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Improving Electricity Supply Security in Ghana – the Potential of Renewable Energy

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Abstract

For decades, Ghana's economy has been fuelled by abundant inexpensive hydropower. As a developing economy, Ghana's electricity demand has long been relatively low, though rising in recent times due to increasing economic growth, urbanization and industrial activities. However, the rapid demand growth, as well as periodic hydrological shocks, leaves the country increasingly reliant on expensive oil and gas-based generation power plants, with a resultant drain on the national economy. The main electricity generation company, the Volta River Authority, is not able to generate enough electricity for all the demand sectors. The electricity supply-demand margins–the difference between peak demand and available supply–of the country fall short of the recommended engineering practice and thus presents a high supply security risk. The country has been experiencing an increase in the frequency of power cuts over the last ten years. It is clear that Ghana will have to expand and diversify its generation capacity in order to improve supply security. This paper provides a review of the assessed potential renewable energy resources, their current exploitation status, and their potential contribution to the electricity supply of the country. The paper also presents the barriers to their utilization and the existing policy and regulatory instruments to overcome those barriers, plus the current and expected future impacts of these instruments. The results show that Ghana has several RES, such as wind, solar PV, mini hydro and modern biomass that can be exploited for electricity production. While their exploitation for electricity generation is currently very low, providing just 0.13% of the country's generation, the review shows a great potential for RES generation to increase substantially over the next decade, looking at the government commitment and legal frameworks that are being put in place.

Key Words: Ghana, Ghana's electricity demand, renewable electricity supply, electricity supply security.

1. Introduction

The major global energy challenges are: a) securing a sufficient energy supply to meet growing demand, b) providing everybody with access to energy services, and c) curbing that energy's contribution to climate change [1]. In developing countries, access to affordable and reliable energy services is fundamental to reducing poverty and improving health, increasing productivity, enhancing competitiveness and promoting economic growth [2]

As Ghana is a developing country, the electricity demand in that country has long been relatively low, although demand has been rising in recent times due to increasing economic growth, urbanization and industrial activities. In 2007, electricity accounted for about 9% of the country's 9.50 Mtoe total final energy consumption [3]. Biomass and petroleum fuels accounted for 64% and 27% respectively of final energy consumption. About 65% of the country's electricity is generated from a large hydropower station, with the remaining 35% provided mainly from an array of thermal power plants that operate on gas, diesel and light crude oil [4]. Fig. 1 shows the final energy consumption mix of Ghana. The national access to electricity is currently about 71%, with the access of urban inhabitants at 78% and the rural population access rate of less than 30% [5]. The government's national electrification scheme policy objective is to electrify all communities with populations above 500 by the year 2020 [6].

Fig. 1. Energy supply mix of Ghana in 2007 (total 9.50 Mtoe) [3].

Ghana's electricity sector is saddled with many supply challenges. The existing power plants are not able to attain full generation capacity due to fuel supply constraints, as well as the uncertainty of rainfall and water inflows into the hydroelectric power facilities. The rapid demand growth and periodic hydrological shocks leave the country increasingly reliant on expensive oil and gas-based generation power plants. However, the power tariffs are based on the costs of base-load hydropower priced at about $0.05/kWh, which means that more expensive oil-based generation plants operate at annual financial losses to the Volta River Authority (VRA), the state-owned company, which owns and operates the country's generation assets. The low tariff regime, which does not allow for a full cost recovery, has slowed down capacity expansion [7]. The recent power shortages have been attributed to the lack of capacity addition to meet the growing demand [8]. It is estimated that Ghana will require a new capacity addition of about 200MW each year to catch up with increasing demand in the medium to long term [4].

The transmission and distribution infrastructure of the country has been extensive since the National Electrification Scheme was instituted in 1989, but has deteriorated since then, resulting in frequent interruptions to power supply, transmission bottlenecks, overloaded transformer sub-stations and high system losses [9]. The losses in the transmission and distribution systems are estimated at 25%, while wastage in the end-use is estimated at about 30% [10]. Rolling blackouts and severe restrictions on energy consumption are often employed by the main utility companies (VRA, GRIDCo, and ECG) to manage power supply constraints [9, 11]. It is clear that Ghana will have to improve its network infrastructure, as well as expanding and diversifying its installed capacity in order to improve supply reliability.

The three most important factors in selecting new energy resources that ensure supply security are that they must be renewable, locally available at reasonable costs, and environmentally friendly [12]. The government energy policy objective aims at expanding generation assets by investing in renewable energy systems and energy efficiency measures [13]. The aim of this paper is to investigate the potential contribution of renewable energy resources to the improvement of the electricity supply security of the country. The paper also identifies barriers for utilizing these resources for electricity generation, and reviews government policies and programs to promote utilization of renewable energy.

The results show that Ghana has several renewable energy resources (RES) such as wind, solar PV, mini and small hydro, and modern biomass that can be exploited for electricity production. The installed capacity of hydropower, for instance, is small compared to the exploitable potential. The development of solar power has been limited to a few homes, usually in the form of solar home systems. Despite a good wind and biomass resource potential, the technologies to harness them for electricity production have so far not been demonstrated on a commercial scale in the country. While about 0.13% of the country's electricity is generated from these resources, the review shows great potential for this to increase substantially over the next decade, due to government commitment and legal frameworks which are being put in place.

2. Electrical energy situation in Ghana

Ghana's total electricity generation in 2010 was 10,232.11 GWh, with 68% being generation from hydropower, 31% from thermal power plants and the remaining 1% coming from imports (Fig. 2).

Fig. 2. Ghana's electricity generation mix in 2010 (total 10,232.11 TWh) [4].

The total plant capacity at the end of 2010 was 2,186 MW [4] as shown in Table 1. These numbers remained relatively the same until the end of 2013 when the 400 MW Bui Hydroelectric Dam in the Tain District of the Brong Ahafo Region was commissioned. However, the country's total generation has not improved, due to over 60% reduction in the volume of the gas supply through the West Africa Pipe Line Project to power existing thermal power plants [14].

Table 1. Ghana's portfolio of installed generation capacity as at December 2010.

2.1 Supply Structure

About 88% of the generation assets in Table 1 are owned by the state-owned company Volta River Authority (VRA) with the remaining 12% being owned by independent power producers (IPP). The Ghana Grid Compony (GRIDCo) operates the National Grid and manages the power system as System Operator. There are two power distribution companies in Ghana: the Electricity Company of Ghana (ECG), responsible for the distribution in the south and the Northern Electricity Department (NED), responsible for distribution in northern Ghana. Fig. 3 shows the structure of Ghana's electricity supply sector. Enclave Power Company, a small power company, has a contract agreement with the Electricity Company of Ghana to supply electricity to the Tema Free Zone Enclave. The Free Zone provides focal points for the production of goods and services for foreign markets.

Fig. 3. The structure of Ghana's electricity sector.

2.2 Electricity demand

The electricity demand in Ghana is divided across 40 load centres, which include cities, clusters of small towns and villages, and large industrial sites such as mines. About 40% of all electricity is consumed by the residential sector. The industrial sector accounts for nearly half of the consumption, with the rest consumed by non-residential customers, which are mainly small businesses [4]. The relative weight of the demand sectors has been changing, as evidenced in Fig. 4. The residential electricity sector has been the fastest-rising consumer sector, with consumption growing at an average of 6.3 % over the last decade [4]. The demand from this sector is projected to exceed 4,400 MW by 2020 [15], thereby exceeding consumption in the industrial sector. This can be explained from the increasing grid connections, rising per capita income, penetration of appliances in higher income households and no apparent incentives for more efficient utilization of energy.

