern for Ghana from 2006 to 2016.

3 LITERATURE REVIEW

The round economy affords a built-in viewpoint of the economic system where biomass is treated as a useful financial resource that can be used for the production and consumption in order to achieve viable increase (George et al, 2015).

Regarding the conventional market economy where the effective utilization of biomass energy, such as agricultural and municipal solid waste can affect the reduction of energy cost while the capital invested in this technologies stays within the local economy. As a provision of alternative supply of energy for many countries across the globe, biomass can generate fuel especially for industrial facilities with a high demand of thermal or electricity consumption. Biomass essentially serves as a great deal of renewable energy sources for many countries mostly in Europe which in long run has enabled them to manage particularly their municipal solid waste to preserved their environment.

3.1 Theoretical Background

Biomass energy is a vital element of every household energy consumption especially in rural areas. Moreover, under the exploitation of current levels, the energy resources always come with both theoretical and practical constraints, putting serious obstructions to its effective utilization. Over many decades, biomass energy continues to be the most important element of energy consumption in everyday lives, existing in the contributions of both economic and social developments.

Biomass to energy is undeniably renewable energy however, it is vital to be aware that biomass energy is intrinsically distinctive from other traditional renewable energy sources such as photo voltaic (solar energy) and wind power. Such energy sources are normally managed by way of the type of natural forces that people have limited capacity to change. This scenario confers on them a very great factor of sustainability. However, biomass energy is increasingly more, which is well managed with the aid of mankind appearing to override natural forces. Only when biomass energy sources are utilized within the scope of their resources- carrying capability. (ESWET, 2019)

The improvement of biomass as an energy supply is affected through numerous of elements due to the facts of the multi-purpose nature of biomass

3.2 Definition of Biomass Energy.

Energy from biomass can be of various forms for different purposes depending on the technologies used. This can either be in liquid, solid or gaseous state. Biomass utilization is mainly achieved through the various biomass conversion technologies depending on the type of biomass being utilized. These technologies for biomass transformation and utilization cover a wide range of, from traditional or local to advanced technologies, or to deep researched technologies. The most common conversion technologies of biomass are:

- Gasification
- Combustion
- Pyrolysis
- Fermentation
- Anaerobic Digestion

The diagram below labelled as figure 6 briefly describes the configuration of the various process of the biomass conversion technologies into useful energy form.

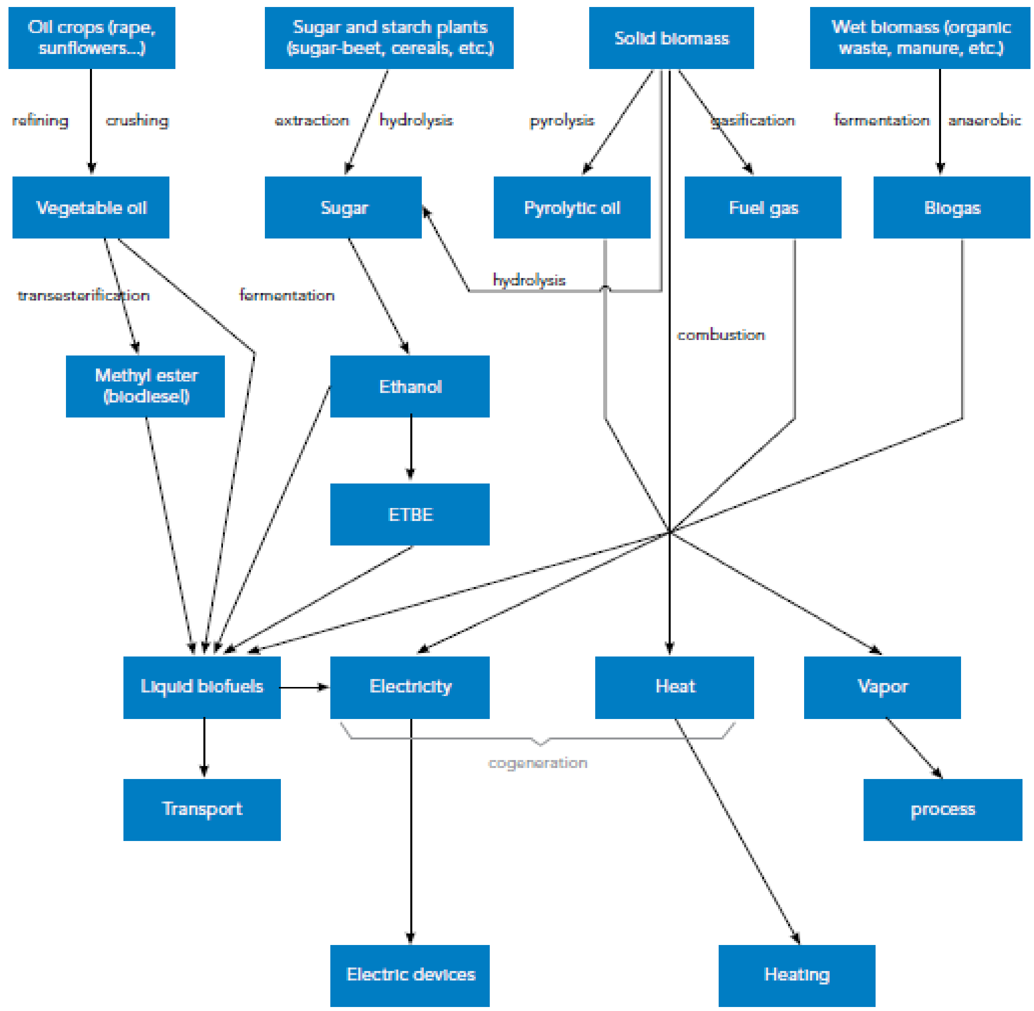


Figure 6. Biomass Energy conversion Overview. (Renewable Energy world, 2006)

Biomass to energy is to generate electricity from municipal solid waste, animal manure, commercial and industrial waste, forestry and agricultural waste through the appropriate technologies utilization.

Biomass could also be described as renewable energy source from all organic matters that stem from flora (including algae, timber and crops). Biomass can also be described as energy generated from green plant life which turns sun energy into plant materials through photosynthesis and consists of all land and water-based vegetation, as well as all organic wastes. Biomass is regarded as the only renewable energy source, which has the potential to store carbon into its structure through the process of photosynthesis. The use of biomass as an energy source, with emphasis on its potential use as a supplementary gasoline for energy generation, also contributes a lot to global economic growth. Moreover, the utilization of landfill, agricultural waste and other types of biomass resources for biomass energy as already stated with the help of Figure 6 above would be briefly discussed in this section. (Kamausuor et al. 2014)

Moreover, advanced application of biomass energy with a wide range of various forms of technologies can be categorized into four main groups, such as biomass -fired electric power plant, liquid fuel and biogas production, improved cookstove and kilns technologies.

Below are some of the examples of the various types of biomass energy:

- Ethanol.
- Biogas
- Biofuels (Biodiesel)
- Solid waste Fuels

Biomass resources comprise of primary, secondary, and tertiary sources. The generation of primary biomass are directly obtained through the process of photosynthesis. These primary resources are basically from waste agricultural products which include perennial short-rooted woody crops, herbaceous crops, residuals obtained as a result of the harvesting of agricultural crops. Secondary biomass resources are obtained from the process of primary biomass resources either physically (for example, saw dust production through milling, municipal solid waste), chemically (production of black liquor from pulping) or biologically which can be through manure obtained from livestock. Tertiary biomass resources can also be obtained from for example animal fat and greases and, used vegetable oils. (Mensah et al. 2014)

3.3 Benefits of Biomass Energy

There has been increased awareness of the significance of the social, economic and environmental benefits of energy technology activities from biomass. Although RES are generally related to lower exterior impacts comparatively to fossil fuel fired plants, in precise to coal, they are now not in reality impact free.

With regard to environmental benefits, as with different types of combustion, biomass gasoline combustion emits air pollutants. The quantity and kind of pollutants depend on both the combustion process concerned and on the extent of controlled burning. Compared with fossil fuels, a combustion plant fueled with forest residues emit comparable ranges of nitrogen oxides, however significantly less sulphur dioxide. Moreover, different researchers point out that carbon uptake by using an improved biomass technology takes place slower than carbon release during the process of combustion. It is estimated that about 13 percent of the carbon launched from residue combustion may stay in the surroundings.

Also, when it comes to energy generation from biomass, the availability of biomass does not rely on weather conditions, seasonal or diurnal times and can as well be reserved for use on demand. This represents a vital merit, permitting power generation from biomass to be exceedingly predictable and contributing to base load capacity. The opportunity of combining the storage of other RES with the generation of energy from wind, hydro or solar, can be a choice to mitigate many of the energy problems the country will encounter in the future. Furthermore, it is a domestic power supply and contributes to the diversification of the fuel combination and to the security of energy supply. Bioenergy programs involving electricity plants can make some significant contributions to rural income or employment increment. Biomass energy plants particularly in rural areas can influence changes in agricultural labor patterns and provide significant contributions to rural economic diversification. (Milbrandt, 2009)

3.4 Global Overview of Biomass Potential for Energy

Currently biomass is dominating as a renewable energy source for multiple uses in heat, power and transportation fuels. A gradual substitution of fossil fuels by renewable energies in the coming decades needs a great attention of the ways or methods of increasing the growth of all renewable energy carriers such as wind, solar, bioenergy, hydro, and geothermal and bioenergy. (ESWET, 2019)

The availability of biomass can be commonly described in terms of hierarchy of potentials from highest to the decreasing size. These are;

- Theoretical Potential
- Technical Potential
- Economic Potential
- Realistic Potential

Table 1 below briefly illustrates the hierarchy of biomass resources potentials in common use.

Table 1. Hierarchy of biomass resources potentials in common use. (Smeets, et al., 2007, Fischer, et al, 2001b, Lauer, 2009, Hoogwijk, et al, 2005, Offermann, et al, 2010)

Name	Definition
Theoretical potential or Ultimate potential	This describes the amount of biomass that can be produce or grow annually, limited by fundamental, physical, and biological barriers. The theoretical potentials change if conditions change for example due to climate change. This biomass category is not convenient for analyzing biomass production, except as a comparator of biomass production vs. total global primary production.
Technical potential or Geographic potential	This refers to all the data gathered from the theoretical potential and also taking into account ecological constraints, land area constraints, agro- technological constraints, and topographic problems. Another definition that can be considered is the proportion of the theoretical potential that is not limited by the demand for land for food, housing etc.
Economic potential	This refers to all biomass available up to a specific price level by taking into consideration the price elasticity of competitors on the market. For example, the potential at a given price is determined by where the supply and the demand curve intersect. This is highly variable as economic conditions may change dramatically overtime. Moreover, markets may not exist for many biomass feedstocks or may not be imperfect.
Realistic or Implementation potentials	All biomass available without inducing negative social, environmental or economic impacts and respecting technology and market development issues. May be estimation using recoverability fraction or accessibility factor multipliers, reflecting what is considered the realistic maximum rates of energy of energy use of biomass residues. Deciding what is the most appropriate multiplier to use in any particular instance is often a matter of expert judgment

3.5 Review of Thailand’s Biomass Energy System

Biomass remains to be one of the essential renewable energy sources in Thailand and currently ranks the second major energy resources in the country, most particularly for household and majority of small scale industries. The provision of basic energy requirements for cooking, residential heating and manufacturing section as well as energy for traditional industries sorely depends on biomass energy. Biomass energy in Thailand is mostly obtained from four major resources which are sugar cane, rice, oil palm and wood wastes which can give the total potential of about eighty million tons annually. Thailand as a nation of advancement from a low middle income to upper middle income position with bioenergy generation segment. This offers a great opportunity for Ghana to do likewise.

Thailand's Ministry of Energy has provided an estimation that the attainable energy production in the country from biomass, municipal solid waste and biogas is around 3,700 MW in the year 2011. (Amranand 2008).

In addition to the utilization of bagasse, paddy husk and woodchips (sawdust), other sources with precise attainable are municipal wastes, manure from pig farms and other livestock, corn cob, wastes from oil palm factories and any other kinds of agro-based industries. In addition to this, The Ministry of Energy in Thailand has implemented a fifteen - year renewable energy plan for the period 2008-2022. This implemented plan pursuits to maximize the country's potential to make provision for other alternative power sources to 20.4 percent. Biomass accounts for 84 percent of the whole power generation from the renewable source in the plan. Additionally, 91 percent of the thermal energy functions from the total thermal energy comes from renewable sources. The generation of biofuels in Thailand which are derived from biomass, represents 29 percent of the whole renewable energy demand in the country. (DEDE, 2008).

Briefly, with an overview of biofuels production in Thailand, as of 2010, there were nineteen ethanol power plants in the country with a potential of 2.93 million liters per day (DEDE2010a). However, solely 60- 70 percent of the total has been utilized. This illustrates how potential biomass is, with it being the major traditional energy source in Thailand. The cause of development of renewable energy most especially biomass has promoted several policy measures, such as implementation of compensation mechanisms to eliminate external costs of biomass energy generation, implementation of several measures to have easy access to power grid under free and fair terms and conditions. The Thai Government has also done so well to establish a foundation to provide adequate assistance to project developers and farmers to compensate the differences between production and market price of biomass energy. These and many other incentives are exampled which the Thai Government has implemented in the biomass energy system to maximize their potentials. Ghana can also learn a lot from this to come out with good solution from biomass as well.

3.6 Review of Finland Biomass Energy System

Finland is one of the leading countries in the world in the production and utilization of renewable energy. Bioenergy is one of the most significant sources of renewable energy, accounting to approximately one-fifth of Finland's total energy consumption. Finland had the target to increase the share of renewable energy from 28.5% in 2005 to 38% by 2020. This is equal to 124 TWh, the increase being 37TWh during the same period. About 80% of the Finnish renewable energy comes from bioenergy. In Finland, half of the heating demand is covered by this form of energy. It is produced from forest plants, CHP plants in cities as well as in small-scale regional heating plants. In 2010, about 70% of the Finnish bioenergy was produced by the forest industry, which in Finland has developed progressive bioenergy processes based on black liquor, bark and saw dust.

