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Energy Technology, Sustainable Technology and Business

Master's Thesis

MODELING THE TRANSITION TOWARDS SUSTAINABLE ENERGY SYSTEMS FOR GHANA

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ABSTRACT

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This research involves the modeling of the energy system of Ghana towards renewable technologies. The main objectives of this study was to examine the composition of Ghana's current energy system, model a ten percent renewable energy in the energy mix and finally model a minimum thirty percent renewable energy in the mix by 2030, while investigating the impact of the models on cost and environment. To achieve the objectives set out in this work, past studies conducted on the topic were extensively but not exhaustively reviewed for an insight to the research area. A secondary data was sourced and the models built by the Long – range Energy Alternative Planning (LEAP) tool by the Stockholm Environment Institute of USA. The results show that Ghana's current energy system is comprised mainly of thermal plants and hydroelectricity dams. The current system is cost intensive due to oil and gas imports that makes it difficult to meet the energy demands of the people, thereby forcing the system operators to engage in load shedding. Renewable energy potential of Ghana is high, especially utility scale solar, however, due to low incentives and little government commitments, renewable energy has little share in the energy mix. The research further revealed that if interest rates and inflation can be brought to the barest minimum, renewable energies could become cost competitive in Ghana in near future. If renewable energy could provide about 30% of Ghana's electricity, energy related emissions would be reduced significantly because thermal plants are the main pollution sources in the energy mix. Although the cost recovery factors used in the cost calculations are based on Finnish projections, it was concluded that renewable energies could become Ghana's energy sources if government further incentivize private power producers to generate renewable energy electricity.

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Moses Kwame Aglina

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LIST OF SYMBOLS AND ABBREVIATIONS

BPA	Bui Power Authority
CEL	CENIT Energy Limited
CO_2	Carbon dioxide
ECG	Electricity Company of Ghana
ECOWAS	Economic Community of West African States
EDI	Energy Development Index
GARCH	Generalized Autoregressive Conditional Heteroscedasticity
GDP	Gross Domestic Product
GHGs	Greenhouse Gases
GJ	Gigajoule
GoG	Government of Ghana
GRIDCo	Ghana Grid Company
Gt	Giga ton
GW	Gigawatt
GWh	Gigawatt Hour
HDR	Human Development Report
HFO	Heavy Fuel Oil
IEA	International Energy Agency
IPP	Independent Power Producers
ISSER	Institute for Statistical, Social and Economic Research
KWh	Kilowatt Hour
LCO	Light Crude Oil
LCOE	Levelized Cost of Electricity
LEAP	Long – range Energy Alternative Planning
LPG	Liquefied Petroleum Gas

MMBtu	Million Metric British thermal unit
mmscf	Million Standard Cubic Feet
MW	Megawatt
MWh	Megawatt Hour
NEDCo	Northern Electricity Distribution Company
PV	Photovoltaic
SAPP	Sunon – Asogli Power
SDGs	Sustainable Development Goals
T3	Takoradi 3
TAPCO	Takoradi Power Company
TICO	Takoradi International Company
TT1P	Tema Thermal Plant 1
TT2P	Tema Thermal Plant 2
TWh	Terawatt Hour
UN	United Nations
UNDP	United Nation’s Development Program
UNFCCC	United Nations Framework Convention on Climate Change
VRA	Volta River Authority
W.H.O	World Health Organization
WAGPCo	West African Gas Pipeline Company

1. INTRODUCTION

Energy undoubtedly has been the main driving force behind development, in agriculture, industry, economic, health, education and wealth creation. In the face of abundant renewable energy sources, the UNDP and WHO (2015) projected that close to 3 billion people in the world live without access to any form of energy. The World Energy Outlook (2015) revealed that more than 1 billion people live without access to electricity and more than 2.7 billion people are dependent on the use of traditional biomass for cooking which results in indoor air pollution.

In the year 2012, the United Nations Secretary General Mr. Ban Ki – moon inaugurated the 'Sustainable Energy for All' by 2030. At the inauguration, the Secretary General said ''Sustainable energy can revitalize our economies, strengthen social equity, and catalyze a clean energy revolution that benefits all humanity. Acting together, we can open a new horizon today and help power a brighter tomorrow''.

Sustainable development as defined by the Brundtland Commission is the development that ''meets the needs of the present generation without the compromising the ability of the future generations to meet their own needs'' (United Nations, 1987). The biggest threat to sustainable living and the environment is the pollution substances that are emitted from energy use which are derived from the use of fossil fuels.

Fossil fuels are major contributors to the emission of greenhouse gases (GHG) which also contribute to climate change and atmospheric polluting substances. Fossil fuels based electricity production methods and transport and heating are believed to have resulted in more than 70% of emission of GHG such as carbon dioxide, methane, and sulphur dioxide and nitrogen oxide (Frauke 2009). The environmental harms associated with fossil fuel use require that countries limit their emissions in order to limit global emission and keep the atmospheric temperatures within safe limits.

Ghana has a varied energy mix with biomass, oil, natural gas, hydro, and solar. Biomass alone produced more than 60% of the total energy consumption in Ghana, while hydro, oil, natural gas and a little contribution from solar in the electricity generation. Ghana's economy is one of the fastest growing economies in the Sub Saharan Africa with as much as 14% GDP growth in 2011 (World Bank). The growth of the economy coupled with a population growth of more than 2% per annum require that Ghana's energy supply is enough to meet the demand. However, due to lack of generation capacity, the drop in the water levels in hydro power stations and economic challenges, the country's supply fall short of demand, which plunge the nation into power crisis for more than four years. The power crisis resulted in the loss of more than $3billion for the four years according to the Institute for Statistical, Social and Economic Research of Ghana (ISSER, 2014) with a loss of $ 680 million in the year 2014 (Multimedia Group Limited 2016).

The demand for energy is growing at 12% per annum in Ghana. To manage the situation and bring the power rationing to an end, the country mobilized about 800 MW of emergency thermal power in the 'shortest' possible time. One of Ghana's largest hydroelectricity dams, the Akosombo hydro dam now is operating at 40% of its capacity due to low water level in the Volta River. The cost of thermal generation is higher which increase the cost of electricity to the consumers (Mahama 2016).

Ghana has a strategic energy vision to achieve availability and universal energy access for households, businesses and for export by the year 2020. To achieve the vision, the challenges of infrastructure development, energy efficiency, health, safety and environmental effects must be overcome. To overcome the challenges confronting the energy sector and meet the targets set in the strategic vision, the energy sector was sub divided to provide special focus in each area. The strategic policy of Ghana is to achieve 10% renewable energy in the energy mix by the year 2020 (Ministry of Energy 2010).

Article 1 subsection 1 of the Renewable Energy Act of Ghana stated the objectives of the act as to' 'provide for the development, management and utilization of renewable sources for the production of heat and power in an efficient and environmentally sustainable manner''

The Act further provide in article 1 subsection 2 a, b, c, and d as follows.

2. a, i. the framework to support the development and utilization of renewable energy sources; and ii, an enabling environment to attract investment in the renewable energy sources; (b) the promotion of the use of renewable energy; (c) the diversification of supplies to safeguard energy security; (d) improved access to electricity through the use of renewable energy sources.

Section 2 of the Act defined renewable energy as an energy sourced from non-depleting sources such as wind, solar, hydro, biomass, bio – fuel, landfill gas, sewage gas, geothermal energy, ocean energy and other available sources as the minister responsible may write.
This research is designed to model the energy transition of Ghana towards sustainable energy systems. In line with the 10%, renewable energy is the energy mix by the year 2020; the research will model the government's target and then model 30% of renewable energy by 2030

1.2 THE RESEARCH QUESTION

To achieve the objectives of the research, the research would attempt to answer the following question:

1. What is the current electricity system model operated by Ghana? How does the renewable electricity integration change the system?
2. What would be the best electricity system model for Ghana in the policy scenarios?
3. What impacts (if any) would the policy scenarios have on the electricity generation system of Ghana?

1.2 METHODOLOGY

The research data was athered from the relevant state institutions and other international organizations via desktop secondary sources. The World Bank and the Ghana Statistical Service data on Ghana's economy and demographics were used. The database of the Energy Commission of Ghana has be used and where data is not available, other sources were used.

The data analysis was conducted with (Eviews) statistical application to test any relationship between energy demand and other economic and demographic indicators. Energy demand and supply was analyzed with Longe – range Energy Alternative Planning software developed by the Stockholm Environment Institute based in Boston, Massachusetts in the USA.

1.3 SCOPE OF THE STUDY

The research covers the energy demand and generation sectors of the energy system of Ghana. The generation technologies in the energy mix of Ghana and the inclusion of possible new technologies in the generation mix in future in the policy scenarios. The demand sectors covered were household, industry, commerce, services, and agriculture. Transportation demand sector was not part of the study, although the commerce and services sector as listed by the Ghana Statistical Service has some components of transportation.

1.4 LIMITATIONS OF THE STUDY

This study was limited by the unavailability of reliable data on the technical aspects of the existing power plants. Conducting this research based on a secondary data limits the reliability of the results due to data constraints. Land use and land use change in the renewable scenarios and competition for land in building mega solar power plants can be a major concern; however, this study did not investigate the impact of renewable ground- mounted solar panels on food production.

2. ENERGY AND SUSTAINABLE DEVELOPMENT

In 2002, the United Nations summit on sustainable development in Johannesburg, South Africa, emphasized the important role of energy in poverty alleviation, economic development and social equality. The summit also discussed the catastrophe and the havoc caused to the environment and human health because of energy production and natural resource exploitation. The eminent dangers posed by the production of energy and natural resource exploitation required the development of regulatory frameworks that create economic, social and institutions needed for increase access to energy services that are reliable and environmentally sustainable. (Sghari, Hammami 2016).

The relationship between energy consumption, economic growth and carbon dioxide emissions has produced varied results. There is however, a clear and intrinsic relationship between energy and climate change. Sustainable energy can be defined as the production, conservation and use of energy resources that promote long-term wellbeing of humans and the environment. Sustainable energy is mainly focused energy security and management of energy source and protecting the environment. A sustainable energy should be seen with zero CO_2 emissions, less environmental impacts, security of the energy transition, reduced cost of production and the use of renewable green energy sources (Ozturk, Yuksel 2016).

Modernized energy services support increase income opportunities that can support poverty reduction methods. An assessment done globally and cited by (Sovacool, 2012) showed that between 20% and 30% of the poor's income are used on energy and another 40% of their income and remotely connected to the energy use. To end that cycle, a reliable and efficient supply of lighting, heating cooking and mobility is needed. In the Practical Action (2013), it was evident that poor nations also lack access to modern energy services (Aglina, Agbejule & Nyamuame 2016).

The environmental impacts of lack of access to energy include among others, deforestation, biodiversity loss, changing land use and greenhouse gas emissions. In a World Health Organization report 2014, it was estimated that some two billon people used traditional biomass as fuel for cooking, heating, and about 2 million tons of biomass is burned daily. Due to limited forest and growing population, the tendency for deforestation has increased (Aglina, Agbejule & Nyamuame 2016).

The United Nations and the International Energy Agency defined energy poverty as lack of access to energy services with the assumption that people who lack access to energy are poor because income and prices are implanted in energy access levels. These bodies sometime assume that access to physical energy automatically means consumption. In a recently designed Energy Development Index (EDI) concept, the IEA and UN used four main indicators to measure energy poverty. They are; (i) per capita commercial energy consumption which was the measure of a country's overall economic development. (ii) electricity consumption per capita in the residential sector as the measure of the reliability of the energy service and people's ability to pay for the energy services, (iii) share of modernize fuels in the residential energy use as an indicator of clean cooking facilities and (iv) the share of population with access to electricity (Khandker, Barnes & Samad 2012).

Lack of energy access or energy poverty has been defined also by indexes like cooking, heating, lighting and mechanical power. These categories are qualitatively ranked between zero and five, describing lowest and highest levels respectively. Access to energy has been defined by affordability with the household income taking into consideration the expenditure poverty line. Energy access is defined also by the useful consumption. In this, the change in energy levels and patterns over a given period with the change in population (Khandker, Barnes & Samad 2012).

In economic development, education, health, recreation, science and technology, defense, medicine and politics, energy is a crucial component. While energy is an integral part of human development and survival, the environmental burdens associated with energy production due to greenhouse gas emissions and land degradation, required that sustainable energy sources and harnessed in tandem with sustainable development goals.

The challenges posed by climate change are enormous and efforts at reducing the impacts of climate change on humans must be pursued vigorously. As shown in figure 6, carbon dioxide emissions associated with electricity and heating sector contributes more that 40% of the world carbon dioxide emissions in 2008. The trend has not changed much nearly a decade after, it is therefore necessary that sustainable development and sustainable energy are pursued. In figure

1, Murat (2016) shows the relationship between energy, environment, economy and social sustainability. It is established the basis for promoting sustainable development in tandem with the three areas of concern.

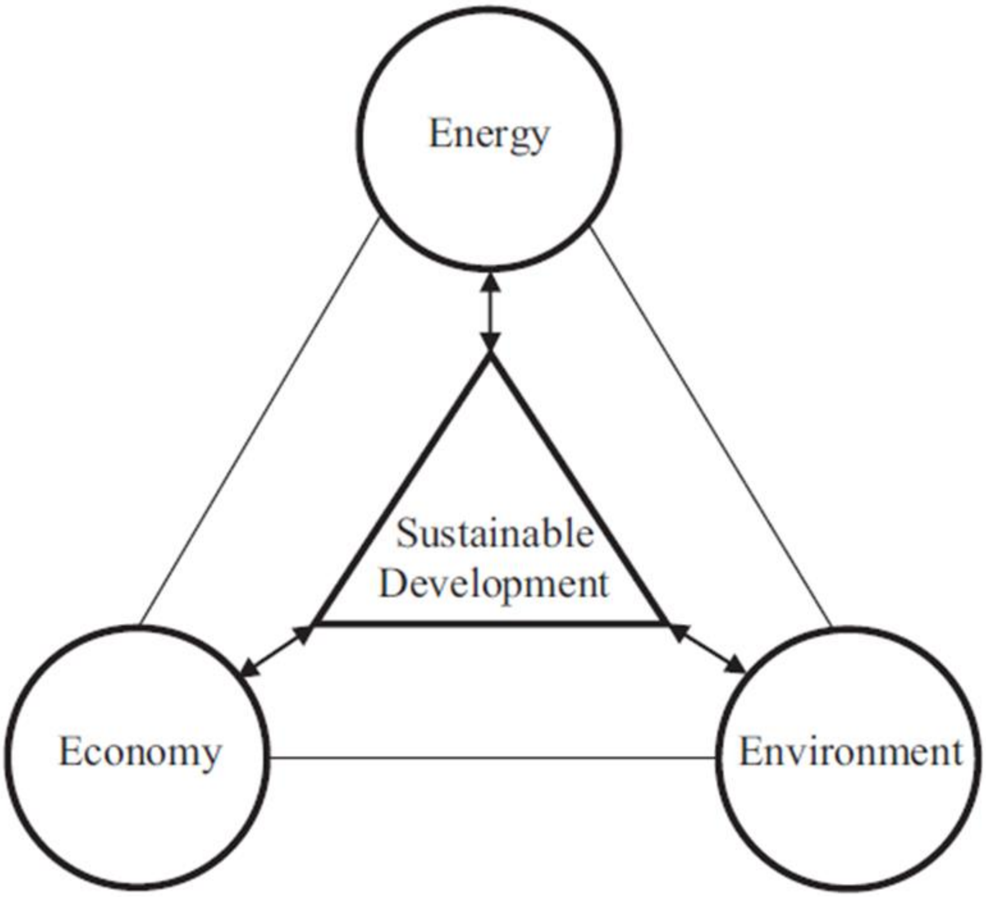

Figure 1: The relationship between energy and sustainable development (Murat, 2016).

2.1 SUSTAINABLE ENERGY SOURCES

Renewable energy sources are classified as clean and less polluting energy resources with less damaging impacts on the environment. When optimally used, renewable energy sources produce less waste and are sustainable in relation to today and future economic and social needs of society. They provide a good opportunity for climate change mitigation when used as a substitute for conventional fossil fuel energy sources which produces greenhouse gases with its attendant global warming potentials (Panwar, Kaushik & Kothari 2011).

Renewable energy sources are the energy sources that can be used in energy production repeatedly. They are self-replenishing energy sources from nature. Examples are solar energy, wind energy, biomass energy, geothermal energy, wave energy, tidal energy, hydropower, etc., and different methods of energy production from the traditional fossil fuel based sources (Panwar, Kaushik & Kothari 2011).

In 2014, renewable energy sources grew against the backdrop of growing global energy demand, particularly in developing economies in the face of plummeting crude oil prices. Although the global energy use increased in 2014, world carbon dioxide emissions which accompany energy production and use has remained relatively stable due to energy efficiency and increasing share of renewables in the global energy mix. There is global awareness of renewable energy sources in mitigating climate change, opening new business and economic opportunities for people and addressing the challenges of lack of energy access to many millions of people without access to any form of energy (REN21, 2015).

In 2013, renewable energy sources were estimated to have supplied close to 20% of world final energy consumption. Renewable heat production was steady and renewable transport fuels increased for the second year running. The fastest growth and biggest capacity increase happened in the electricity generation sector spearheaded by wind, solar photovoltaic and hydropower. The growth in renewable energy has been attributed to many factors, including specific policies targeted at renewable energy sources like feed – in – tariff, guaranteed access to the grid, tax incentives and the growing cost – competiveness of renewables (REN21, 2015).

The four main renewable energy source are; biomass, hydro, wind and solar. Geothermal energy is limited due to its location specific.