Ghana's electrical appliance market is flooded with imports of used low-efficiency appliances which are relatively less expensive compared to new ones [11]. As more communities are connected to the grid, they will naturally demand more of these appliances, which will ultimately result in increased electricity consumption. Ghana has an average household size of 3.4 people [16]. Using the current population of about 25 million, this means that there are approximately 7.4 million households in the country with the potential to own electrical appliances. With the expected increase in household income, the number of households that could afford major household appliances, such as refrigerators, microwave ovens etc., is expected to increase, with the prospect of many consumers buying inefficient appliances and thereby unnecessarily burdening the national grid.

The maximum peak demand of all sectors was 1471 MW in 2010 and occurred in the evening, between 19:00 – 21:00 hours, suggesting a high level of the residential sector's contribution to the system's peak load. Large-load centres in the big cities account for about 70% of the peak [9]. Fig. 5 shows a typical Ghana load profile. With a load factor of more than 90%, the load curve does not suggest large peak-load reduction opportunities.

Fig. 4. The pattern of electricity consumption by sector in Ghana since the year 2000 [4].

Fig. 5. A typical daily load profile of Ghana showing peak demand periods [9].

2.3 Electricity supply challenges

Ghana’s electricity sector has long been saddled with challenges regarding supply security and power quality. One of the main factors affecting supply is the over-dependence on hydro-power in the generation mix. The total amount of energy that can be delivered is constrained by several factors, which include the variability in rainfall that results in variability of the amount of electricity that can be generated from the hydro plants. Almost all of the recent power crises (1998, 2002 and 2007) have been triggered by low rainfall patterns in the Volta basin that supply water into the Akosombo dam [8]. The low demand/supply gap is also partially responsible for many power outages in the country [9]. Fig. 6 shows Ghana’s total available capacity compared with peak demand over the last decade.

Fig. 6. Ghana’s total available capacity compared to peak demand [9].

Another supply challenge is the unreliable supply of natural gas from the West Africa Gas Pipeline (WAGP), which feeds the country from Nigeria. The WAGP project consists of the development of an onshore/offshore gas distribution network delivering gas from Nigeria to commercial customers in the neighbouring countries of Benin, Togo and Ghana, but unfortunately the project has not been able to provide a reliable supply of the gas [17]. There are also problems related to inadequate and outdated infrastructure; underfunding and underinvestment; managerial problems; and low tariffs coupled with under-recovery and the inability to collect bills etc. – all of which have led to unreliable supply and long power outages, high system losses and unsustainable debt levels [18, 19].

2.4 Ghana Situation in the Context of ECOWAS

Despite the electricity supply challenges, Ghana’s national electricity access rate of 71% is still the highest after Cape Verde in the Economic Cooperation of West

Africa (ECOWAS) states (Fig. 7) [20]. Ghana’s access rate is ranged the fourth in the whole of Sub-Sahara Africa; after South Africa (75% access rate) Cape Verde (95 access rate) and Mauritius (99.4 access rate) [21]. Ghana’s per capita electricity consumption of about 247 kWh per annum is the highest in the West African sub-region. The losses in transmission and distribution, though quite high, is still better than many of the countries in the sub-region [22]. The share of renewable energy including hydro electricity in the generation mix is on the better side compare to countries like Cote d’Iviore, Benin and Togo that depend essential on thermal power generation with significant drain on the national economy [23]. In a nutshell, while Ghana electricity supply situation is not the best that one would hope for; the supply indicators are still among the best in the ECOWAS sub-region.

Fig. 7 Electricity Access Rate in ECOWAS Countries 2005 and 2010 [24]

3. Renewable energy resources for power generation in Ghana

Apart from large hydro, Ghana has several other renewable energy resources (wind, solar, mini hydro, modern biomass) that can be exploited for electricity generation. The total share of these resources in the electricity generation mix is currently negligible (at 0.13%) [6]. The government has recently passed the Renewable Energy Act to ensure a target of 10% share of these renewables in the national electricity generation mix by the year 2020. [17]. A successful integration of renewable energy technologies into the existing energy structure depends on a detailed knowledge of the renewable resources [25]. This section gives a review of the assessed RE resources of the country with the aim of finding their potential to improve the current electricity supply situation.

3.1 Wind energy

Wind energy is emerging as one of the most promising alternative sources of energy due to its potential to meet rising demand for electricity at relatively cheaper costs compared to other renewables [1, 26]. The wind speed in most parts of Ghana has been assessed to be between 1.7–3.1 m/s at 2 m height by the Ghana Meteorological Services Department (MSD). Because of obstructions and surface roughness near the ground, 2 m data are not generally useful for assessing the wind resource for utility scale power generation [27]. The Ghana Energy Commission has undertaken measurements along the coast of Ghana but at much higher altitudes along the East and West of the Meridian for the purpose of assessing wind resources for power generation. The monthly average wind speed at 12 m was found to be 4.8 – 5.5 m/s [28].

A more comprehensive wind resources assessment of Ghana was carried out by the U.S. National Renewable Energy Laboratory (NREL) in 2002 as part of a global project to supply high quality renewable energy resource information, the so-named Solar and Wind Resources Assessment (SWERA) [27]. Using a combination of analytical, numerical and empirical methods, NREL developed high resolution (1 km) wind energy resource maps for Ghana. This assessment covered the whole of Ghana with the primary focus being the potential for large-scale grid-connected wind turbines. The data for this assessment were taken from many sources, including Ghana Energy Commission wind resources measurement, satellites, and Ghana MSD. Information was also taken from the DATSAV2 global climatic database obtained from the U.S. National Climatic Data Center (NCDC), which contains 21 stations in Ghana. NREL found approximately 413 km^2 area with good-to-excellent wind resource (wind class 4–6) which could support a little over 2,000 MW of wind power development**,** and if moderate-to-excellent wind resources were included, that could go up to 5,640 [27]. Fig. 8 shows the wind resource map of Ghana. According to SWERA maps, the strongest wind regime (wind speed 7.8– 9.9 m/s) occurs along the eastern border with Togo, and that can yield a wind-power density of 600 – 800 Watt/m^2 in the area of about 300 – 400 km^2. The total wind energy potential of this area is estimated at around 300 MW. Fig. 9 shows the wind capacity of Ghana classified by wind-class at 50 meters height by NREL.

Fig. 8. Wind energy resource map of Ghana (wind speed at 50m height) [29].

Fig. 9. Wind energy resource of Ghana at 50m height [27].

An update of the wind energy resource is being conducted using very modern equipment and technologies at selected sites in the coastal areas of Ghana [30]. Five meteorological masts of 60 m height, shown in Fig. 10 were installed at five wind-resource sites in November and December 2011. The five wind-resource sites are Ningo in the Greater Accra Region, Ekumfi Edumafa and Gomoa Fetteh in the Central Region, and Avata and Atiteti in the Volta. Since installation and commissioning, these masts have been measuring the wind conditions at the sites. The wind speed has been measured at 40 m, 50 m and 60 m above ground, whereas the wind direction has been measured at approximately 47 m and 57 m above the ground. The analysis of the one year data collected was extrapolated to predict the expected wind speed at potential hub heights of commercially available wind turbines at 80 m and 100 m above the ground. Furthermore, the expected energy yield was simulated by placing virtual wind turbines at each measurement site. The capacity factors obtained give an indication of the economic feasibility of wind-farm projects at the sites examined [30]. Fig. 11 shows the wind-speed measurements obtained.

Fig. 10. NRG 60 m wind energy masts XHD.

Fig. 11. Measured wind speed at 40 m, 50 m and 60 m height of NRG 60 m XHD wind mast [30].