Finland makes good use of its MSW generated by the utilization of the various waste treatment methods. The total recycling rate of MSW in Finland can be given as 41% as in 2015 since composting and anaerobic digestion are regarded as recycling in waste statistics (Eurostat, 2016b.). Figure 7 below shows the various types of waste treatment methods and their share in 2015.

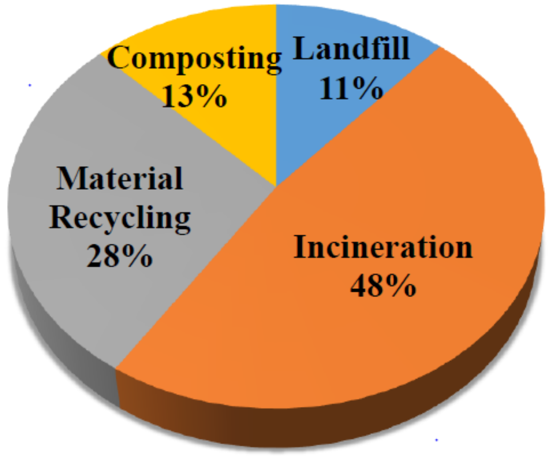


Figure 7. Share of municipal solid waste treatment methods in Finland 2015.

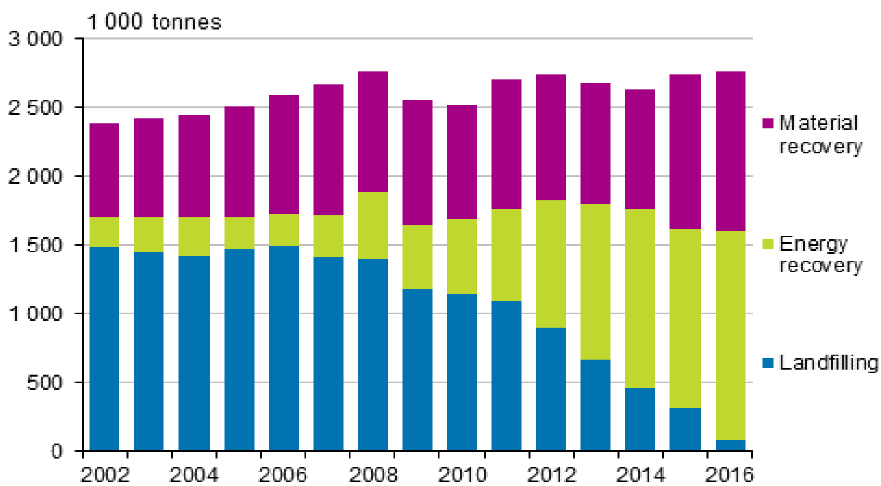


Figure 8. The amount of MSW in Finland by treatment method from 2002 to 2016. (Waste Statistics 2016, Statistics Finland)

Municipal solid waste in Finland has become a significant energy fuel for district heating production for built-up areas. Biomass energy in Finland has contributed immensely to the generation of energy in the country. Since 2010, the use of solid biomass stabilized between 320 and 350 PJ. Liquid biofuels were introduced between 2005 and 2010 up to a level of 11 PJ; from 2013 to 2014 there was a step increase of liquid biofuels to 24 PJ. (World Energy Balances, OECD/IEA 2018)

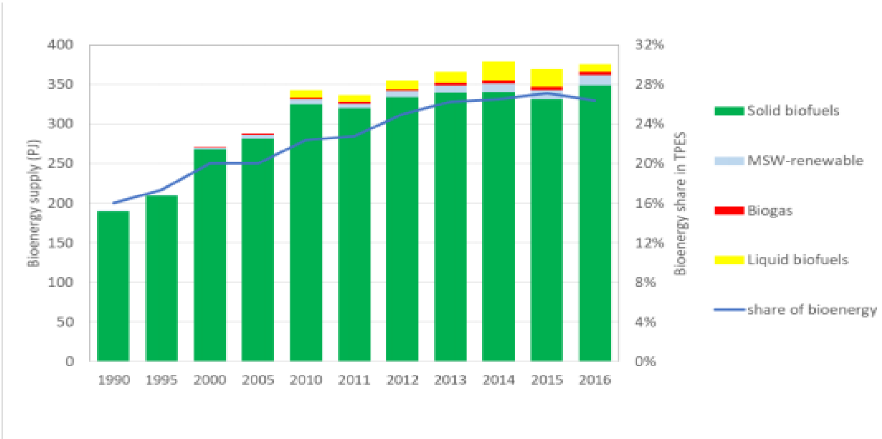


Figure 9. Development of total primary energy supply from Biomass in Finland from 1990 to 2016. (World Energy Balances, OECD/IEA 2018)

3.7 The Current Energy Profile in Ghana

Ghana currently has the population of about 30 million inhabitants with an annual population growth rate of 2.2 percent since 2016. Although the country is blessed with many natural resources yet faces serious energy crises. The country is described as a low-income developing nation in terms of economic growth and infrastructural development. The overall installed generation capacity which was available and in operation as at the ending of year 2015 was estimated to be 3,174 Megawatt with about 12 percent improvement in the following year 2016. The overall maximum installed generation capacity was estimated to be 3,737 Megawatt the year 2016 ending (Renewable Energy Situation in Ghana 2016).

With this overall total installed capacity, which was in operation in 2015 and 2016 respectively, the various installed generation power plants, such as hydro power plants, thermal-based power plants and other renewable power plants contributed to these installed capacity. (Renewable Energy Situation in Ghana, 2016)

The figures below show the contribution in percentages of the various power producing plants the year 2015 and 2016 with insignificant renewable energy contribution of approximately 0.1 and 0.2 percent respectively.

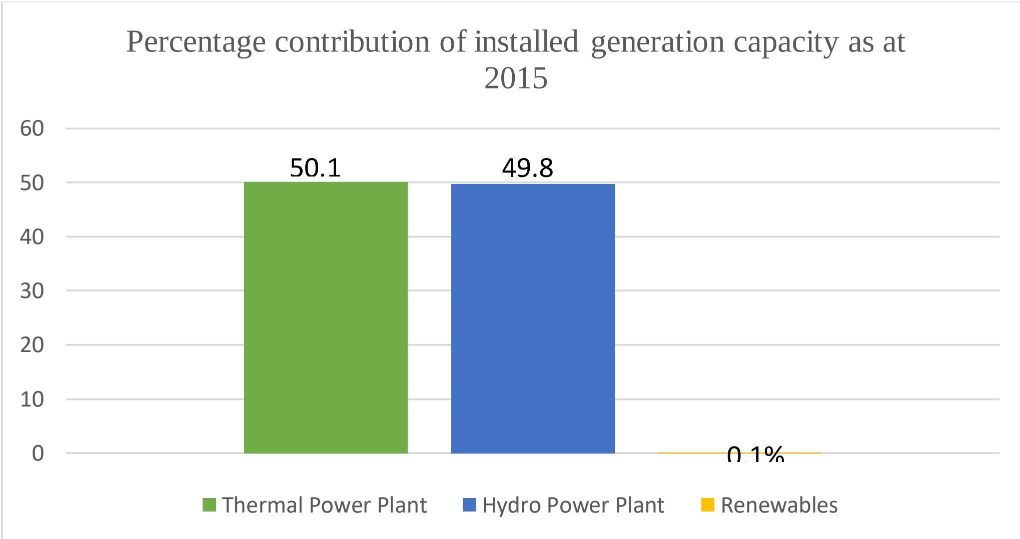


Figure 10. Percentage contribution of installed generation capacity, 2015. (Current Renewable Energy Situation in Ghana 2017)

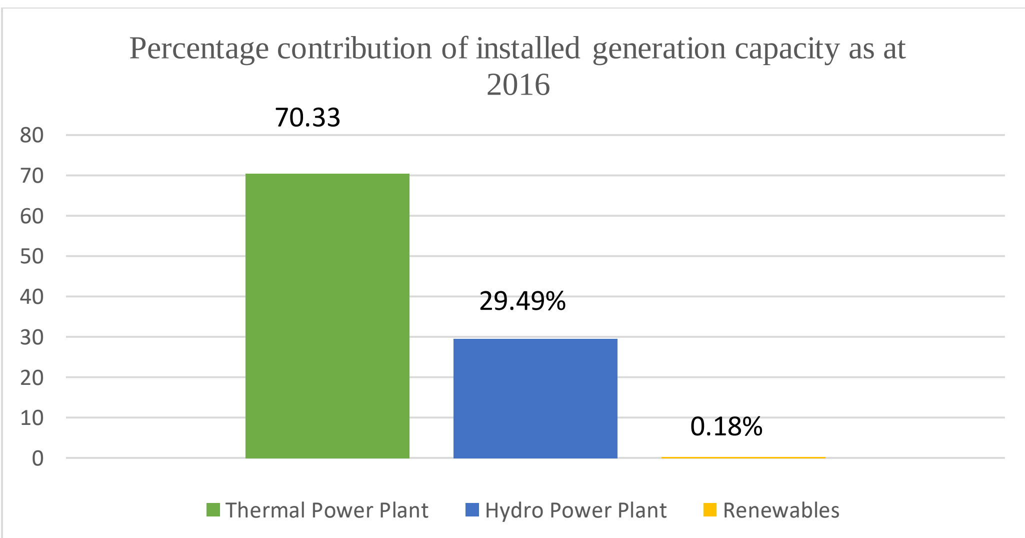


Figure 11. Percentage contribution of installed generation capacity in 2017. (Current Renewable Energy Situation in Ghana 2017)

3.8 Biomass Potential Resource

Biomass resource are all forms of organic materials, including plant matter both living and in waste form, as well as animal matter and their waste products. Different types of bio-waste or feedstock can be utilized for the generation of bioenergy. An appropriate choice of technology for a specific biomass project can sorely depend on the type of bio-waste used, its availability, effective suppliers and desirable quantity to be delivered to the plant site. The sources of biomass for energy production can be obtained from different sources includes:

- Forestry residues
- Municipal solid waste (MSW)
- Sewage
- Agricultural residues such as Stover, cane trash, green agriculture waste and others
- Agro- industrial waste
- Waste from wood industries
- Animal waste
- Food processing waste (bio-waste)

The three main classification of biomass energy are described in table 2 below:

Table 2. Classification of biomass for energy. (Global biomass potential Report 2016)

Main Sector	Sub sector	Examples
Agriculture	Dedicated crops – main products	Crops for biofuels (corn, sugarcane, rapeseed, oilpalm, jatropha, sorghum, cassava etc), energy grasses (miscanthus, switch grass), short rotation forests, other dedicated crops for energy
	By – products and residues	Herbaceous by – products: straw from cereals, rice, corn, bagasse, empty fruit bunch from oil palm, prunings from stover, empty corn cobs etc.
		Woody biomass, regeneration orchards, vineyards, olive and oil palm plantains
		Other forms: processing residues such as kernels, sunflower shells, rice husks, animal manure
Forestry	Main product	Stems, wood fuel from forests or trees outside forests, woody biomass from landscape cleaning
	By – Product and residues	Residues of forest harvest (branches, tops, stumps), residues of wood industry (bark, sawdust, other wood pieces, black liquor, tail oil, recycled wood)
Organic waste		Municipal solid waste (MSW), food waste from stores, restaurants and households, used kitchen oil, waste from the food industries (from dairy, sugar, beer, wine, fruit juice industry, from slaughter-houses), sewage sludge.

3.8.1 Biomass Classifications

Due to the considerable variations in terms of selection and amount of biomass, and their completely different integrative characteristics, there is no conclusive method for classifying biomass. They are sorted on purpose and scope according to origin, operation and final product. Usually biomass is grouped into two categories;

1. Biomass existing in nature (according to ecology or form of vegetation)
2. The utilization and application of biomass as feedstock

In spite of these two main categories of biomass classifications, there are other general forms of classifying biomass into different groups namely:

- ❖ Wood and woody biomass
- ❖ Herbaceous biomass
- ❖ Aquatic biomass
- ❖ Animal and human waste biomass
- ❖ Biomass mixtures

  (Biofuels Research Journal, 2019)

3.8.2 Wood and woody biomass

Generally, the woody biomass consists of carbohydrates and lignin which could be in a form of trees and roots residues, bark and leaves of shrubs. These types of biomass are mostly converted into useful energy by direct combustion or gasification. (Biofuel Research Journal, 2019) Currently, woody biomass is considered to be one of the sustainable source of renewable energy worldwide. The utilization of woody biomass across the globe in 2010 resulted in energy production close to 30 EJ whiles about 16 EJ was attributed to domestic fuelwood and 14 EJ to industrial biomass. (Lauri et al., 2014)

3.8.3 Herbaceous biomass

Herbaceous biomass generally consists of two main groups; they are, energy crops and agricultural residues.

Agricultural residues can be term as waste product from food industries, manure from livestock, crop residues and fibres. Energy crops such as maize, white sweet, millet, sudan grass and many others are in many cases purposely cultivated for energy production.

3.8.4 Aquatic biomass

In reality, it is considered that, about fifty five thousand species and over one hundred thousand strains of brackish water, freshwater, and terrestrial water contain protectant organisms. The major advantage of the exploitation of these key organisms is their ability to convert daylight, water, and carbonic acid into a wide form of metabolites and chemicals which can result into a protectant (algae) biomass (Horan, 2018). Aquatic biomass is currently considered as a perfect staple for the production of third-generation biodiesel, because it is not in competition with food crops besides the advantage of manufacturing significantly larger amounts of biomass per area unit compared to land crops. However, there are still considerable economic and technological challenges to be overcome before such biofuels can be effectively commercialized. Moreover, it must be noted that there are numerous factors influencing the acts of aquatic biomass like levels of irradiation, carbonic acid gas and O_2 concentrations, temperature, pH, salinity, and nutrients (Mckendry, 2001).