2.1.1 Biomass

Biomass energy sources include firewood, animal waste, agricultural residues. Livestock farming wastes, forestry and wood industry wastes, municipal solid waste and vegetable oils. There are many conversion technologies for biomass into heat production, electricity generation and transportation fuels. The biomass potential depends on many factors for a particular location between times. The variation does not only depend on the biomass characteristic but the land use, land cover, labor cost, legislation and policy regime in place. Some of these factors are difficult to measure, thereby making assessment dependent on combined data from observations, mathematical models and narratives (Panwar, Kaushik & Kothari 2011, de Vries, van Vuuren & Hoogwijk 2007).

In 2014, the demand for total primary energy associated with biomass was estimated to be 16, 250 TWh. The share of biomass in the world total primary energy has remained steady at about 10%. The share of traditional biomass in the bioenergy share of the total primary energy ranges between 54% to 60%, consisting mainly firewood, charcoal, agricultural residues, animal dung burned in ovens and open fires for heating and cooking (REN21, 2015).

An approximated 12,500 TWh of heat was produced by biomass in 2014, an increase from 12,360 TWh in the previous year, contributing almost 77% of world total primary energy demand. About 8805 TWh of the global primary energy use for heat was produced from traditional biomass with the rest coming from modernized biomass heat production. The traditional biomass used for energy production was mainly in Asia and Africa with 5305 TWh and 3,222 TWh respectively. Modernized biomass heat production happens in Europe, developing economies in Asia and North America (REN21, 2015).

Power production from biomass increase by 5GW in 2014 making a total capacity of biomass power production to 93 GW. Power production from biomass moved from 396 TWh in 2013 to 433 TWh in 2014. Globally USA, Germany, China, Brazil and Japan led the pack with 69.1 TWh, 49.1 TWh, 41.6 TWh, 32.9 TWh and 30.2 TWh respectively while world biofuel production went up by 9% to 127.7 billion liters worldwide (REN21, 2015).

2.1.2 Hydropower

The International Hydropower Association defined hydropower as a force of water in motion that can be used to produce electricity and many useful applications. The association listed three main hydropower typologies. There are;

Run – of – river hydropower: is the technology that channels running from a river through a penstock to spin a turbine. Typically, a run – of – river has no water storage medium, and provides nonstop electricity for base load operations and an amount of flexible operations due to fluctuations in daily demand which is controlled (International Hydropower Association 2016).

Storage hydropower: A large system uses a storage reservoir or a dam where electricity is generated by releasing water through gates that spins a turbine, the turbine then turns a generator. This technology can provide both the base load, a peak load and has higher full load hours.

Pumped – storage – hydropower: this technology alternate water between two reservoirs, an upper reservoir and a lower reservoir. When electricity demand peaks, water is released from the upper reservoir to the lower reservoir through turbines to generate electricity. The water in the lower reservoir is pumped back to the upper reservoir to keep the cycle. There is a growing tidal wave electricity production. There is some overlapping in these technologies where run of river technology may have a storage and the dammed technology may use pumps to aid the velocity increase of the water (International Hydropower Association 2016).

The total global hydropower increased by 3.6% in 2014 making 1055 GW of available hydropower. The electricity produced in 2014 from hydropower was estimated at 3,900 TWh, which was an increase of 3% in 2013. China, Brazil, India, Canada and Russia are the leading countries with significant installed capacity of hydropower in 2014. China, Brazil, USA, Canada, Russia and India accounted for about 60% of installed hydropower capacity with China adding as much 22 GW of installed capacity in only 2014.

2.1.3 Wind energy

Electricity or power production from wind energy is relatively mature currently and is used in many parts of the world. An emission free technology transforms the energy in the wind to electrical power or mechanical power with turbines. In electricity generation, wind energy comes next to hydropower among renewable energy sources globally and growing rapidly. The power produced from a wind turbine depends on many factors, mainly the wind speed, surface roughness of the location, the full load hours and hub height of the turbine (Panwar, Kaushik & Kothari 2011).

In 2013, wind energy production declined but picked in 2014 with 44% increase from the 2013 figures. In 2014, more than 51 GW of wind energy was installed globally, adding up to 370 GW in global capacity. The 10 leading countries contributed 84% of the end of year capacity with changing situations in emerging markets. There were commercial activities in about 85 countries by the end of 2014 with more than 10MW of installed win energy in about 74 countries and 1 GW installed in some 24 countries. In Denmark, Spain, Nicaragua and Portugal, wind energy produced more than 20% of electricity in 2014 (REN21, 2015).

In the last few years, the capital costs of wind energy have plummeted, due to competition and improvements in the capacity factors of wind turbines. Based on price per kWh, onshore wind energy is almost competitive with a newly constructed coal or natural gas power plants without the renewable energy support incentives. Between 2009 and 2014, an estimate indicated that the levelized cost of onshore wind energy dropped by 15%. Onshore wind energy has become competitive in USA, Brazil, Turkey, Mexico, Australia and host of other nations (REN21, 2015). See figure 2 for the global trend in wind energy installations.

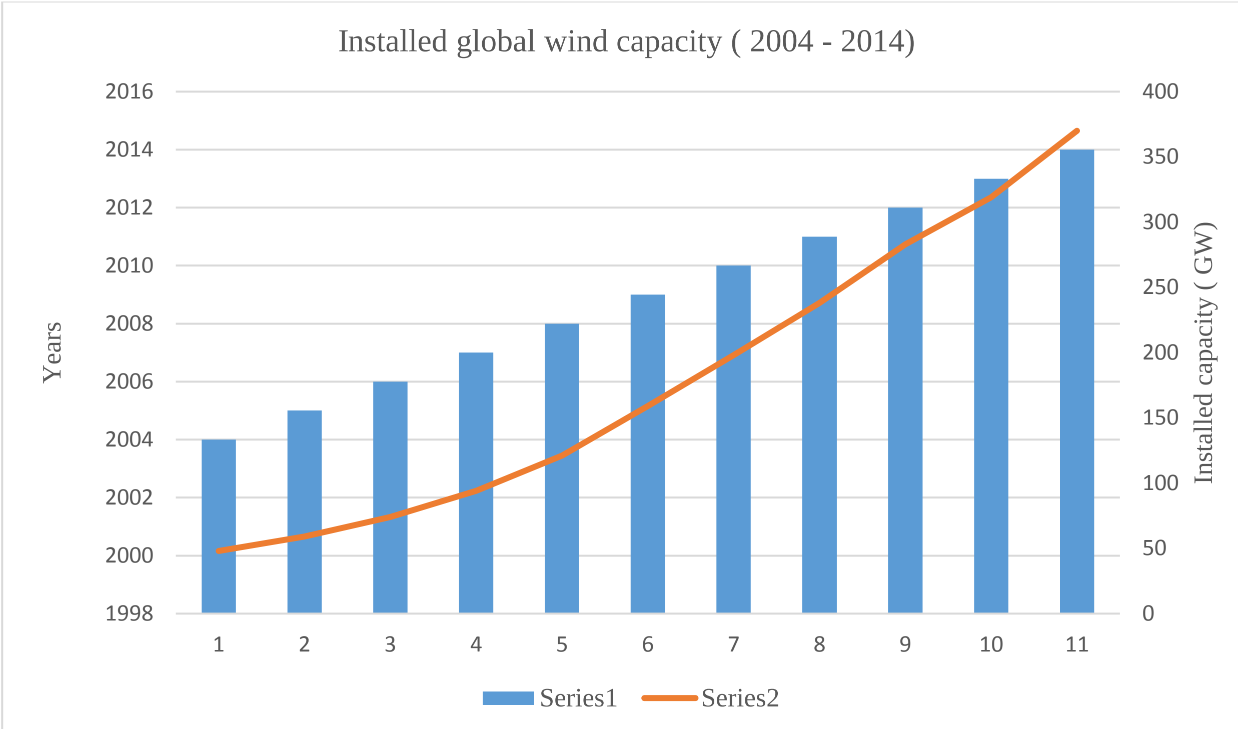

Figure 2: Installed global wind capacity (REN21, 2015).

2.1.4 Solar energy

The National Renewable Energy Laboratory of the Department of Energy of the United States of America defined solar energy as powerful energy source that is capable of heating, cooling, lighting and powering businesses and industries. This is possible because the energy from the sun in an hour is enough to meet the energy needs of world in one year. There are varied technical methods to convert the sun radiation into a useful energy. The most used methods are the solar photovoltaics (solar PV) and concentrated solar power (CSP) (National Renewable Energy Laboratory 2016).

2.1.4.1 Solar photovoltaics

Solar energy is directly converted into electricity conventionally by solar photovoltaic cells, which produce the (PV) effect. The effect is dependent upon the interactions of the photons, with the energy, which equals or higher than the band gap of the photovoltaics material. To avoid losses due to band gap limits, the semiconductors are cascaded with different band gaps. This module produce electricity directly without noise, emissions or vibration and require large surface area for relatively little amount of electricity production (Panwar, Kaushik & Kothari 2011).

In 2014, the production of the semiconductors for PV cells increased with estimates of 45 GW to 60 GW and 50 GW to 70 GW for modules. The cost for electricity produced from PV has become competitive with fossil fuels without subsidies in many countries due to fall in the average module prices. The total installed capacity of solar PV by 2014 was 177 GW with about 40 GW added in 2014 alone. In that year, china added 10.6 GW of solar PV while Japan, United States of America, United Kingdom and Germany added 9.7 GW, 6.2 GW, 2,4 GW and 1.9 GW respectively (REN21, 2015).

2.1.4.2 Concentrated solar power

Solar thermal electricity generation source is a system that use the sun radiation to produce energy through thermal conversion. The solar energy is converted to electricity by the use of solar collector and other accessories. The collector is a heat exchanger that converts the sun radiation energy to an internal energy. The concentrated solar power technology has the ability to store heat energy in cheap and efficient method (Panwar, Kaushik & Kothari 2011).

The CSP market is less developed than other renewable energy sources. Although the market is less developed, there was 27% increase in capacity in 2014, which increased the world capacity to 4.4 GW. Between 2009 and 2014, the world capacity of CSP increased by 46% with the USA leading the market for two consecutive years with capacity increase in India and South Africa. Spain has an installed capacity of 2.3 GW of CSP as the leading world leader in CSP power production. South Africa installed 300 MW of concentrated solar thermal power by the year 2014 (REN21, 2015).

Solar energy significantly contributed to global space heating, cooling and hot water production over the years and is a renewable clean energy sources.

3. METHODOLOGY

3.1 Data collection

Data for the research was gathered from secondary sources. Demographic and economic data was from the Ghana Statistical Service, the Ministry of Finance and the World Bank. While the technical data on the power generation plants and fuel requirements are from the Energy Commission of Ghana. The capital cost, operation, and maintenance cost of renewables were adapted from Child and Breyer (2015) cost estimations for renewable energy technologies in Finland. Where data is not available, other sources were used.

3.2 Data analysis

In order to model the transition based on the energy demand, four key parameters were selected as the factors, which could influence the demand in Ghana. These are population growth rate, rate of urbanization, economic (GDP) growth rate and years (season). To test the assumption that the indicators influence energy demand; an Econometric Views (Eviews) statistical tool is used. Eviews is a statistical tool used for time – series analysis. It was developed by Quantitative Micro Software which is part of a UK based Information Handling Services (HIS). The application can be used for forecasting, estimation, econometric and general statistical analysis. Energy demand is indexed as a dependent variable, which has four independent variables listed above. Data from 1960 - 2015 on the independent variables were used for the estimate.

The Least Square Method was used with an assumption of normal distribution.

The Least Square Model was favored because it is parsimonious. In addition, the residual diagnostics from the models favored the use of the simple Least Square. The Least Square has lower values for the Akaike and Schwarz information criteria. The Least Square model exhibiting higher log likelihood ratio also supports the choice of the simple Least Square.

To account for the noise generally inherent in the data from emerging markets due to paucity and non-synchronous data, a moving average (MA) factor is included in the Least Square model.

In the Least Square Method, population growth was statistically significant indicator for energy demand with probability of 0.0088, indicating the significance at 1%. The rate of urbanization and year are equally significant at 5% levels. This method has an R-Squared of 0.991549 and adjusted R-Squared of 0.980986.

In the Akaike information criterion, the smaller the value, the better the relationship and in the Log likelihood, the bigger the value, the better the relationship, the Least Square Method is of stronger. It is therefore fair to base the energy demand on the four main indicators.

The scenarios were modeled with the Long – range Energy Alternative Planning (LEAP) tool. The tool is scenario – based application for energy policy assessment, environmental accounting and climate mitigation. It is applicable in energy production, consumption and natural resource extraction in an economy. LEAP was developed by a Boston; Massachusetts based Stockholm Environment Institute, United States of America (Kemausuor, Nygaard & Mackenzie 2015).

The tool is applicable for state, regional, national and world scales models. It is simple and good for modeling the energy demand and energy conversion at every stage. It can be used to trace energy demand and its associated environmental burdens. The technology and environmental database of the tool has both technical characters and environmental burden associated with each energy production technology advanced and developing economies (Kemausuor, Nygaard & Mackenzie 2015).

The LEAP software has three main program parameters, the energy scenario, allocation and the environmental database. The energy scenario parameter consist of energy demand, transformation, energy resources, environmental estimates and comparisons. The model uses exogenous data inputs as the main parameters. The energy scenarios develop energy demand for end-uses that depends on demographic factors such as population growth, household size, urbanization and others. The demand side management of the system involves technological efficiency and conversion improvements (Kemausuor, Nygaard & Mackenzie 2015).

The energy demand by any sector of the economy is estimated as the result of an activity level in relation to the level of required energy service and the intensity of the required energy. To project the energy demand of the future, the software uses growth in GDP, population and urbanization.

$$f = TA, bst\ x\ EI, bst \qquad (1)$$

Where f is the energy demand, TA is the total activity, EI is energy intensity, b is the branch, s is the scenario and t is the year (which ranges from the base year to the end year).

$$Q = Stock, ty\ x\ Milleage, ty\ x\ FE, ty \qquad (2)$$

Where Q is the transport fuel demand $_{t,}$y, stock is the number of cars existing in a given year, mileage is the yearly distance travelled per a vehicle and the fuel economy is fuel consumed per unit of vehicle distance travelled, t is the vehicle type and y is the calendar year (Kemausuor, Nygaard & Mackenzie 2015).

In the transformation parameter, energy transmission and distribution from extraction to consumption are run differently for the various methods of conversion such as electricity production, biofuel and charcoal production and many more. Other scenarios are used to represent changes in transformation designs, which shows assumptions in technology and policy changes.

In the electricity generation, available power plants, present and planned power plants, availability factors, and the merit order of dispatch are input by the exogenous method to meet the demand. The fundamental output of the application is the transition or change from a base over a given time period of energy demand, use of renewable energy sources and traditional fossil fuels. There is a detailed analysis provision in LEAP for economic factors of any scenario (Kemausuor, Nygaard & Mackenzie 2015)

4. GHANA'S ENERGY AND SUSTAINABILITY

Electricity has become an important commodity just like water, as an input material for many sectors of the economy. Industry, manufacturing, communication, education, commerce, construction and the entertainment use electricity for daily operations. While electricity has become a necessity, the performance of power sector in Ghana has been saddled with erratic power supply on daily basis in recent times. The World Bank in its outlook 2015 stated that electricity is the second most serious constraint to doing business in Ghana and almost 1.8% of gross domestic product was lost through the energy crisis in 2007(Energy Commission of Ghana 2016, Adom, Bekoe & Akoena 2012) .

The Institute for Statistical, Social and Economic Research (ISSER) of the University of Ghana in 2014 published a study, which indicated that Ghana is losing an amount of $ 2.1 million on daily basis or $ 55. 8 million every month through electricity outages. In 2014, nearly $ 680 million, representing almost 2% of the GDP was lost through the energy crisis. The report further stated that companies lack access to enough electricity supply, which result in less output and loss of sale between 37% and 48%. Reliable, consistent and sufficient supply of electricity is a prerequisite for economic development. Ghana is rated as a lower middle income country by the world Bank with an average per capita electricity consumption of 400 kWh as against the world average of 500 kWh for lower middle income developing nations (Energy Commission of Ghana 2016).

The electricity production, transmission and distribution is largely state – owned. The Volta River Authority (VRA) is the responsible state institution mainly for generation of electricity, the Bui Power Authority (BPA) is responsible for operating the Bui hydroelectric dam and some independent power producers in the generation value chain. The Ghana Grid Company (GRIDCo) is the responsible state institution in charge of transmission while the Electricity Company of Ghana (ECG) and the Northern Electricity Department (NEDCo) that are wholly state – owned are responsible organizations for distribution as shown in figure 3 (Adom, Bekoe & Akoena 2012).

