1. Introduction

The SWERA Ghana Project is an integral part of the Global SWERA Project which was implemented in 13 developing countries in Africa, Asia, Central and South America. The project was funded by the Global Environment Facility (GEF) and United Nations Environment Programme (UNEP). The Ghana project was handled by the Energy Commission and the Meteorological Service Department (MSD). The Mechanical and Geodetic Engineering Departments of the Kwame Nkrumah University of Science and Technology (KNUST), Kumasi, Ghana provided local consultancy for the project while the National Renewable Energy Laboratory (NREL) of USA and German Aerospace Institute provided international consultancy.

The Mechanical Engineering Department compiled the solar and wind resources data obtained from its Solar Energy Centre and MSD.

The Department of Geodetic Engineering developed the Geographic Information Systems (GIS) data sets of the Electricity Company of Ghana grid network, road network and land cover and mini hydro sites.

NREL produced medium resolution (40km) solar resource maps of Ghana on direct, diffuse, global and latitude tilt radiation.

The German Aerospace provided high resolution (10km) solar resource map of Ghana.

The SWERA Ghana project began in August, 2002 when the Energy Commission of Ghana signed a contract with the UNEP for the execution of the project. The project was supposed to have ended in December 2004 but had to be extended to the end of 2005 to the project to be completed fully.

The project assessed every part of Ghana for indications: of wind energy potential with focus on the potential for large-scale grid connected wind turbines for power production; and solar energy resource for the deployment of solar energy technologies for various applications (non-grid, grid connected, heating, etc). The assessment was based on data available, local data provided and site inspection.

1.1. Objective

The goal of the SWERA project is to develop adequate, accurate and reliable solar and wind energy resources data and information and evaluation tools for energy planning and policy.

1.2. Methodology

The following methodology was used in the implementation of the project:

1. The existing information was reviewed.
2. Discussion with relevant persons and institutions
3. Evaluation of existing data.
4. Inspection of selected wind measurement sites.
5. Analysis of data.

2. Overview

2.1. Solar Resource

The success of all solar energy technologies depend largely on the availability of accurate and reliable solar energy data. The Meteorological Services Department (MSD) until recently have been solely responsible for collecting solar energy resource data. Together with other institutions such as the Solar Energy Applications Laboratory of KNUST they have collected and analysed solar energy data from all over the country. Prior to SWERA, data was collected mainly by the Meteorological Services Department (MSD) using Bellani-distilation pyranometres. Data collected included solar radiation, sunshine hour duration, relative humidity and air temperature. The MSD measured global solar radiation data until 1988 when they changed over to measuring duration of bright sunshine using Campbell-Stokes sunshine recorders.

Table 1: Comparison of KNUST and MSD Monthly Hourly Mean Solar Radiation (W/m^2) Data for Kumasi in 1988.

MONTH	KNUST	MSD	%ERROR
JAN	266.67	314.08	-17.78
FEB	333.33	371.00	-11.30
MAR	380.25	416.42	-9.51
APR	405.08	403.67	0.35
MAY	413.75	400.25	3.26
JUN	341.33	350.33	-2.64
JUL	300.42	321.50	-7.02
AUG	236.75	242.75	-2.53
SEP	292.00	298.58	-2.25
OCT	374.67	378.25	-0.96
NOV	351.50	364.33	-3.65
DEC	303.83	319.00	-4.99
AVERAGE	333.30	348.35	-4.51

Independently, the KNUST measured solar radiation (global and diffuse) using Kipp and Zoen radiometers connected to a data logger. The Kipp and Zoen radiometers (5% margin of error) are more accurate than the Bellani-distillation pyranometres (15% margin of error). Except for 1988 when solar radiation data was available at both institutions facilitating straight forward comparisons, there was the need to convert the measured sunshine hours into global irradiation before any comparison of the two measurements from the MSD and KNUST could be made. Table 6 shows the results of the monthly comparison for 1988 when both institutions were measuring actual global solar irradiation

In comparing the MSD solar radiation with KNUST data, the MSD monthly averages were higher than the KNUST monthly averages. The average percentage error margin was - 4.91% for 1988 when both institutions measured actual global solar radiation. From 1995 to 2002 the average percentage error margin increased to 10%. This could be attributed to errors introduced in the use of empirical formulae to convert the measured sunshine hour duration to monthly mean global irradiation. Table 7 shows results of the comparison after the conversion of the MSD data from sunshine hours to irradiation with the KNUST data.