3.2 Solar energy

Ghana solar energy resource assessment was carried out in 2002 in a UNDP project. The high resolution solar radiation assessment was based on data from the geostationary satellite Meteosat [31]. The average solar insolation was found to be about 5 $kWh/m^2/day$. Fig. 12 shows the annual average total daily sum of GHI in $Wh/m^2/day$ of the country. Extremely large solar radiation resources are available in many parts of the country, especially in the northern regions where the electrification rate is very low. Considering that many parts of the country receive 5–8 hours of sunshine per day at 1 kW/m^2, the potential for using solar for electricity generation is very high. Fig. 13 shows the wind speed at some selected locations of the country[32, 33]

Fig. 12. Ghana's annual average total daily sum of GHI in $Wh/m^2/day$ (3-years average) [31].

Fig. 13. Potential of Solar energy resources at some selected locations in Ghana [32, 33].

3.3 Small and medium hydro

Ghana has an estimated additional hydropower potential of 2,000 MW, of which 1,200 MW is expected to be produced from proven large hydro sources, with the rest coming from small and medium-scale hydro sources. Approximately 70 feasible small (less than 1 MW) and medium (1–100 MW) hydro sites, with a total potential of 800 MW have recently been identified. However, none of these sites has been developed, to date, for power generation [34]. The only small hydro pilot project which was initiated in the 1980s, was abandoned midway for unexplained reasons [35]. The potential for utilization of small hydro is high in five regions: Brong Ahafo, Ashanti, Volta, Eastern and Central Region [36]. Fig. 14 shows the distribution of small and medium hydro resources in Ghana.

Until a few years ago, there was little economic interest in generating electricity from mini-hydro plants in Ghana, as an excess of cheap power from the main hydro power plants at Akosombo and Kpong was available. As a result, many of the small hydro sites that were found suitable for development for rural electrification were not built; and, as of now, many of these villages have either been connected to the grid or are within a few kilometres from the grid [35]. Consequently the development of the sites for rural electrification has been weakened considerably. Any consideration for developing these sites should include connecting them to the national grid.

Fig. 14. The distribution of small and medium hydro resources in Ghana [37].

3.4 Biomass resources

Biomass energy accounts for 50% of Africa's total primary energy supply, and about 60% in sub-Saharan Africa [38]. Biomass resources cover about 20.8 million hectares of the 23.8 million hectare land mass of Ghana [13] and supply about 64% of the total energy used in the country. Biomass is used in the domestic sector for cooking, and for many other applications, such as water heating. Biomass is also used in many education establishments throughout the country. Extensive reviews of biomass energy resources in Ghana have been provided in [3] and [39]. The vast arable and degraded land mass of Ghana has the potential for the cultivation of crops and plants that can be converted into a wide range of solid and liquid biofuels.

Agriculture is a major industry in Ghana, and consequently, large amounts of by-products/residues that can be used for energy production are generated. It has been estimated that there are 553,000 tonnes of maize cob and stalk produced with a potential energy of 17.65–18.77 MJ/kg and 19 tonnes of paddy rice husks with a potential energy of 16.14 MJ/kg. As well, 193,000 tonnes of oil palm shells, 136,000 tonnes of sorghum stalks, 150,000 tons of millet stalks and 56,000 tonnes of groundnut shells are also produced [40].

Municipal waste-to-energy projects have become a very important mechanism for the management of the growing sanitation problem facing urban communities, as well as a means of contributing to energy supplies and security in many countries. Significant amounts of waste are generated in Ghana. The waste generation per day in the city is about 0.6 kg/person [41]. Fig. 15 shows the composition of average household waste in Ghana.

Fig. 15. Average household waste composition in Kumasi [41].

4. Renewable energy utilization status

The section above shows that Ghana has good renewable energy resources that can offer significant electricity generation capacity to the country. Though technologies to convert the resources to electricity are currently available, Ghana is yet to see a significant deployment of these technologies for power generation. So far, only about 2 MW grid solar capacity has been developed [17], with another 155 MW expected to come online in 2015 [42]. It is reported that over 4,500 solar systems have been installed in over 89 communities throughout the country as shown in Table 2.

Table 2. Installed solar PV systems in Ghana [40]

So far, in Ghana, wind energy and small hydro power technologies have not been used on a commercial scale. A total of 1.954 MW of biomass-fired co-generation plants that could be expanded have been installed in the country. Table 3 provides the installation status of biomass co-generation plants in Ghana.

Table 3. Installed biomass co-generation plants in Ghana

5. Barriers to RE utilization in Ghana and policies to overcome them

The barriers to renewable energy exploitation in Ghana include higher electricity costs compared to the non-renewably-sourced electricity; compatibility with existing transmission and distribution networks; the remoteness of resources from key electricity demand sectors; technological immaturity; institutional inexperience and the lack of skilled technical manpower to oversee renewable energy projects [34]. These barriers can be grouped in five main categories: technical, social, environmental, economics and policy. The specific technical barriers include unstable operation of the electric network, high power swings in the feeders, voltage fluctuations at certain nodes, load management and management of the energy networks. [34]. Table 4 gives a summary of barriers at the individual resource level, and offers recommendations based on international experience for overcoming them.

Table 4. Summary of barriers to RES and recommendations to overcome them

5.1 Policies for promoting RE in Ghana

Ghana has a history of strategies and policies to promote renewable energy as illustrated in Table 5. However, looking at renewable energy installation status, one can say that these policies are yet to have significant impact on the renewables industry. The recently passed Renewable Energy Act to generate 10% of the country's electricity from modern renewable energy sources by the year 2020 is expected to promote renewable energy business in the coming decade. It has created the enabling environment for the exploitation of the renewable energy resources in the country through the introduction of the following [43]:

- feed-in-tariff (FIT) scheme which is made up of feed-in-tariff rates,
- mandatory purchase of electricity generated from renewable sources,
- free access to the distribution and transmission systems, and
- creation of the Renewable Energy Fund dedicated to the promotion development of the renewable energy sub-sector in Ghana.

The technology-specific feed-in-tariff rates for the electricity generation are as shown in Table 6.

Table 5. The development of renewable strategies and policies in Ghana

Table 6. Technology specific feed-in-tariff of Ghana

In forecasting the investment potential, it is envisaged that the expected Renewable Energy Sector would attract over 1.0 billion USD in investment in the next 8 years (table 7). These investments will be successful mainly through private sector participation.

The other commitments from the government can be seen in the establishment of the University of Energy and Natural Resources in 2011 to train people in Renewable Energy Engineering and other energy related skills [44]. The premier technical university in Ghana (KNUST) has also introduced programs in renewable energy technology and has established an Energy Center to provide training, research and advisory services to public and private actors in energy technology, policy and management [45].

Table 7. Expected targeted renewable energy investments in the next decade[46]

5.2 Ghana's RE Potential within the ECOWAS states

Ghana's renewable energy potential is among the best in the ECOWAS sub-region. Of the total 1411 MW medium to large scale identified renewable energy projects in the ECOWAS sub-region, about 11.5% is located in Ghana [24]. In terms of the identified specific project potential, Ghana has the highest concentrating solar power potential (40 MW), and the second highest wind power potential (100 MW) [24]. Ghana is among the few ECOWAS countries that had included RE integration in their energy policy documents as at 2011. It is among the few countries in the region that have adopted long term RE target of 10% by the year 2020. Other include Senegal with 15% of RE penetration by 2020, Mali with10% of RE penetration respectively by 2020 and 2022 and Nigeria (10% of the installed electric capacity by 2020, and Cote d'Ivoire with 5% of RE penetration by 2015) [47]. Compared to many ECOWAS states, Ghana has good democratic system of governance that encourages foreign direct investment This is expected to improve investment in RE in the medium to long term period [48]. Many foreign companies are currently investing in renewable energy in Ghana compared to the other countries in the sub-region.