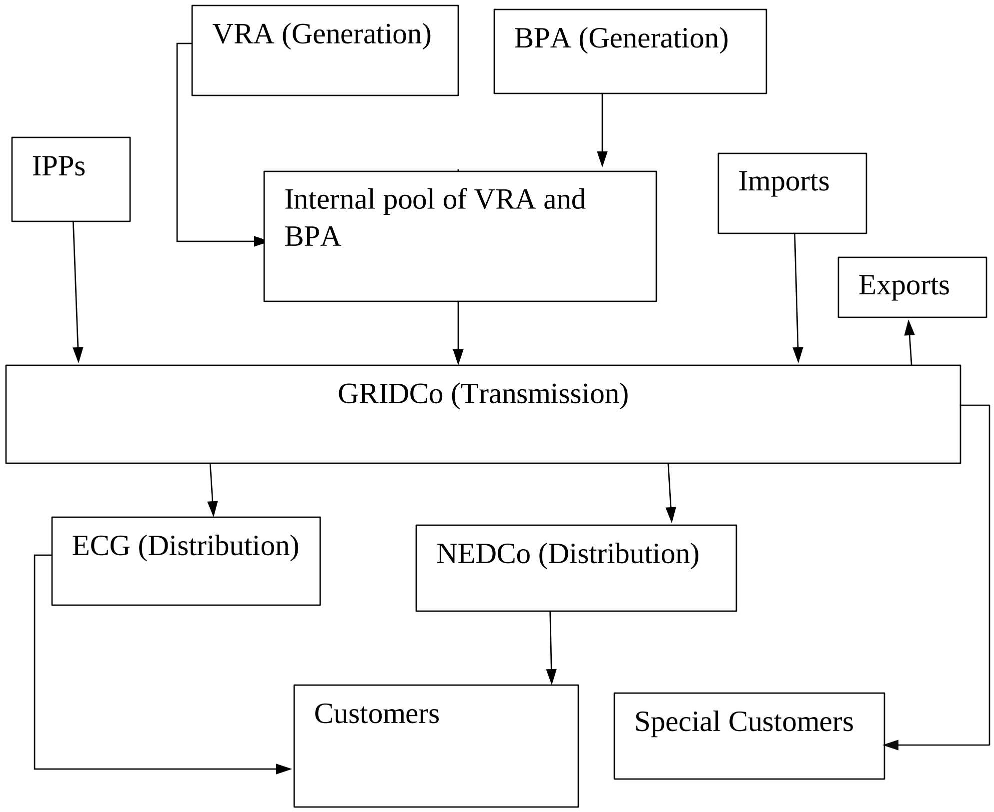

Figure 3. The structure of Ghana's power system (Adapted from Thiam et al 2012).

4.1. CURRENT ENERGY GENERATION SOURCES IN GHANA

Ghana's power generation sector has a mix of various forms of sources. It is largely hydro, thermal, biomass, solar and other sources. Ghana has an unreliable demand projection of electricity. While the energy commission states the actual peak load and the system peak load at 1,970 MW and 2 061 MW respectively for 2014, and projected a growth of 10 to 20% which should make the total peak load of about 2, 400 MW, the system peak load for the third quarter of the year 2016 was 1,700MW. The Africa Centre for energy Policy however describes the 700 MW drop in the system peak load as "unrealistic and defies logic" because the consumption is not possible to record such a margin of drop (Africa Centre for Energy Policy 2016).

4.1.1 Hydro

The Volta River Authority operate the Akosombo hydroelectric dam, the Kpong hydroelectric dam, and dozens of thermal power plants. The authority has an installed capacity of 2,434 MW out of which 2,195 MW was available. The total hydroelectric capacity owned and operated by the authority is 1040 MW of the total available capacity. The rest of the power production comes from thermal power plants, which run on natural gas, light crude oil and other hydrocarbon fuels. The authority has an installed capacity of 2.5 MW solar power (VRA, 2016).

The power generation in the Akosombo and Kpong hydroelectric dams depend on the inflow of water in the Volta Lake. The reservoir elevations in the dams vary according to the inflows from the Volta Lake because of the maximum and minimum operating levels of the reservoirs.

The Akosombo dam has a maximum operating level of 278 ft. while the minimum is 240 ft. see figures 11 and 12 for the elevation trajectory of the Volta Lake and the Akosombo dam.

The Akosombo hydroelectric dam has an installed capacity of 1020 MW with 900 MW availability, out of which 375 MW was available for power generation due to the water levels in the reservoir. The 375 MW of available power produced 4156 GWh of electricity by end of 2015 while the Kpong Dam produced 819 GWh from140MW available capacity (Energy

Commission of Ghana 2015). See figures 4 and 5 for the elevation trajectories of the Volta Lake and the dam.

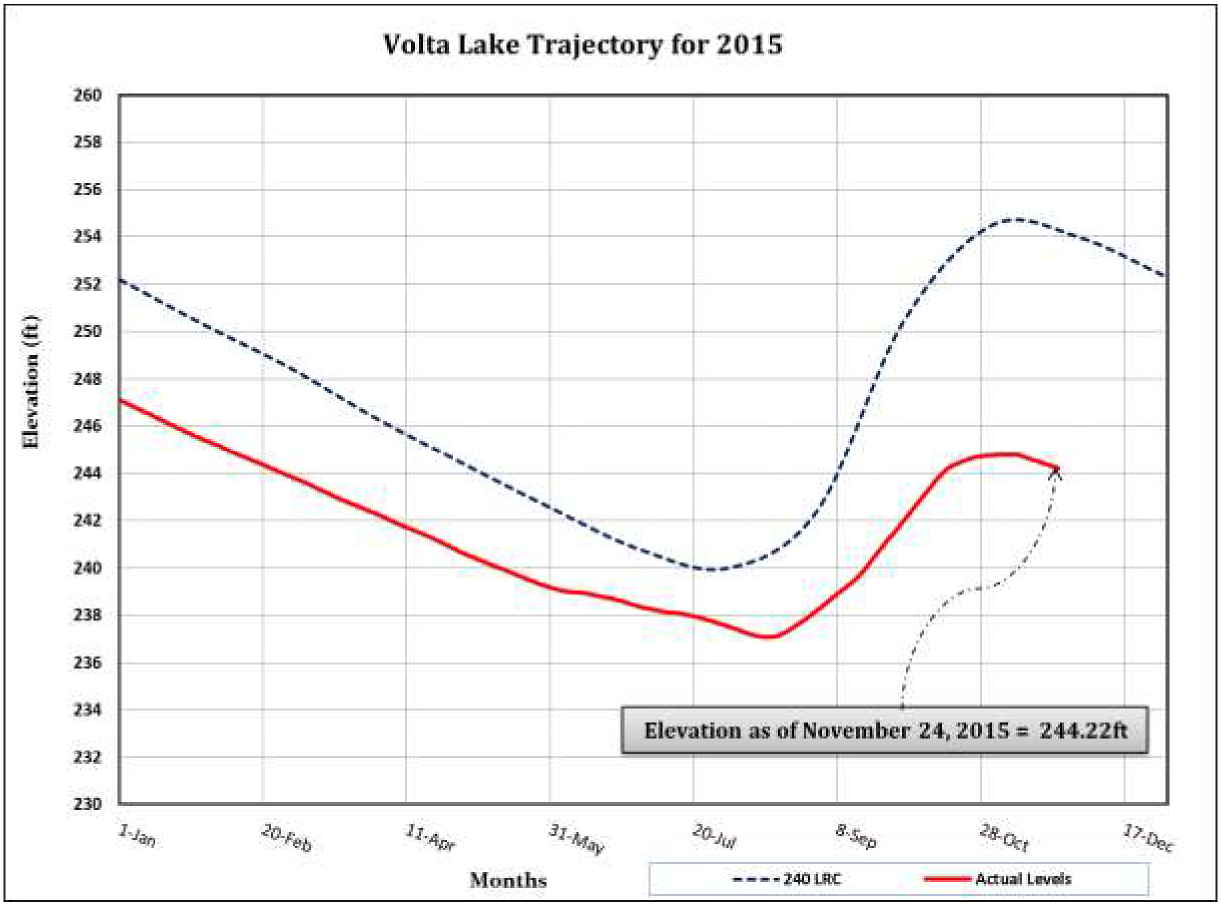

Figure 4: The Volta Lake Trajectory for 2015 (Energy Commission, 2016).

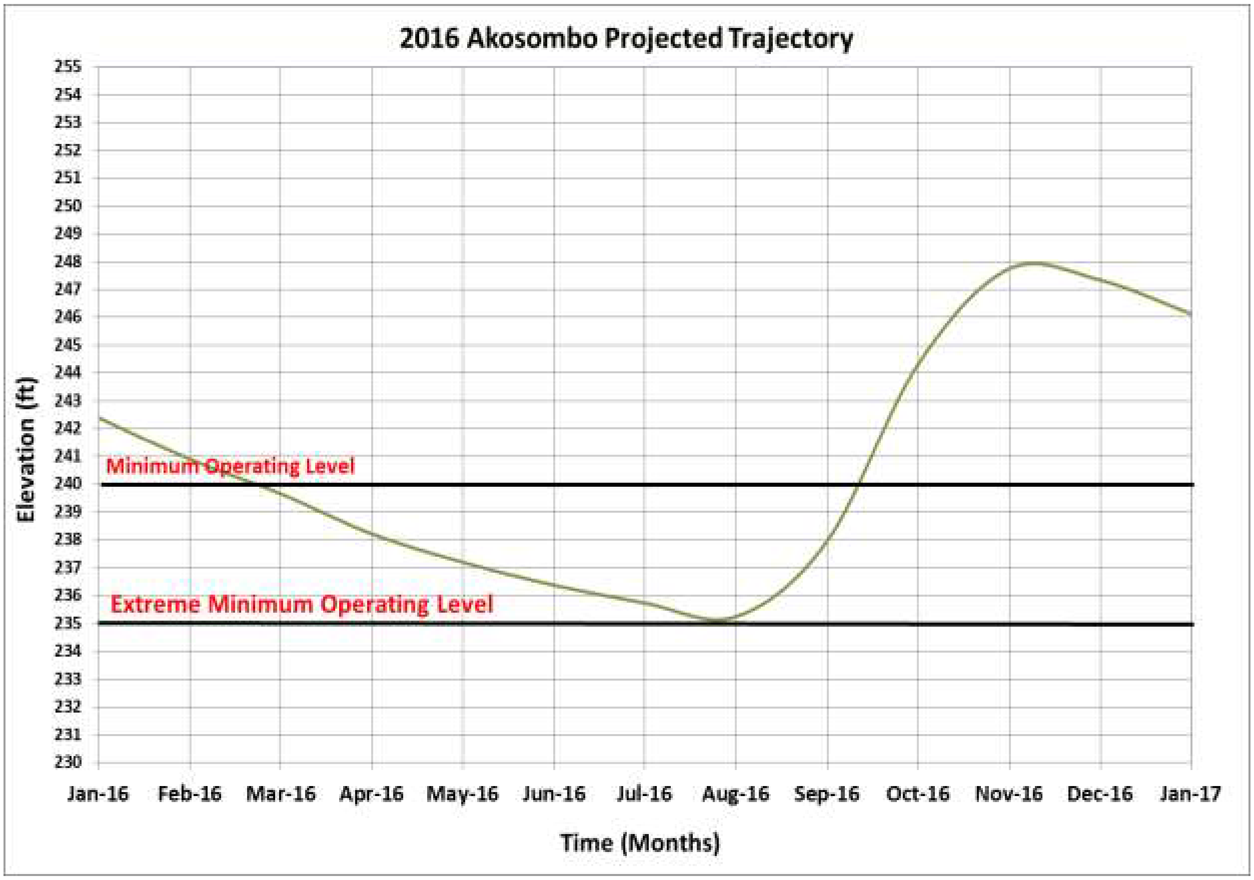

Figure 5: The Akosombo Dam Trajectory, 2016 (Energy Commission, 2016).

The Bui Hydroelectric dam has an installed of 400 MW and dependable capacity of 340 MW with a maximum reservoir elevation of 183 m and was projected to generate about 926 GWh of electricity by December 2016. The dam had a reservoir elevation of 177.3 m and generated about 870 GWh of electricity in 2015 (Energy Commission of Ghana 2015). Figure 6 shows the reservoir trajectory of Bui dam and the operating levels.

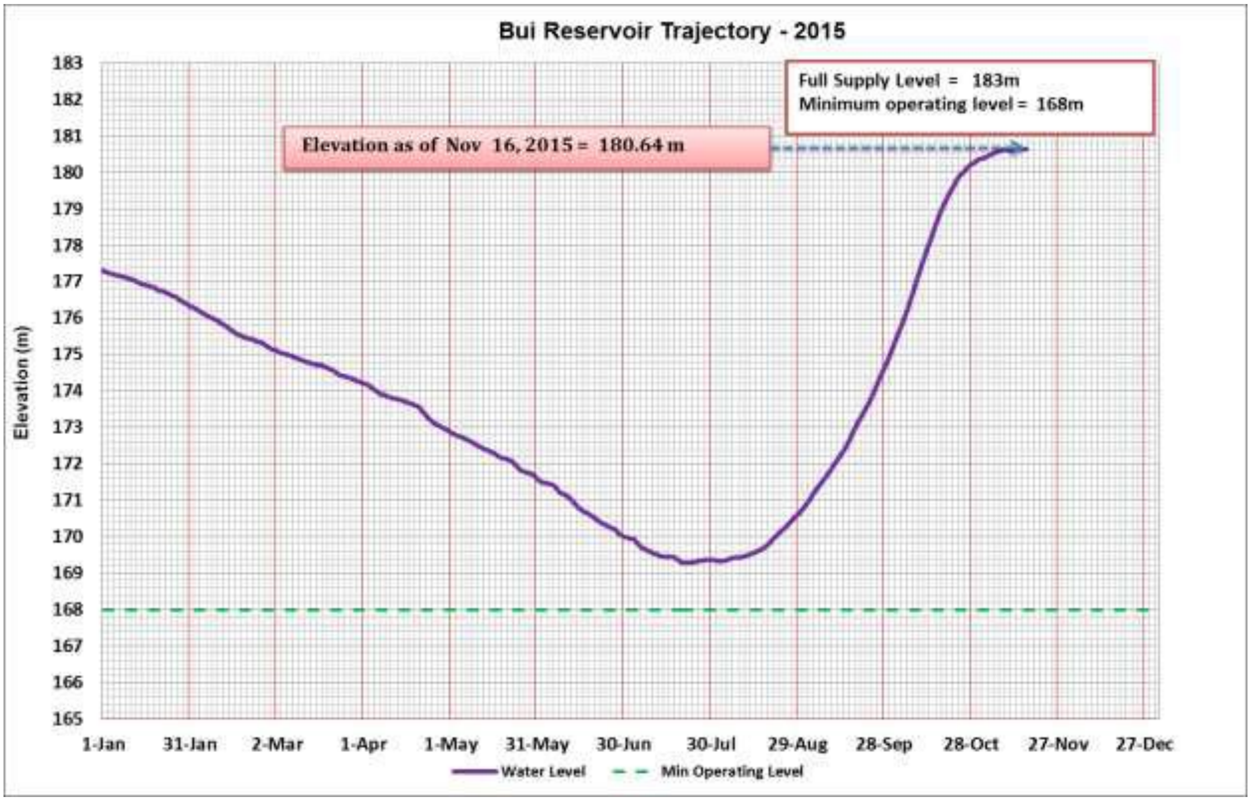

Figure 6: The Bui Reservoir Trajectory, 2015 (Energy Commission, 2016).

4.1.2. Thermal

Total thermal power capacity installed by 2015 was 1,591.5 MW out of which 1376 MW was available. The availability of the thermal plants dropped due to fault is some thermal units to 1298.6 MW and produced 5643 GWh representing 49.1% of the total generated electricity in 2015. This include production from Independent Power Producers (Energy Commission of Ghana 2015). The table 1 below shows the various power plants, their availability and fuel use as at December 2015 and are expected to be available while table 2 shows the expected additions in 2016.

Table 1. Available generation sources for 2016 (Energy Commission, 2016).

Available generation sources for 2016					
Plant	Installed capacity (MW)	Dependable Capacity (MW)	Available Capacity (MW)	Fuel	Availability Factor (%)
Akosombo	1020	900	375	Water	100
Kpong	160	140	105	Water	72
TAPCO (T1)	330	300	300	LCO/ Gas	85
TICO (T2)	330	320	320	LCO/ Gas	85
TT1PP	110	100	100	LCO/ Gas	88
TT2PP	49,5	45	30	Gas	85
MRP	80	70	40	Gas	80
TROJAN	20	18	18	Diesel/Gas	85
SOLAR	2,5	0	0	Sun	18
SAPP	200	180	180	Gas	92
CENIT	110	100	100	LCO/ Gas	92
BUI	400	360	345	Water	92
TOTAL	2812	2533	1913		85

Table 2. Expected additional generation for 2016 (Energy Commission, 2016).

Expected additional Generation sources for 2016				
Plant	Installed capacity (MW)	Dependable Capacity (MW)	Fuel	Availability Factor (%)
KTTP	220	200	Gas/ Diesel	85
VRA/ AMERI	250	230	GAS	90
KARPOWER	250	225	HFO/Gas	90
TT2 PP-X	36	33	Gas	85
SAPP2	186	180	Gas	85
CR Solar	20	0	Sun	15
Total	962	868		

4.1.3 Solar energy

The installed solar energy is mainly the 2.5 MW Volta River Authority project in Navrongo, which generated 4.0 GWh of electricity in 2015 and the 20 MW installed in the central region of Ghana expected to be available in 2016. The projects have availability rate of 15% and 18% respectively. The Ministry of Power in collaboration with the Energy Commission is implementing the Rooftop Solar PV program throughout the country. This program started in 2015 is expected to provide a relief of about 200 MW.

4.2 FUEL FOR ELECTRICITY PRODUCTION

The West African Gas Pipeline Company in 2015 supplied a gas of 46, 911,854 MMBtu or 46, 912 mmscf amounting to 44% of gas used, while the Atuabo gas plant supplied the remainder of 56%. In 2014, the total gas flow was 23, 633.724 MMBtu or 23, 631 mmscf. It is estimated that the gas required to fire all the thermal plants in 2016 will be between 12,000 and 146, 400 mmscf and the projected available gas will be 54, 900 mmscf leaving a supply shortfall of 65, 100 to 91, 500 mmscf. The shortfall translate into a requirement of 5.9 million barrels of light crude oil (LCO), 1.51 million barrels of diesel and 2.8 million barrels of heavy fuel oil (HFO) (Energy Commission of Ghana 2015). See figure 7 for trend of electricity generation by fuel in Ghana.