A similar trend in the variation of the monthly averages of global irradiation was shown when a time series data was developed for 10-year duration for 9 synoptic stations (Table 8). January to April for each synoptic station saw a steady increment in global irradiation results. The average percentage increase from January to April was thirteen (13) percent. This steady increment was followed by a steady reduction from April to August with an average of seventeen (17) percent and then a steady rise after the decline from August to November. The average percentage increment was thus estimated to be twenty (20) percent when they were measuring global solar radiation. The measurement finally dropped in November to December seeing a seventy (70) percent reduction in the mean global irradiation.

From the 1995 to 2002 monthly averages computed for Kumasi, the highest level of solar irradiation occurs in June (5.696 KWh/m^2-day) with the minimum occurring in August (4.112KWh/m^2-day).

Table 2: Yearly Comparison of KNUST and MSD Solar Irradiation Data (KWh/m^2/ day) for Kumasi.

YEAR	KNUST	MSD	%ERROR
2002	4.30	4.83	-12.21
2001	4.36	4.82	-10.38
2000	4.233	4.715	-11.38
1999	4.609	4.759	-3.27
1998	5.323	4.652	12.62
1997	6.739	4.630	31.29
1996	7.309	4.565	37.54
1995	4.355	4.861	-11.63
AVERAGE	5.154	4.729	8.237

A similar 10-year monthly average computed for 19 synoptic stations out of 22 in the country revealed that, Wa, the capital of the Upper West region, has the highest level of solar irradiation (5.524 KWh/m^2-day) across the country. May is the month with the highest solar irradiation (5.897 KWh/m^2-day), with August recording the lowest measurement (4.937kWh/m^2-day) in Wa. Akim Oda on the contrary is the location that records the lowest radiation (4.567kWh/m^2-day) measurements across the country. The highest measurement in Akim Oda was recorded in the month of April (5.176kWh/m^2-day) and the lowest in August (3.802kWh/m^2-day).

Upon validation, it was established that although the MSD is using lower accuracy equipment in measuring sunshine hour duration, the comparison with the KNUST data indicates that the MSD data is fairly accurate and can be relied upon. Satellite data obtained from NASA was also compared with MSD ground measurements obtained from the 22 synoptic stations in the country for 10 year duration. The satellite data on the average exceeded the ground measurements by about 5.4% with the maximum being

15.9% (Akuse) and minimum 1.3% (Kete Krachi). The satellite measurements thus, compare favourably with the MSD data. Table 9 shows a summary of the comparison of the results.

Table 3: Year Monthly Averages of Solar Irradiation (kWh/m^2-day) at 9 Synoptic Stations

MONTH	KUMASI	ACCRA	AXIM	NAV'GO	HO	ADA	K'DUA	WENCHI	TAMALE
JAN	4.818	4.660	4.882	5.391	4.872	4.995	4.711	5.193	5.124
FEB	5.313	5.206	5.399	5.400	5.224	5.381	5.139	5.495	5.479
MAR	5.305	5.256	5.569	5.783	5.509	5.649	5.260	5.483	5.613
APR	5.356	5.665	5.605	5.958	5.716	5.937	5.434	5.711	5.890
MAY	4.709	5.416	5.051	5.934	5.576	5.570	5.287	5.507	5.869
JUN	4.029	4.613	3.936	5.719	4.916	4.978	4.641	4.972	5.510
JUL	4.036	4.189	4.242	5.339	4.601	5.064	4.074	4.356	4.954
AUG	3.783	4.527	4.230	5.098	4.187	5.065	3.842	4.120	4.841
SEP	3.992	5.107	4.382	5.324	4.663	5.510	4.437	4.405	5.004
OCT	4.707	5.623	5.178	5.677	5.500	5.872	5.174	4.927	5.472
NOV	5.000	5.510	5.466	5.616	5.624	5.480	5.241	5.127	5.695
DEC	4.552	4.930	4.986	4.824	5.074	5.359	4.857	4.905	5.213
Av'ge	4.633	5.059	4.911	5.505	5.122	5.409	4.841	5.017	5.389