6. Conclusion

This review has shown that Ghana has renewable energy resources that can be harnessed for power generation. It is among the countries in the ECOWAS region with high renewable energy potential. All the major RE sectors like solar, biomass, hydro have considerable potential to improve electricity generation for the country. The average daily solar irradiation level of the country ranges from 4-6kWh/m^2, with the highest potential occurring in the northern part of the country where the electrification rate is very low. This presents very high potential for off-grid and grid-connected solar power applications. Wind speed of over 6m/s at 50 m height has been estimated for some locations with potential for grid and off-grid electrification as well as for water pumping. The potential for hydropower and bio-electricity is very high and could provide sufficient energy to support the country's economic growth. To keep pace with the high growth rate of the population and the increased economic activities in the country, it is inevitable that there will be exploitation of RES to compensate for increases in electricity demand, especially in the area of rural electrification. Effective deployment of distributed generation technologies in strategic rural locations where the resources are available can help mitigate the present energy crisis in Ghana. Diversification of energy sources to include renewables remains a key policy objective of government. While government policy commitment and policies in the past have not resulted in significant renewable energy installation, there are indications that the recently passed Renewable Energy Law to provide the necessary fiscal incentives for renewable energy development by the private sector (IPP), could result in the growth of the renewable energy industry over the next decade and beyond.

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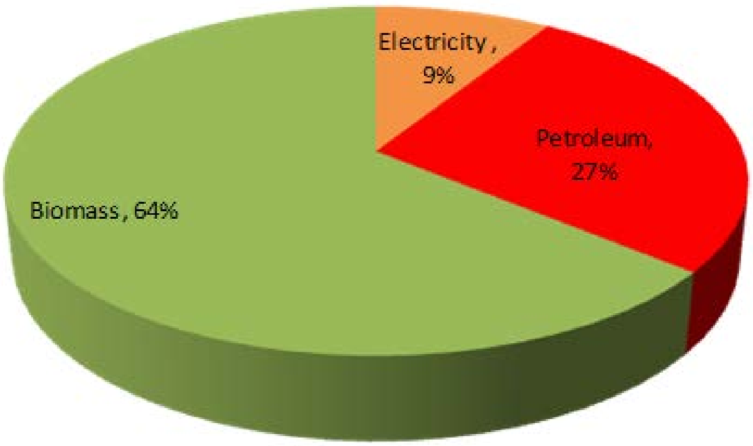

Fig. 1. Energy supply mix of Ghana in 2007 (total 9.50 Mtoe) [3].

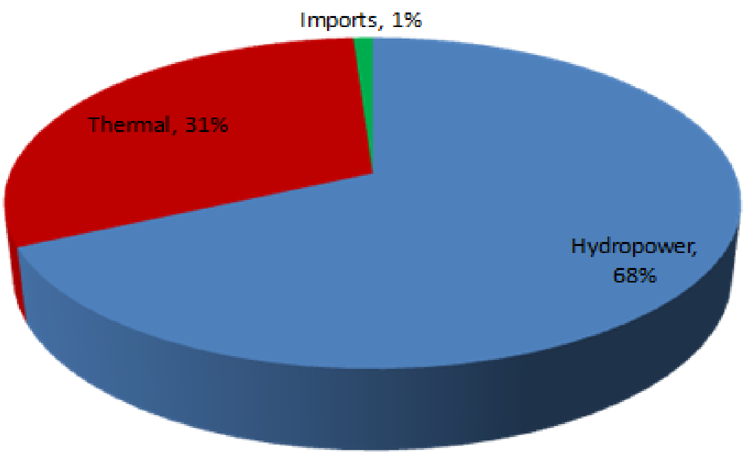

Fig. 2. Ghana's electricity generation mix in 2010 (total 10,232.11 TWh) [4].

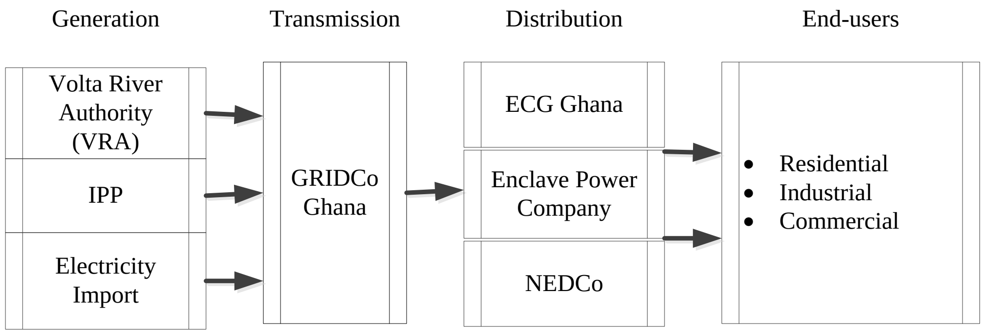

Fig. 3. The structure of Ghana's electricity sector.

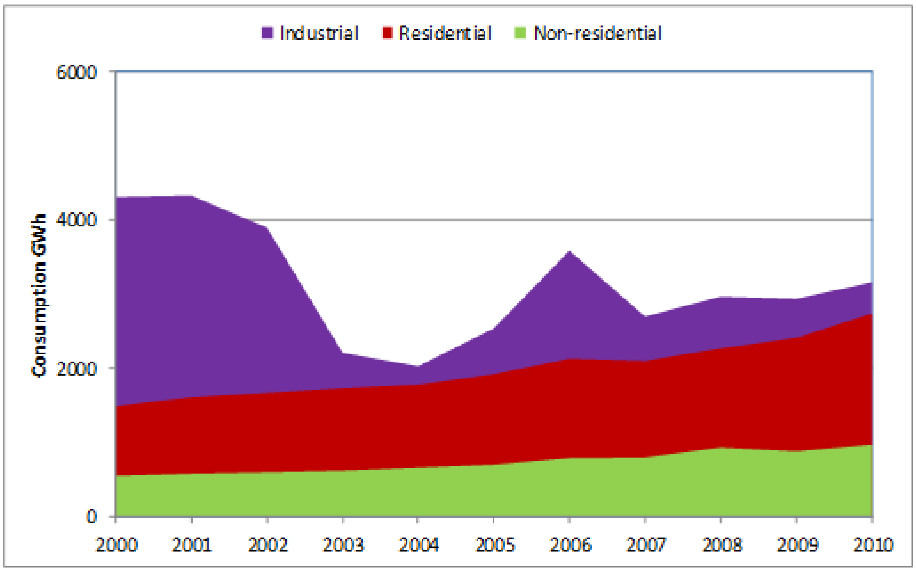

Fig. 4. The pattern of electricity consumption by sector in Ghana since the year 2000 [4].

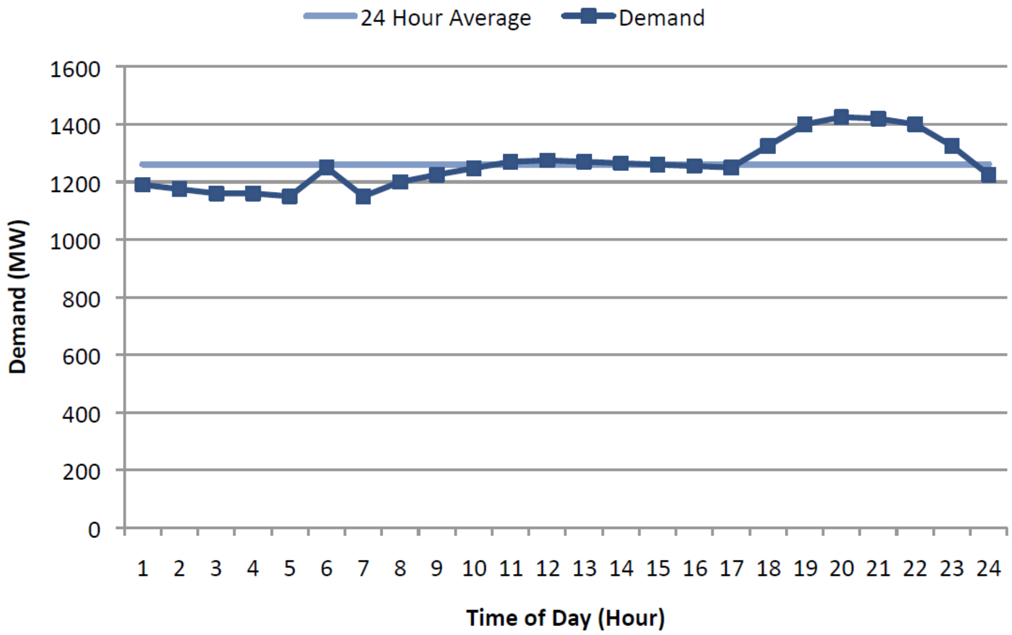

Fig. 5. A typical daily load profile of Ghana showing peak demand periods [9].