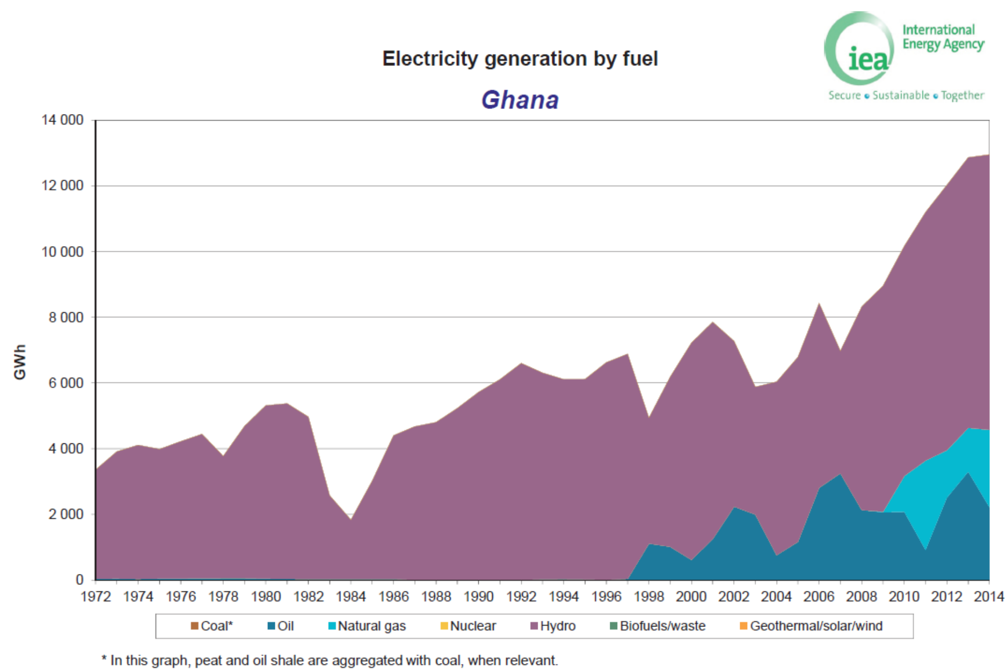

Figure 7: Ghana Electricity Generation by fuel, 2014 (IEA, 2016)

Ghana's energy sector is dominated by biomass mainly in the forms of charcoal and firewood. Charcoal and firewood are the main fuels for cooking and space heating. Figures 8 and 9 shows the energy balance of the energy system of Ghana and final energy consumption of Ghana.

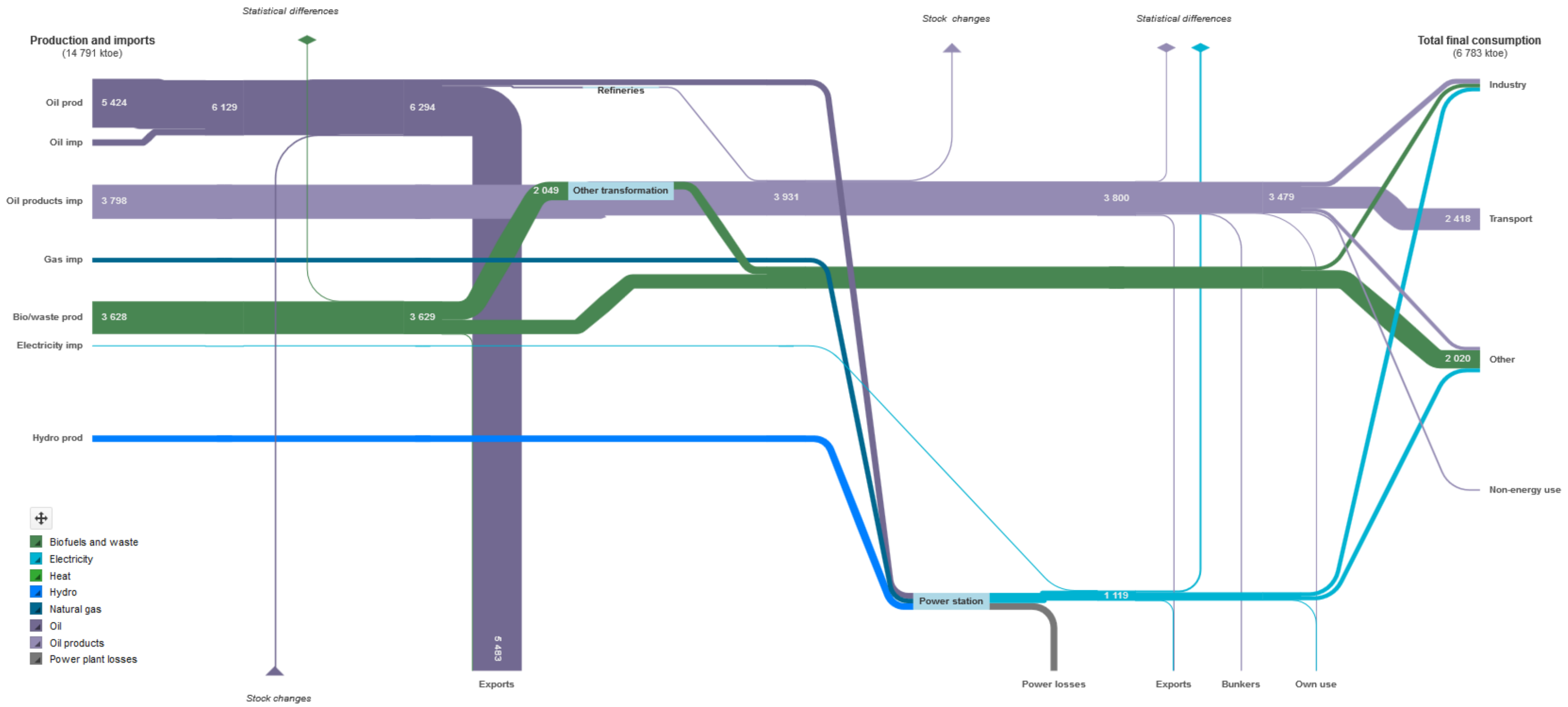

Figure 8: Total Final Energy Consumption, Ghana (IEA, 2014).

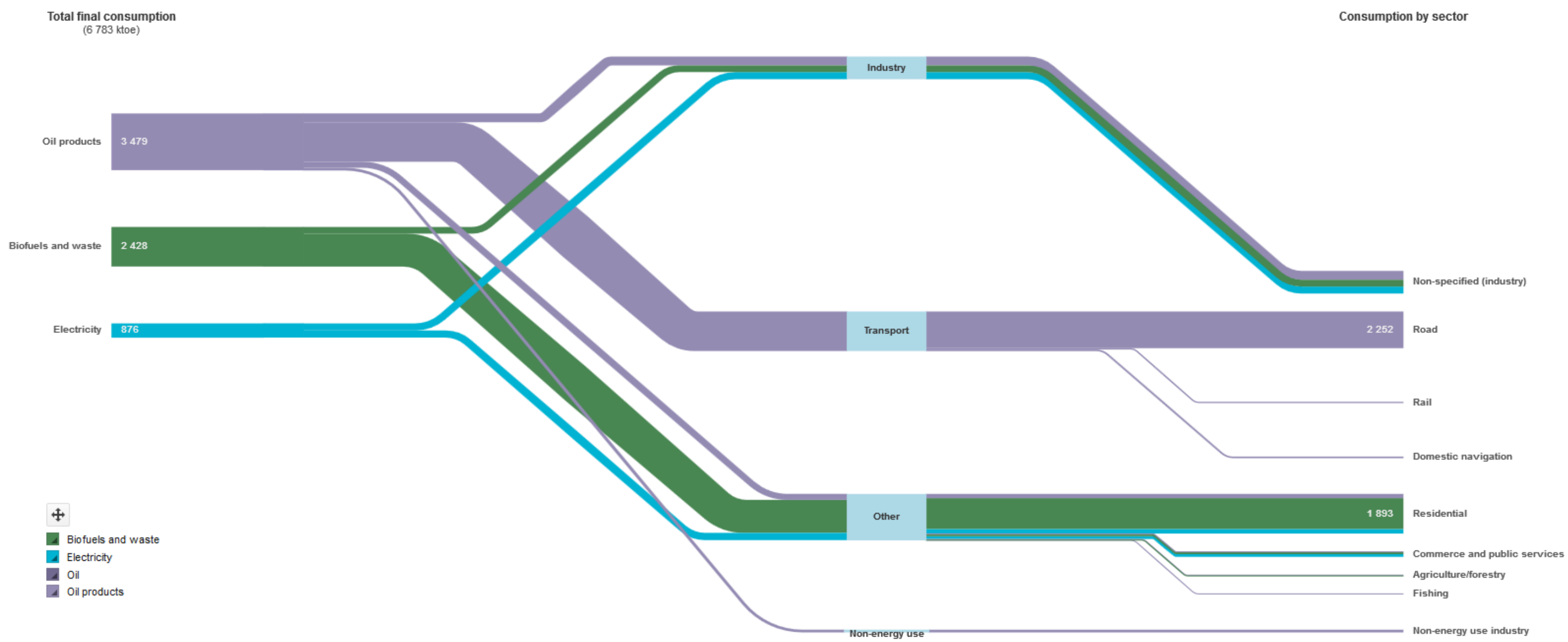

Figure 9: The Energy Balance of Ghana (IEA, 2014).

4.3 SUSTAINABILITY OF THE CURRENT SYSTEM

The current system of Ghana's energy sector may have sustainability concerns from the economic, environmental and social points of view. The economic sustainability concerns may arise from the fluctuating fuel prices and the unreliable supply from the West African Gas Pipeline (WAGPCo). The Energy Commission of Ghana stated that the shortfall of fuel to power the thermal plants in 2016 are light crude oil of 5.9 million barrels at $46 per barrel will amount to $354 million while HFO of 2.8 million barrels at $72 per barrel will amount to $201. 6 million, natural gas of 54,900 mmscf at $ 9 per mmscf will cost $ 489 million and diesel estimate of 1.4 million barrels at $90 per barrel will amount to $ 136 million. The total money required to meet the fuel need of the plants amount to $ 1.18 billion. See the table 3.

Table 3. Estimated fuel needed for thermal plants and cost for 2016 (Energy Commission, 2016).

Type of fuel	**Delivery cost per unit (US $)**	**Quantity**	**Total cost (US$)**
Gas	9/mmscf	54900	489,000,000
LCO	60/bbl	5,9 million	354,000,000
HFO	72*/bbl	2,8 million	201,600,000
Diesel	90*/bbl	1,51 million	135,900,000
Total			**1,185,600,000**

72*l = 1.2 LCO delivery cost and 90* = 1.5 LCO delivery cost

The current generation mix and the projected mix for the 2016 puts Ghana into the category of 'very expensive' grid tariff in Africa. The increase in tariff due to the generation mix has the potential to reduce electricity consumption by commerce, services and industry, which are critical sectors for wealth creation. The expected reduction in electricity consumption in those sectors is expected to affect the overall economic growth of Ghana that is projected to grow marginally from3.5 – 3.9% to 4% in 2016. The current mix is not only detrimental to wealth creation, it will impose extra tariff on residential consumers (Energy Commission of Ghana 2016).

The African Centre for Energy Policy stated that in 2016, thermal power plants provided some supply stability at a "huge cost to consumers as electricity increased by more than 60%". This huge increase in prices did not however guarantee a consistent electricity delivery to the power grid.

The net effect of the statements from the Energy Commission and the Africa Centre for Energy Policy is that the current energy generation mix of Ghana is not economically sustainable as it imposes burden on consumers and the government and power producers. Table 4 shows the tariff for non-residential consumers in 3 years running and table five shows selected tariffs for some customers' categories.

Table 4. Tariffs for nonresidential consumers (Energy Commission, 2016).

Consumption Category (kWh)		**Rate**					
		Gp per kWh			**US cents per kWh**		
	Year	**2014**	**2015**	**2016**	**2014**	**2015**	**2016**
0 - 300		45,2	60,79	96,79	16,99	16	25,47
301 - 600		48,1	64,69	102,99	18,08	17,02	27,1
601+		75,9	102,08	162,51	28,53	26,86	42,77
*US $ 1 = GHC 2,66	2014						
*US $ 1 = GHC 3,80	2015						
*US$ 1 = GHC 3,80	2016						

Table 5. Electricity tariffs for selected customers in 2016 (Energy Commission, 2016).

Consumption Category (kWh)	Residential		Nonresidential		Industries	
	Gp per kWh	US cents per kWh	Gp per kWh	US cents per kWh	Gp per kWh	US cents per kWh
51 - 300	67,33	17,72	96,79	25,47		
301 - 600	87,38	22,99	102,99	27,1		
601+	97,09	25,55	162,51	42,77		
STL - Low Voltage					100,8	26,55
STL - Low Medium Voltage					78,09	20,55
STL - High Voltage					71,71	18,88
STL - High Voltage Mines					113,97	29,99
*US$ 1 = GHC 3,80, March 2016						

Ghana was classified by the World Bank as a lower middle-income country in 2011, Ghana's per capita electricity consumption fell short of the average consumption per capita in the lower middle-income countries. This could be attributed to the erratic power supply due to the fall in the water levels of the reservoirs of the Akosombo and Kpong hydroelectric dams and unstable gas supply for power generation by the thermal plants. Figure 10 shows the per capita electricity consumption by the economic classifications.

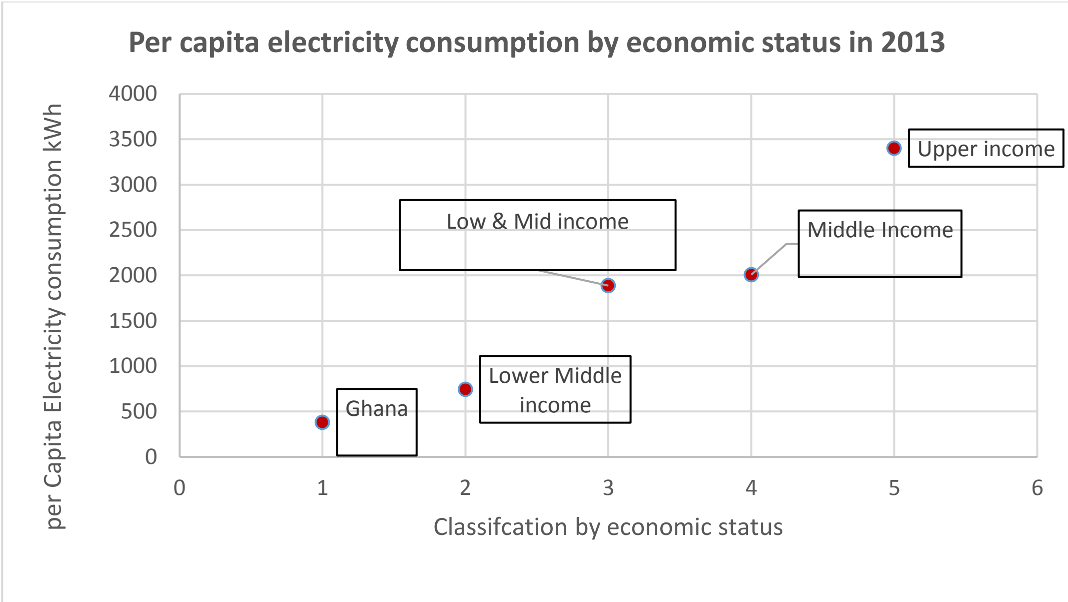

Figure 10: Per Capita electricity consumption by economic classifications, 2013 (Prepared from the World Bank Data).

The electricity consumption per capita for Ghana is approximately 400 kWh while the average per capita electricity consumption for the income category of lower middle income countries is more than 700 kWh. If Ghana's economy status is to improve into the income categories of low and middle income, the capita electricity consumption must increase by more than 1000 kWh, if all things are equal. To achieve that in the current energy generation mix requires substantial gas, LCO, HFO and diesel procurement whose prices are unstable due to international situations. This in turn makes the price of electricity expensive for the consumers, thereby making the system unsustainable economically. This assertion is further strengthened by the ISSER report, which stated Ghana lost close $ 680 million in 2015 due to the power crisis.

One of the major problems of the energy sector of Ghana is the insufficient access to modern energy facilities. The problem has made the dependence on traditional biomass sources like fired wood and charcoal very high to meet household energy needs. It has been reported that 76% of household in Ghana use firewood and charcoal for heating and cooking. This dependency on firewood and charcoal has led to loss of forest resources and environmental degradation, which has been of concern to both stakeholders at all, levels of governance. It has been argued that the dependence on fire wood and charcoal for household cooking and water heating is the main driver of the loss of the nation's forest cover which is estimated at 2% loss per a year (Mensah, Marbuah & Amoah 2016).

The over reliance on traditional biomass to meet the heating and cooking needs of more than 70% of Ghanaian if not controlled will compromise the environmental sustainability efforts by the government of Ghana. To limit the environmental consequences of deforestation due to felling of trees for fuel wood and charcoal, the government launched a liquefied petroleum gas utilization program which saw LPG use more than doubled from 1990 to 2004 (Mensah, Marbuah & Amoah 2016).