Table 4: Summary of comparison results (solar irradiation in kWh/m^2-day)

Synoptic Station	Ground (kWh/m^2-day)	Satellite (kWh/m^2-day)	% Error
Kumasi	4.633	5.155	-11.3
Accra	5.060	5.180	-2.3
Navrongo	5.505	5.765	-4.7
Abetifi	5.150	5.192	-0.8
Akuse	4.814	5.58	-15.9
Wa	5.520	5.729	-3.7
Akim Oda	4.567	5.177	-13.3
Wenchi	5.020	5.093	-1.5
Ho	5.122	5.223	-2.0
Kete Krachi	5.280	5.345	-1.3
Takoradi	5.011	5.200	-3.8
Yendi	5.370	5.632	-4.8
Bole	5.323	5.570	-4.6

The abundance of solar energy is particularly conducive for the installation of solar energy systems. In spite of this high potential, solar energy technologies are not as widely diffused into the Ghanaian society as one would have wished mainly due to the low level of information and technical know-how about solar energy technologies in general.

Deng Solar Energy Systems are in the process of developing and assembling solar PV systems in Ghana. They also produce solar water heaters suitable for homes, hospitals and industrial pre-heating. This single investment shows that there is a vast potential for solar energy systems in Ghana. There are a whole lot of places where solar energy systems could be more economical than the other conventional energy systems. The rural areas have long been recognised as areas where it is cost effective to harness renewable energy for development.

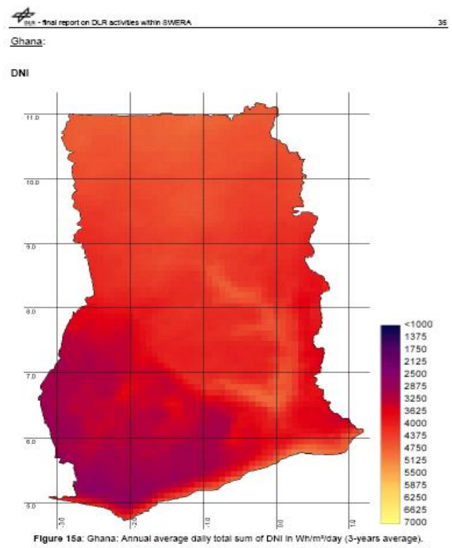
An inventory of PV installations in the country taken by the Ministry of Energy revealed that the installed solar PV capacity could exceed 1MW. The Ministry has also installed a 50kWp PV-grid integrated roof demonstration facility at its premises and has also produced technical specifications for solar home systems and communal systems for schools, community and health centres.

New Assessment – Validation and Improved Resolution

Under the SWERA project NREL provided satellite data at 40km resolution on global, latitude tilt, direct and diffuse radiation. Additionally DLR produced DNI and GHI Maps of Ghana from 10km resolution satellite data. See Maps in Appendix ---

Global and Latitude Tilt Radiation:

The global and latitude tilt radiation levels are almost the same at every part of the country. The radiation is highest at the Northern



2.2 Wind resource-

Winds are large scale movements of air masses in the atmosphere. The movements are created on a global scale primarily by different solar heating of the earth's atmosphere. Wind speeds, of up to about 13 ms^{-1} can be harnessed by wind turbines to provide sufficient power in remote areas.

Wind data collection in Ghana (Accra) dates back to 1921 by the MSD, using a wind vane. In 1936, MSD installed a cup counter anemometer and dines pressure tube anemometer to measure instantaneous wind speed and direction. They have since recorded wind speed and direction data at 2 metres above ground level (a.g.l.) from all their 22 synoptic stations sited within every latitude (between 4^0 40' and 11^0 11'N) and longitude (between 3^0 11'W and 1^0 11'E) of the country. The data obtained from the MSD indicate wind speeds of approximately 2.4ms^{-1} at 2 m a.g.l at stations set up with objectives other than for energy applications. The sites were deliberately selected for their low wind regimes as the measurements were made for meteorological and agricultural applications. The obtained data could therefore not be used as a true assessment of the wind energy potential in the country. For a long time, the lack of dependable countrywide data on wind energy has been the main obstacles for harnessing wind energy.

Nonetheless, it is quite obvious that Ghana has some winds that could be tapped to supplement her energy requirements.

