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WIND ENERGY ASSESSMENT AS A POTENTIAL ALTERNATIVE ENERGY SOURCE IN KISUMU CITY IN KENYA

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ABSTRACT

As a developing nation, Kenya urgently needs new sources of affordable and clean energy to meet its growing energy demand. Among them is wind energy, which is potentially attractive because of its low environmental impact and sustainability. This work investigated the wind power production potential of Kisumu city in Kenya. Wind speed data over a 10-year period (2002-2012) measured at a height of 10 m from Kisumu meteorological station is presented. Frequency distributions of wind speeds and wind power densities, seasonal variations of wind speed, and estimates of power likely to be produced by small turbines are included. To assess the wind power potentials, the Weibull parameters were calculated by different methods in the analysis of wind speed data in order to establish a better method for estimation. The wind speed distributions were represented by Weibull distribution. The yearly values of k (dimensionless weibull shape parameter) and the average annual Weibull distributions for the two towns calculated were used to predict the type of wind turbines suitable in the two regions under study. The data was analyzed by use of Weibull distribution model with the help of computer software microCal origin (version

7). The results revealed that the annual mean wind speed at a height of 10 m for Kisumu was 2.38m/s, with the annual mean power density being 127.99 W/m^2. The annual mean wind energy density was 93.25kWh/year. It was further shown that the mean annual value of the most probable wind speed was 2.45m/s, while the annual value of the wind speed carrying maximum energy is 2.85m/s. The yearly value of k (dimensionless weibull shape parameter) was 4.51 while the yearly value for c (Weibull scale parameter) was 2.61m/s. It was concluded that Kisumu has marginal potential based on the wind speeds measured at a hub height of 10m. However with new turbine technology and based on the vertical wind profile it was established that Kisumu has a potential for wind energy applications at higher heights between 50 m and 100 m.

Abbreviations And Acronyms

δ^2	Standard deviation
V_{mp}	Most probable wind speed (m/s)
$\bar{p}$	The monthly average air pressure (pa)
$\bar{v}$	Mean wind speed in m/s.
A	Area (m^2) Area swept by the rotor diameter of a wind Turbine
c	Weibull scale parameter in m/s
f(v)	Probability of observing wind speed
k	The dimensionless Weibull shape parameter
KIPPRA	Kenya Institute for Public Policy Research and Analysis
KW	Kilo watt
LTWP	Lake Turkana wind energy project
MW	Mega watt
P (v)	Wind power density (W/m^2)
P_H	The corrected power available in wind at a height of H metres
R_d	The gas constant for dry air R_d = 287 j/(kg.k)
T	Average air temperature in Kelvin;
TWh	Terra Watt Hour
W/m^2	watt per square meter
WEC	Wind energy conversion
WED	Wind energy density
WPD	wind power density.

Standard air density at sea level with a mean temperature of 15^0c and pressure of 1 atmospheric pressure 1.225 kg/m^3 gamma function.

$V_{\max E}$ Wind speed carrying maximum energy Speed of sound Velocity of gas flow.

INTRODUCTION

1.1 Background to the study

Energy is essential for support of human life. The advancement in technology has led to environmental pollution which in turn led to climate change. Furthermore the increasing global population has led to the depletion of the fossil reserves (Sinan *et. al., 2009*). As a result, problems such as environmental pollution, climate change and the energy crisis are of utmost concern in the 21st century. Reduction in over dependency in fossil fuels is seen as a way to alleviate these problems. Thus the focus is on the alternative sources of energy.

The large gap between demand and supply of electricity, increasing cost of imported fossil fuels and worsening air pollution require an urgent search for energy sources that are cost effective, reliable and environmentally friendly. Energy derived from wind has played a vital role in the history of mankind and is receiving considerable attention because of its free and non-polluting character.

With the development of wind energy technologies and the decrease of wind power production cost, wind power has shown a remarkable development around the world over the last two decades. By the end of 2010, global installed wind power capacity had reached 196,630 MW and the annual output was approximately 430 TWh (Ebubekir *et al*., 2011).

During the last decade, the average growth rate of installed wind power was approximately 28 % (Ebubekir *et al*., 2011). A feasibility analysis is one of the first steps in evaluating a wind power project investment, which must be performed before the installation of a wind power plant. Several wind energy feasibility and characteristics analyses have been made over the last two decades all over the world (Ebubekir *et al*., 2011). During the feasibility study of wind power plants, the most important meteorological parameters are: wind speed, wind speed distribution, air density, ambient temperature, air pressure, and turbulence intensity. Therefore a detailed analysis of the wind speed profile characteristics is crucial for accurately assessing the power output of a wind farm.

As Kenya aspires to be a middle income economy as envisaged in Vision 2030, it faces huge power energy demand due to the prospects of industrialization and modernization of institutions. The country therefore needs to come up with strategies and investment plans to secure sustainable supply of energy to meet the growing demand. The energy sector comprising of electricity, petroleum and renewable energy is definitely the key enabler to achievement of vision 2030. Currently, studies indicate that wood fuels are the most commonly consumed fuels in Kenya, with petroleum and electricity dominating the commercial sector. Other major energy consumption sectors apart from commercial sector, are transport, manufacturing and residential sectors (KIPPRA, 2010). To meet this growing demand for sustainable development, there is need to explore other renewable sources of energy which have not been fully exploited. Among the renewable sources like wind, solar, geothermal, tidal and biomass energy, wind energy has attracted considerable attention all over the world. According to Sunday *et.al* 2012, the global installed capacity of wind power had sharply increased from 6100 MW in 1996 to about 237669 MW in 2011.