Ghana's projected LPG need for 2016 is between 290,000 tones to 300,000 tones for an estimated economic growth of 4.5% for the year. It is however estimated that if the economic growth is above the 4.5% projection, demand for LPG will be between 300,000 tones and 350, 000 tones due also to the increase in demand from households and transportation. Economic growth makes the demand for LPG as a cooking fuel in homes to grow. While the demand for LPG will grow if the economic growth projected is exceeded, there is a limited storage capacity in the country (Energy Commission of Ghana 2016).

These constraints mean that Ghana's dependence on traditional biomass for cooking and heating will continue until there is enough storage and economic capacity to provide modern energy services. This in effect mean that fetching of firewood and felling of wood for charcoal will continue with its attendant environmental consequences.

Although Ghana is not a heavily industrialized country, the country's CO2 emission has been growing steadily, especially in the last 3 years. In figure 11 below, Ghana's carbon dioxide emission per capita is shown. It can be seen that the emissions per capita has been growing steadily. With a growing carbon dioxide emission, deforestation and land degradation because of search for fuel for primary energy, Ghana's energy sector cannot be said to be environmentally sustainable.

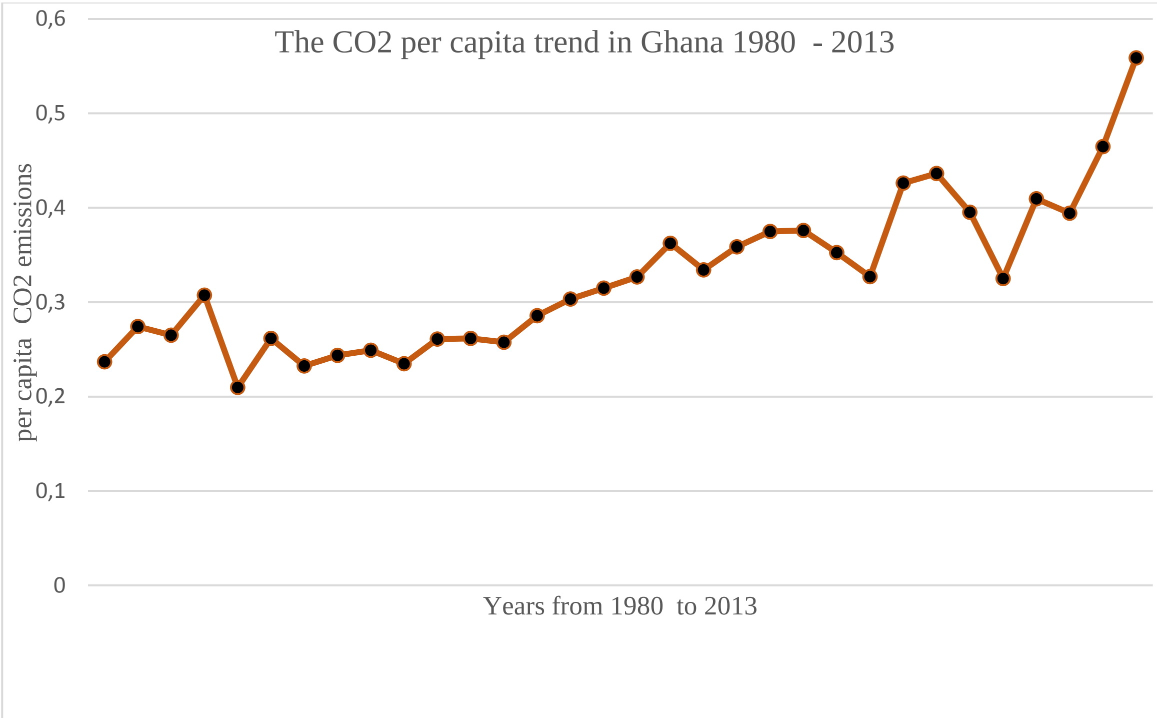

Figure 11: The carbon dioxide emission trend in Ghana (Plotted by the author).

4.4 RENEWABLE ENERGY POTENTIAL IN GHANA

Ghana has an energy policy that outlines objectives to provide reliable, sufficient and cost competitive energy services for industrial, agricultural, transportation and household primary energy sources in line with millennium development goal 6. Ghana is a signatory to many international protocols, conventions, statutes and agreements, including ECOWAS white paper to increase access to energy services (Kemausuor et al. 2011)

Ghana has many renewable energy sources such as biomass, solar, wind and mini hydro, although the latter is limited. The renewable energy potential in Ghana if well harnessed can provide energy security and help mitigate greenhouse gas emissions that are climate change and global warming substances. Ghana’s energy policy has many objectives, among which is to increase renewable energy use in the energy mix to 10% by 2020 and legislate to promote the development and use of renewable technologies (Ministry of Energy 2010).

4.4.1 Biomass

Ghana's biomass resources provide nearly 60% of the total energy use and covers 20.8 million hectares of land cover. The arable and degraded landmark of Ghana if cultivated has the ability to provide biofuels for use. The main challenge with the use of biomass for energy production is the efficiency of the conversion technologies. To use biomass for energy production, the energy policy strategy is to focus on regeneration of forest cover through afforestation and improve the efficiency of the technologies (Ministry of Energy 2010).

There is the mention of solid biofuels, liquid biofuels as well as waste to energy in the energy policy document of Ghana. The waste include municipal solid waste, which can be either solid or liquid, the industrial waste and agriculture residues as biomass for energy production. Combustion, gasification, pyrolysis, anaerobic digestion, fermentation and esterification are some the conversion techniques outlined in the policy document to produce energy from biomass.

Ghana has crops that can be used as feedstock for liquid biofuels. Some of them are sugarcane, sorghum, maize, oil palm, sunflower, soy beans jatropha and coconut. Ghana has agricultural crop residues such straw, cereal stalk, maize, corn, millet and cocoa pods. Cocoa husk, coconut shell and husk, rice husk, oil seed cakes, sugarcane and forest biomass which with an estimated size of 5.52 million hectares. The country has logging residues with 75% rate of recovery for commercial purposes, wood processing wastes such as bark, sawdust, discarded logs, municipal solid waste and food industry waste that can be used in energy production (Duku, Gu & Hagan 2011) .

4.4.2 Hydropower

Ghana has the potential for about 70 small and mini hydropower generation from the identified sites. In the hydro map below, various sites for mini hydro potentials have been shown. It has been estimated that hydropower with capacity of 1.2 MW to 4 MW using the run –of-river hydro technology can provide electricity to rural communities off the national electricity grid while hydropower with capacity ranging from 4 MW to 14 MW which can be connected to the grid (Kemausuor et al. 2011).

In one research, it was shown that the flow of water into some of the rivers has dropped drastically in decades because of the rapid forest loss in their catchment areas making the technical feasibility of the dams difficult. Notwithstanding the dangers pose to the technical feasibilities of some of the identified dams, hydropower potential in Ghana is still doable. The research recommended for instance that for hydro sites in the Volta region of Ghana, which has low heights, an integrated irrigation system should be considered with hydropower where electricity can be generated for the grid and the pumps of the system can provide irrigation for farming services (Kemausuor et al. 2011).

The feasibility study conducted on the identified 70 sites; show that 800 MW is the total potential with medium capacity between 1 and 100 MW. The hydropower utilization of the small hydro is mainly in the Brong Ahafo, Ashanti, Volta, Eastern and Central regions (Gyamfi, Modjinou & Djordjevic 2015).

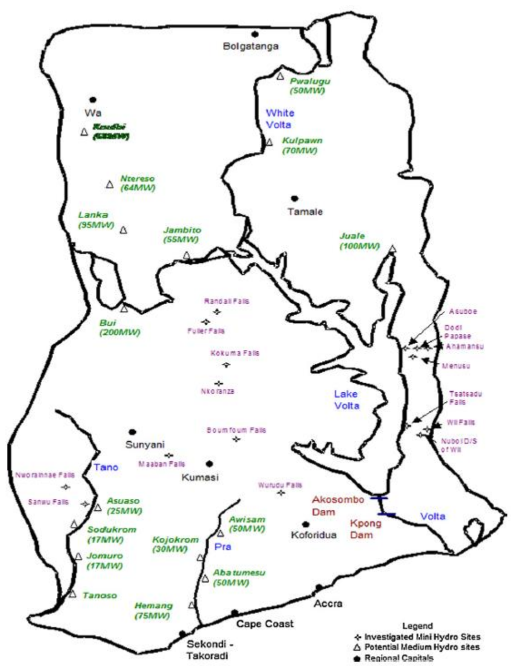

Figure 12: The hydropower map of Ghana (Kemausuor, 2011).

Ghana's hydro potential faces a bleak future in the face of changing climate and rampant deforestation that is attributable to the search for primary energy in the form of firewood, charcoal and other solid biomasses. It is therefore important that reliable and affordable electricity is made available to save the degradation associated with energy needs.

4.4.3. Wind energy

For over two decades, a rigorous assessment of the potential of wind in Ghana gas been carried out. Available data shows that the coastal areas of the country have a wind speed good for wind power generation. Wind speed differ from 3.33 m/s to about 6 m/s taken from the height of 12 m. It has been shown that, the technically and economically feasible wind energy based on the available technology can be achieved at 50 m hub height with wind speeds of moderate 7.1 m/s and 9.0 m/s excellent. While few wind turbines are seen in the country, there is a limited research on the viability of wind energy's share in the energy mix for meeting access to electricity in the country (Kemausuor et al. 2011).

The Ghana meteorological service measurements show that most parts of the country have a wind speed of between 1.7 and 3.1 m/s at 2 m ground height. The surface roughness obstructions make the data from the 2 m ground distance not suitable for large-scale power production. The strongest wind area of Ghana is the south eastern part bordering Togo with a speed between 7.8 and 9.9 m/s and a potential power density about 600 to 800 W/m^2 covering an area of 300 to 400 km^2. The wind potential of the area is projected at 300 MW (Gyamfi, Modjinou & Djordjevic 2015).

A research to update the wind energy areas and potential in Ghana identified Ekumfi, Gomoa Fetteh in the central region, Ningo in the Greater Accra region and Avata and Atiteti in the Volta region as the wind resource sites of Ghana (Gyamfi, Modjinou & Djordjevic 2015). Figure 13 shows the wind map of Ghana.

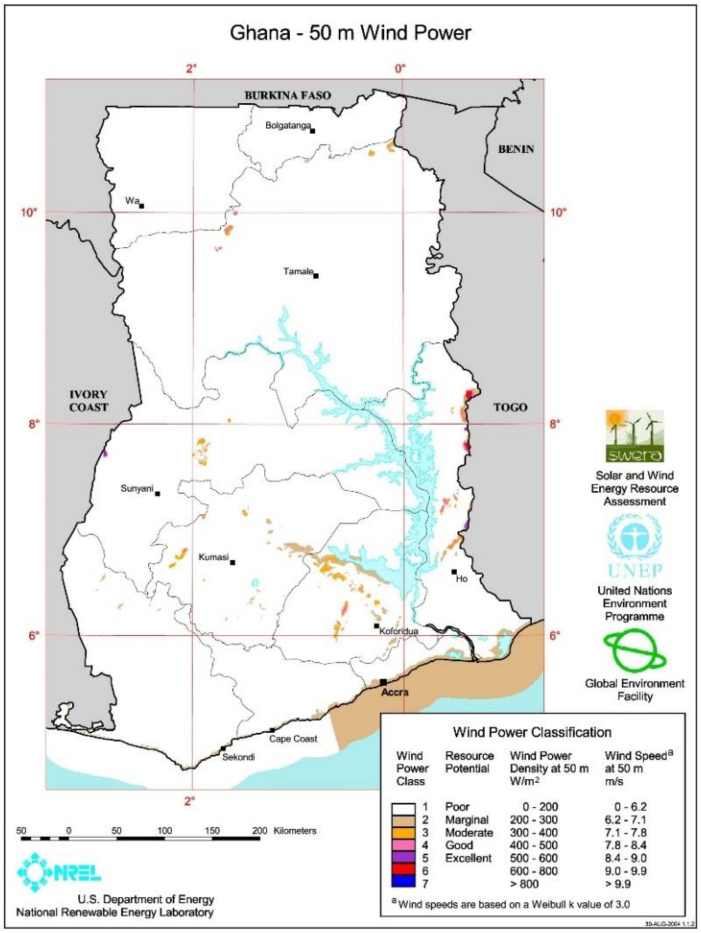

Figure 13: The wind map of Ghana (Gyamfi et al, 2015).

4.4.4 Solar Energy

Ghana is geographically tropical, therefore receives all year round solar radiation. The daily sun radiation in Ghana is between 4.0 and 6.5 kWh/ m^2 with full load hours of 1800 and 3000 in a year. Solar photovoltaics have provided, to some extent electricity access, household lighting and pumping of water across the country, mostly is rural areas. Although there is little information on the actual amount of energy contribution from solar PV, the statistical service of Ghana estimated that about 0.2% of total energy use in Ghana comes from solar energy through lighting (Kemausuor et al. 2011).

Available data shows that the solar radiation is extremely high in most parts of the country, mainly the three northern regions where access to electricity is low, and most people receive electricity supply from the grid for 5 hours to 8 hours a day and the potential for electricity production from solar is high (Gyamfi, Modjinou & Djordjevic 2015).

In figure 14 below, the solar radiation distribution is shown. The entire nation has a good solar radiation to produce electricity from solar PV and rooftop solar energy. The northern regions have the highest radiation while the western, eastern and southern parts of the country have relatively low solar diffusion, nevertheless solar electricity can be produced on large scales.

The literature review on the availability and the potential of renewable energy use in Ghana show that, the country has enough biomass, sun radiation and mini hydro potentials to meet the energy demand of the people. Although large wind energy is not suitable for most part of the country, the eastern part of the country, bordering the Republic of Togo has a wind energy potential that can be harnessed for use.

The biomass potential in form of municipal waste, forest residues, cocoa shells, palm shells and forest woods are in abundance for exploitation for energy production. Deploying the appropriate technologies and the legislative framework for biomass energy sources can help meet the energy needs of Ghana and reduce the over reliance on fossil fuels and natural gas which are driving the prices of electricity to end user.

The most potent renewable electricity for Ghana is solar as the country receives solar radiation throughout the day. Solar PV and rooftop solar energy should be able to provide lighting for communities without the grid.

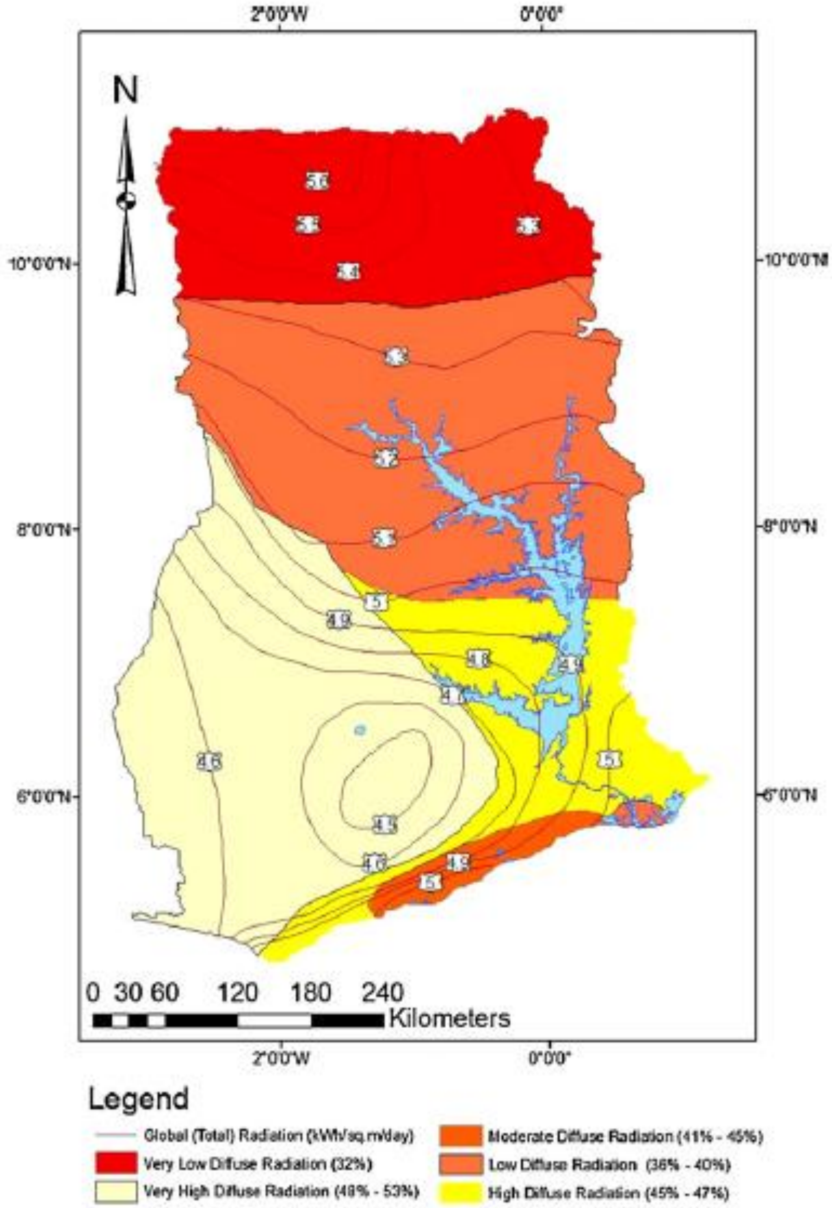

Figure 14: The solar Map of Ghana (Gyamfi et al, 2015).