The Energy Commission in 1999 started wind energy resource measurement along the coast of Ghana with the view to develop adequate, accurate and reliable wind energy data and evaluation tools as an integral part of Ghana's energy planning and policy framework. Measurements were taken at 11 sites East and West of the Meridian. Fig.4 shows the Energy Commission's wind measurement sites. The sites east of the Meridian were Tema, Adafoah, Lolonya, Pute, and Kpone with the sites west of the Meridian being Asemkow in Takoradi, Warabeba in Winneba, Mankoadze, Bortianor, Gomoa Fetteh and Aplaku. These studies and others made by private concerns at six coastal sites east of Tema in 1999 indicated the existence of fairly strong winds that could be utilised for power generation. The data collected included average wind speed, average wind direction and standard deviation. The monthly average wind speed measurement at 12 m a.g.l varied in the range of 4.8 to 5.5 m/s. The data somehow validated a six year satellite-borne measurement provided by the U.S National Renewable Energy Laboratory (NREL), which suggested that Ghana has appreciable wind resource for power generation.

A wind energy system usually needs an average annual wind speed of at least 4 m/s to be practical (Table 10). The NREL data was computed from satellite ocean wind measurements by the US military, off the coastline of Ghana. The maximum energy that could theoretically be tapped from the country's available wind resource for electricity using today's technology is about 500 – 600GWh/year.

Over the last decade, there has been a marked change towards offshore wind as a key energy resource. Increased wind speed and reduced wind turbulence offshore are much more appreciated now, and this in conjunction with more cost effective infrastructure has reduced the predicted cost of energy from offshore projects. Offshore Ghana has a considerable high potential for wind energy from the conducted studies undertaken by NREL. Fig. 5 shows the Global Telecommunication System surface meteorological stations in Ghana. They are part of NREL's global database

Table 5: Average wind speeds for coastal Ghana; between Latitude 5^o–6^oN and Longitude 0^0-1^0E

Sensor Height* (m/s)	**July**	**Aug**	**Sept**	**Oct**	**Nov)**	**Dec**
12 metres	4.56	5.41	5.49	6.36	5.08	4.74
40 metres	5.41	6.31	6.54	7.54	6.02	5.18
Satellite(NREL) ¤	5.4 – 6.0	4.6 – 5.2	4.8 – 5.3	4.5 – 5.0	3.5 – 3.7	3.6 – 4.2

*[*These are monthly average wind speeds at Tema and four other surrounding coastal towns, namely; Kpone, Lolonya, Adafoah and Pute in 1999 compiled by the Energy Commission.*

¤ *Extracted from Wind speed data from 1988 – 1994 for Ghana Coastal Region compiled by NREL and computed from Satellite Ocean Wind Measurement conducted by U.S satellites].*

The average wind speed measured about 10 kilometres off the coastline in the direction of the sea is about 5.5 ms^{-1}. It is about the same in the western and central regions which constitute about two thirds of the total coastline of Ghana. The offshore wind energy potential is huge and worth pursuing.

Over land, with the wind speeds recorded medium power turbines could be operated as alternative to large-scale turbines. Some investors have shown considerable interest in the exploitation of wind energy in Ghana. Indeed, some private firms are already in touch with the Energy Commission on the possibility of setting up wind farms for power generation.

From the statistical analysis of the wind speeds measured at 12 m a.g.l the potential of wind power in the coastal sites was investigated by digitizing the wind data measured at ten minutes interval over a one year period, by year, by month, day and hour. The average wind speed of the extrapolated data for all the 22 synoptic stations were in the range of 2 to 5.1 m/s at 12 m a.g.l. and 3.5 to 8.4 m/s at 50 m a.g.l. Adafoah recorded the highest average wind speed whiles Sefwi Bekwai registered the lowest. Figures 6 and 7 show the wind speed distribution at 12 m and 50 m respectively for four selected sites across the country. The highest potential sites were along the coast except Abetifi (3^{rd} highest).

The average wind speed along the coast was in the range of 4 to 5.1m/s at 12m a.g.l. and 6 to 6.4m/s at 50m a.g.l. along the coast, west of the meridian, Mankoadze recorded the highest mean speed of 6.08m/s whilst Oshiyie recorded the lowest of 3.33m/s. The predominant direction for Mankoadze was 30^0 with a directional mean wind speed of 6.7m/s and frequency 28% and followed by 60^0 with frequency 18%.