The main sources of energy in Kenya are wood fuel, petroleum and electricity accounting for 69%, 22%, and 9% of total energy use respectively. More precisely, 67.5% of electricity is generated using renewable energy sources which are predominantly Hydro with 47.8% and Geothermal with 12.4% respectively, while 32.5% is from fossil fuels. The current population accessible to electricity is shared by less than 20% of the population, and more than 80 percent of the population remaining without access to the electricity. The present contribution of wind as a source of energy is only 0.3% (wind sector prospectus (Kenya) - September 2013).

The proposed wind energy projects in Kenya include Lake Turkana wind energy project (LTWP) in Marsabit district near Lake Turkana with proposed number of 365 turbines of 850 KW capacity expected to produce 310 MW to the national grid once completed. The site has a huge wind energy potential as it maximizes the very high speed winds in the low jet stream corridor (Madeline *et al.,* 2006). Other wind projects currently in different stages of development in Kenya include Kipeto Wind Park in Kajiado County which is expected to have an installed capacity of 102.06 MW and comprises of 63 wind turbines each of capacity of 1.62 MW, Kinangop Wind Park expected to produce 60.8 MW, Isiolo wind project expected to produce a total of 150 MW when completed in two phases, Ngong wind park expansion which has a total of 25.7 MW and the planned Mount Meru wind park in Meru

County projected to produce 400MW. In overall, Kenya plans to increase the wind generation to 630MW by the end of 2016. This is in addition to current 25.7MW already in operation by Kengen at Ngong Wind Park (Rahul- Kumar *et al.*, 2014).

The potential of wind generation in Kenya is one of the highest in Africa with a total of 346 W/m^2. Despite the remarkable potential for wind generation in Kenya, several challenges still remain. Among the challenges include land acquisition for wind plants, inadequate infrastructure such as roads, and transmission lines to the areas tend to be far from electricity demand centers apart from security in reaching these areas posing a great concern. The supply of auxiliary equipment, related services and availability of technical know-how concerning wind generation is also limited.

The Wind Energy Resource Atlas of Kenya (see appendix IV) gives indicative information about the wind potential in various parts of Kenya. The Atlas provides broad information on a national scale. According to the wind energy resource assessment carried out by WinDForce in September 2013, it showed that over 73% of the total area of the country experience annual mean wind speeds above 6 m/s at 100 m above the ground (wind sector prospectus Kenya September 2013). This fact depicts the immense potential for wind energy utilization in Kenya. The wind map atlas in appendix II shows the wind regimes in various parts of the country. To exploit wind energy in a utility scale, detailed feasibility studies are required for each site since wind energy resource potential is site-specific.

Wind energy potential is not easily estimated because, contrary to solar energy, it depends on the site characteristics and topography to a large degree, as wind speeds are influenced strongly by local topographical features (Sahin *et al.*, 1998). The classification and characterization of an area as of high or low wind potential requires significant effort, as wind speed and direction present extreme transitions at most sites and demands detailed study of spatial and temporal variations of wind speed values. Before determining the wind farm site, the daily and monthly mean wind speed, wind speed distributions as well as the wind power densities should be analyzed.

1.2 Statement of the problem

The rapid increase in the world energy demand and the depletion of the conventional energy sources calls for an alternative source of energy. This is occasioned with rising demand in automation, newer uses of energy as a result of eco-friendly initiatives, increased urbanization and mechanized agriculture among others. However, this notwithstanding, there is a problem of managing the existing energy supplies as seen in power outages, uneven distribution of power and supply as most of the remote parts in Kisii and Kisumu are not connected to the grid power and therefore require an alternative source of energy which is cheaper and sustainable, thus diversifying power generation alongside eco friendly utilization is construed important. Thus there is need to carry out a wind energy resource assessment in the two regimes to establish the extent to which wind energy can be an alternative substitute to supplement the already established sources of energy like hydro power and biomass.

1.3 OBJECTIVES

1.3.1 Main objective

To carry out a wind energy resource assessment at a specific site in Kisumu city for siting standalone wind power system.

1.3.2 Specific objectives

i To assess the trend (speed, energy density, power density) of wind for a span of 10 years from 2002 to 2012 with existing meteorological data.

ii To determine whether trend of wind in the area under study can translate into energy power.

iii To assess the amount of energy (power) that can be generated from the wind harnessed in the region.

iv To determine the extent to which wind energy can be alternative substitute to power consumption in Kisumu.

v To determine the type of wind turbines that can be installed for wind power generation in the locations under study to sustain the alternative substitute power consumption.

1.4 Rationale of the study

Kisumu is an agriculturally productive region and much of the generated energy goes into support of agro- mechanical applications. Thus there is need for extra energy sources that are cleaner and reliable. For that reason, this research provide these industries with alternative energy source that is eco-friendly and reliable; Wind energy investors will also be endowed with the information on whether the two towns are suitable potentials to invest in wind energy generation. The residents of the two regions under study who are not served with the grid energy will also be provided with an alternative source of energy which is cheaper than the grid or hydropower. Finally, the study will establish the extent to which wind energy can be alternative substitute to the other existing energy sources like hydroelectricity and biomass.

LITERATURE REVIEW

2.1 Review of Related Work

In this section, previous research work on wind energy is analyzed in view of establishing the existing knowledge gap in wind energy in the world and Kenya in particular.