3.8.5 Animal and human waste biomass

Animal and human waste biomass are commonly sourced from meat meal, bones, all kinds of animal manures and human metabolic wastes. In recent decades, animal and human waste biomass are retrieved and processed as fertilizers for agricultural purposes. But due to civilization and introduction of environmental regulations on pollution, health implications and odour control, has resulted in abolishing of these method of fertilizer applications for agricultural purposes. One key and suitable technological method of converting this waste into useful product is through anaerobic digestion. For example, biogas produced from this biomass conventional technology could be used to produce electricity in turbines and internal combustion engines and many other applications (Horan, 2018).

3.8.6 Biomass Mixture

Biomass mixtures occur when different substrates from other types of biomass as mentioned above are mixed together. Biomass comes with challenges which attributed to it as fuel for commercial power production irrespective of the type of biomass feedstock been used. This challenges can be associated with them (Horan, 2018).

Table 3 below shows the biomass classifications as already discussed above.

Biomass classification: groups, varieties, and species.

Table 3. Biomass Classifications. (Biofuel Research Journal, 2019).

Biomass group	Varieties and species
Wood and woody biomass	Coniferous or deciduous; Angiospermous or gymnospermous; Stems, branches, foliage, bark, chips, lumps, pellets, briquettes, sawdust, sawmill and others from various wood species.
Herbaceous biomass	Grasses and flowers (alfalfa, arundo, bamboo, bana, brassica, cane, cynara, miscanthus, switchgrass, timothy, others); straws (barley, bean, flax, corn, mint, oat, rice, rye, sesame, sunflower, wheat, others); other residues (fruits, shells, husks, hulls, pits, pips, grains, seeds, coir, stalks, cobs, kernels, bagasse, food, fodder, pulps, cakes, etc
Aquatic biomass	Marine or freshwater algae, macro algae (blue, green, blue-green, brown, red) or microalgae; seaweed, kelp, lake weed, water hyacinth, etc.
Animal and human waste biomass	Bones, meat-bone meal; various manures, etc.

3.9 Biomass Characteristics

The characteristics of biomass are important factors to consider because they have great influences on a particular choice of energy conversion method as well as their associated difficulties that may arise. The sources of biomass could also be affected by the form or state of energy in which it is required to be converted irrespective of the type of choice of the energy conversion method or the state of energy to be converted. The following biomass characteristics become very critical in the process of biomass conversion into useful energy. These characteristics are as follows:

- Moisture content
- Calorific value
- Properties of fixed carbon volatile matter
- Ash/Residue content
- Alkali metal content

- Cellulose/ lignin ratio
- Carbohydrate content
- Liquid / fat content
- Protein content
- pH content

  (Mckendry, 2001).

3.9.1 Moisture content

The moisture content can be categorized into two main forms as follows;

- Intrinsic Content: This type of moisture content of biomass is not influenced by the effects of the weather.
- Extrinsic Content: Contrary to the intrinsic moisture, this type of moisture has direct influence of prevailing weather conditions most especially the harvesting season of biomass (Mckendry, 2001).

Table 4 below illustrates a typical intrinsic moisture content of a range of biomass materials.

Table 4 . Proximate Evaluation of selected Biomass feedstocks. (Mckendry, 2001).

Biomass	Moisture (%)	VM (%)	FC (%)	Ash (%)	LHV (mJ/kg)
Wood	20	82	17	1	18.6
Wheat Straw	16	59	21	4	17.3
Barley Straw	30	46	18	6	16.1
Lignite	34	29	31	6	26.6
Bituminous coal	11	35	45	9	34

3.9.2 Calorific Value

The calorific value of biomass is described as the energy content or value of heat discharged when burnt in the presence of oxygen. The unit of CV is energy content per unit mass or volume. This implies that, CV for solids are in a unit of MJ/kg and MJ/L for liquids or MJ/Nm^3 for gases. Calorific value of biomass can also be put into two forms, which are commonly known as higher heating value (HHV) and lower heating value (LHV).

The HHV is the total amount of energy discharged when the biomass fuel is burnt in the atmosphere, which comprises of the latent heat accommodated in the water vapour and thereby expresses the ultimate energy content possibly restorable from a given source of biomass. Technically, the latent heat contained in water vapour cannot be utilized effectively hence, the LHV is the convenient value of energy to be utilized in most cases and energy available for sub sequential use (Mckendry, 2001).

3.9.3 Proportion of fixed carbons and volatile matter

Evaluation of fuel properties from biomass has been established based on solid fuels from biomass such as coal, which contains chemical energy in a form of fixed carbons and volatiles. The volatile content (volatile matter) is that section of a solid fuel which is usually taken off with its description as gas including moisture. The fixed carbon content (FC) is termed as the portion of mass that remains after the discharge of volatiles with the exception of ash and moisture contents.

Experimental analysis are commonly used to dispose the VM and FC contents of the biomass fuel. The test on fuel properties established on volatile matter content, ash and moisture with the FC resolved by variation is described as the proximate analysis of some selected biomass, with a given values of lignite and coal as a reference. (Biofuel Research Journals, 2019) Properties of some biomass materials are given in table 5 as shown below:

Table 5. Properties of selected biomass materials. [a] Dry basis, unless stated otherwise. (Mckendry, 2001).

						Alkali metal content (as

Material	Moisture content (%H_2O)	HHV[a] (MJ/kg)	FC content (%)	VM content (%)	Ash content (%)	Na and K oxides) (%)
Fir	6.5	21	17.2	82.0	0.8	-
Danish pine	8.0	21.2	19.0	71.6	1.6	4.8
Willow	60	20.0	-	-	1.6	15.8
Poplar	45	18.5	-	-	2.1	16
Cereal straw	6	17.3	10.7	79.0	4.3	11.8
Miscanthus	11.5	18.5	15.9	66.8	2.8	-
Bagasse	45-50	19.4	-	-	3.5	4.4
Switchgrass	13-15	17.4	-	-	4.5	14
Bituminous coal	8-12	26-2	57	35	8	-

3.9.4 Ash/ Residue Content

The chemical disintegration of biomass by thermo-chemical or biochemical processes produces a residue in a form of ash. This is commonly known as ash/residue content of the biomass fuel, and it is usually produced by direct combustion air. Biomass ash content has a great influence on both the treatment and the expenses during processing of the total biomass and the expenses on biomass conventional technologies. In the course of biochemical convention, the share of solid residue will be more than the formation of the ash content during the process of combustion of the comparable material. (Mckendry, 2001)

3.9.5 Alkali metal content

Biomass fuel with alkali metal content such as Sodium, Magnesium, Phosphorus, Potassium and Calcium is very important for the processes of thermo-chemical conversion. The counteraction of alkali metal with silica given in the ash results in the formation of a sticky, mobile liquid state, which can pilot to hindrances of airways in the furnace and boiler plant. (Mckendry, 2001)

3.9.6 Cellulose/lignin ratio

Cellulose and lignin percentages contained in biomass are very critical when biochemical conversion processes are used. The rate of cellulose breakdown is more rapid than that of lignin, so the total conversion of the carbon-containing plant material taken as cellulose exceeds plants with greater percentage of lignin. (Mckendry, 2001) The table below shows a cellulose/hemicellulose for soft woods and hard woods, with a comparability of wheat straw and switch grass. Table 6 gives a cellulose/lignin content of few selected biomass.

Table 6. Cellulose/lignin content of selected biomass. (Mckendry, 2001)

Biomass	Lignin (%)	Cellulose (%)	Hemicellulose (%)
Softwood	27-30	35-40	25-30
Hardwood	20-25	45-50	20-25
Wheat straw	15-20	33-40	20-25
Switchgrass	5-20	30-50	10-40

4 ENERGY CONVERSION METHODS OF BIOMASS

4.1 Types of Biomass Energy Conversion Technologies.

Various technologies can be considered when it comes to the utilization of biomass resources into power, heat and other types of fuels across the globe. Many of these technologies for converting biomass resource into bioenergy are commercial today while others are considered as non-commercial or still in research and development.

The processing technologies for converting biomass into useful energy can be group into two main types:

- Thermochemical process
- Biochemical process.

The thermodynamic process can be briefly described as the dry process conversion, which includes combustion, gasification, pyrolysis and torrefaction.

Biochemical process can be referred as a wet process which include anaerobic digestion (methane fermentation), alcohol fermentation and production of bio-hydrogen. The two main types of conversion technology under biochemical process are fermentation and anaerobic digestion.

Bioenergy in general consist of solid, liquid, or gaseous fuels. Liquid fuels can be directly used in the road transportation and aviation transportation network, as well as in engines, turbines and electrical power generators. Solid and gaseous fuels can also be used for the production of electrical power specifically for running either a direct or indirect turbine-equipped power plants. This chapter describes the various types of technologies which are used for the conversion of biomass into bioenergy. The table below also illustrates the overview of the energy conversion process of biomass using the various technologies. (Basu, 2010)

4.2 Combustion

The combustion process is one of the oldest and the traditional methods of converting biomass resources into energy. In the combustion process, oxygen reacts with carbons chemically to produce carbon dioxide, water and heat as by-product.

Effective and efficient combustion process can be achieved by constant feeding of wood wastes and other bio- wastes resources with low a moisture content during the process.

During the process of combustion, raw materials (burnt biomass resources) reverts with oxygen at a very high temperature of about 800 degree Celsius in the combustion reactor.

One of the key points to understand in the process of solid fuel combustion process is that, only fuel gases burn and release heat energy, that liquid and the solid do not burn by themselves, but actually consume heat in the drying and the gasification stage, which is needed for them to be chemically converted into useful fuel gases. The main fuel intermediate are the volatile hydrocarbons and energy rich organic molecules, carbon monoxide (CO) and the hydrogen (H_2) as figure 12 below describes the process. (Basu, 2010).

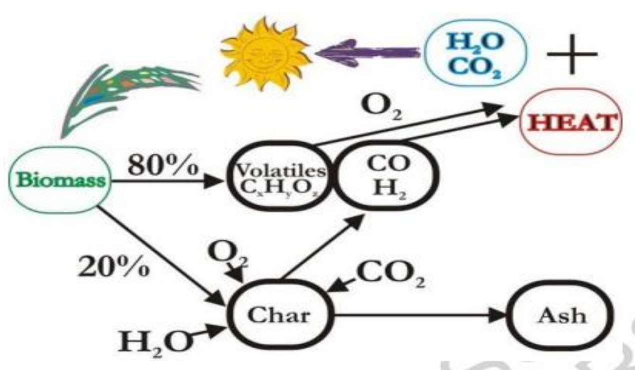


Figure 12. Biomass combustion and carbon cycle closed loop diagram

4.3 Gasification

Gasification can be described as a thermochemical process in which the production of syngas is achieved by the effective utilization of biomass as a main feedstock.

Biomass gasification process consists of many other processes such as drying of biomass, pyrolysis, oxidation and the stage of reduction or a reduction step. During the process of pyrolysis, breaking down of large hydrocarbons molecules into smaller molecules occurs in the absence of oxygen. Relatively high volatile compounds of biomass are produced as a result of this process to be isolated from the pyrolysis chamber. In the gasification process, the most common feedstock used are wood, bark, sawdust, energy crops and other wood-based raw material. (Micre, 2011)

4.3.1 Types of Gasifies

Gasification process can be classified into three main types according to the types of gasifiers used for the process. These are as follows:

- ❖ Updraught or counter current gasifier
- ❖ Downdraught or co- current gasifier
- ❖ Cross-draught gasifier

4.3.2 Updraught/counter-current gasifier is the oldest and the simplest type of gasifiers as shown in the diagram 8 below.

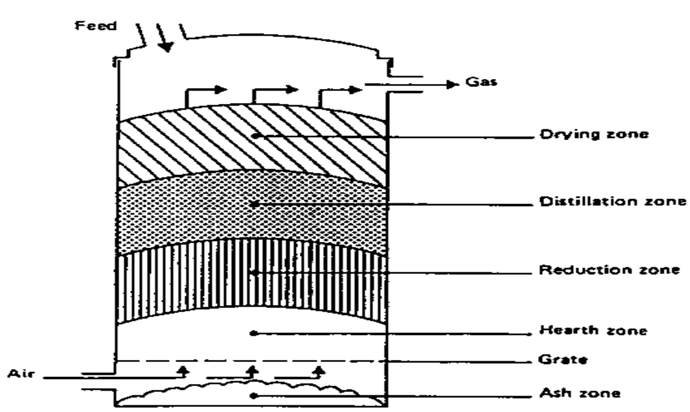


Figure 13. Up draught/co-current gasifier (Micre, 2001)

In this type of gasifier, the air intake is at the bottom and the gas exits is located at the top. Combustion reactions occurs near the grate at the bottom which are followed by a reduction reaction somewhat higher up in the gasifier. The tars and volatiles produced during the process will be carried in the gas stream. The major merits of this type of gasifiers are its simplicity, high charcoal burn-out and internal heat exchange leading to low gas exit temperature and high equipment efficiency. Some major demerits of this type results from the possibility of explosive situation and the necessity to install automatic moving grates as well as from the problem associated with disposal of the tar- containing condensates that results from the gas cleaning operations.

4.3.3 Downdraught/co-current gasifiers are perfect solution to the problem of tar formation in the gas stream. I these the primary gasification of air is introduced at or above the oxidation zone in the gasifier. The produced gas is removed at the bottom of the apparatus, in order for gas and fuel to flow in the same direction, as shown in the figure 14 below.