5. THE SCENARIOS, RESULTS AND ANALYSIS

5.1 THE SCENARIOS

This section provide the scenarios under which the energy transition in the energy mix of Ghana is expected to follow in changing scenarios from 2015 - 2030. There are three scenarios, the baseline scenario based on current data and inbuilt data in LEAP, the ten percent (10%) Government of Ghana's renewable energy target in the electricity generation mix by 2020 and the final scenario of more than thirty percent (30%) in the energy mix by 2030.

5.1.1 The Baseline scenario (2015)

To make future projections of energy demand, LEAP's base year is 2010. In this work however, 2015 is the base year, where data is not available, the latest year for which data is available is used. Energy demand is projected from 2015 to 2030 based on available data. The demand sectors considered in this research are household, agriculture, commerce and industry. The energy demand for the agriculture, commerce and industry are usually based on the economic value added or the outputs based on produce. In this research, apart from household demand, all other demands are based on the economic value added, i.e. the share of GDP held by the sectors.

The residential sector is divided into urban households and rural households, and urban and rural further divided into connected to the grid and not connected to the grid. The Ghana Statistical Service defined urban areas as a location with 5000 or more people while rural areas is a location of less than 5000 people. The energy consumption by the households differ significantly based on the location. For example, LPG has a higher consumption percentage in the urban households than the rural households, where firewood consumption is higher in the rural areas than urban households. Assumptions have been made into the model based on the estimates and projections made in the population growth and consumption shifts.

In the transformation branch of the model, technologies for electricity production is computed based on the 2015 power generation data provided by the Ghana Energy Commission. Transmission and distribution branch of electricity and natural gas is also contained in the transformation branch. There is a reserve margin of 15% in the system, a percentage needed to prevent light out or dumsor as it is locally called.

5.1.2 The Ten Percent Scenario (2015- 2020)

The ten percent (10%) renewable energy scenario examines how the energy mix of Ghana will change over time until 2020 based on the government's renewable energy target in the electricity generation mix. Energy demand estimates are based on projections for population growth and per capita income growth of 2.3% and 3.1% respectively.

Based on the 2010 population and housing census, Ghana has estimated 5.5 million households, with the 2.3% population growth rate, households in Ghana will reach more than 6 million by 2020. Ghana in the baseline scenario has urban population of 54%, which is expected to reach 58% by 2020. Because urban areas consume more energy than the rural areas, an increase in urban population has the potential to increase the demand for energy services such electricity, liquefied petroleum gas (LPG), charcoal and firewood.

Electricity production in the baseline scenario was derived from the 2016 Energy Demand and Supply Outlook for Ghana prepared by the Energy Commission. The Outlook further provided expected additional electricity generations to be added to the stock of power plants in 2016, this scenario assumes that all expected power generation sources in 2016 have been added to meet the demand and therefore meet the renewable energy target. The total hydroelectricity capacity installed in the baseline scenario is 1550 MW; however, maximum capacity available has an average of 80% due to the water level in the reservoirs.

Because of the changing rainfall pattern, this scenario assumes availability factor of 70% in 2020 for the hydroelectricity plants. Thermal power plants fired by natural gas in the baseline scenario totaled 1591MW with maximum availability of 70%, which is mainly from the Independent Power Producers (IPPs). This scenario assumes 60% maximum availability by 2020 due to the erratic supply of gas from the West African Gas Pipeline Company (WAGPCo) and the Ghana Gas Company, the main gas suppliers for the power plants in Ghana. In reality, some thermal plants that run on dual fuel, (LCO or Natural Gas) but the scenario assumes only natural gas as the fuel source due to cost considerations and lack of information on when the plant may run on natural gas or light crude oil.

Solar energy's contribution in the baseline scenario out of the total installed capacity was less than 1%, that was the only renewable grid electricity available and an additional 20MW is expected to be available in this scenario. The Energy Commission's 2016 Outlook shows that a permit to build more than 2000MW ground mounted solar power plants has been granted, based on that permit; this scenario assumed an additional capacity of 1000MW could be available in 2020. Although permits have been granted to build many other power plants that are renewable, solar is the only one with a relatively short construction time due to the processes that others must go through. Government has given approval for a 700MW super critical bituminous coal power plant scheduled to be available by 2020.

5.1.3 The Final Scenario (2020 – 2030)

In the final scenario, Ghana's households will be more than 7.5 million based on the yearly population growth and the energy demand is expected to grow commensurate with the growth in the population. The fuel demand is expected to grow, as LPG and charcoal consumption are expected to increase in share as firewood declines. Energy intensity of the appliances such as refrigerator, fan, bulbs and television are expected to reduce due to government policies to replace old refrigerators and high intensity bulbs with compact fluorescent bulbs. Urban population is to reach 65% of the population by 2030 in this scenario.

In the transformation branch, existing hydro plants are to have 65% maximum availability while new mini hydro dams are to be constructed with total capacity of 500 MW and 55% Availability. Wind power, additional solar, wave power plant, biomass fired plant and municipal solid waste fired power plants are assumed in this scenario to meet the energy demand of the system.

In this scenario, urban households are assumed to have 100% access to electricity while the share of fuel provided by charcoal, LPG and firewood are 35%, 30% and 35% respectively. Rural Electrification is assumed to increase from the current 41% to 60% by 2030, while charcoal, LPG and firewood provides 40%, 20% and 40% of rural fuels respectively. Kerosene is the main fuel for lighting in areas without access to electricity

5.2 RESULTS AND ANALYSIS

In this section, the results from the scenarios are presented and analyzed.

5.2.1 THE BASELINE SCENARIO

In the baseline scenario, final units of energy demand is totaled 46.8 million GJ with household, commerce, industry and agriculture having 15.6 million GJ, 8.5 million GJ, 17.0 million GJ and 5.7 million GJ respectively.

Urban households with 85% electricity access amounted to a total consumption of 1440 GWh with refrigeration and lighting taking the most shares with 1247.3GWh and 110 GWh respectively. In figure 15, the fuel demand by urban area in charcoal, LPG, firewood and kerosene amounted to 3012 GJ with shares of 1110 GJ, 224 GJ, 1665 GJ and 13 GJ respectively. Firewood is the dominant fuel in the rural fuel demand with 2511.0 GJ out of the total fuel demand of 3258 GJ as shown in figure 16. In figure 17 below, the total fuel demand for the households is about 16000 GJ with urban area having more than 50%.

The demand for electricity in rural Ghana with 41% electricity access is estimated at 43 GWh with refrigeration demand being more than 80% with 38 GWh. Although urban population is more than the rural population, fuel demand in rural Ghana is slightly high in ratio to the population distribution. This phenomenon could be attributed to the efficiencies associated with the cooking facilities. LPG and Charcoal combustion in advanced stoves and ‘coalpots’ have better efficiencies than the traditional three legged stoves mainly used in rural areas.

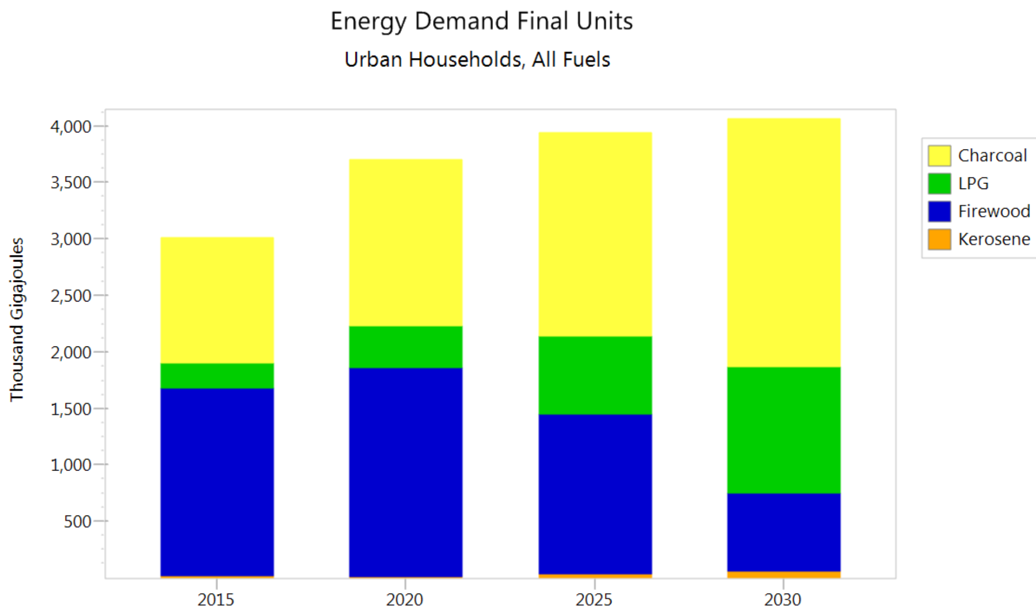

Figure 15: Urban Household Fuel demand

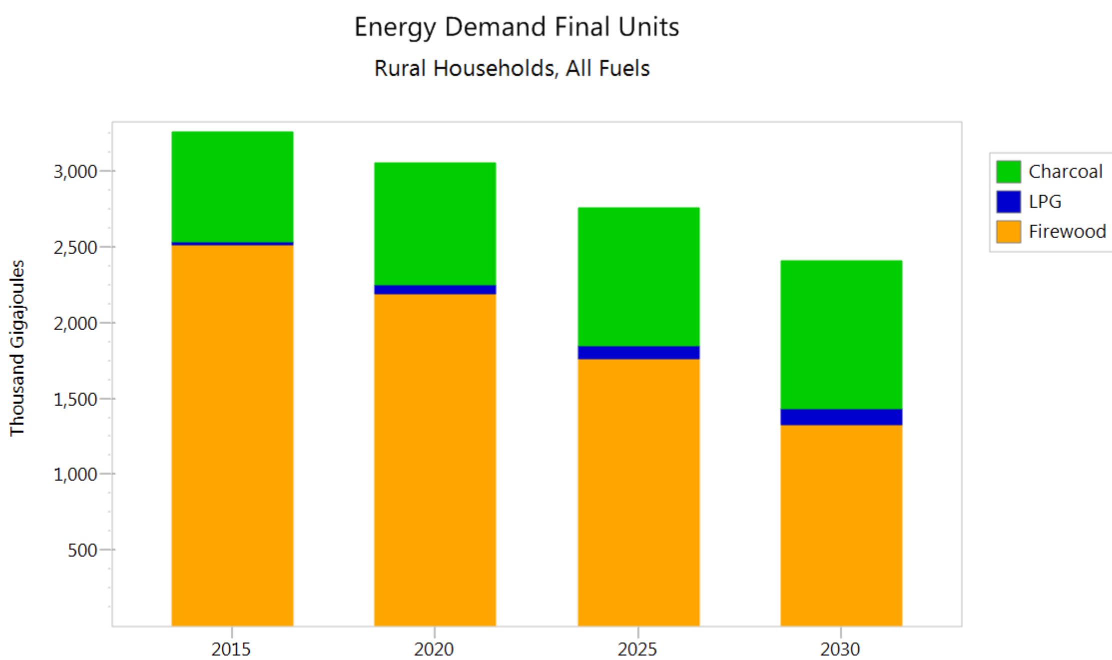

Figure 16: Rural Households Fuel demand

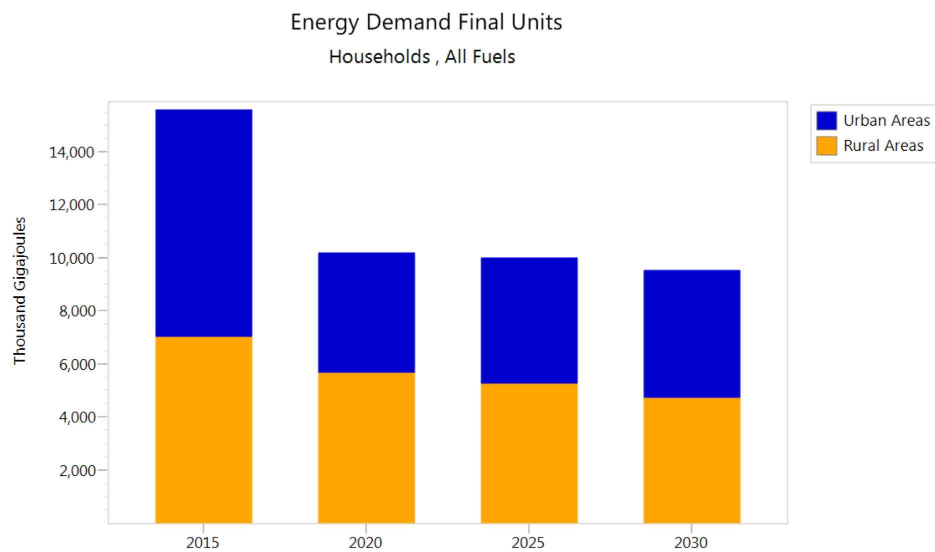

Figure 17: Household energy demand

Commerce and services sector's demand for energy amounted to 8.5 million GJ, which is mainly electricity and Charcoal with 6.6 million GJ and 1.7 million GJ respectively. Industry energy demand totaled 17 million GJ, mainly electricity, oil and wood. Electricity demand of 5.9 million GJ, oil of 7.9 million GJ and wood of 3.5 million GJ. Industry's share of the GDP in 2015 was 28% of economic value added while Commerce and Services contributed more than 50% of economic value. Agriculture has a demand of 5711.8 GJ, which is entirely oil with 21% share of economic value added in the GDP. In table 6, the industry and household biggest demand sectors with more than 36% and 33% respectively of the total demand, while commerce and agriculture held the lower shares with 18% and 12% respectively.

Table 6. Energy Demand by sector in 2015

Energy Demand Final Units All Fuels Branch: Demand Units: Million Gigajoules				
Branches	2015	2020	2025	2030
Households	**15,6**	10,2	10,0	9,5
Commerce and Services	**8,5**	15,6	29,7	58,2
Industry	**17,0**	25,3	39,5	61,7
Agriculture	**5,7**	6,3	7,2	8,2
Total	**46,8**	57,4	86,4	137,6

The total installed capacity of the electricity generation was about 3000 MW with hydro constituting about 1500 MW and thermal plants being the rest. The electricity production from the hydro power plants amounted to 6 TWh while thermal plants produced 5 TWh making a total electricity produced of 11 TWh. The low electricity production out of the installed capacity could be the result of the low availability of the hydro plants due to the low water levels in the reservoir and lack of sufficient fuel to fire the thermal plants.

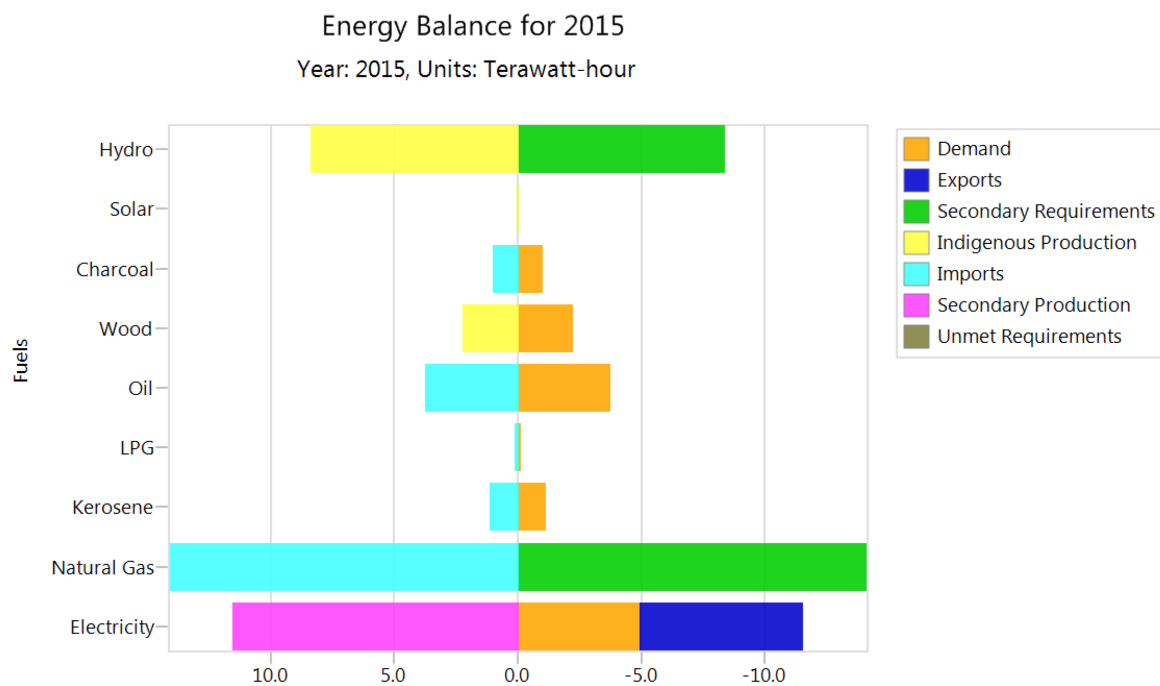

Figure 18: Energy Balance, Baseline Scenario

The figure 18 above shows the energy balance of the baseline scenario. Natural gas, LPG, kerosene, oil and charcoal are imported into the system to meet demand and secondary requirements. The biggest imported fuel is the natural gas of about 15 TWh used to power the thermal plants. It must be stated that the Ghana Gas Company, which is a state-owned gas-processing plant provides a certain amount of gas for energy generation, however, data on the supply is scanty, therefore an assumption is made that all natural gas is imported. Charcoal is produced in Ghana as a fuel for domestic and commercial use, but due to the unreliable data on production output, assumption is made to have imported all charcoal need in the baseline scenario.