Keyhan *et al.* (2010) studied an assessment of wind energy potential as a power generation source in the capital of Iran, Tehran. In their investigation, they studied the wind characteristics with the help of meteorological and Weibull methods. In their study, the statistical data of eleven years' wind speed measurements of the capital of Iran, Tehran, were used to find out the wind energy potential. Long term data source, consisting of eleven years (1995–2005) of three-hour period measured mean wind data, was adopted and analyzed. Based on these data, it was indicated that the numerical values of the shape and scale parameters for Tehran varied over a wide range. The yearly values of k (dimensionless Weibull shape parameter), ranged from 1.91 to 2.26 with a mean value of 2.02, while those of c (Weibull scale parameter), were in the range of 4.38–5.1 with a mean value of 4.81. Corresponding values for monthly data of whole year were found to be within the range 1.72–2.68 and 4.09–5.67, respectively related to k and c Weibull parameters. Results revealed that the highest and the lowest wind power potential were in April and August, respectively. It was also concluded that the site studied was not suitable for electric wind application in a large-scale.

Ahmed *et al.* (2010) studied monthly and seasonal assessment of wind energy characteristics at four monitored locations in Liguria region (Italy) using wind speed data collected over a period of 7 years (2002-2008). The results show that Capo Vado was the best site with a monthly mean wind speed between 2.80 and 9.98 m/s at a height of 10 m and a monthly wind power density between 90.71 and 1177.97 W/m^2 while the highest energy that could actually be generated reached 3800 MWh in the month of December during the period of study. His study provided useful information for developing wind energy sites and planning economical wind turbines capacity for electricity generation in Liguria region. Other researchers Gholamhassan Najafi and Barat Ghobadian, (2011) studied wind energy resources and development in Iran and their findings presented a brief introduction to the resource, status and prospect of wind energy in Iran. Zhou *et al.* (2011) studied the assessment of onshore wind energy resource and wind generated electricity potential in Jiangsu, China based on meteorological data from 1979 to 2008 and results show that Jiangsu has abundant energy resource which is gradually increasing from the coast to the inland.

Cumali *et al*. (2010) studied the determination and utilization of wind energy potential for Turkey and found that the investigated sites had fairly satisfactory wind energy potential for the utilization. In his study on the current status of wind energy in Turkey and the world, he found out that wind energy utilization in Turkey and throughout the world has sharply increased.

Sinan *et al*. (2009) also studied estimation of wind energy potential using finite mixture distribution models in four stations in Turkey over a period of 8 years (1998-2005). Among the empirical correlations used, were the Weibull distribution and the maximum entropy principal. In their study, it was observed that wind energy distributions could not accurately represent all wind regimes observed in that region though a singularly truncated from below normal Weibull mixture distribution and a two component mixture Weibull distribution offered less relative errors in determining the normal mean wind power density. The parameters of the distributions were estimated using the least squares method and a statistical software.

Carolin *et al*. (2007) studied growth and future trends of wind energy in India. His results showed that new technological developments in wind power design contributed so much to the significant advancement of wind penetration which showed India being ranked fourth in the world in 2007 with an installed capacity of 6018 MW.

Ulgen *et al*. (2004) studied the wind variation for a typical site and found Weibull and Rayleigh distributions suitable as they provided a better approximation of the wind potential at different heights by extrapolation. Availability of wind energy and its characteristics at Kumta and Sirsi in Uttar Kanada district of Karnataka were studied by Ramachandra *et al*. (1997) based on primary data collected for a period of 24 months. Using a given type of wind electric generator and from official meteorological data, Ramachandra *et al*. (2003) derived the maximum output of power; the analysis showed that coastal and dry arid zones have good wind potential.

Oludhe (2010) carried out a project on wind energy assessment and utilization in Kenya and his study concluded that Kenya has a huge wind energy potential which is capable of driving various types of wind energy machines. Barasa (2013) conducted a study on wind regime analysis and reserve estimation for Kenya at three sites- Ngong, Kinangop and Turkana. His study concluded that Ngong exhibits high variability with mean wind speeds of 11.5m/s whereas Kinangop indicated less variability compared to Ngong and Turkana with mean wind speed of 9.96 m/s.

Solar and wind energy resource assessment (SWERA) a UNEP project led by Mr. Daniel Theuri in 2008 conducted Kenya's wind resource assessment including data capturing and analysis, computation and mapping using GIS and other relevant technologies and produced a wind atlas map at 50 m height for Kenya using 10 stations at 10 m height data.

Kabok *et al.* (2014) studied variation of wind speeds at the lake shore of lake Victoria (Kenya). In his study he determined the temporal and spatial wind speeds variation and empirical relations with height and location within the lake shore. 2 m height data collected between 1996- 2011 were analysed and extrapolated to estimate the wind speeds at 10 m for installation and utilization of wind energy. It was established that the wind speeds at 2 m fitted the Weibull distribution parameters. The power law index $\alpha = 0.4$ was used in estimating wind speeds at 10m from 2 m. It was further established that hourly measured data for every month was found adequate in establishing the wind speeds at a particular site. Wind speeds measured in different Meteorological stations further revealed that Muhuru and Rusinga stations with higher wind speeds are nearest to the Lake water while Kadenge and Kisumu, Kibos and Ahero with lower wind speeds are furthest from the lake water. The extrapolated mean wind speed from the 2 m height data for Kisumu was found to be 2.3 m/s at a hub height of 10 m for the period of study.