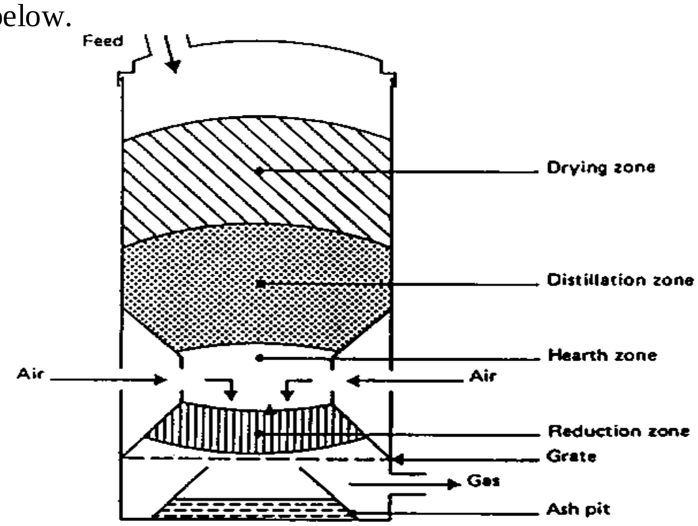


Figure 14. Downdraught/co-current gasifier. (Micre, 2011)

The main advantage of this type is that if gasifier lies in the possibility of producing a tar-free gas suitable for engine applications. A major drawback of this equipment lies in its inability to operate on a number of unprocessed fuels. In specifically, fluffy, low density materials give rise to flow complications or challenges and excessive pressure drop, since the objective requirement of the operation is that, the solid fuel have to be pelletized before used. Another drawback of this type as compared to updraught gasifier is its low efficiency resulting from the lack of internal heat exchange as well as low heating value of the gas.

4.3.4 Cross- draught gasifier

Cross-draught gasifier has an adaptation for the use of charcoal. Charcoal gasification results in a very high temperature, 1500 degrees Celsius and above in the oxidation zone which can lead to material problems. In cross draught gasifiers, insulation against these high temperatures is provided by the fuel (charcoal) itself.

The advantages of this type depends on a very small scale at which it is designed to be operated. An installation below 10 KW (as shaft power) can be economically feasible under some conditions.

The disadvantages of cross-draught gasifiers is their lower tar-converting capabilities and the consequent need for high quality charcoal. Below is the diagram of a cross-draught gasifier in figure 15.

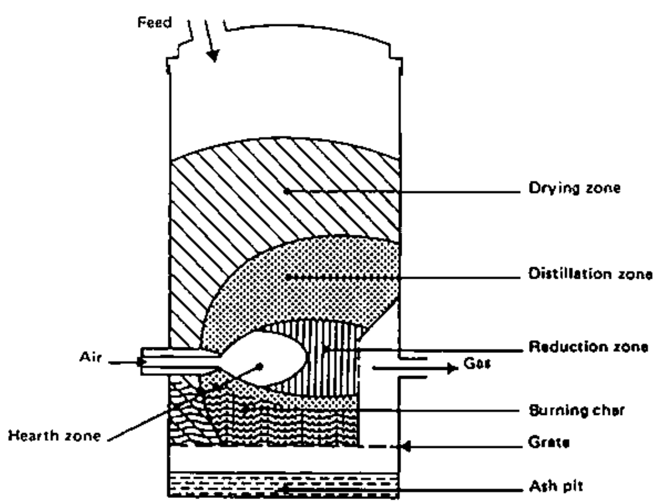


Figure 15. Cross-draught gasifier. (Micre, 2011)

4.4 Pyrolysis

Large molecules of hydrocarbons breaks down into very small molecules in the pyrolysis process. Drying and milling are the basic or the initial stages in the pyrolysis process. In the stage of milling, raw materials (biomass resources or organic feedstock) are retained in the pyrolysis chamber at a relatively high temperature. This process is normally piloted under very low concentration of oxygen with the temperature range between 300 -1100 degrees Celsius. When organic feedstock is used as raw material in the process of pyrolysis, production of bio-oil, Syngas and biochar are obtained as by-products.

Pyrolysis can be divided into two main types which are:

- Slow pyrolysis
- Fast pyrolysis

In the slow pyrolysis, biomass is heated slowly to the pyrolysis temperature of 400-800 degrees Celsius with a long residence time. The slow pyrolysis produces more tar and charcoal and less gases. The purpose of the fast pyrolysis is to maximize the yield of liquid or gases. In the process of fast pyrolysis, biomass is heated rapidly to the adequate temperature (650 degrees Celsius), and held there only for a few seconds or even less than a second. Considerable pyrolysis gases can be condensed into bio-oil, which can be utilized for vehicles or in CHP- units. Figure 16 below illustrates pyrolysis plant technology. (Basu, 2010)

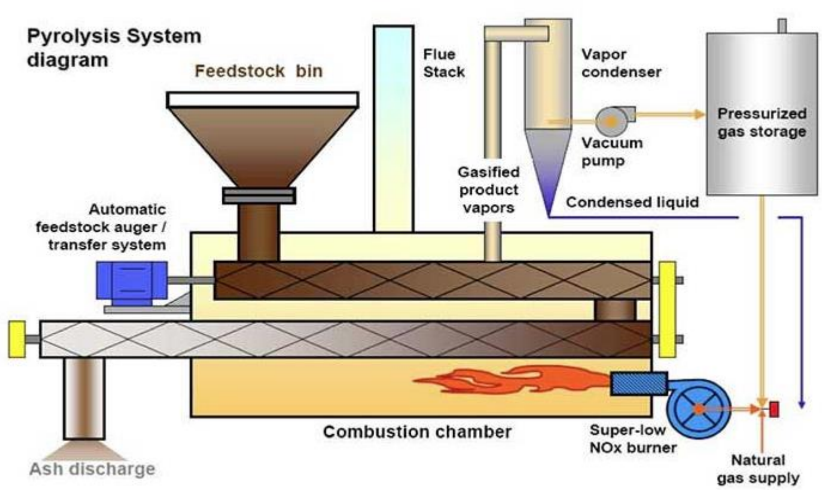


Figure 16. Pyrolysis Plant installation technology

4.5 Torrefaction

The torrefaction process and pyrolysis have common properties since both methods involve a thermal process to convert biomass into useful energy. Torre faction involves the heating of biomass in the absence of oxygen to a temperature of about 200-400 degrees Celsius. The structure of the biomass varies in such a manner that the material becomes so brittle and more hydrophobic. The degree in weight is about 30% and the energy loss is 10%. A combustible gas is produced during the Torre faction process, which is the utilized to produce heat energy to provide heat for the process.

More gas is reguired in the increasing moisture content in order to achieve auto-thermal operation and also as an outcome of the degree to which the torre faction will increase. (Basu, 2010)

4.6 Anaerobic Digestion

Anaerobic digestion (AD) can also be described as one of the oldest technologies of converting waste organic matters into useful energy. This technology comprises the process of decomposition and decay, whereby organic matters breaks down into the smallest and simplest chemical compounds without the presence of oxygen to produce methane and carbon dioxide. There is a relatively small amount of hydrogen sulphide and ammonia with a little trace amount of other gases contained in the biogas produced from AD technology. Usually biogas produced by AD needs to be upgraded because of compounds and other impurities that it contains which can cause destruction to engines or boilers.

Anaerobic digestion can be categorized into four main processes pre-treatment, digestion, and gas upgrading and digestion treatment. The degree of pre-treatment depends on the type of feedstock used as raw material for the process. For example, when MSW is used as feedstock, if first needs to be carefully sorted and tattered while for instance when manures are used as feedstock, it only needs to be mashed up for the process to be initiated. The schematic diagram below illustrates atypical general process of a co-digestion plant of AD technology. (Basu, 2010)

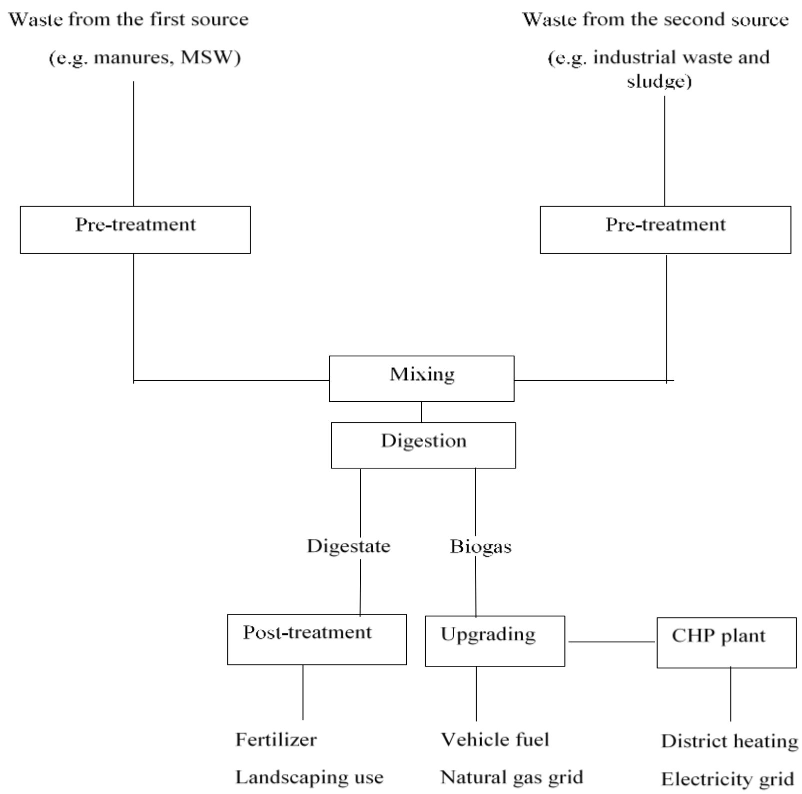


Figure 17. General process for an AD codigestion Plant. (Amranand 2008).

4.7 Alcohol fermentation.

Biomass can also be transformed into useful energy in a form of ethyl alcohol or ethanol fuel through the process of alcohol fermentation. In the fermentation process, carbohydrates are broken down into smaller compounds in order to produce ethyl alcohol. It is an anaerobic enzymatic transformation of these organic compounds (carbohydrates) into simple forms. Biomass fermentation is similar to the process of alcohol brewing industries. When the ethyl alcohol is obtained from the biomass resources, it then undergoes another process known as yeast fermentation for the ethyl alcohol to be converted into ethanol fuel. Ethanol fuel is a type of biofuel, which can be used as direct and sustainable energy source. (Basu, 2010)

Below is a line diagram of fermentation plant illustrating the various stages of production indicated as figure 18.

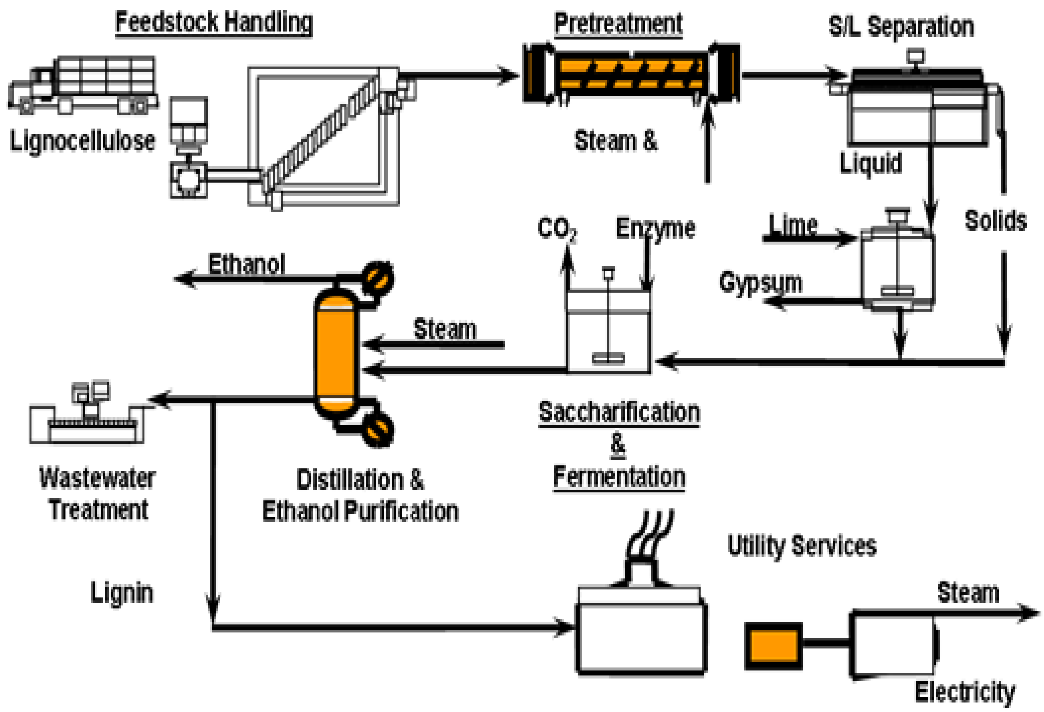


Figure 18. Fermentation plant installation technology

5 THEORETICAL MODEL

This section describes the model used to address the potential of biomass energy in Ghana. The model uses the PESTEL analysis to explore the potential of biomass and factors to consider when developing biomass in Ghana.

Biomass energy generation has become one of the essential RES, which the world cannot cope without, due to its numerous positive impacts, it has contributed to energy mix globally. However, biomass to any useful energy form can be influenced by some key factors, which needs to be addressed. These factors aid in the planning phases of a successful biomass plants as well as appropriate technologies to be applied. Recognition of these factors also helps to address some issues, which may oppose the success of energy generation from biomass. Below is the detailed discussion of these key factors.