5.2.2 THE 10% RENEWABLE ENERGY BY 2020

The final units of energy demand are estimated to grow from 47 million GJ to 57 million GJ, a percentage increase of more than 22%. Households' energy demand is estimated to decline from 15 million GJ to 10 million GJ. The drop in the household energy demand is due to the energy efficiency programs launched by the government to ensure about 10% reduction in the energy intensities of refrigerators and lights. Urban household electricity demand for refrigeration will be 123 GWh followed by lighting with about 10 GWh. television, fan, iron and other appliances will make the rest of the demand.

Urban household fuel will be charcoal, LPG, firewood and kerosene that amounted to 3698 GJ. Charcoal demand is projected to grow from 1110 GJ to 1466 GJ while LPG demand is expected to move up from 224 GJ to 373.2 GJ. Firewood will continue to be the dominant fuel in in the year 2020 with slight upward adjustment from 1665 GJ to 1848 GJ as kerosene is expected to decline to 10 GJ from 13 GJ due to increase in share of the urban population with access to electricity.

Rural population's electricity demand is expected to grow in relation to the population growth with refrigeration and lighting as the leading demand appliances. The share of rural population without access to electricity uses kerosene and the main lighting fuel and the demand in this scenario is estimated to decline from 3607 GJ to 2450 GJ as access to electricity is increased in the rural areas.

Rural fuel demand in 2020 is projected to decline in this scenario from 3258 GJ to 3051 GJ due to the rural urban migration, which puts the urban population at 59 % in 2020 and the penetration of LPG use in line with the government's policy of promoting clean cooking facilities. Charcoal and LPG shares in the fuel mix are estimated to increase significantly from 724 GJ and 23 GJ to 806 and 57 GJ respectively, while firewood demand will drop from 2511 GJ in 2015 to 2187 GJ.

Commerce and services sector's demand is projected to grow by 83.5% from 8.5 million GJ to 15.6 million GJ. This projection could be assigned to the expected growth of 3% per year of the sector. Electricity demand is calculated to reach 14 million GJ while oil, wood and charcoal will be 0.4 million GJ, 0.1 million GJ and 1.1 million GJ respectively.

Industry's demand is projected to grow from 17 million GJ in 2015 to 25 % in 2020, an increase of approximately 49%. The main industry fuels are electricity, oil and wood with electricity providing about 50% of the total demand. Industry's share of economic value added is estimated to grow at 4% in line with the average GDP growth of Ghana in 2015 as shown in figure 19.

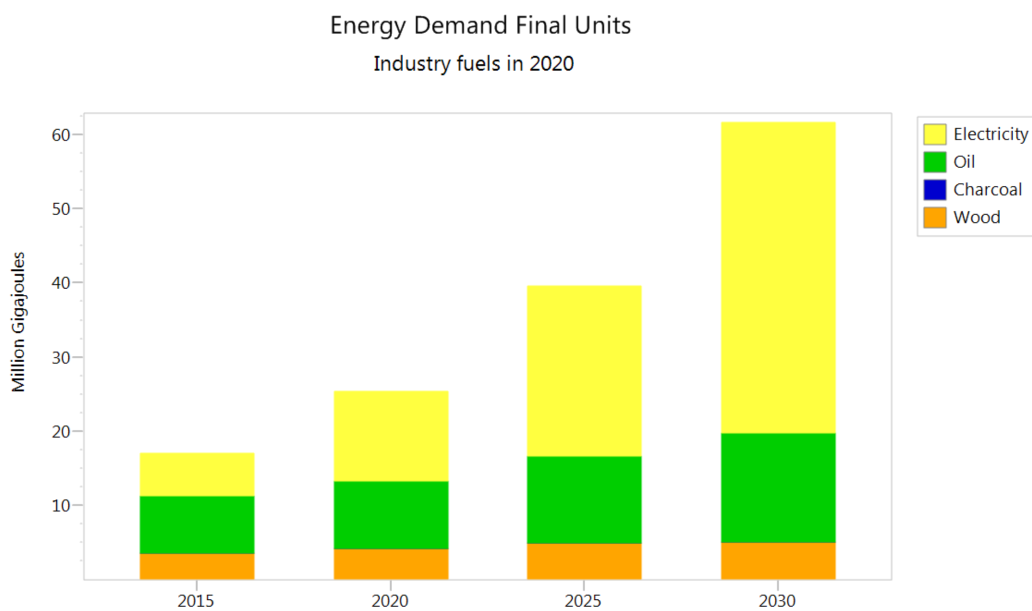

Figure 19: Industry Fuel demand in2020

Oil is estimated to remain the main fuel for agriculture in the year 2020 with the sector's demand increasing from 5711 GJ in 2015 to 6268 GJ. Oil demand for agriculture is projected at 6266 GJ while electricity will remain very low with 1.3 GJ. The dominance of oil in the agriculture sector can be linked to the low levels of irrigation farming and the unorthodox methods of farming.

In energy production for this scenario, additional power plants are expected to be added because of the permits issued for their construction. A coal power plant of 700 MW, an estimated solar plant of 1000 MW, a waste energy plant of 200 MW, a 591 MW natural gas fired thermal plant and 100 MW each for wind and wave plants. The availability of hydro power plants are estimated to reduce from 1550 MW to 1000 MW due to rainfall pattern changes which has affected the water levels in the dams. The availability of thermal plants of 1591 MW is projected to reduce to 1200 due to fuel and financing constraints.

The total installed capacity of power plants will amount approximately 5000 MW in 2020 with renewable energy sources amounting to 1400 MW representing 28% of the capacity.

The outputs by the various plants with varied efficiency and availability factors are estimated to be 8 916 GWh. Hydro and thermal plants amounted to an output of nearly 5000 GWh. The rest of the renewable energy sources are estimated to generate more than 3500 GWh of electricity, representing more than 39% of electricity as shown in the figure 20.

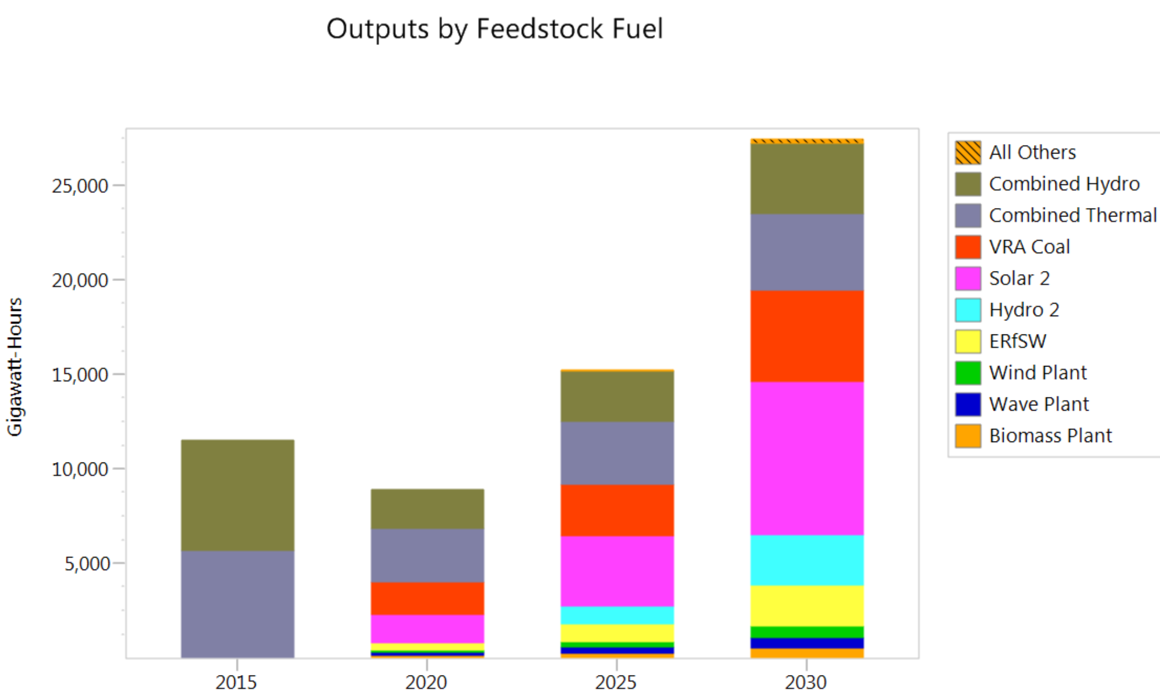

Figure 20: Outputs by the Plants

The energy balance of the system is shown in figure 21 below. It is important to note that due to the reduction in the availability of the thermal plant, natural gas importation has been reduced to 7.0 TWh more than half of the baseline import. Bituminous coal of close to 5.0 TWh is imported to meet the coal demand for the coal-fired plant. Oil imports are estimated at 5.0 TWh in order to meet oil demands.

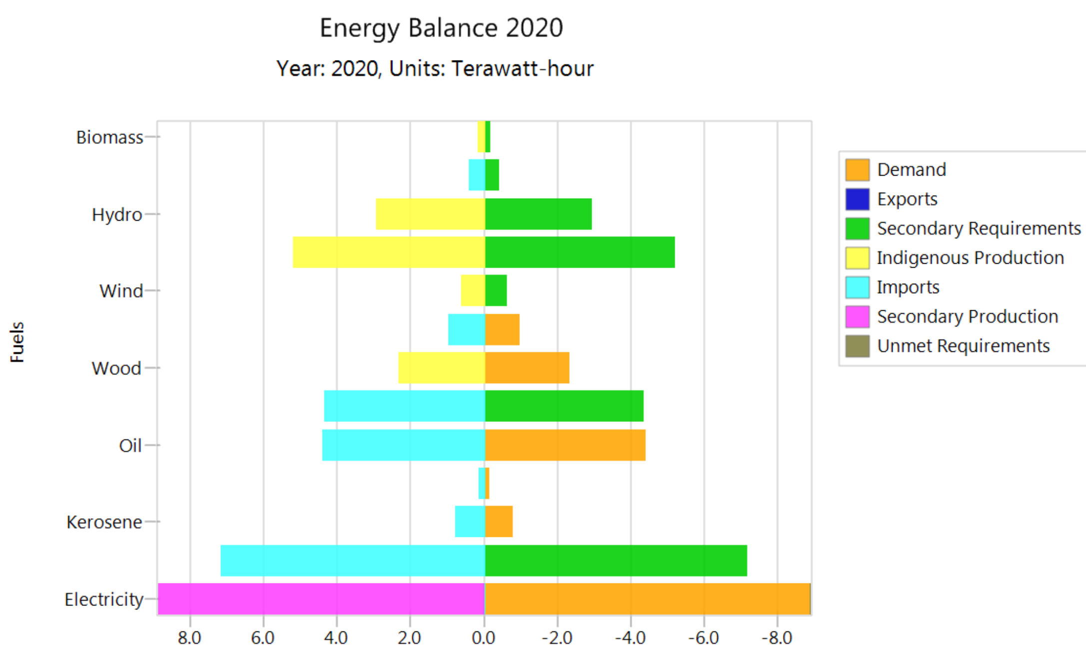

Figure 21: Energy Balance, 2020

Based on the cost estimates of Child and Breyer (2015), the capital expenditure and operation and maintenance expenditure of hydroelectricity power plants will be increasing steadily while solar, wind and other renewable energy sources will decline with time. This phenomenon will make the renewable energy sources more competitive and fossil fuels become scarce and expensive to drill. The cost contained in the table 7 however differs from Child and Breyer (2015) due to full load hours taken from the model for Ghana's system.

In table 7 below, the levelized cost of electricity is presented based on cost recovery factors adapted from Child and Breyer (2015). Offshore wind will be the most expensive power source with more than $75 per MWh and electricity production from municipal solid waste will be the lowest with $ 7 per MWh. Hydroelectricity with the dam technology will become the second most expensive energy source as availability of hydro declines due to unreliable rainfall. Solar energy and natural gas power generation units are estimated to cost $18 and $ 13 per MWh respectively.

Hydro and thermal power plants dominate Ghana's energy mix. The thermal plants are fired by natural gas, heavy fuel oil and light crude oil. In the 2020 scenario, solar energy is estimated to provide more than 20% of electricity generation. This is expected to lower the price per kWh of electricity to consumers.

Table 7 Estimated cost of electricity in 2020

2020	units	All Others	Hydro 1	Thermal	Coal	Solar 2	Hydro 2	ERfSW	Onshore wind	offshore wind	Biomass
CAPEX	$/MWe	300	3060	820	1890	900	3060	216	1100	2500	1600
OPEX FIXED	% Capex	4,26 %	4 %	3,80 %	3,60 %	2 %	4 %	7,40 %	4,51 %	4,55 %	2,50 %
Variable Opex	% Capex	0	0	2,50	2,2		0	0	0	0	0
FUEL	$/Mwhe		0	0	0	0	0	0	0	0	
EFFICIENCY	%	30	70	40	38,5	30	80	70	45	45	40
USEFUL YEARS	Years	20	50	30	40	20	50	20	20	20	30
Full Load Hours	Hours	3504	6132	6132	6132	3942	7008	4818	3504	3504	4500
CRF	%/year	6 %	6 %	6 %	6 %	6 %	6 %	8 %	6 %	6 %	6 %
LCOE	$/MWhe	8,78	49,90	13,11	29,59	18,26	43,66	6,90	32,99	75,27	30,22

5.2.3 THE 2020 – 2030 ENERGY SCENARIO

The final units of energy demand is estimated to more than double in the year 2030 from 63 million GJ to 140 million GJ. Industry and commerce are expected to be the biggest demand sectors with 62 million GJ and 58 million GJ respectively. Households' energy demand is expected to decline further to 12 million GJ while agriculture will be up by 30% from 6.3 million GJ to 8 million GJ. Electricity is estimated to become the main fuel for industry, moving from 3.3 TWh in 2020 to 11 TWh in 2030 while oil is expected to provide 4 TWh of industrial energy and wood 1.4 TWh.

In the commerce and services sector, demand for electricity is projected to reach 15 TWh, oil will provide 1 TWh as charcoal and firewood are phased out. Oil will continue to dominate the agriculture sector with demand of 8245 GJ as electricity provides only 20% of the demand at 8 GJ. Ghana's urban population is projected to reach 69.1% of the total population by 2030; however, due to the energy efficiency measures that have started, energy demand in household will continue to be stable.

Urban population refrigeration will require 391 GWh of electricity while lighting will demand 27 GWh out of the total household electricity demand of 435 GWh. Charcoal demand for urban household will grow from 1466.5 GJ in 2020 to 2195 GJ as firewood is expected to reduce from 1848 GJ in 2020 to 692 GJ. Liquefied petroleum gas, (LPG) is estimated to become the second highest household fuel in urban Ghana by moving from 373 GJ in 2020 to 1117 GJ in 2030. Although urban Ghana is expected to have 100% electricity access, kerosene is projected to be up from 10 GJ to 59 GJ in 2030. This could be attributed to the reduction is firewood use in households for lighting.

Rural areas in Ghana will demand 388 GWh of electricity for refrigeration, 109 GWh for lighting and about 4 GWh for fan, television and other appliances. Firewood and charcoal are projected to remain the main fuels for rural household, although firewood demand is expected to reduce from 2187 GJ in 2020 to 1326 GJ in 2030, representing close to 50% reduction. Charcoal demand will grow from 806.1 GJ in 2020 to 977.3 GJ in 2030 constituting 21% increase. The LPG project by the Government of Ghana is expected to fast track the diffusion of LPG use in rural household. This policy is expected to increase LPG demand from 57 GJ in 2020 to 104 GJ, which will represent more than 80% increase in share.

Total electricity production is estimated to reach 27460 GWh in 2030 with solar producing more than 8000GWh from an installed capacity of about 3000MW. Production from existing hydro plants is expected to be 3700GWh while thermal and coal will produce more than 4000 GWh each in 2030. Onshore and offshore wind plants are expected to generate about 500 GWh each of electricity while biomass and waste power plants will generate 500 GWh and over 2000 GWh of electricity respectively. The total electricity production would amount to more than three times the output of the 2020 with solar production representing more than 29% of the total production.

Ghana's current hydroelectric plants are dammed with reservoirs; therefore, the availability of the plants is affected by the water levels in the reservoir. As shown in the earlier part of the work, the Akosombo and Bui stations are affected by water levels. To avert the challenge, future hydroelectric plants are to be a mini hydro with a run-of-river technology that will increase the availability of the plants. Because of the technology choice for hydro plants, hydro 2 has a higher availability in 2030 as shown in figure 29 below.

Thermal power plants and all existing hydro plants will have less availability than the future mini hydro plants. The coal plant is expected to have availability of more than 50% due to environmental concerns associated with it while solar and wind will have an availability of close to 30%. The waste energy plant is expected to be more than 40% available as shown in figure 22.