RESEARCH METHODOLOGY

3.1 Summary of Research Methods

In this study, statistical data from Kisumu meteorological department that was collected from 2002 to 2012 were used. The data has wind speed measurement collected daily for duration of three hours a day. The data was analyzed and wind parameters for the selected areas determined. Weibull distribution model was used to determine the wind parameters (k, the dimensionless Weibull shape parameter, and c, Weibull scale parameter) with the help of computer software MicroCal origin version 7. The magnitudes of the wind parameters obtained from the selected areas were then used to determine whether wind energy is sufficient to supplement the grid energy.

In Kisumu meteorological station, Munro wind system was used in data collection. The munro wind system has a cup counter anemometer fitted at a hub height of 10 m. This height is chosen due to less interference of wind speeds by topographical features and buildings. The wind speed data collected is sent to the data logger where it is recorded and transmitted to the nearby forecast office.

Figure 3.1: Munro wind system (courtesy of Kenya meteorological Department).

3.2 Theoretical Framework

3.2.1 Weibull probability density function

In determining the wind speed, the probability density function given in equation (1) was used;

$$F(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1}\exp\left(-\left(\frac{v}{c}\right)^{k}\right),\ k>0,\ v>0,\ c>1 \qquad (1)$$

Where F (v) is the probability of observing wind speed v, c is the Weibull scale parameter and k is the dimensionless Weibull shape parameter (Keyhani, 2010).

The Weibull parameters k and c characterize the wind potential of the region under study. The scale parameter c indicates how windy a location may be. The shape parameter k indicates the peakedness of the wind distribution. This implies that when the wind speeds are closer to a certain value, the distribution will have a high k value thus highly peaked. The scale factor c of the Weibull distribution is related to the average wind speed at different heights. The weibull shape parameter k reflects the breadth of the distribution. Since the wind speeds increase with height, the scale parameter too follows the trend. Thus the shape parameter increases with height and makes the distribution to have less variation in the wind speed. Once the mean wind speed value $\bar{v}$ and the variance δ^2 of the data are known, the approximation below was used to calculate the Weibull parameters c and k;

$$k = \left(\frac{\bar{v}}{\delta}\right)^{-1.086} \quad 1 \leq k \leq 10 \tag{2}$$

$$c = \frac{\bar{v}}{\Gamma\left(1+\frac{1}{k}\right)} \tag{3}$$

Where the average wind speed $\bar{v}$ is calculated using equation (4);

$$\bar{v} = \frac{1}{n}\sum_{n=1}^{n} v_i \tag{4}$$

The variance δ^2 of wind energy recordings was calculated using equation (5);

$$\delta^2 = \frac{1}{n-1}\sum_{i=1}^{n}(v-\bar{v})^2 \tag{5}$$

Average wind speed was also calculated on the basis of the Weibull parameters by using equation (6) and the variance using equation (7);

$$\bar{v} = C\Gamma\left(1+\frac{1}{k}\right) \tag{6}$$

$$\delta^2 = C^2 \{\Gamma(1+2/k) - \Gamma^2(1+2/k)\} \tag{7}$$

Where the gamma function $\Gamma(x)$ standard formula is calculated by equation (8);

$$\Gamma(x) = \int_0^{\alpha} e^{-u} u^{x-1} du \tag{8}$$

If the value of k =2, then the Weibull distribution is referred to as Rayleigh distribution.

Wind energy conversion (WEC) turbine manufacturers normally provide standard performance figures for their turbines using this special case of the Weibull distribution. The main limitation of the Weibull density function is that it doesn't accurately represent the probabilities of observing zero or very low wind speeds. However for purposes of estimating wind potential for commercial use of wind turbines this is usually unnecessary as the energies available at low wind speeds are negligible. Wind energy is proportional to the cube of wind velocity. The cut in wind speed is usually between 2.5 m/s and 3.5 m/s. (Keyhan *et. al.*, 2010).

3.2.2 Wind power density

The power of the wind that flows at speed v through a rotor blade increases with the cube of the wind speed and the area given by equation (9);

$$P(v) = \frac{1}{2}\bar{\rho}v^3 \qquad (9)$$

Where ρ is the standard air density at sea level with a mean temperature of 15^0c and pressure of 1 atmospheric pressure and is taken as 1.225 kg/m^3 and $\bar{v}$ is the mean wind speed in m/s. The corrected monthly air density $\bar{\rho}$ (kg/m^3) is calculated by equation (10);

$$\rho = \frac{\bar{p}}{RdT} \qquad (10)$$

Where $\bar{p}$ is the monthly average air pressure (pa); T is the average air temperature in Kelvin; R_d is the gas constant for dry air R_d = 287 j/(kg.k).