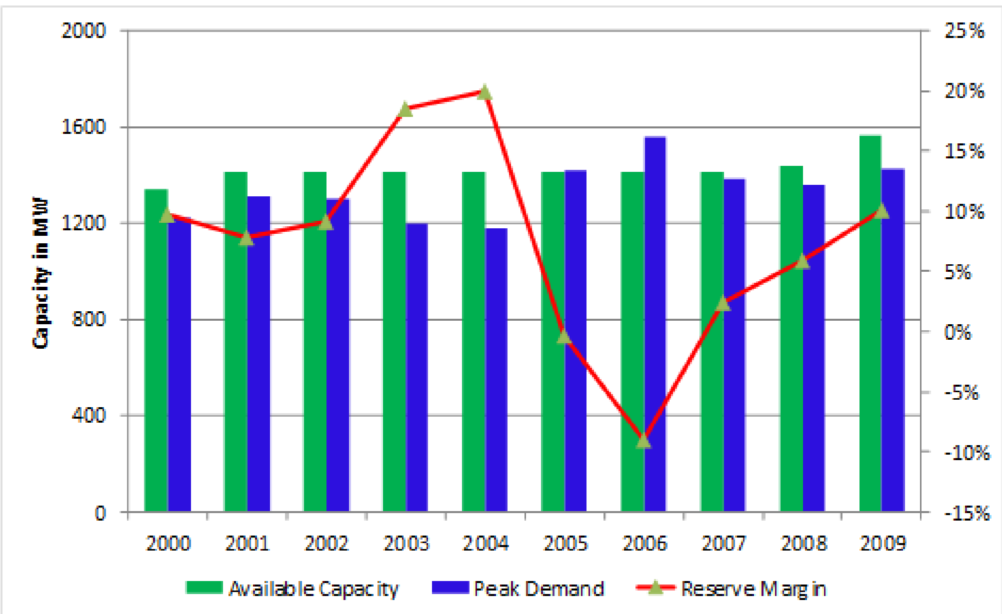

Fig. 6. Ghana's total available capacity compared to peak demand [9].

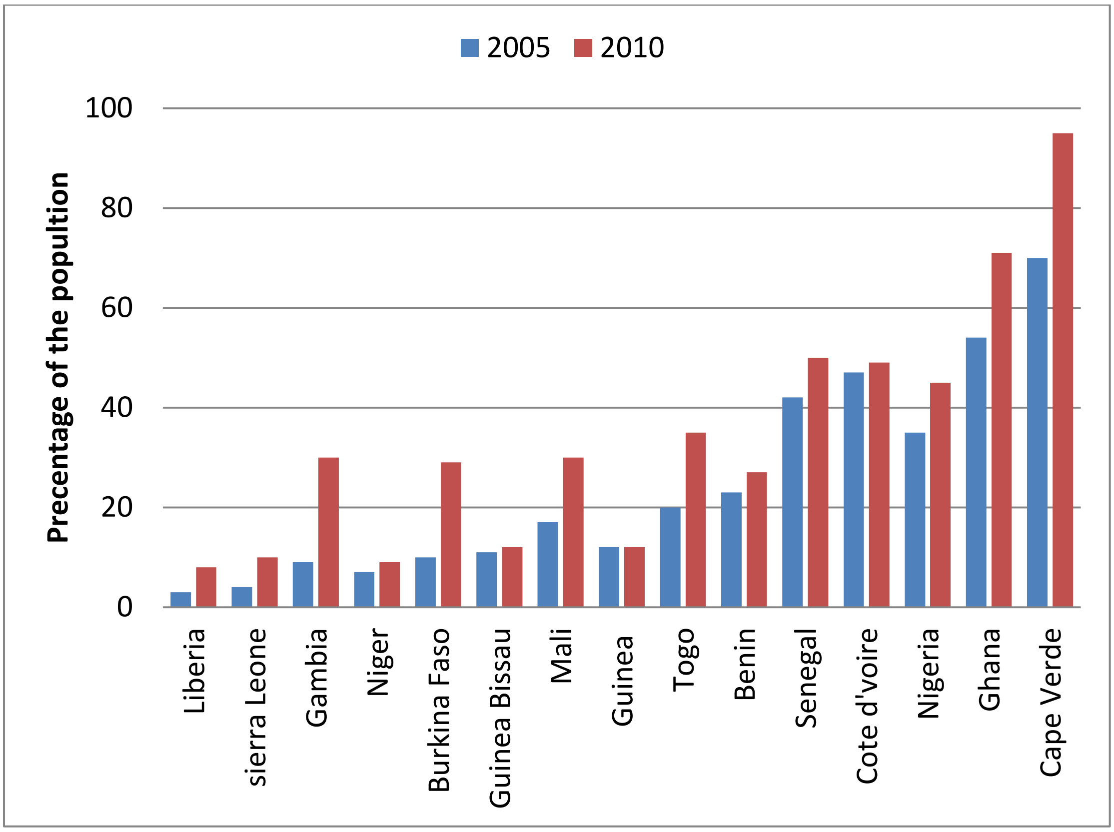

Fig. 7. Electricity Access Rate in ECOWAS Countries 2005 and 2010 [24]