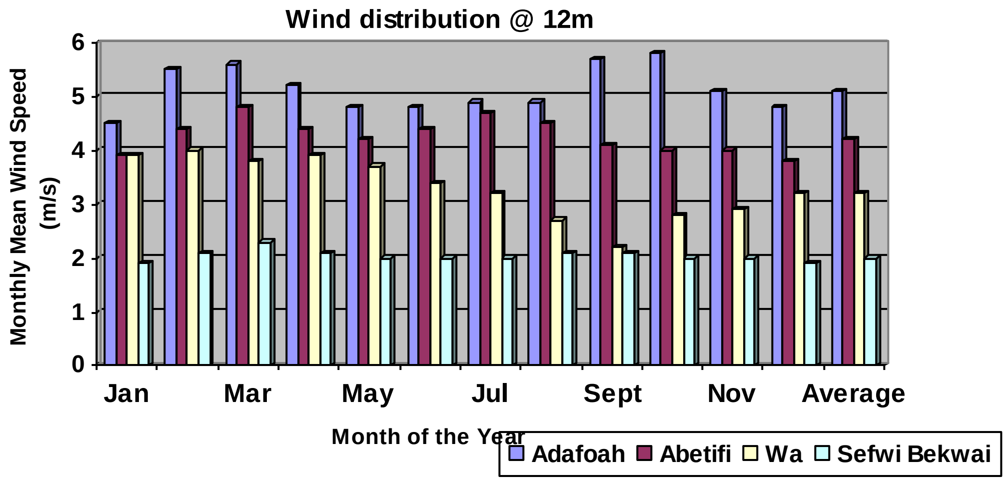


Fig.6: Wind speed distribution at 12 m a.g.l. across the country.

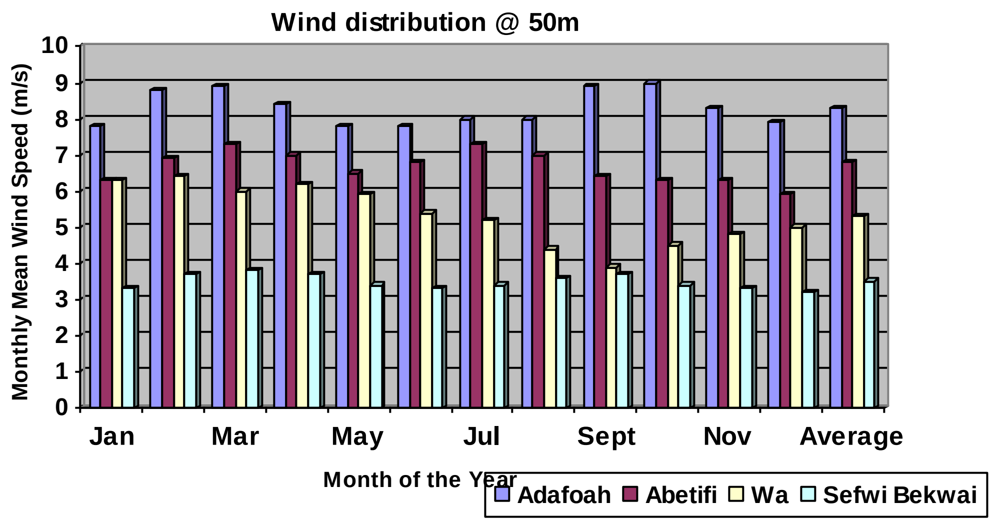


Fig.7: Wind speed distribution at 50 m a.g.l. across the country.

On the east coast of the meridian, Lolonya gave the highest wind speed of 5.43 m/s and the predominant direction of the wind speed was 240^0 with a corresponding mean wind speed of 5.66 m/s and frequency 47%. For Adafoah the mean wind speed was 5.33 m/s and the predominant direction of the wind speed was 240^0 with a corresponding mean wind speed of 5.52 m/s and frequency of 47% followed by 210^0 with mean speed of 5.69 m/s and frequency of 31%.

The analyses of the available wind data indicate that the mean wind speed for Mankoadze, Lolonya, Adafoah, Petu, and Aklaku were in the range of 5 to 6.1 m/s at 12 m a.g.l with corresponding power densities of 119 to 410W/m^2. With these speeds electric power generation is favourable. Fig 8 and 9 show the wind power classification maps.