The corrected power available in wind at a height of H metres can be calculated using the following equation;

$$P_H = \frac{1}{2}\bar{\rho}\bar{v}^{\,3} \quad (W/m^2) \qquad (11)$$

Wind power density expressed in (W/m^2 takes into account the frequency distribution of the wind speed and dependency of wind power on air density and the cube of the wind speed. Thus wind power density is considered a better indicator of the wind resource than wind speed. The average wind power density in terms of wind speed was calculated using equation (12);

$$WPD = \frac{\sum_{i=1}^{N}\frac{1}{2}\rho v_i^3}{N} \qquad (12)$$

Where i is the measured three hourly wind speed daily and N is the total sample data used for each year. Besides calculation of wind power density based on the wind speed provided by field measurements it was also developed by Weibull distribution analysis using equation (13)

$$\frac{P}{A} = \int_0^{\infty}\frac{1}{2}\rho v^3 f(v)dv = \frac{1}{2}\rho c^3\Gamma\left(\frac{k+3}{k}\right) \qquad (13)$$

3.2.3 Wind energy density

Once the wind energy of the regime is given the wind energy density for a desired duration T was calculated using equation (14);

$$\frac{E}{A} = \frac{1}{2}\rho c^3 \Gamma\left(\frac{k+3}{k}\right)T \quad (14)$$

This equation was used to calculate the available wind energy for any defined period of time using a wind speed frequency distribution for different periods of time. This is however the theoretical total energy available for doing work on the wind turbine. However, only a fraction of the total energy would be extracted. The maximum extractable energy from a system working at its optimum efficiency is given by a coefficient of performance called Betz limit (16/27 = 0.593). Thus the Betz limit which has been used in wind calculations requires that a wind turbine would not extract more than 59.3% of the available wind power. Therefore the maximum extractable power from the wind was given by the product of the factor 0.593 and the calculated result from equation (13).

3.2.4 Most probable wind speed

The most probable wind speed denotes the most frequent wind speed for a given wind probability distribution and was determined by equation (15);

$$V_{mp} = C\left(1-\frac{1}{k}\right)^{\frac{1}{k}} \text{ m/s} \quad (15)$$

3.2.5 Wind speed carrying maximum energy

This represents wind speed which carries maximum wind energy and was determined by equation (16);

$$V_{\max E} = C\left(1+\frac{2}{k}\right)^{\frac{1}{k}} \text{ m/s} \quad (16)$$

This is actually expressed as the optimum wind speed for a wind turbine which denotes the speed that produces the most energy. When choosing a wind turbine for a specific site, the rated wind speed should match this maximum energy wind speed to maximize the energy output. Once the wind carrying maximum energy is determined for one site, the rated velocity of a wind turbine can be found. (Rated velocity of a turbine is the lowest wind velocity corresponding to its rated power that due to technical and economical reasons the turbine is designed to produce constant power).

RESULTS, ANALYSIS AND DISCUSSIONS

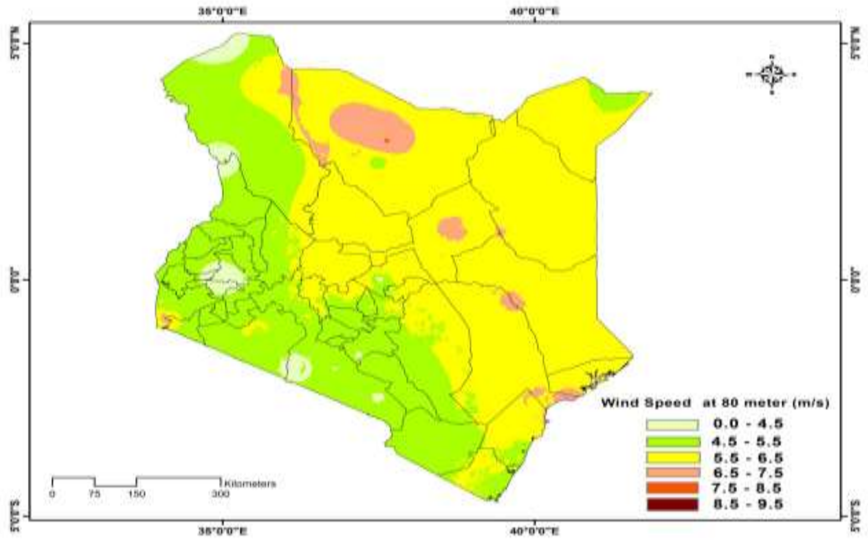
4.1 Introduction

In this study, wind speed data for Kisumu from 2002 to 2010 were analyzed. Based on these data, the wind speeds analyzed were processed using MicroCal origin (version 7) software to obtain mean wind speed. Calculations were then done to obtain the Weibull distribution parameters k (dimensionless Weibull shape parameter) and c (weibull scale parameter in m/s). Using these two parameters, the measured and predicted mean wind power and wind power density were then calculated. The main results obtained from the present study can be summarized as follows.

Appendix I: Installed world Capacity of Wind Power Plants for 2008 and 2009 (Cumali, 2011).