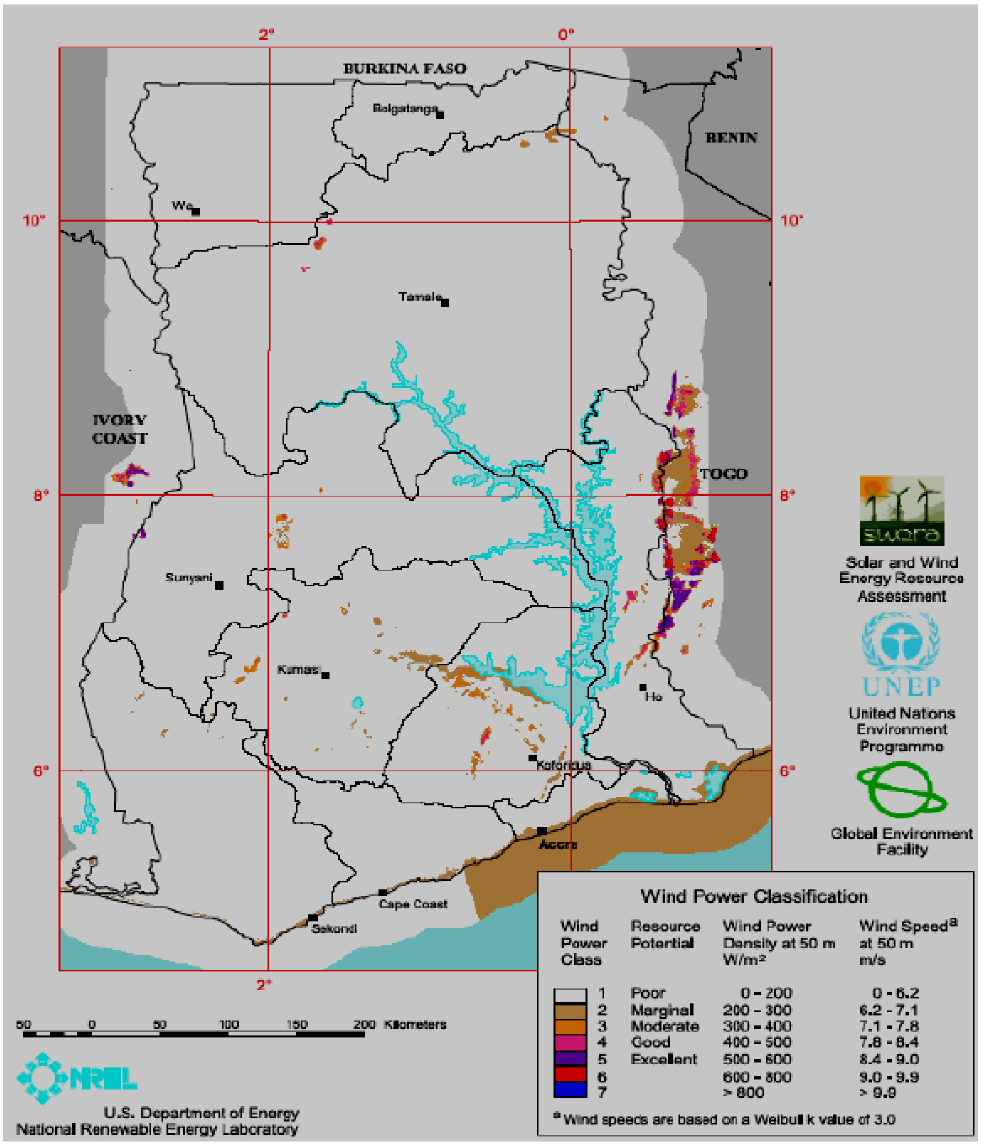

Fig. 8. Wind energy resource map of Ghana (wind speed at 50m height) [29].

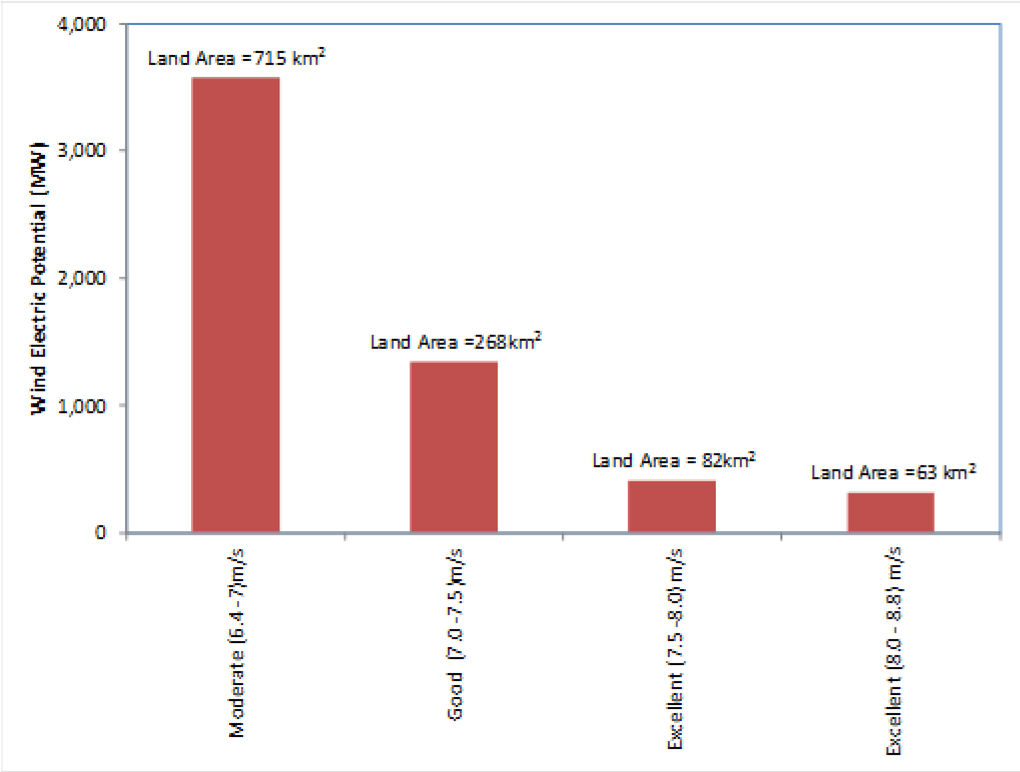

Fig. 9. Wind energy resource of Ghana at 50m height classified by wind class [27].

Fig.10. NRG 60 m wind energy masts XHD.

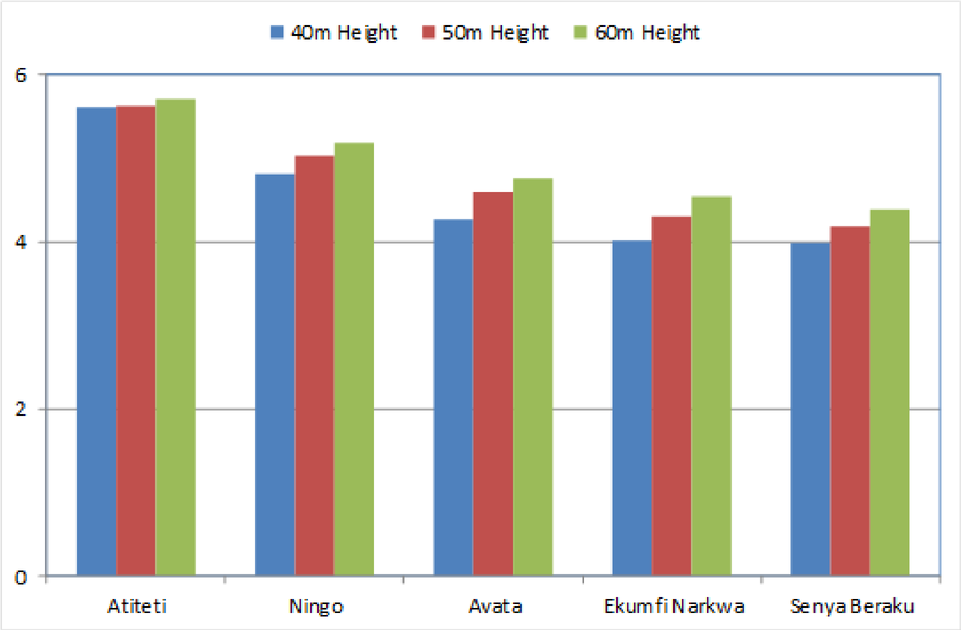

Fig. 11. Measured wind speed at 40 m, 50 m and 60 m height of NRG 60 m XHD wind mast [30].