5.1 Political Factors

The success of every important project in any country relies on how politically sound and stable the country is. Projects that require the involvement of foreign traders are also stimulated through policies in support of the project in the structure of incentives and even conducive surroundings to allow the smooth establishment and strolling of the project facility. Biomass energy initiatives are very sensitive tasks which have vast impacts on a country's energy sector. Hence, they thrive on government policies in order to be feasible. The feasibility of biomass energy project in any country is relative to the shape of the availability of all the biomass residues needed for efficient energy generation and the government's willingness to create opportunities and provides enough support for biomass energy initiatives. The government incentives and other insurance policies in biomass initiatives will serve as a motivation to investors. Biomass energy initiatives are of greater benefits in countries where there is enough support from the government.

Biomass energy tasks are also viable when the energy sector of the nation is well structured and the customers for the energy to be generated is clearly defined. The energy can be sold to a single customer for consumption or resale. The purchaser might also be a utility distributor with a present distribution of power to the community for district heating or cooling. Government policies in the power sector distinctly influence the success of the project. This is because the energy sector is commonly owned by the state (public) in several countries. These insurance policies outline the feed-in-tariff for power producers. (Otoo, 2017)

5.2 Economic Factors

Biomass plant in general requires high funding expenses with a large share of foreign exchange and high operational and maintenance costs. For these reasons, general treatment price for other biomass residues to energy is excessive compared to the stock exchange on the foreign market on daily bases. Biomass feedstock for example, municipal solid waste can be financed with tipping fees, extensively wide-spread levies and public subsides, income of the power produced and residues from burnt waste when treated. Considerations have to be made on the capability and willingness of the public to pay tipping charges to avoid the occurrence of uncontrolled dumping or burning of waste. In making sure of the existence of biomass plant, there should be a 20 to 25 years' stability sketch with relatively constant or predictable prices for consumables, spare parts, residue disposal and sale of energy. In addition, tipping costs should be lower than the costs charged at landfills to impact the ability and willingness to pay. Consistency in the other source of waste circulation from biomass is also relevant in figuring out the internet therapy fee over a longer period.

Investment cost for biomass plant depends on a huge range of factors. The dimension of the plant (the variety of metric tons of biomass feedstock per day or year) and the lower calorific fee of these feedstock are some essential factors. Low capacity plants are more expensive than high capacity plants in phases of investment cost per metric ton capacity. Moreover, the investment value is based on the kind of power production, either a simple cooling of all excess warmness or a mixed heat and energy production.

A stable demand for energy can be necessary in some instances to secure the plant financing, and energy income settlement with distributors. (Maiza et al.2015)

Public subsidies from authorities or donor businesses can decrease the user's tariff burden. Subsidies may consist of grant financing, beneficial term loans for plant facilities, or wide spread tax levies. Subsidies can be financed from the budget or linked to environmental taxes. (Otoo, 2017)

5.3 Environmental Factors

Biomass energy technology is an excellent and reliable way to defend the environment with the aid of correctly converting stable biomass residues especially MSW, agricultural residues and other forms of biomass feedstock into any form of energy, hence, making it safe to human health after going through the process. The energy techniques need to be cautiously monitored to make sure that there are no environmental related issues. These worries are regularly associated with flue gases from combustion launched into the environment. However, flue gas treatment of incineration plants has shortly developed over these few years with improved requirements from the global environmental law bodies. To ensure that biomass plant services do not have any poor impact on the environment, an Environmental Impact Assessment (EIA) is needed for such an important project. This assessment points out the negative components of the venture with regard to the area and the mitigation plan for these concerns. The EIA helps to investigate troubles related to noise, odour, chemical usage, waste water discharge and emissions. The public is allowed to take part in these methods through expressing their sentiment with regard to the project. The EIA approaches and rules differs from country to country: however, they have similar goals around the globe. (Asase et al. 2009)

5.4 Legal Factors

Biomass technologies can be carried out with the support and directive of a felony framework. Legislations need to entail series of ordinances and regulations designed to manage and control how effective biomass residues can be preserved for effective utilization of energy without any negative health implications. There are common legislations, such as landfill directive, waste framework directive, waste incineration directive, measures for organic cure and landfill ban on organic waste. There are frequently additional guidelines on which technology is to be implemented under the Best Available Technology (BAT) framework. This stipulates that the technological know-how must be efficient, and prices related to it have to be sensible to performance. (George et al. 2015)

5.5 Geographical Location of the Facility

The geographical area of a biomass facility is very important in order to minimize worries on fitness and environmental risks. The place must usually be carefully chosen with consideration to both monetary and environmental issues. The environmental impact should also be assessed. A well-constructed and managed biomass plant will have a comparable environmental impact, plausible public nuisance, transport networks and other infrastructure desires as a medium to heavy industry. For this reason, the place of the plant should be at land-use zones devoted to medium or heavy industry. It must be positioned close to the appropriate energy buyers and additionally to the source of biomass feedstock to prevent vans from travelling long distances to the facility to deliver the biomass feedstock.

Air quality and noise are conditions that need to be properly controlled. Hence, it is necessary to site the biomass facility at an open place where there will not be any challenges to such situations. (Dinar et al. 2008)

5.6 Summary of Pestel Classification of Factors of Biomass and Implications

The pestel classification of factors of biomass and their implications on biomass energy in Ghana is summarized in Table 7.

Table 7. Pestle classifications and impacts of biomass in Ghana

Political Factors		
Factors	Description	Impacts on biomass
Government stability	Strong and good government that can keep it power and have a fair and democratic control over the nation without any external influence.	Stable government provides certainty for potential investment in the biomass sector.
Local government plan	Good policies for future development of local areas	Good policies (policy development plans) in energy sector helps in the development and strengthen of biomass energy system. Ghana has renewable energy sector plans as policy development to address renewable energy sector and provides an investment-focused framework for the next 10 years.
Influence on politicians	Behavior and character of leaders on specific issues	Implementation of good strategic measures to solve problems related to biomass energy generation motivates more investors into biomass energy generation.
Economic factors		
Availability of funds	Financial assistance available for biomass projects or other initiatives	Adequate financial assets and incentives provides certainty for individuals and other potential investors in the biomass sector. Ghana's Renewable Energy Master Plan in 2019 has a total investment of USD 5.6 billion. The plan shall be implemented in a 12-year time-space from 2020-2030. This has positive impact on biomass energy.
Interest and tax	Application of interest and tax on goods and services.	Low interest rate and reasonable taxation on goods and services attracts more foreign investors to endow in biomass energy generation. Although interest rate and taxes are considerably higher in Ghana but according to the report on Renewable Energy Master Plan in 2019, which states that Government will implement a substantial tax reduction on renewable energy initiatives.
Potential income from biomass energy	Monetary benefits from biomass energy	Monetary benefits from biomass energy provides positive impact on social-economic development through job creations and stability of Ghana's energy sector.
Legal factors		

National/International directives	Guidelines for environmental protection and instructions issued by national/international organizations on energy securities	Provisions of effective guidelines on environmental protection issues gives more education and certainty on biomass energy. Ghana has effective regulatory bodies/agencies for directive measures and implementations on the energy sector. For instance, Ghana Standard Authority for developing standards for renewable energy technologies and biofuels in Ghana.
Local Policy	Policies that set guidelines to determine and check actions	Good example of such policies are the Renewable Energy Master Plan in 2019.This will help check actions and strengthens renewable energy in the next decade.
Environmental factors		
Environmental guidelines	Local guidelines that set specific environmental standard.	Environmental guidelines on RES such as biomass also aid in knowing the best technologies for biomass energy. According to the report on Ghana's Renewable Energy Master Plan, it will strengthen the Ghana Standard Authority to ensure that local production of renewable energy technologies to meet national or international standards.
Local weather conditions	Local weather conditions at a specific place and time	Bad weather conditions may have negative influence on biomass energy in some cases. Most local weather conditions in Ghana could be considered favorable for biomass energy. For example, good weather for planting of special plants purposely for biomass energy.
Technological factors		
Skilled workers	Expertise with good knowledge and technical know-how and ability to perform best	Availability of good expertise with potential knowledge on biomass energy is of the factors that helps every country to develop faster in biomass energy system. Lack of skilled workers/ expertise is one of the major challenges that affects biomass generation in Ghana.
Applications of appropriate technologies for biomass energy	Application of technology that is best design for efficient operation.	The right choice of technology for biomass energy helps attained effective results in the operation. Difficulties in technology applications for utilization of various biomass resources in Ghana is also a major factor.

6 RESEARCH METHODOLOGY

6.1 The research structure and the data collection techniques are further explained in this chapter.

This thesis is based on secondary data collection from open sources as already mentioned in the previous chapter and exploratory research with the main intention of determining how biomass can serve well as an alternative energy source in Ghana. Data collection for this study will also help to analyze the trend of waste generation and its composition currently in Ghana. The thesis provides some basic ideas or level of information on biomass energy potentials for power generation, and further feasibility study of biomass energy in the near future in Ghana.

6.2 Design of Research

All information gathered and other relevant materials which are used for this thesis research, are retrieved from previous studies done by other people on similar topics. Other sensitive information has been obtained from the official website of the Ministry of Energy in Ghana, Energy commission of Ghana, Ministry of Food and Agriculture of Ghana, (MoFA) and other energy agencies relating to biomass energy generation. The research data strategy was basically secondary data and other open source. Some data were quite old while others are currently sourced. The trends were similar with just mere variation at some instances. This is the fact that there has been some increment in population which will eventually affect the generation of other biomass resources such as municipal waste generation and other biomass production comparing the figures of both the old and the recent data which makes this variation visible. The evaluation of these data was done to analyze the energy values and the total energy potentials per ton of biomass residues to be utilized to energy with appropriate biomass energy technology.

6.3 Data Collection Method

General information and other basic data for this study was gathered by literature review, assessment and analyses of other studies relating to this topic research. The evaluation and estimation of data were established in some instances from the previous studies to come out with best results due to lack of data and difficulties of data research in some cases. Since the integrity and the quality of data collection is very crucial as well as its credibility when it comes to data collection method, careful analyses and observation were done on every data obtained for this research studies in order to deliver the best outcome in this studies

6.4 Research Quality

The credibility of research can be described through the extent in which the statistics collection techniques and analysis methods will yield steady findings. The four major threats to obtain quality and reliability are participant error, participant bias, observe error and observant bias. Most of the research done for this study are based on the various articles and other literature materials from previous studies on similar research topic. Most of the authors have had privileges to have personal interactions with people and other staffs in the related field of studies in this topic and their responses have been based totally on documentation that carefully prepared to give precise and good results during the survey and data collection procedures. These open sources, where most of the sensitive information and other empirical analyses have been gathered with appropriate citation and analysis given to them in this research work.

7 EMPIRICAL ANALYSIS

Solutions to the research questions in this thesis are discussed with detailed analysis of other findings which helps with better understandings of these solutions to the research questions as presented in this chapter.

Research question 1: **What is the energy potential from biomass resource in Ghana?**

Various energy potentials of biomass residues are analyzed and estimated in this section. This aid in identifying the estimated amount of energy potential from these biomass residues hence providing realistic answer to this research question.

Due to lack of data on MSW in Ghana, an estimation is made from the review of the previous literature survey that the rate of Municipal solid Waste generation in Ghana was 0.47 kg/person/day which transforms into 14105 tons of waste per day per the current population of 30,011,304 as in May 17, 2019. Since the organic content in MSW is very high, this offers a great potential for waste-to- energy industries for it to be utilized into useful energy. MSW to energy is much more effective when anaerobic digestion technology is applied. It is very necessary for this biomass residues to be sorted and separated **before it can be used.**

7.1 Data Analysis and Potential Feedstock for Biomass Energy Technologies in Ghana

Moreover, the varieties of agriculture crops, such sweat sorghum, yam, cassava, potatoes, sugar cane, cowpea, maize and many others in Ghana also offer great potentials for the production of ethanol. Manure (animal waste) from agricultural livestock, other cash crops and forest residues as well as a large amount of various industrial waste are in abundance in Ghana, which can serve as biomass resources for energy production through anaerobic digestion.

7.2 Biomass energy potential from Anaerobic Digestion.

There are many factors which need to be recognized and taken into account when it comes to biomass potentials into useful energy. These factors include the concentration of organic fraction of MSW (Cofmsw), concentration of total solid (CTS), biomethane potential of the waste (BMP), residue to product ratio (RPR), recoverability of manure(Rmanure) 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 are used. (Ofori, 2016)

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

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

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

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

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

Biogas yield from municipal solid waste is calculated 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 0f 64% was used for this thesis. (Ofori, 2016). The total solid concentration (541) used was calculated based on estimation from Ofori (2016). Moreover, data for MSW was calculated based on the amount of waste generated per person in Ghana in a day, and it was assumed that the amount of waste generated is 0.47kg/person/day.

The annual waste for the entire population is 5,148,325 tons which is approximately 5.14Mt. An analysis of biogas production from municipal liquid waste can also be established from equation (2) to be the outcome of quantity of waste, concentration of total solid and biomethane capacity. The concentration of total solid for municipal liquid waste (MLW) and the biomethane potential of MLW is considered to be 8.9 gTS/100g and 0.34 m^3 CH4/kgTS respectively (Ofori, 2016). The capacity of biogas production from manure is also established in equation (3) which is formulated as a product of number of livestock, the recoverability of manure, total solid concentration and the biomethane potential.

Equations (4) and (5) show the potential amount of biogas which can be obtained from lignocellulose by product (waste) with the influence of residue to product ratio, biomethane potential which is the estimation from Buswell's formula for glucan and hemicellulose in a specific residue (Ofori G, 2016).

An estimation of 0.58 Mt/yr. and 0.47 Mt/yr. was made for the quantity of MLW and forestry residue

Also, energy potential is estimated with an assumption that $1m^3$ biogas equals 3.6×10^{-8} PJ with an efficiency of 40% in converting into thermal capacity from the various biomass resources been used. A brief illustration of various estimation made on some of the biomass residues is shown below;

$$Biogas_{MSW} = Q_{MSW} \times C_{of\ MSW} \times CTS \times BMP_{of\ MSW}$$

$$= 5148439.201 \times 0.64 \times 541 \times 0.32$$

$$= 570430588.5$$

$$= 570\ Mm^3CH_4/yr.$$

Energy potential from Municipal Solid Waste (MSW)

Since an assumption of $1m^3$ of biogas equals 3.6×10^{-8}PJ was made, the energy potential will be 20.5PJ/yr., (i.e. $570000000 \times 3.6 \times 10^{-8}$).