Aerial survey by an international team on the SWERA project identified some spots inland Ghana with high wind regimes. These potential sites are yet to be corroborated by ground measurements. For now, the potential is confined to the coastline and the most economic exploitation based on current technology is at 50 metre-height with average wind speeds between 6.0 – 6.3 m/s. The corresponding wind power density ranges from 185 - 210 W/m^2 at 1.225 kg/m^3 air density.

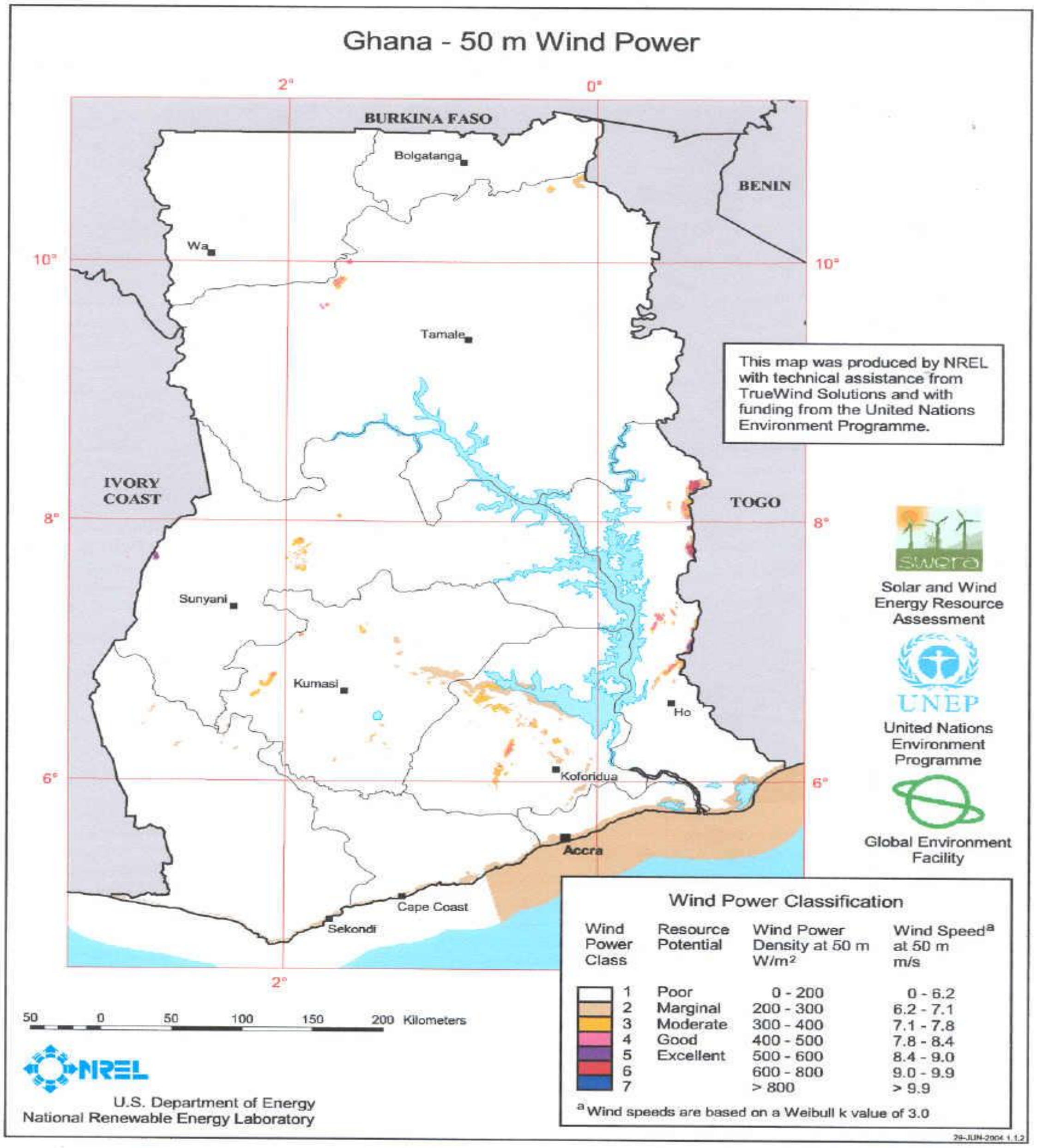


Fig 7: wind power classification map at 50m.