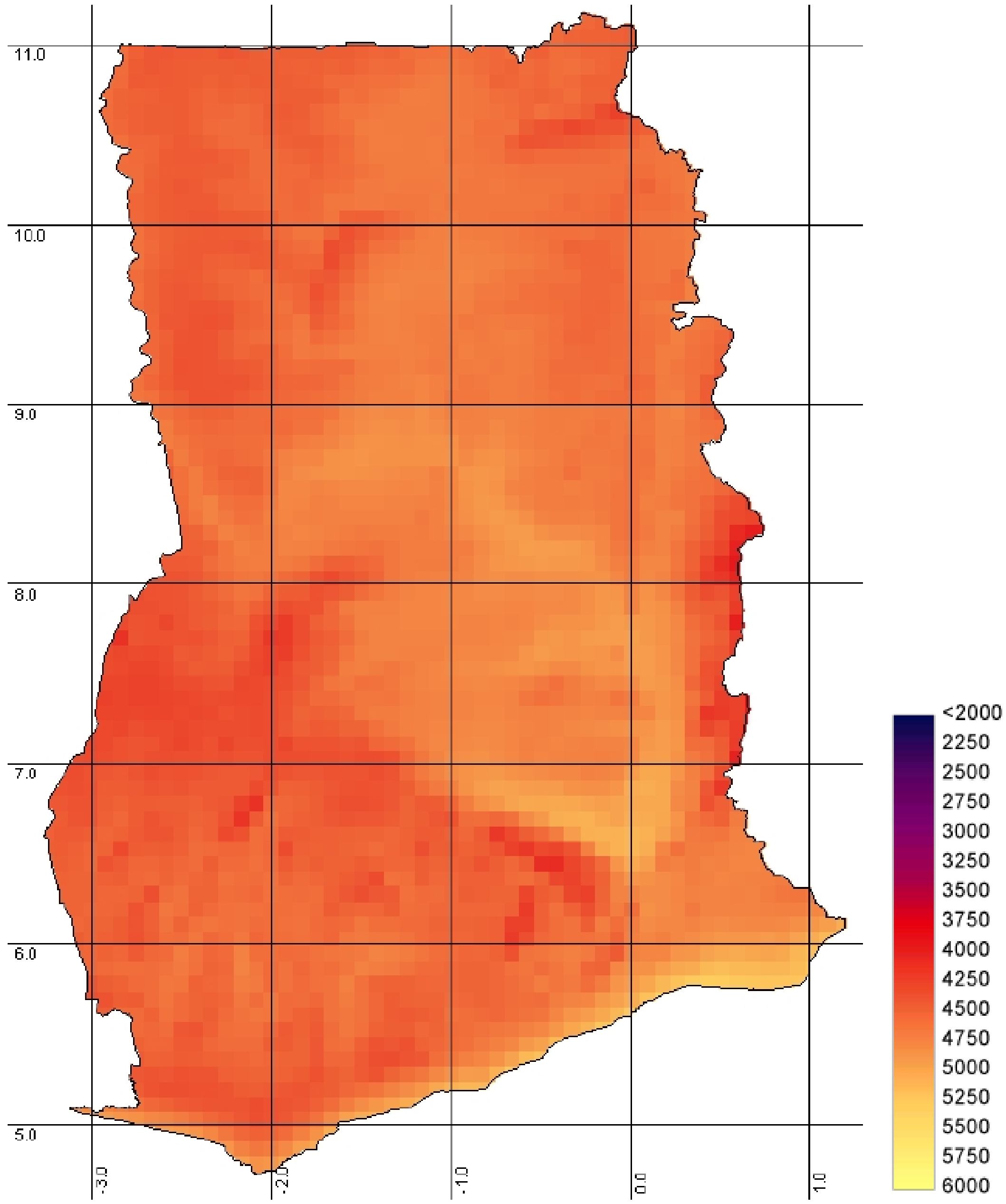

Fig. 12. Ghana's annual average total daily sum of GHI in Wh/m²/day (3-years average) [31].

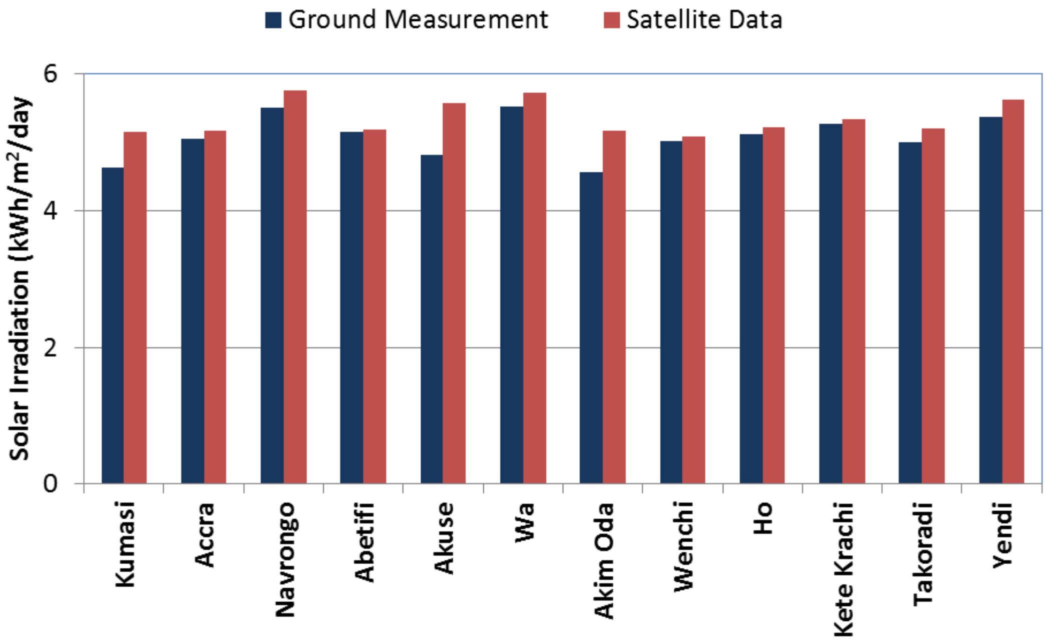

Fig. 13. Potential of Solar energy resources at some selected locations in Ghana [32, 33].

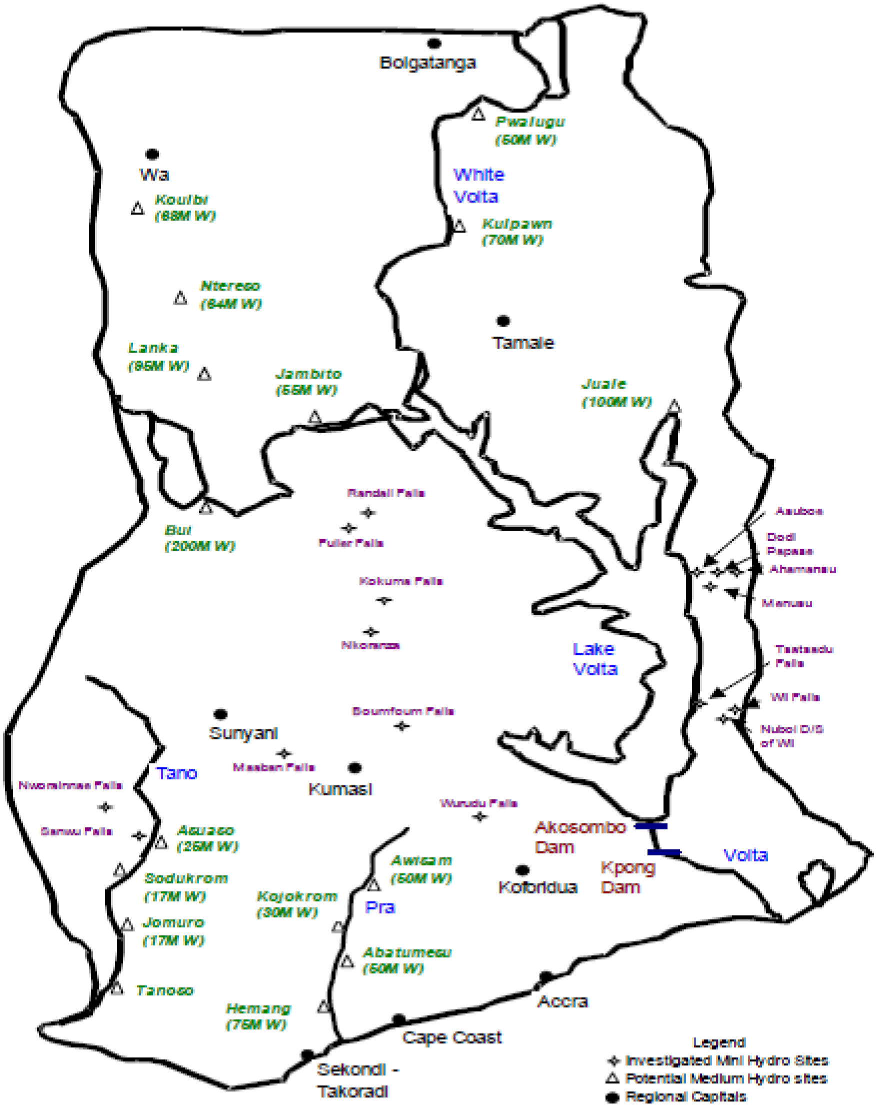

Fig. 14. The distribution of small and medium hydro resources in Ghana [37].