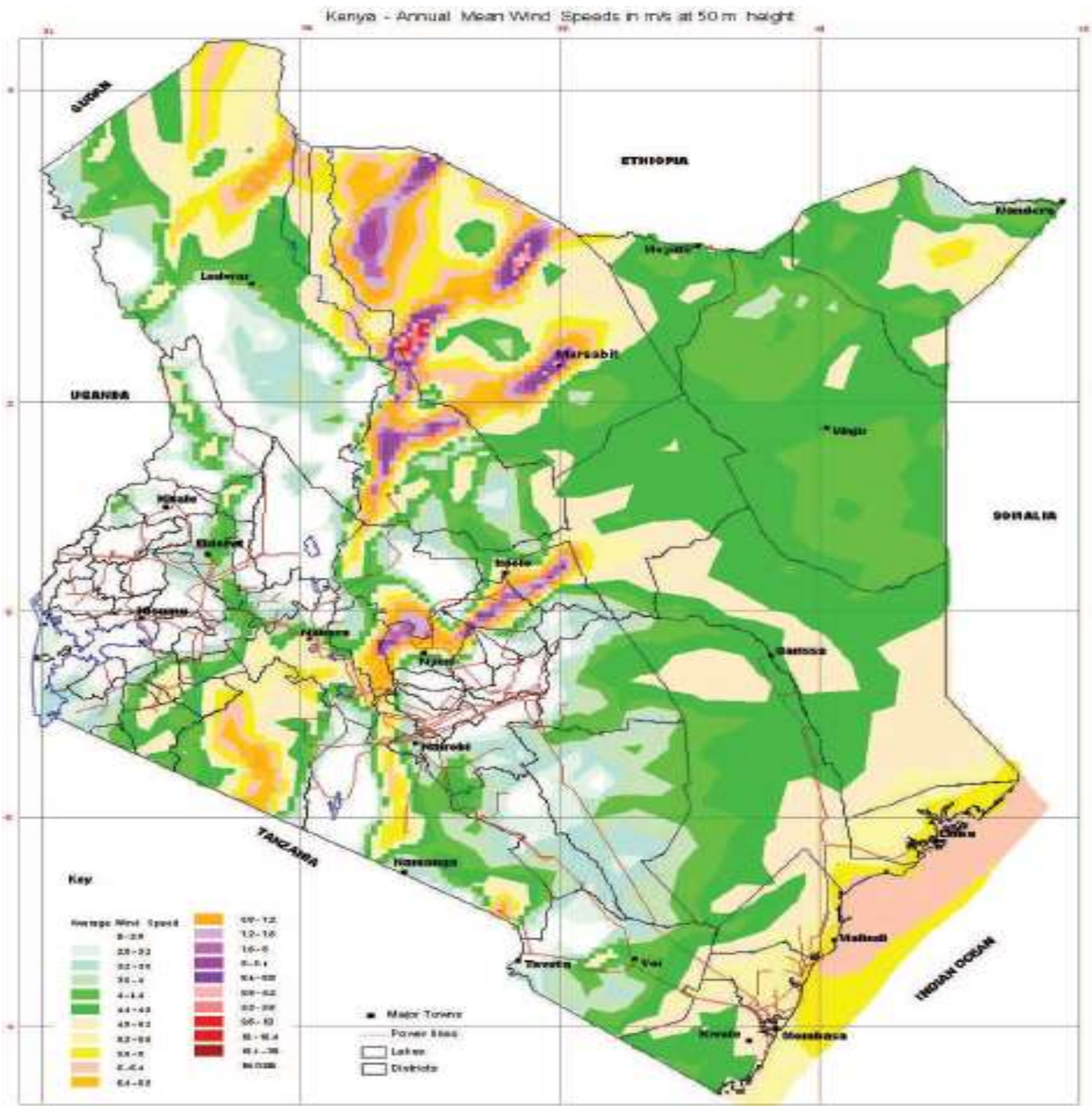
Pacific region	**2008 (MW)**	**2009 (MW)**
Japan	1538	1675
Australia	824	824
New Zealand	322	322
Philippines	25	25
Pacific islands	24	24
total	**2733**	**2870**
Middle east and Africa		
Egypt	230	310
morocco	124	184
Iran	67	67
Tunisia	20	54
Reunion (France)	10	10
Israel	8	8
Cape Verde	3	3
South Africa	3	9
Jordan	2	2
Total	**467**	**647**
Canada	1846	1846
USA	16971	25408
Latin America	547	670
Asia	14191	19524
Europe	57126	63889
World Total	**93881**	**115254**