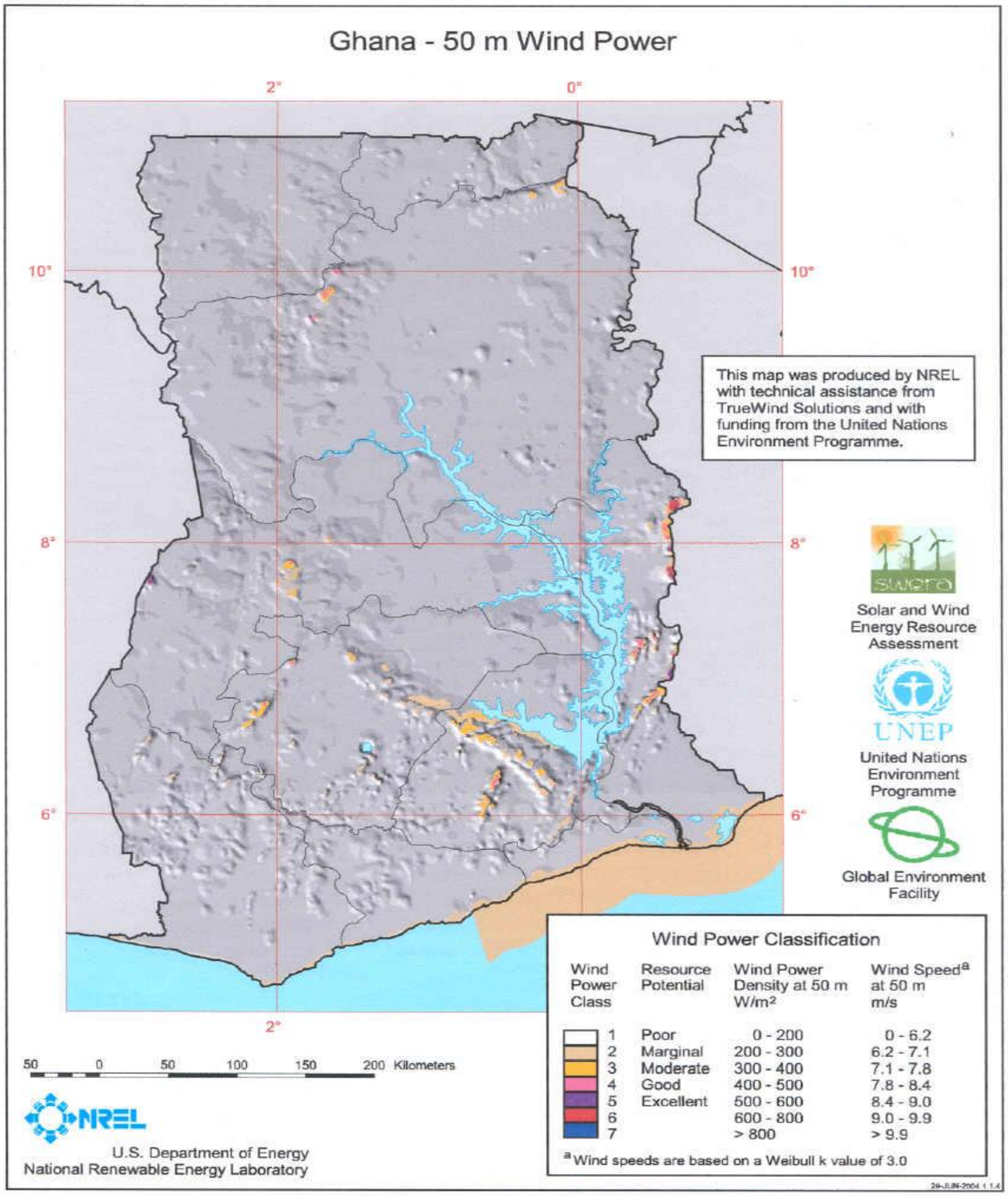


Fig 8: wind power classification map at 50m

Data Analysis

Solar Data Analysis

The three components of solar radiation were provided by NREL. These data were analysed.