For energy conversion into electricity, the efficiency rate of 35-40% can be used. 35% efficiency and 40% efficiency conversion rate was used for electricity and thermal capacity respectively.

For potential thermal capacity (rate of 40%)

40% X 20.5 PJ/yr. = 8.2 PJ/yr.

In the case of MLW, biogas potential as shown in equation (2) is the product of quantity of MLW (Q_{MLW}) concentration of total solid (CTs) and the biomethane potential (BMP_{MLW}). The CTs and BMP_{MLW} are assumed to be 8.9 TS/100 and $0.34m^3CH_4/kg$ Ts respectively (Ofori 2016). The quantity of MLW was estimated to be 0.58 Mt/yr.

This implies that:

$$Biogas_{MLW} = Q_{MLW} \text{ x } CTs \text{ x } BMP_{MLW}$$

$$= 0.58 \text{ X } 8.9 \text{ X } 0.34 = 1.75$$

$$= 17.5 \text{ Mm3CH4/yr.}$$

7.3 Estimation of Biogas Potential from Animal (Livestock) Manure

Below is table 8 showing the biogas and energy potential from various categories of livestock manure The estimations are based on livestock population in the 2014 MoFA Report. Table 8 shows the estimation of biogas potential from animal manure.

Table 8. Estimation of Biogas Potential from (Livestock) Manure

Categories of agricultural livestock	estimated population (million)	estimated manure (kg/head/day)	Recoverability (kg)	Manure Available (Mt/yr)	CTs gTs/100g	BMP_{MANURE} $M^3/kg/Ts$
Poultry	51	0.03	0.5	279	25	0.22
Cattle	1.65	13	0.2	1565	12	0.22
Sheep	3.9	1.5	0.2	427	25	0.22
Pigs	0.63	3	0.5	344	11	0.22
Goat	5.1	3	0.2	1116	25	0.22

$$Biogas_{manure} = [Q_{LIVESTOCK} \text{ X } Q_{MANURE} \text{ X } R_{MANURE}] \text{ X } C_{TS} \text{ X } BMP_{MANURE}$$

$$= \text{Manure Available X } C_{TS} \text{ X } BMP_{MANURE}$$

For biogas potential from poultry manure,

$$Biogas_{Poultry} = Manure_{Available} \text{ X } C_{TS} \text{ X } BMP_{Manure}$$

$$= 279 \text{ X } (22/100) \text{ X } 0.22$$

= $15Mm^3CH_4/yr$

For Biogas potential from cattle manure:

$Biogas_{cattle}$ = $Manure_{Availability}$ X CTs X BMP_{Manure}

= 1565 X (12/100) X 0.22

= 41 Mm^3CH_4/yr.

$Biogas_{sheep}$ = Manure $_{Available}$ X C_{TS} X BMP_{Manure}

= 427 X (25/100) X 0.22

= $23Mm^3CH_4/yr$.

$Biogas_{pig}$ = Manure $_{Available}$ X C_{TS} X BMP_{Manure}

= 344 X (11/100) X 0.22

= $8Mm^3CH_4/yr$.

$Biogas_{Goat}$ = Manure $_{Available}$ X C_{TS} X BMP_{Manure}

= 1116 X (25/100)

= $61Mm^3CH_4/yr$.

Total biogas manure from the livestock = 15 + 41 + 23 + 8 + 61

= 148 Mm^3CH_4/yr.

With the same assumption of $1m^3$ biogas is equal to 3.6×10^{-8},

148,000,000 X 3.6×10^{-8} = 5.3 PJ/yr.

Thus, the potential thermal capacity from manure at efficiency of 40% = 40% x 5.3

= 2.12 PJ/yrs.

7.4 Biomass Potential from Crop Residues

Table 9 summarized the estimation of biomass potential from crop residues based on estimations from previous studies and the formula given previously in this chapter.

Table 9. Estimation on biomass potential from crop residues.

Types of crop residues	Quantity of potential waste (mt/yr)	Biogas Potential (Mm^3CH_4/yr.)	Energy Potential (PJ/yr)	Thermal capacity Potential (PJ/yr)
Maize	3.18	681	24.5	9.8
Yam	2.7	348	12.5	5
Cocoyam	0.74	91	3.3	1.32
Sweet Potato	0.08	2.9	0.1	0.04
Rice	0.4	71	2.6	1.04
Sorghum	0.55	128	4.6	1.84
Millet	0.29	43	1.5	0.6
Cowpea	0.81	189	6.8	2.72
Plantain	17	85	3.1	1.24
Cassava	0.87	261	9.3	3.72
Sugar cane	0.031	4.11	0.15	0.06
Cotton	0.059	9	0.3	0.12
Soya bean	0.47	112	4	1.6
Cocoa beanspods	0.68	44	1.6	0.64
Coconut	0.27	84	3	1.2
Palm oil	0.84	134	4.8	1.92
Groundnut	1.01	136	4.9	1.96
Total	29.98	2423.01	87.05	34.82

A summary of potential resource of biogas and energy production from biomass residues in Ghana are given in table 10 below.

Table 10. Potential resource of Biogas and Energy Production from Biomass Residues in Ghana.

Types of Biomass Resources	Estimated Quantity (Mt/yr.)	Potential Biogas (Mm^3CH_4/yr.)	Energy Potential (PJ/yr.)	Potential Thermal Capacity (PJ/yr)
Municipal Solid waste	5.15	570	20.5	8.2
Municipal Liquid Waste	0.58	17.5	0.63	0.25
Livestock Manure	3731	148	21.02	8.41
Forestry Residues	0.47	19.1	0.68	0.2
Agricultural Crop Residue	14.63	2423.01	87.05	34.82
Total	3751.83	3177.61	129.88	51.88

In table 11 below, Municipal Solid Waste and crop residues illustrate the largest contribution to the generation of energy and biogas production with the individual contribution of 17.93% and 76.25% respectively to the total biogas production. The share of forestry residues of biogas production was estimated to be 0.60% with an insignificant difference to the share of MLW which is estimated to be 0.55%. The total share of biogas is 4.65%. From this estimation, there is clear evidence that biogas from biomass can contribute immensely to the stability of energy development in Ghana and help minimize the current energy crises the country is facing.

Table 11. Share of Total Biogas Potential of Biomass in Ghana.

Types of Biomass Resources	Potential Biogas (Mm^3CH_4/yr)	Total Share of Biogas (%)
Crop Residues	2423.01	76.25
Municipal Liquid Waste	17.5	0.55
Municipal Solid Waste	570	17.93
Livestock Manure	148	4.65
Forestry Residues	19.1	0.60
Estimated Total	3177.61	100

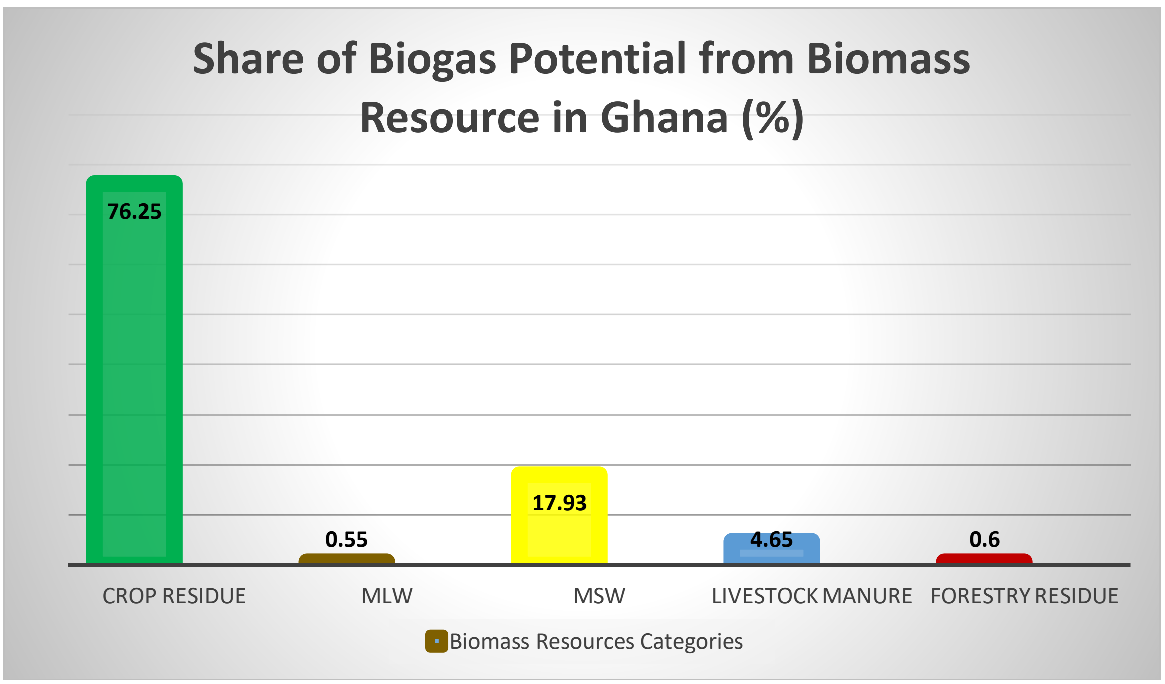


Figure 19. Share of Biogas Potential from Biomass Resource in Ghana (%)

Research question 2: **How can biomass energy be developed in Ghana?**

Solution to this research question is also given based on the references of biomass energy system of one developed country-Finland and one developing country-Thailand which has been reviewed previously in chapter 3. Many emphasis has been made on the biomass energy systems of these two countries in third chapter in this thesis and how Ghana can learn from these emphasis. These reviews provides some good answers to the second research question as discussed in details below.

7.4.1 Biogas Potential from Cocoa Pod Husks in Ghana

Case Study: Tema Cocoa Processing Company (CPC)

Ghana is the second largest cocoa exporter worldwide. Cocoa remains the main cash crop and it contributes to about 30% of the total export earnings in the country. Cocoa is a very vital cash crop due to its numerous profits such as the provision of food, income, employment creation, raw materials and other resources for poverty alleviation most especially in the developing countries in Africa. Apart from the above mentioned benefits it provides for millions of small scale farmers, cocoa also supply raw materials for multibillion chocolate industries across the globe. (Preprah k, 2015)

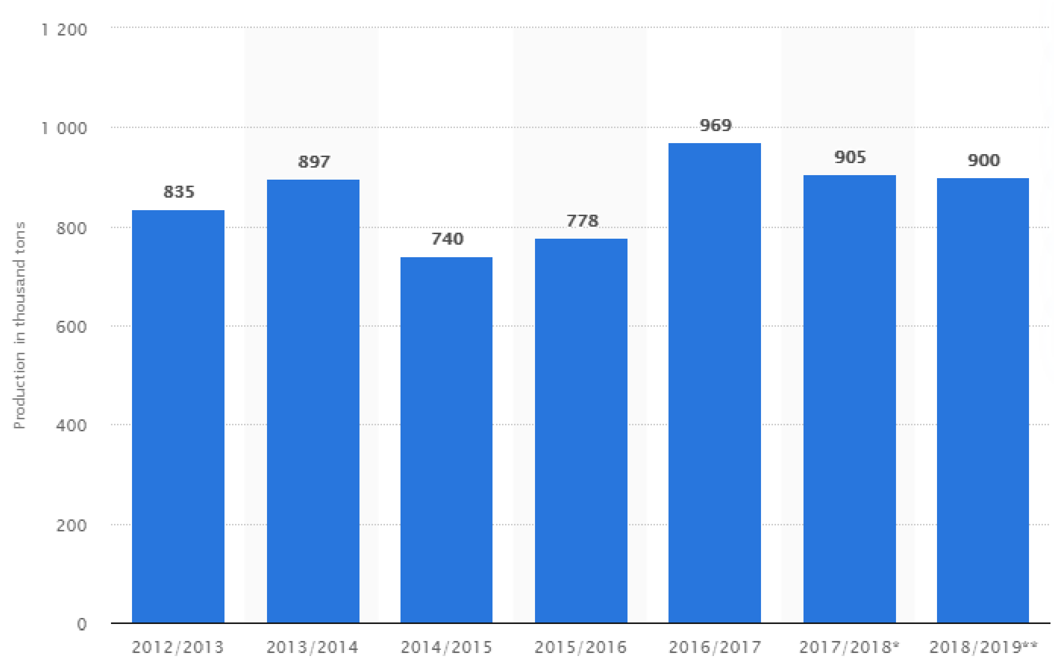
Research states that, in the year 2013 – 2016 season, cocoa production were depreciated from 897,000 to 778,000 tons annually in Ghana. Since then there has been a lot of reforms and introduction of many incentives such as Free Mass Spraying Exercise, Subsidized Fertilizer, Free Irrigation, Free Mass Pruning and many other attractive incentives from the government to cocoa farmers which has help improve cocoa production in Ghana. (Fountain A. et al. 2018) Currently, in 2018/2019 harvest season, statistics shows that, 900,000 tons of cocoa beans were produced in Ghana. (Shahbandeh M, 2016) Figure 20 below illustrates the statistics on cocoa beans production in Ghana from 2012/2013 – 2018/2019.

Cocoa planting and harvesting in Ghana mostly take place in the country's rain forest zone particularly in Ashanti, Brong - Ahafo, Central Region, Eastern Region, Western Region and Volta Region with a rainfall of about 1000 – 1500 millimeters annually. Cocoa harvesting comes in early October till September in the next subsequent year. Production of cocoa provides about 60 % of employment rate in labor force in the agriculture sector in Ghana. (MoFA, 2013).