Appendix II: Wind speed map of Kenya at a height of 80m



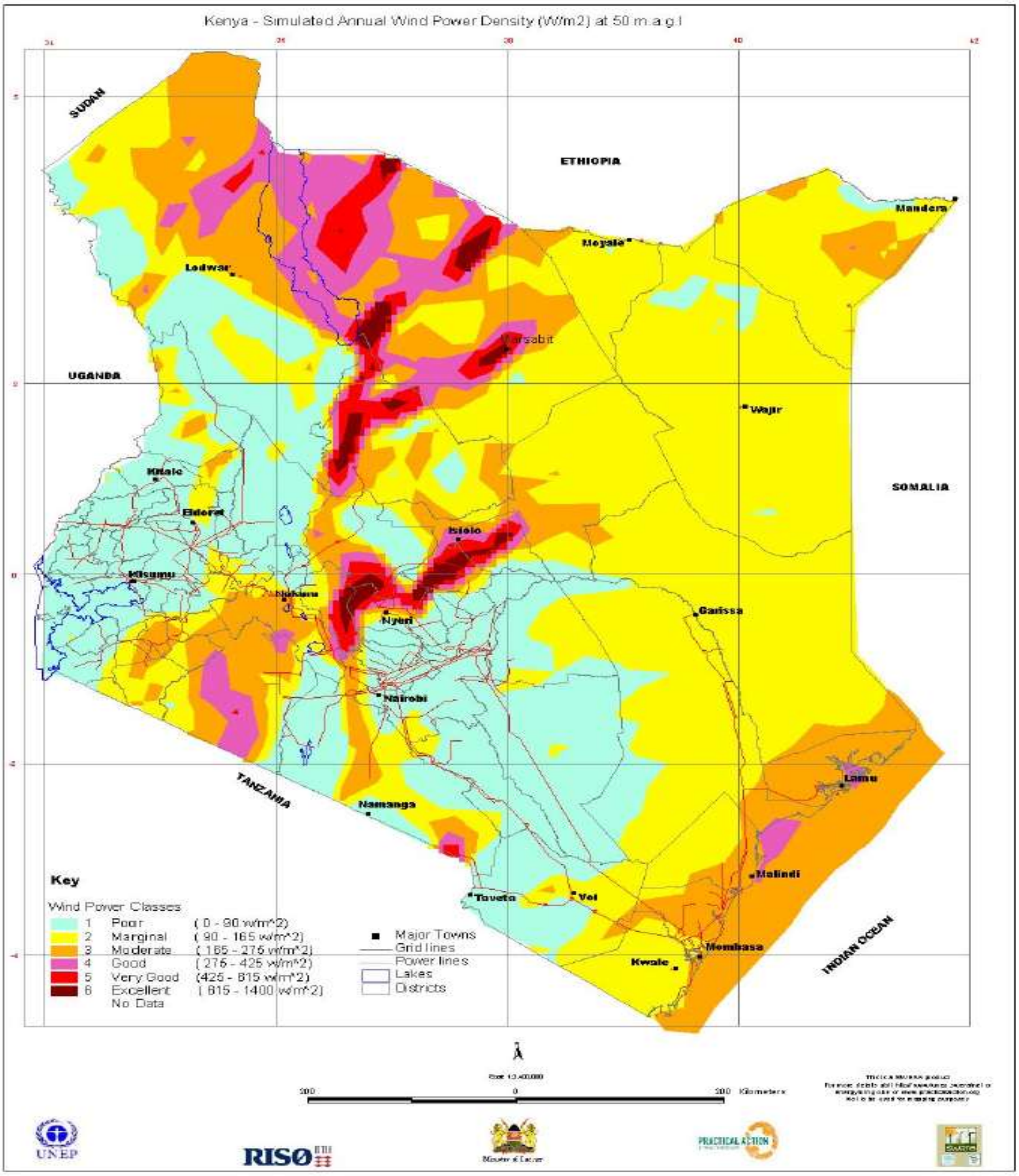
Source: Rahul (2013)

Appendix III: Annual mean wind speed classes at 50m height (m/s) (Kenya)



Source: Kenya Country Report (SWERA)

Appendix IV: Simulated Wind power density in W/m^2 at height of 50m



Source: UNEP: Kenya country report

Appendix V: Wind Classification in Kenya

Kenya Wind Classes				
Class Nr.	Classification	Speed in m/s	Wind Power Density in W/m^2	Colour code
1	Poor	0 - 4.5	0 - 90	
2	Marginal	4.5 - 5.5	90 - 165	
3	Moderate	5.5 - 6.5	165 - 275	
4	Good	6.5 - 7.5	275 - 425	
5	Very Good	7.5 - 8.5	425 - 615	
6	Excellent	> 8.5	>615	

Source: Kenya Country Report (SWERA)

4.2 Results and Discussion for Kisumu

The monthly mean wind speed values v and standard deviations δ for Kisumu were determined and presented in the table 4.1.

Table 4.1: Monthly mean wind speeds and standard deviations in Kisumu.

Year	parameter	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec	whole year
2002	Mean (m/s)	2.806	3.429	2.887	2.167	2.532	2.033	2.435	2.419	2.633	2.581	2.533	2.242	2.558
	δ	0.891	0.649	0.667	0.592	1.169	0.629	0.602	0.564	0.524	0.467	0.669	0.514	0.661
2003	Mean (m/s)	2.629	3.304	3.387	2.333	1.806	1.833	1.839	2.387	2.267	2.129	2.367	2.419	2.392
	δ	0.516	0.712	0.727	0.621	0.511	0.514	0.554	0.692	0.583	0.718	0.642	0.502	0.608
2004	Mean (m/s)	2.500	2.810	2.742	2.306	1.742	1.933	2.548	2.581	2.567	2.016	2.083	2.661	2.374
	δ	0.632	0.660	0.590	0.715	0.463	0.553	0.522	0.647	0.626	0.491	0.437	0.723	0.588
2005	Mean (m/s)	2.887	3.054	2.565	2.032	1.952	1.767	2.000	2.403	2.400	2.565	2.367	2.952	2.412
	δ	0.495	0.906	0.528	0.682	0.522	0.653	0.500	0.597	0.635	0.461	0.571	0.687	0.603
2006	Mean (m/s)	2.855	3.071	2.887	2.067	1.871	2.117	1.968	2.387	2.433	2.597	2.000	2.210	2.372
	δ	0.685	0.539	0.727	0.653	0.482	0.597	0.547	0.655	0.487	0.625	0.557	0.479	0.586
2007	Mean (m/s)	2.419	2.446	2.484	2.150	2.032	1.717	1.855	2.000	2.383	2.565	2.367	2.597	2.251
	δ	0.502	0.550	0.626	0.659	0.618	0.503	0.608	0.632	0.639	0.544	0.615	0.583	0.590
2008	Mean (m/s)	2.952	3.000	3.032	2.217	1.823	1.833	2.097	2.097	2.417	2.097	2.167	2.742	2.373
	δ	0.687	0.641	0.894	0.568	0.541	0.497	0.712	0.597	0.588	0.507	0.562	0.530	0.610
2009	Mean (m/s)	3.226	2.893	3.242	2.217	1.871	2.200	2.403	2.516	2.683	2.065	2.583	2.339	2.520
	δ	0.656	0.438	0.546	0.727	0.619	0.677	0.569	0.555	0.594	0.629	0.658	0.583	0.604
2010	Mean (m/s)	2.065	2.339	2.048	1.833	1.806	2.000	2.210	2.403	2.350	2.323	2.283	2.581	2.187
	δ	0.772	0.594	0.553	0.514	0.628	0.491	0.479	0.676	0.659	0.585	0.611	0.743	0.609