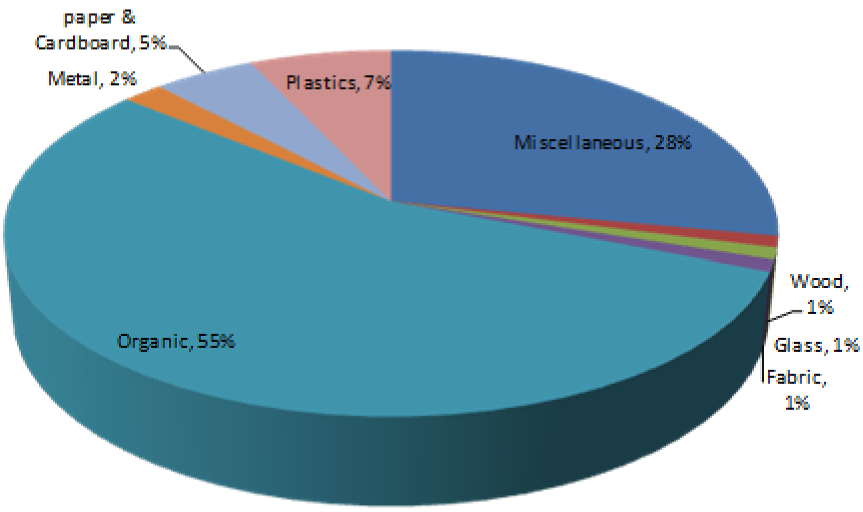

Fig. 15. Average household waste composition in Kumasi [41].

Table 1. Ghana's portfolio of installed generation capacity as at December 2010 [4].

Generation Plant	Fuel Type	Capacity in MW		
		Installed	Available	% Availability
Hydro Power Plants				
Akosombo	Water	1,020	960	94
Kpong	Water	160	140	88
Thermal Power plants				
Takoradi Power Co. (TAPCO)	LCO/NG/Oil	330	200	60
Takoradi International Company (TICO)	LCO/NG/Diesel	220	200	91
Sunon-Asogli (SAPP)	NG	200	180	90
Tema Thermal 1(TT1P)	LCO/NG/Diesel	126	100	79
Tema Thermal 2(TT2P)	NG/Diesel	50	45	90
Mines Reserve Plant (MRP)	NG/Diesel	80	40	50
Total		2,186	1,865	85

Table 2. Installed solar PV systems in Ghana [40]

Solar PV Systems	Installed Capacity (kW)	Generation (GWh)
Rural home system	450	0.70 - 0.90
Urban home system	20	0.05 - 0.06
School system	15	0.01 - 0.02
System for lighting health centres	6	0.01 - 0.10
Vaccine refrigeration	42	0.08 - 0.09
Water pumping	120	0.24 - 0.25
Telecommunication	100	0.10 - 0.20
Battery charging system	10	0.01 - 0.02
Grid connected system	60	0.10 - 0.12
Solar streetlights	10	0.04 - 0.06
Total	**853**	**1.34 - 1.82**

Table 3. Installed biomass co-generation plants in Ghana [40]

Location	Installed Capacity (kW)	Average Annual Generation (GWh)
Kwae Oil Palm	420	1.50
Juanben Oil Palm	424	1.50
Benso Oil Mill	500	1.90
Twifo Oil Palm	610	2.10
Total	**1954**	**7.00**

Table 4. Summary of barriers to RES and recommendations to overcome them

RES	Barriers to developing	Recommendations to remove barrier
Solar	High start-up cost, limited access to information, limited financing schemes, small market.	Identify innovative financing mechanism: soft loans, grants and flexible financing schemes. Organize awareness campaign, education and training programs and workshops.
Small Hydro Power	Absence of policy framework, lack of information on available resources, lack of financing mechanism, low electricity tariffs.	Update hydro resource map, demonstration projects, extend the grid for rural electrification.
Wind	High start-up cost, limited qualified personnel, low electricity tariff, intermittency.	Private sector participation, advance forecasting, energy management systems (to minimise intermittency).
Biomass	Water shortages, no promotion policy, financial schemes, high cost, small market, low awareness, competition with food industry and agriculture about the land use.	Support for promotional and training activities (workshops), finalisation of feasibility studies and business plans, incentives, enforcement of existing environmental laws.

Table 5. The development of renewable strategies and policies in Ghana

RES	Year	Policy Type	Policy Target
Renewable Energy Act	2011	Feed-in tariff, RE purchase obligations, establishment of RE fund, tax exceptions,	RE energy for heat and power
National energy policy	2010	No specifics mention of policy types. Just mentioned energy sector challenges and government objective to overcome them.	Covers the whole energy sectors including waste to energy, solar, Hydropower, Geothermal, Multiple RE Sources, Power, Bioenergy, Biofuels for transport.
National Electrification Scheme	2007	Research, Development and Deployment (RD&D), Research programme , Technology deployment and diffusion, Economic instruments, Fiscal/financial incentives, Grants and subsidies,	Wind, Onshore, Bioenergy, Biomass for power, Multiple RE Sources, Power, Solar, Wind
Ghana Energy Development Access Project	2007	Economic Instruments, Fiscal/financial incentives, Loans, Economic Instruments, Fiscal/financial incentives, Grants and subsidies, Economic Instruments, Fiscal/financial incentives, Tax relief	Wind, Solar, Solar PV
Strategic National Energy Plan 2006 – 2020.	2006	Policy Support, Strategic planning	Multiple RE Sources for Power, Heating
Renewable Energy Service Program (RESPRO)	1999	Economic Instruments, Direct investment, Infrastructure investments	Solar, Solar PV
Tax and Duty Exemptions	1998	Economic Instruments, Fiscal/financial incentives, Tax relief, Economic Instruments, Fiscal/financial incentives, Taxes	Wind

Table 6. Technology specific feed-in-tariff of Ghana [43]

Technology	Capacity Factor	Rate (U$ Cent/kWh)
Solar	19	20.3000
Wind	28	12.5521
Biomass	50	12.2759
Waste to energy	50	12.5900
Hydro	55	11.1336

Table 7. Expected targeted renewable energy investments in the next decade[46]

Energy Source	Exploitable Potential	Investment Requirement (Million US$)
Wind	300	250 - 400
Solar	20	100 - 150
Medium and Small Hydro	150	200 - 300
Biomass	90	90 - 150
Total	560	640 - 1000

Table 8. First pipeline of Medium-Large Scale Commercial Power Plants identified in the ECOWAS Sub-region (2011to 2016) [24]

	PV	**CSP**	**Wind**	**Small Hydro**	**Biomass (MW)**	**Other**	**TOTAL per country**
Benin	6		10	26	20		62
Burkina Faso	43	30		39			112
Cape Verde	18		27				45
Cote d'Ivoire				20	40		60
Gambia	10		19				29
Ghana	20	40	100				160
Guinea				20			20
Guinea Bissau	5						5
Liberia				10	38		48
Mali	110	30		16	15	30	201
Niger		30	30				60
Nigeria	40	40	20	139	20		259
Senegal	10		150		30		190
Sierra Leone				10	100		110
Togo	10		20				30
TOTAL per Technology	272	170	376	280	263	30	1391