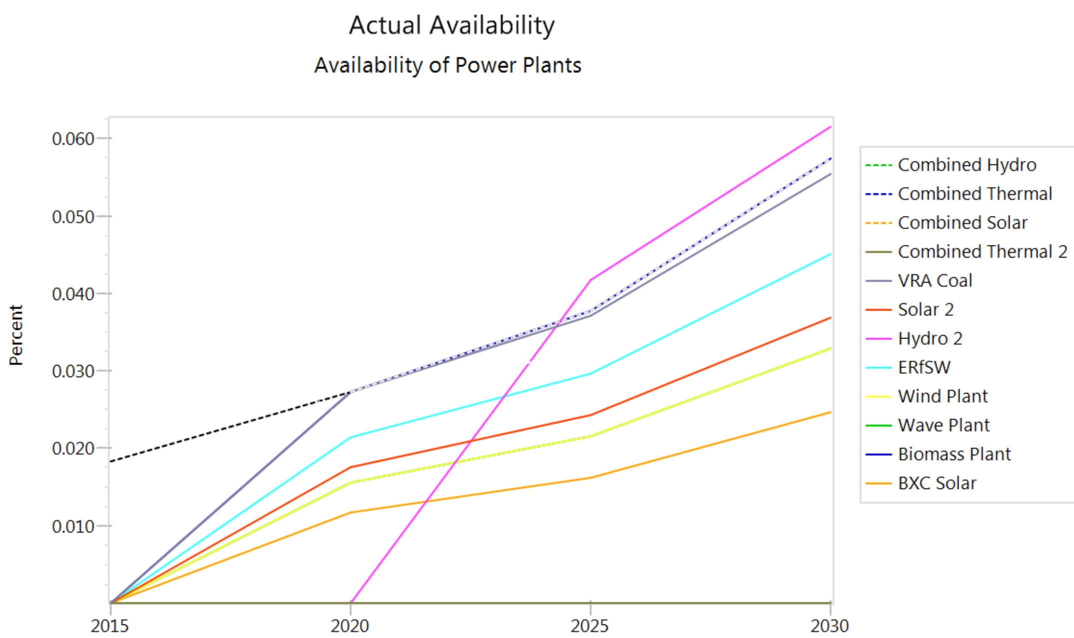

Figure 22: Actual Availability of the Plants

In figure 23, the system peak demand is expected to move from 1300 MW in 2015 to more than 2400 MW in 2020 and about 7000 MW in 2030. The peak demand growth is steady in line with the population growth and expected GDP growth in Ghana.

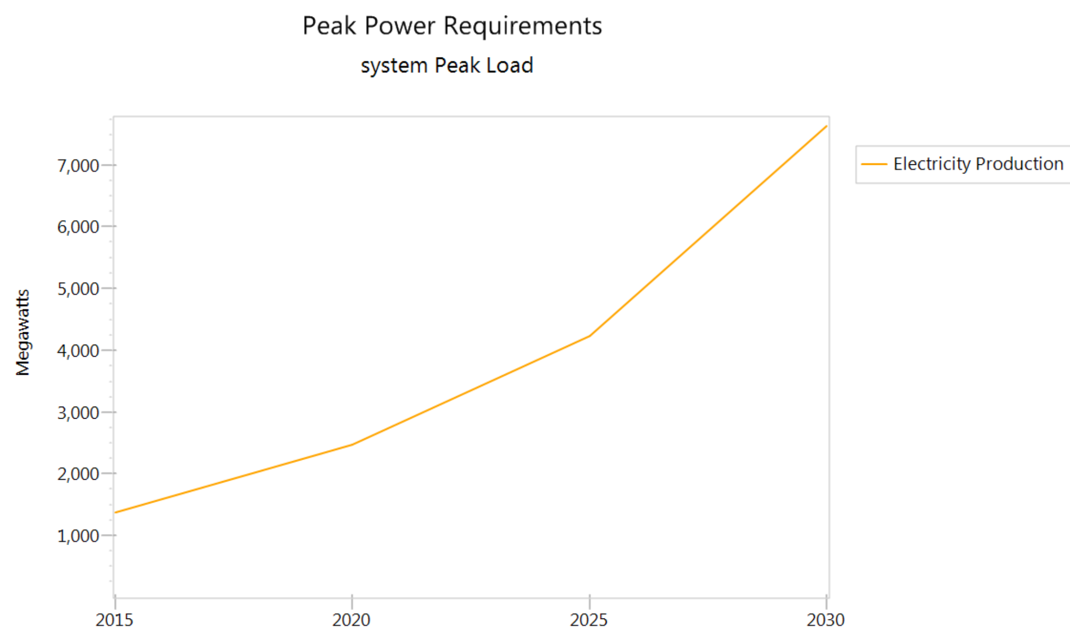

Figure 23: System Peak demand

In the table 8 shown below, the total primary energy supplied in 2030 amounted to 75.8 TWh. Solar providing 27.5 TWh, natural gas provided 10.1 TWh, and coal had 12.6 TWh and hydro provided 8.7 TWh. Total electricity demand was estimated at 27.5 TWh and oil ha 7.7 TWh. The total demand for the system is projected at 38.9 TWh in 2030, a more than 100% increase from 17.4 TWh in 2020.

Table 8 Energy Balance in 2030

Energy Balance for Ghana Year: 2030, Units: Terawatt-hour	Electricity	Natural Gas	Kerosene	LPG	Oil	Coal Bituminous	Wood	Charcoal	Wind	Solar	Hydro	Municipal Solid Waste	Biomass	Total
Production	-	-	-	-	-	-	1,9	-	2,6	27,5	8,7	-	0,6	41,4
Imports	0,0	10,1	0,6	0,3	7,7	12,6	-	0,9	-	-	-	2,2	-	34,4
Exports	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Primary Supply	0,0	10,1	0,6	0,3	7,7	12,6	1,9	0,9	2,6	27,5	8,7	2,2	0,6	75,8
Transmission and Distribution	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Electricity Production	27,5	-10,1	-	-	-	-12,6	-	-	-2,6	-27,5	-8,7	-2,2	-0,6	-36,9
Total Transformation	27,5	-10,1	-	-	-	-12,6	-	-	-2,6	-27,5	-8,7	-2,2	-0,6	-36,9
Households	0,9	-	0,6	0,3	-	-	0,6	0,9	-	-	-	-	-	3,4
Commerce and Services	14,9	-	-	-	1,3	-	-	-	-	-	-	-	-	16,2
Industry	11,7	-	-	-	4,1	-	1,4	0,0	-	-	-	-	-	17,1
Agriculture	0,0	-	-	-	2,3	-	-	-	-	-	-	-	-	2,3
Total Demand	27,5	-	0,6	0,3	7,7	-	1,9	0,9	-	-	-	-	-	38,9
Unmet Requirements (Waste)	-	-	-	-	-	-	-	-	-	-	-	-	-	0,0

The levelized cost of electricity in table 9 is estimated to reduce in the future with solar, waste and natural gas plant at a cost of $ 9, $ 7 and $ 12.9 per MWh respectively. Onshore win will decline to $ 26 per MWh and coal at $ 30 per MWh. Offshore wind declined by 38% from $ 75 per MWh to $ 54 per MWh and hydroelectricity with run – off river technology projected to cost $ 39 per MWh and coal estimated to cost $ 30 per MWh. With the exceptions of hydro dams and coal plants, solar energy is projected to be dominant the energy mix of Ghana. It is expected that cost of energy to the consumers will decline further in 2030.

Table 9 Estimated cost of energy in 2030

2030	units	All Others	Hydro	Thermal	Coal	Solar	Hydro 2	ERfSW	Onshore Wind	Offshore Wind	Biomass
CAPEX	$/MWe	900	2750	820	2030	300	2750	216	900	1800	1700
OPEX FIXED	% Capex	4,26 %	4 %	3,66 %	3,03 %	5 %	4 %	7,40 %	4,26 %	4,55 %	2,50 %
Variable Opex	% Capex	0	0	2,50	2,2	0	0	0	0	0	0
FUEL	$/Mwhe		0	0	0	0	0	0	0	0	
EFFICIENCY	%	30	70	40	38,5	30	80	70	45	45	40
USEFUL YEARS	Years	20	50	30	40	20	50	20	20	20	30
Full Load Hours	Hours	3504	6132	6132	6132	3200	7008	4818	3504	3504	4500
CRF	%/year	6 %	6 %	6 %	6 %	6 %	6 %	8 %	6 %	6 %	6 %
LCOE	$/MWhe	26,35	44,85	12,92	29,89	9,85	39,24	6,90	26,35	54,20	32,11

The cost of energy to the consumers is based on the cost recovery factors of the Finnish energy system. The actual cost in Ghanaian cedi may still be less competitive in today's terms; however, renewable energy infrastructure cost has been widely projected to decline as the technologies mature. If interest rates in Ghanaian economy substantially reduced in the near future, renewables could become cheaper than hydro and natural gas.

5.2.4 COMPARISON OF SCENARIOS

The scenarios defer in various aspects with a steady growth in energy demand by all sectors, with a little change in households energy demand. Total energy demand in the baseline scenario was estimated to be more that 46 million GJ or 11 TWh. The estimated energy demand by Ghana's energy commission for the year 2015 was 17 TWh, covering all the sectors of the economy. It is reasonably accurate in this analysis to project 11 TWh energy demand in the four main sectors of the economy. The energy production in the baseline scenario was dominated natural gas fired thermal plants and hydroelectricity.

The 10% scenario has a substantial increase due to the predicted economic growth and population growth in the year 2020 from the baseline year. The energy demand in household is expected to decline, although the refrigeration's share of the demand would increase. Industry, commerce, agriculture and services energy demand projections are expected to increase commensurate with projected growths. Energy production methods have changed with upscale renewable energy in the energy mix. Hydro and thermal energy shares in the energy mix are estimated to decline while solar energy growth is expected to increase from 22 MW of installed capacity to more 1000 MW by 2020.

Solar energy installed in the 2030 scenario is projected to grow from 1000 MW to more than 2000 MW by 2030. The energy demand is estimated to increase more than 100% from 11 TWh in 2015 to 38 TWh. Hydro energy sources are projected to run at half availability due to the change in weather pattern that is affecting the water levels in the hydro reservoirs. Industry, commerce and services sectors of the economy are estimated to grow on average of 5%, the projected growth would increase energy demand.

6. FINDINGS, CONCLUSIONS AND RECOMMENDATION

This section presents the findings, conclusions and recommendation.

6.1 FINDINGS

The analysis of the energy system of Ghana and the scenarios shows varied results. Amongst the findings are numerated below.

1. Ghana's energy sector is fast shifting away from the hydroelectricity to thermal power plants that are dependent on light crude oil, natural gas and heavy fuel oil. The energy crisis faced by the country may not be due to lack of generation capacity but due to erratic fuel supply from the West African Gas Pipeline Company and lack of adequate funds to procure fuels.
2. Ghana has an energy deficit of 200 kWh per capita by the country's economic classification of lower middle-income country. The average per capita energy consumption in the economic category of Ghana is more than 600 kWh. The energy demand of Ghana, which was estimated at approximately 17,000 GWh was based on the 400 kWh per capita. To cover up for the deficit of 200 kWh, the demand estimates will grow by 50%.
3. The diffusion of utility scale renewable energy is very low, making it difficult or impossible for Ghana to meet the 10% renewable energy supply in the energy mix by 2020. There is the potential to achieve the 10% renewable energy in the energy mix; however, the commitments and projects expected to commence in 2016 and 2017 are progressing slowly or yet to begin.
4. The cost structure of the energy system is such that industries pay more per kWh than domestic users. This development may encourage industries to find alternative power sources, which, in Ghana's case will be diesel power plants. The use of diesel plants will add to the environmental burdens due to noise and emission of climate harming substances and further add extra economic cost to goods produced.
5. Ghana may produce renewable electricity at a cost competitive price for industries and domestic end users if solar energy is more than 20% of the total energy generation. While this is possible, the government of Ghana in its 2017 budget is expecting to add more generation capacity of 1200MW, but only 200 MW of solar will come from it.
6. The new government of Ghana is however projecting the installation of 38, 000 off-grid solar systems, 55 mini – grids and 15, 000 solar rooftops. There is a new target of 2% to 3% of renewable energy technologies in the generation mix of Ghana.

7. Ghana's energy demand is estimated to reach about 38 TWh from the current demand of 16 TWh by 2030. Industry, commerce and services will be the biggest demand sectors while the production will be mainly solar and other renewables, although the expected coal plant will be significant in the energy mix. Run-off river hydro, onshore and offshore wind, biomass and municipal solid waste generation units are projected to contribute significant shares of energy in the energy mix.
8. The cost of electricity with renewables dominating the energy mix by 2030 is estimated to be relatively cheaper in the near future, if the domestic economic indicators improve. Renewable energy estimates in 2030 could be as much as 60% with solar energy producing as high as 40%.
9. There is the potential for Ghana to deploy mainly renewable energy to meet the demands if adequate measures are in place. The operation and maintenance cost of renewable energy technologies expected in the energy mix are lower than that of the fossil fuels, thereby making the energy system less capital intensive and relatively cheap to operate.
10. Oil dominates Ghana's agriculture sector with near 100% supply. This could be the result of lack of irrigation and other modern farming gadgets in the sector. Agriculture is projected to employ more than half of Ghana's workforce; however, its contribution to the GDP was about 21%. The lower output in share of GDP of the sector could be because of the low electricity use.
11. Charcoal and firewood will continue to be the leading fuels for both urban and rural households, although LPG use is expected to improve over the years. Electricity is projected to become the main fuel for industry and commerce as oil and charcoal shares declines.

6.2 CONCLUSIONS

The industrial and commerce sectors of the demand side of energy in Ghana may become the main drivers of growth in demand in the near future if economic growth projections are right. Although population growth is rapid, domestic energy demand growth will be slow due to energy efficiency measures adopted by the government. Oil will dominate the agriculture sector as the main fuel.

The energy demand projections will increase the demand by more than 100% to 39 TWh by 2030 and total installed capacity of plants could be more than 7000 MW by the same year if all planned, expected and licensed projects are developed. This arrangement may reduce the fuel cost and the financial demands by the system. By today's calculations, Ghana has installed capacity of more than 4000 MW, a projection made by the 2020 model to produce more than 27 TWh of electricity, which is more than 50% of the current demand (17TWh). However, due to erratic fuel supply and lack of funding to purchase light crude oil, electricity production is below the demand, forcing the system operators to engage in power rationing.

Ghana's renewable energy potential is enormous, solar radiation intensity in Ghana is enough to generate electricity on industrial scale if government incentives are improved and implemented. Hydro potential should only be developed as mini- hydroelectricity plants around 100 MW in each catchment area identified. Although the hydro potentials can be used, the cost of relocating residents in the catchment areas and damage to farmlands should be carefully assessed and a cost – benefit analysis should be conducted before developing them.

Waste and biomass potential in the country can support renewable energy generation in Ghana on large scales, however, the effect on land use, land use change in the case of biomass should be studied, and challenges that may arise should be addressed. LPG use as domestic fuel is growing at faster rate due to government initiatives, however, if economic growth in rural Ghana remains at current levels, firewood will continue to be the dominant fuel beyond 2030, which has the potential to continue the depletion of forest reserves of Ghana.

The wind potential as documented in Ghana can be developed at commercial scales; however, the logistical problems associated with large-scale wind farms, both onshore and offshore can be difficult for an emerging economy like Ghana to surmount. The proposed coal plant of 700

MW will help Ghana's energy supply and provide some stability in the generation, however, the associated environmental burdens should be critically assessed and all environmental standards that come with coal combustion must be complied.

In conclusion, Ghana has the potential to produce renewable solar energy on a utility scale to meet the demand and the 10% target by 2020 if government commitment to renewable energy is re-focused. There is renewable potential for biomass, wind and mini – hydro, however, due to the increasing capital and operation expenditure of hydro as well as the erratic rainfall patterns, government's renewable incentives should be targeted at large scale solar and rooftop solar for rural households. Unless there is a drastic measure and financial commitments from the government and other investors and independent power producers, Ghana cannot meet the 10% renewable energy target by 2020.

Solar electricity generation on large scale has the potential to lower the cost of electricity in the long term. Because the domestic electricity demand growth is expected to be slower than industry and commerce demands, mini – grid solar energy can be useful for rural areas with more than 1000 people while rooftops are used for remote rural areas where grid access is not available. The current energy system has a debt of $ 2.4 billion according Ghana's president Nana Addo Dankwa Akufo –Addo during his 2017 State of the Nation's Address.

The debt with the current system is mainly due to fuel purchase and other related fuel handling costs. Renewable energy systems have zero or minimal fuel cost, therefore it is prudent to minimize the cost of Ghana's energy system by integrating more renewable energy into the system.

6.3 RECOMMENDATIONS AND SUMMARY

It is recommended that Ghana government should provide good incentives and a strong regulatory framework for the development of renewables, especially solar energy in the generation mix of the country. Solar energy seems be the only alternative now if the renewable energy target of the country is to be achieved, because it will take relatively short time to build than other renewable energy sources. Ghana's energy system is shifting towards thermal plants powered by natural gas, light crude oil and heavy fuel oil. If this phenomenon continues, the financial problems facing the energy sector is likely to continue, unless a pragmatic financing and fuel supply system is developed. If Ghana's natural gas production should be expanded for thermal generation, if the system is to depend on thermal as the main energy generation source.

Renewable energy technologies have the potential to introduce competition for land, affect land use, and land use change, therefore a study into the impact of renewables on land use and land use change for Ghana may be conducted to ascertain the impact. This study did not consider natural gas production from the Ghana Gas Company as an indigenous production and expected gas flow from Ghana's oilfields. A study into the impact of the gas production on power generation and domestic use of liquefied petroleum gas (LPG) may be studied.

The cost of running the current system was shown in the literature; however, Child and Breyer's (2015) cost of the 2020 and 2030 scenarios based on projections with Finland economic conditions were used as a guide. To ascertain any deviation from the cost of the energy system of Ghana based on the Ghanaian economic, environmental and political conditions, it will be prudent to gather primary data from Ghana. The acceptability of renewable energy technologies is not yet known, it is therefore recommended that the acceptability by the consumers be ascertained through further studies.

In summary, integrating the renewable, especially large – scale solar energy into the Ghanaian energy mix is possible if government commitment is improved. Incentives for private investment in renewable energy production should be clearly and comprehensively outlined and guaranteed to encourage renewable energy use.

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