The cocoa fruit is made up of pod husks, pulp, cocoa beans and placenta. The cocoa pod husks becomes useful waste after the expulsion of the cocoa beans from the fruit, and it is a potential waste that could be utilized as a feedstock for biogas plant. The pod husk constitutes about 66 – 70 % of the total weight of the fruit. The median calorific value of cocoa pods is estimated to be 23.4MJ/kg (MoFA, 2013)

Figure 20. Production of cocoa beans in Ghana from 2012/2013 – 2018/2019

(Shahbandeh M, 2019)



7.4.2 Tema Cocoa Processing Company (CPC)

The CPC is locally cocoa processing company established in 1981 as Limited Liability in Ghana, Tema. It comprises of two main factory sectors namely The Cocoa Factory and The Confectionery Factory. The CPC factories only add values to the selected cocoa beans in Ghana by the implementation of the various required processes to this premium cocoa beans into various final products such as chocolate Powder, ChocoDelight, Chocolate Bars, Choco Bake and Royale Natural Cocoa Powder.

Currently, the company has a processing capacity of 64,500 tons of cocoa beans annually from its stage installed capacity of 25,000 tons in the year of establishment.

This study is to investigate and evaluate the quantity of cocoa pod husks that can be generated in Ghana annually, and estimate the amount of biogas potential from these cocoa pod husks when used as a feedstock for biogas plant. Below are the data gathered from Ghana COCOBOD through friends and some senior staffs (Jessica Oduro Antwi, Senior Auditor - COCOBOD) for this study.

- 800,000 cocoa farmers are recorded in Ghana in 2018/2019 harvest year
- 900,000 tons of cocoa beans are produced in Ghana annually
- Every 1 ton of cocoa beans harvested generates 10 tons of cocoa pods husks.
- This implies that, for 900,000 tons of cocoa beans can generates:

- 1 ton cocoa beans = 10 tons of cocoa husk pods
  900,000 cocoa beans = ?
  (900,000 /1) X 10 = 9,000,000 tons of cocoa pods husks

This data analysis shows that 9,000,000 tons of cocoa pod husks is generated annually across the country which can be utilized as a potential feed stock for biogas production in Ghana.

In the case of Tema Cocoa Processing Company, since the company currently has a processing installed capacity of about 64,500 tons cocoa beans in every year, it also implies that,

(64500/1) X 10 = 645,000 tons of cocoa pod husks are generated indirectly as a waste by the company annually, which could be put into a medium as feedstock (substrate) for biogas potential for the company to run their production plant.

In order to raise the methane content (CH_4) of the biogas produced from the cocoa pod husks, a small amount of cattle manure (for example, 5000 tons) could be added to the main substrate (cocoa pod husks). This is briefly term as inoculum.

7.4.3 Calculation of Biogas and Electricity Potential from Cocoa Pod Husks (CPH) in Ghana

The total biogas production can be estimated with the formula below;

Biogas Production = amount of substrate (t) x DM (%) x OM (% of DM x maximum

Biogas yield (m^3/t ODM)

Where;

DM = Dry matter content of the substrate

OM = Organic Matter Content

ODM = Organic dry matter

In the case of biogas production from cocoa pod husks (CPH) in this study,

$\text{Biogas}_{\text{CHP}}$ = [$\text{amount}_{\text{CPH}}$ (t) x DM_{CPH} (%) x OM_{CPH} (% of DM_{CHP}) x maximum

Biogas $\text{yield}_{\text{CPH}}$ (m^3/t ODM)] + [$\text{amount}_{\text{co-substrate}}$ (t) x $\text{DM}_{\text{cattle manure}}$

(%) x $\text{OM}_{\text{cattle manure}}$ (% of DM) x maximum biogas production

(m^3/t ODM)]

Table 12 below shows an extract of biogas parameters of the substrates used for this calculations;

Table 12. Biogas yield Table (Extraction from the main Biogas Yield Table)

Feedstock (Substrate)	Dry Matter DM (%)	Organic Matter OM (% DM)	Biogas Yield (m^3/t ODM)	Biogas yield m^3/t Wet	Average biogas yield (m^3/t wet)
Cocoa Pod husks	15.0	90	550	74.3	6.3
Cattle manure	7 – 15	65 - 85	200 - 400	9 - 51	25

For the Co-substrate (Cattle manure), parameters from the extraction of the biogas yield table, the following were assumed for the calculation;

$\text{DM}_{\text{cattle manure}}$ (%) = 15%

$OM_{cattle\ manure}$ (%) = 75%

Biogas Yield (m^3/t ODM) = 350

Therefore,

Biogas Production $_{CPH}$ = [645,000 x (0.15) x (0.9) x 550] + [5000 x (0.15) x (0.75) x

350]

= 47, 891, 250 + 196, 875

Biogas Production$_{CPH}$ = 48,088,125 m^3 biogas/yr

= 48.09 Mm^3CH_4/yr

Electric energy potential of the estimated biogas from cocoa pod husks in Ghana can also be calculated using the formula below;

$\mathcal{P}_{£}$ = ($f CH_4$ x H_vCH_4 x $Biogas_{CPH}$ x ɳe) / (3.6 x 10^6MJ GWh)

Where;

$\mathcal{P}_{£}$ = Electric Energy Potential (GWh/yr)

$f CH_4$ = the fraction of methane content in the biogas

$HvCH_4$= the heat value of methane content in the biogas

BiogasCPH = the total biogas production (m^3/yr)

ɳe = Electricity generation efficiency (%)

Assumption;

1. The conversion fraction from MJ to GWh = 3.6 x 10^6
2. $f CH_4$ is assumed to be 60% for this calculation
3. $HvCH_4$ is the heat value of CH_4 of biogas (39.0 MJ/m^3)
4. ɳe is energy conversion into electricity. Efficiency rate of 35% - 40% can be used (35% is used)

Therefore;

$$PE = (0.6 \times 39.0 \times 48{,}088{,}125 \times 35) / (3.6 \times 10^6 \text{MJ GWh})$$

$$= \mathbf{10.94\ GWh/yr.}$$

7.4.4 Description of the Recommended Technology

The proposed power plant technology for biogas production from cocoa pod husks in this study is anaerobic digestion plant technology connected with a co – generation (CHP) engine. The feedstock (CPH) is crashed into smaller sizes before feeding into the plant. The sizes of the feedstock in biogas production has a great effects on the quality and the quantity of the gas. According to research, a very smaller particles of the feedstock reduces the formation of floating layers in the biogas reactor. Therefore, it is highly recommended to crash the feedstock into a suitable sizes. The crashed feedstock are slurrified and pre – heated to a temperature of about 50 degree Celsius by the utilization of the heat from the CHP engine coupled to the system. The co – substrate (cattle manure) is then pumped from a separate storage to mix with the pre – heated cocoa pod husks. The pre – heating process is done by the CHP engine in order to maintain a constant pre – heating temperature for stable digestion of the substrates for the entire operation. The heated feedstock is then pumped into the digesters through the connecting pipes for the anaerobic digestion process to place. The feedstock are retained in the digester for 30 days. (Retention time) The biogas production is finally achieved after the retention time which is then separated from the digestates and stored in a separate tank. The separation is done by a screw – pressed separator unit. Two types of digestates are produced usually the liquid fraction and the solid fraction. After the separation of the digestates, the liquid fraction is pumped into a storage for treatment and re – used. The solid fractions further pass through a drying process. Both digestates can be used as fertilizer in the agriculture sector.

The biogas produced can used by Tema Cocoa processing Company as a raw source of fuel to run their production power plant and also provide electric energy. The diagram below provides further explanation of the plant technology.

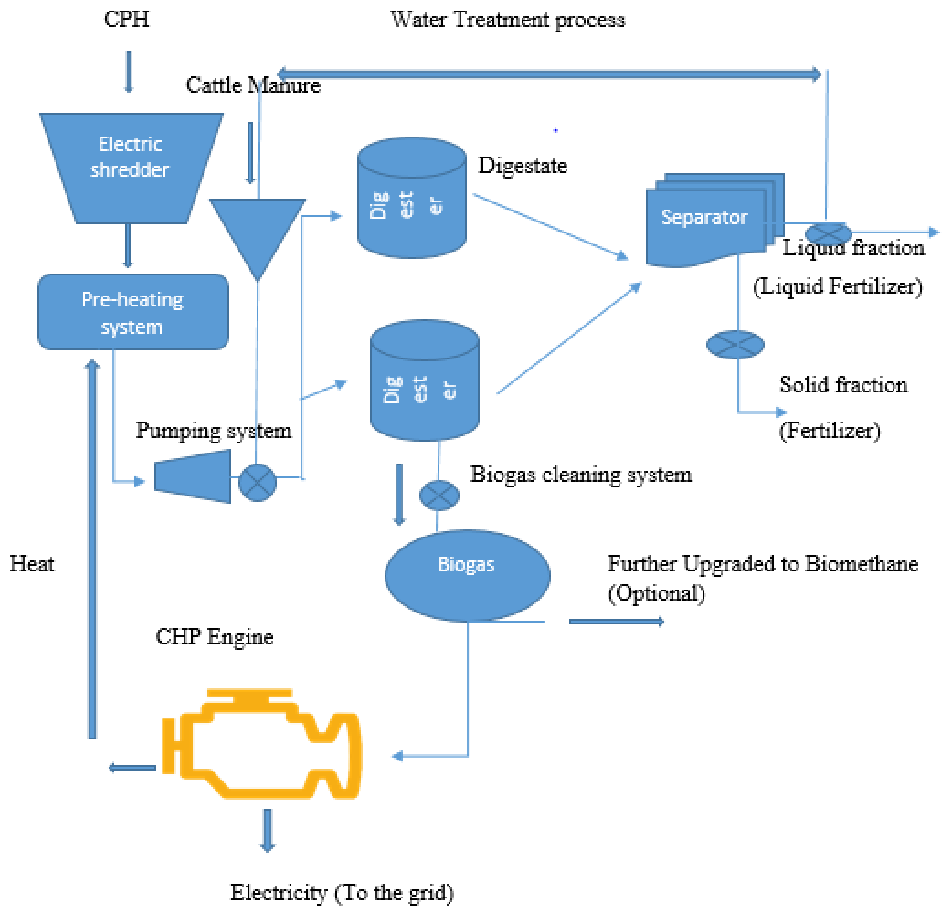


Figure 21. Recommended Anaerobic Digestion Plant Technology

Table 13 shows the parameters of working conditions of the suggested plant technology

Table 13. Summary of Plant Technology Specification

Operational Conditions (Parameters)	Value
Plant capacity	10.94 GWh/yr.
Biogas production	48.09 Mm^3CH_4/yr.
Methane content	60 %
Temperature (Thermophilic)	50 °c

Retention time	30 days
Number of days of operation/ yr.	330 days
Input feedstock/ day	1954.5 tons
Input feedstock/yr.	645,000 tons
PH level	7

7.4.5 Reasons for the Choice of Recommended Technology

Although many suitable technologies for biomass conversion into useful energy has been reviewed previously in chapter 4 but it is critical to make the right choice of technology depending on the type of biomass as a feedstock and the desired by – product. Anaerobic digestion plant technology is recommended as a suitable technology of biogas production from CPH based on it few favorable conditions. Since anaerobic digestion is a wet process, it implies that feedstock with 50 percent of moisture content or more can be feed to the biogas reactor. Also, despite the high volume of water required in this process, water treatment system can be employed in this technology for the part of the water to be re-used. Furthermore this technology generate extra by- product aside the biogas, which is the digestates processed as both liquid and solid fertilizer. This add more potential value to the existing market in the agriculture sector in Ghana.

Though other matured technologies like direct combustion and gasification can be employed in converting CPH into energy but due to the high volume of ash content (8.4 – 13.2 percent) of CPH which could be a potential barrier. (Dimitra M. 2016)

7.5 How to Develop Biomass Energy in Ghana

Since the population of Ghana continues to experience rapid growth every year, there also comes an urgent need to solely expand and develop various sources of energy to supply to the people. The previous and the current energy situation in Ghana obviously points out that, there must be solutions to expand and have varieties of technologies in the energy generation and supply system, which includes a sustainable energy like biogas from biomass resources.

The biomass utilization systems in Thailand and Finland discussed already in this chapter suggest many programs and measures that Ghana can also initiate to help the utilization of the abundant biomass resources in the country to help strengthen our energy generation mix. The review of biomass energy system of Thailand creates an awareness that biomass remains one of the key RES in the country. Biomass energy has possibly been one of the sustainable energy sources in Thailand due to some policy measures that the government of Thailand implemented. Ghana can likewise implement and follow some of these key strategies in order to make biomass more feasible and one of the sustainable energy source to help reduce this energy crises. Ghana has biomass resources in abundance for generation of useful energy. Thai Government has been promoting biomass energy generation through several policy measures and incentives, such as implementation of compensation mechanisms, incentives for cost reduction in biomass production for farmers, provision of adequate assistance for project developers and many other attractive measures which have influenced positively in many ways their biomass system. The same measures could be implemented in Ghana. The availability of expertise and technical know - how, adequate and efficient technology and good management skills are a few factors which were noted from the review of the Finland energy system. Lack of expertise, skilled labour and workforce have become key challenges in Ghana which hinders the application of various biomass technologies. Various biomass resources in Ghana can be utilized effectively through proper waste management systems most especially for municipal waste and landfills. Expertise is needed to train labours and workforce to be equipped with skills and technical know – how and provision of education about the various biomass technologies for power generation. Ghana can also do better in biomass utilization if the Nation is to adopt these strategies of biomass utilization from these two countries been reviewed.

8 Discussions and Conclusion

The analysis and assessment of various feedstock of biomass established in this thesis offers a great opportunity for Ghana to generate energy from biomass most especially crop residues, municipal solid waste and other waste materials relating to biomass. Electricity from MSW has a potential to cover about 17.93% of the national electricity consumption from biomass annually. The production of biogas will assist Ghana to become less dependent on other common traditional energy sources which help reduce the importation of other liquid fuel from foreign countries. This will help the country to save money on import duties and other foreign taxes on crude oil and natural gas. The estimation of biogas potential from cocoa pod husks generated indirectly by Cocoa Processing Company in Tema gives an indication that there is great opportunity for biomass potential as an alternative source of energy in Ghana. The waste cocoa pod husks generated by the Cocoa processing Company represent only 7.1 percent of the total cocoa pods husks generated annually in Ghana.

Also, as a lesson from Finland and Thailand biomass reviewed in this research, the reasons in sorting other biomass residues most especially MSW becomes more feasible and beneficial in terms of biomass to energy utilization. Moreover, review from Thailand biomass energy system points out several policies and incentives which aids in promoting biomass energy generation. Government of Ghana can also implements similar policies of such kind to help biomass energy generation in the Country.

Even though this thesis considered energy that can be generated from various biomass residues, additional energy can be produce from other forms of biomass residues which were not mention or enough details not given in this research especially other composition of industrial waste and some special energy crops that are also in abundance in Ghana. Future research can be done to make analysis and estimates the value of energy potential of biogas (biofuels) in this energy crops and other industrial waste since they are biomass and very abundance in Ghana.

8.1 Limitations

As discussed already in chapter 1, a thesis of this type requires a field survey and observations across the country in question in order to obtain an accurate and feasible data for further analyses. This helps to make vivid conclusions for future references. But due to time and economic constraints, with the exception of the primary data gathered from Ghana COCOBOD through friends and some staffs, all other information and data for this thesis were from secondary sources, including estimations of energy potential from biomass in other related articles in the literature review. Although the thesis was based on secondary data and other relevant information related to similar articles from opened sources, yet detailed analyses and estimations were made to provide better understanding. Other necessary improvements can be made for subsequent thesis relating to this similar research.

REFERENCES

Abubakari, F, 2015. How Africa and rich countries can both profit from renewable energy. Accessed 16 July 2019. http://www.ghanaweb.com/GhanaHomePage/features/How-Africa-and-rich-countries-can-both-profit-from-renewable-energy-374600

Afrane, G. & Ntiamoah, A. (2011). Comparative Life Cycle Assessment of Charcoal, Biogas, and Agriculture, municipal solid waste management systems in Canada and Ghana: a case study of the cities of municipal solid waste management systems in Canada and Ghana.

Alakangas, E. 2016. National Policy Landscape, Finland. Biomass policies Project. Accessed date. https://www.ieabioenergy.com/wp-content/uploads/2018/10/CountryReport2018_Finland_final.pdf

Ali kasap, Ramazan Aktas and Emre Dulger: Economic and Impacts of Biogas, 2011. Alternative Energy Sources IV, Vol. 6, Ann Arbor Science, New York.

Amranand, P., 2008, Alternative Energy, Cogeneration and Distributed Generation: Crucial Strategy for Sustainability of Thailand's Energy Sector, Energy Policy and Planning Office, Ministry of Energy, Thailand. Accessed on 16. April 2019. http://www.eppo.go.th/doc/PiyaRE-in-Thailand.pdf.

Andersen, M. S. (2007). An introductory note on the environmental economics of the circular economy. Sustainability Science Vol. 2, No. 1, pp.133-140.

Antwi, E. K. et al. Land Use and Landscape Structural Changes in the Ecoregions of Ghana. Journal of Disaster Research. 2014, Vol.9 No.4.p.452-467

Arthur, R. (2009). Feasibility study for institutional biogas plant for KNUST sewage treatment plant; MSc. Thesis, Kwame Nkrumah University of Science and Technology (KNUST), Kumasi,

Ayernor, G.S.& Ocloo, F.C.K.(2003). Market potential of industrial alcohol in Ghana, an analysis of import-export data, Sustainable Industrial Market for cassava project, final report 1 on project year 2 activities. Accra.

Ayernor, G.S.& Ocloo, F.C.K.(2003). Market potential of industrial alcohol in Ghana, an analysis of import-export data, Sustainable Industrial Market for cassava project, final report 1 on project year 2 activities. Accra.

Ayres, R.U. & Kneese, A.V. (1969). Production, Consumption, and Externalities. US Biomass Energy System.

Basu Prabir (2010). Biomass Gasification and Pyrolysis. Elsevier Science Publishing Co Inc.

Baykara, S.Z., &Bilgen, E. (1981). A feasibility study on solar gasification of Albertan coal, biomass residue availability and bioenergy yields in Ghana Resources, Conservation and biomass residue availability and bioenergy yields in Ghana Resources.

Demirbas, A., 2009. Biofuels securing the planet"s future energy needs. Energy Conversion and Management, 50(9): 2239-2249. DOI 10.1016/j.enconman.2009.05.010.

Demirbas, M.F., M. Balat and H. Balat, 2009. Potential contribution of biomass to the sustainable energy development. Energy Conversion and Management, 50(7): 1746-1760. DOI 10.1016/j.enconman.2009.03.013.

Department of Alternative Energy Development and Efficiency (DEDE), 2008a, Thailand Energy Situation-2008, Ministry of Energy, Thailand.

Department of Alternative Energy Development and Efficiency (DEDE), 2010a, Latest Information of E85 and Balance of Cassava & Molasses for Food and Ethanol. Accessed 13. August 2019.
http://www.dede.go.th/dede/fileadmin/upload/pictures_eng/pdffile/e85- 17-june.pdf, Extracted on August, 2019.

Dimitra Maleka. Assessment of the Implementation of the Alternative Process Technologies for Rural Heat and Power Production from Cocoa Pod Husks. 2016.

Dinar, R. Hassan, R. Mendelsohn, and J. Benhin, "Climate Change and Agriculture in Africa: Impact Assessment and Adaptation Strategies," London, EarthScan, 2008.

ECG, 2015b. National energy statistics 2005 - 2014. Strategic planning and policy division. Accra, Ghana: PMB, Ministries Post Office.

Economic Review. Vol. 59, No. 3, pp. 282-297.

Energy Commission Act, 1997. Act 541. Accra: State Publishing Company.

Energy Commission of Ghana, 2015a. Energy (Supply and Demand) outlook for Ghana final. Ghana: Energy Commission.

Energy Commission of Ghana. (2016a). National Energy Statistics (2006-2016).

Energy Commission of Ghana. 2009. Renewable Energy Policy Framework for Climate Change.

Energy Commission of Ghana. 2015. National Energy Statistics, 2005-2014, Accra.

Energy Commission, 2010. Draft bioenergy policy for Ghana. Accra: Energy Commission.

Energy Commission. National Energy Statistics 2008-2017; 2018. Accessed 12. February 2019. http://www.energycom.gov.gh/planning/data-center/energy-outlook-for-ghana?download=76:energy-outlook-for-ghana-2018

Energy Commission/Ministry of Energy. Energy Efficiency and Conservation Strategy and Programmes. 2012-2015; 2012.

Energy from field energy crops EA handbook for energy producers. Jyväskylä Innovation Oy. Accessed date. http://www.encrop.net/; 2009.

Energypedia, 2015. Ghana energy situation. Accessed 10th June 2019. www.energypedia.info/wiki/Ghana_Energy_Situation

ESWET Handbook. 2019 Accessed 10th August, 2019. http://www.eswet.eu/waste-to-energy-handbook.html.

Fialeseshie, Emmanuel. Biomass as Source of Energy for Kwame Nkrumah University of Applied in Ghana, 2017. Vamk, University of Applied Sciences.

Fountain A, Huetz-Adams F. Cocoa Barometer 2018. Berlin: Civil Society Organisations; 2018. Available from: www.cocoabarometer.org [Accessed: 21 September 2018]

George, D.A.R., Lin, B.C., &Chen, Y. 2015. A circular economy model of economic growth, Environmental Modelling & Software, Vol.73, pp 60-63

Ghana Statistical Service. Statistics for Development and Progress 2013-2018 report. Accessed 10 June 2019. http://www.statsghana.gov.gh

Horan N.J 2018. Introduction to Anaerobic Digestion processes. Green Energy and Technology. Accessed 10 June 2019.
http://energycom.gov.gh/files/National%20Energy%20Statistics_2016.pdf

http://www.historyworld.net/wrldhis/PlainTextHistories.asp?historyid=ad43
http://www.historyworld.net/wrldhis/PlainTextHistories.asp?historyid=ad43
https://en.wikipedia.org/wiki/History_of_Ghana
https://en.wikipedia.org/wiki/History_of_Ghana
https://tradingeconomics.com/ghana/gdp-growth-annual
https://tradingeconomics.com/ghana/gdp-growth-annual
https://www.frontlinebioenergy.com/en/advantages/economic_benefits/
https://www.frontlinebioenergy.com/en/advantages/economic_benefits/
https://www.globalsecurity.org/military/world/africa/gh-economy-history.htm
https://www.worldbank.org/en/country/ghana/overview

ISSER. (2015). Electricity insecurity and its Impact on Micro and Small Businesses in Ghana. Electricity Insecurity and Its Impact on the Economy of Ghana. Accra: Institute of Statistical, Social and Economic Research.

Kartha S., & Larson E.D. (2000). Bioenergy primer: modernized biomass energy for sustainable

Kemausuor, F., Kamp, A., Thomsen, S.T., Bensah, E.C.,& Østergård, H.(2014). Assessment of Kemausuor, F., Kamp, A., Thomsen, S.T., Bensah, E.C.,& Østergård, H.(2014). Assessment of KITE (2008).

Kwesi Mensah, Samuel Boahen and Kofi Owura-Amoabeng: Renewable Energy Situation in Ghana. A Case study for Recommendation of Ghana's Energy Crises in 2017.

Liquefied Petroleum Gas as Cooking Fuels in Ghana, Journal of Industrial Ecology, Vol. 15, No. Livestock Manure Management Guide. Ohio State University Extension, pp. 1–117.

McKendry P. Energy Production from biomass (part 2) and their conversional technologies.

Meiza, K., Obiri-Danso, K., Kadar, Z., Fei-Baffoe, B., &Mensah, M. Y. (2015) Municipal solid

Mensah, G.S., Kemausuor, F., Brew-Hammond, A., 2014. Energy access indicators and trends in Ghana. Renewable and Sustainable Energy Reviews, 30, 317-323

Micre (2011). Handbook. Accessed date. http://nortech.oulu.fi/ eng/W2E.html

Milbrandt A. (2009). Assessment of biomass. Resources in Liberia. Prepared for the U.S. Agency Mitigation in Ghana.

Ministry of Food and Agriculture (MoFA), 2013). Review of Agricultural Sector in Ghana: Facts and Figures (2012) Statistics, Research and Information and Directorate (SRID).

MoFA (2011). Agriculture in Ghana: facts and figures 2010. Ministry of Food and

Murphy, J.D., McKeogh, E. 2006: The benefits of integrated treatment of wastes for the sustainability of energy supply

Ofori. Grace Maa- Laje. 2016. Waste to Energy. An alternative Energy source for Ghana. Master's Thesis.

Oliver Davies, Donna J. Maier, John D. Fage Ernest Amono Boateng. Report on History of Ghana, 2018. Accessed 10th June 2019. www.britannica.com/place/Ghana
Otoo, Christopher. Municipal Solid Waste in Ghana and its Feasibility for Waste Incineration Technology, 2017. Vamk, University of Applied Sciences.

P. Bucci. Biofuel Research Journal 2019. Review on biomass: importance, chemistry, classifications and conversional technologies.

Patrícia Carneiro, Paula Ferreira. The economic, environmental and strategic value of biomass. Accessed 11 June 2019.
file:///C:/Users/HP/Desktop/biomass%20importance%202.pdf

Peprah K. Sustainability of cocoa farmers' livelihoods: A case study of Asunafo District, Ghana. Sustainable Production and Consumption. 2015; 4: 2-15

PURC (2015). Ghana gazette December 2015, Accra.

Randall J, Maurice L.E., Larry C.B., Kevin H.E., Stephen S.F., & James J.H. (2006).

Raphael Slade, Robert Saunders, Robert Gross, Ausilio Bauen. Energy from biomass: the size of the global resource (2011). Imperial College Centre for Energy Policy and Technology and UK Energy Research Centre, London.

Renewable energy Word 2006. Accessed 11. July 2019. https://www.renewableenergyworld.com/articles/2006/01/geothermal-energy-2005-in-review-2006-outlook-41267.html

Renewable Energy.Vol.36, pp.1510–6. Ghanaian case study. Government of Ghana.

Riedacker, A. 2007. A global land use and biomass approach to reduce greenhouse gas emissions, fossil fuel use and to preserve biodiversity. Fondazione Eni Enrico Mattei, Milan, IT. (Working Papers, 121). Accessed 4. March 2019. http://www.bepress.com/feem/paper121

S. Kumar, P. Abdul Salam, Ram M. Shrestha and Manjula Siriwardhana: Global Network on Energy for Sustainable Development. Case Study analysis in Thailand and Indonesia.

Smeets, E., Faaij, A. Lewandowski, I. and Turkenburg W. (2007) A bottom-up assessment and review of global bio-energy potentials to 2050. Progress in Energy and Combustion Science, 33 56-106.

Shahbandeh M. Statistics of Cocoa Production in Ghana. Online publication. https://www.statista.com/statistics/497844/production-of-cocoa-beans-in-ghana/. Accessed on 18th December, 2019.

U.S Library of Congress. Accessed 6. June 2019. www.countrystudies.us/ghana/63.htm

World Bank. Population Density Data-World Bank Open Data-World Bank Group; 2018. Accessed 6. June 2019. http://data.worldbank.org/indicator/en.pop.dnst

World Bank. Ghana: Agricultural sector policy. In: Agricultural Global Practice AFRO01, Africa. Washington, DC: The World Bank; 2017. pp. 1-63