4.2.1 Wind pattern

Figure 4.1 shows the wind pattern for Kisumu for different years. The trends of the monthly means for the different years were similar. Most of the monthly mean wind speed values were between 2.0 and 2.5 m/s, but some were over 2.5 m/s, while only a few were over 3.0 m/s and under 2.0 m/s. February 2002 showed the highest mean wind speed value with 3.43 m/s while June 2007 showed the minimum mean wind speed value of 2.03 m/s.

The yearly seasonal variation of mean wind speed was also analysed using four seasons: warm season (December- February), Long rains (March- may), cold season (June - August) and Short Rains (September - November) and presented as shown in table 4.2 and illustrated in figure 4.2.

Table 4.2: Yearly seasonal variation of mean wind speed in Kisumu.

Year	December -February	March -May	June-August	September-November
	Warm season	Long rains	Cold season	Short rains
2002	2.826	2.529	2.582	2.296
2003	2.784	2.509	2.254	2.020
2004	2.657	2.263	2.222	2.354
2005	2.964	2.183	2.444	2.057
2006	2.712	2.275	2.343	2.157
2007	2.488	2.222	2.438	1.857
2008	2.898	2.357	2.227	2.009
2009	2.819	2.443	2.444	2.373
2010	2.328	1.896	2.319	2.204
Whole year	2.720	2.297	2.364	2.147

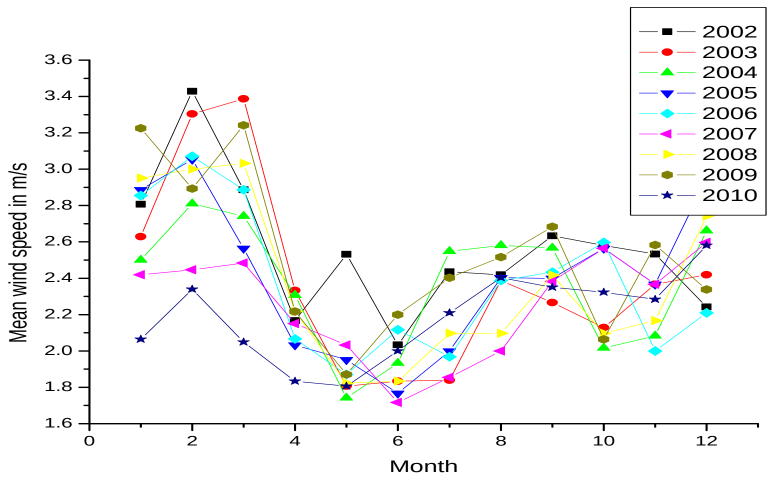


Figure 4.1: Wind pattern for Kisumu (2002 - 2010).

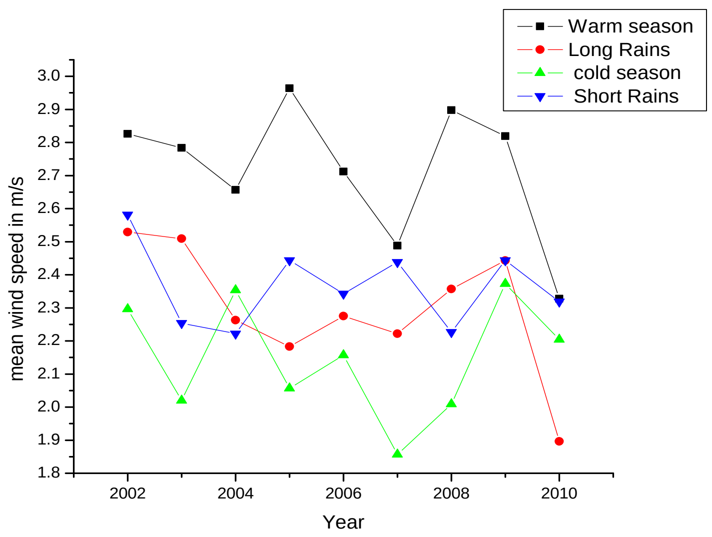


Figure 4.2: Yearly Seasonal variation of mean wind speed for Kisumu.

From table 4.2, it can be seen that the warm season (December - February) had a maximum mean wind speed of 2.72 m/s and the cold season (June-August), had a minimum mean wind speed of 2.36 m/s. This showed that the mean wind speeds in the warm season were slightly higher than the cold season. This is due to the fact that the warming rays of the sun create a difference in air pressure between Lake Victoria water body and the land mass. This considerable difference in air pressure makes the air to flow more quickly and creates high speed winds. The higher wind speeds combined with the colder dense air thus combine to produce a higher energy. The wind speeds were lower during the short rains, long rains and the cold seasons compared to the warm season and this can be attributed to the low temperature differences between the land mass and water mass leading to low difference in air pressure hence low wind speeds.

4.2.2 Monthly mean wind speeds

Having analysed the ten years of wind speed data for Kisumu, it can be observed that the wind speed distribution differed quite remarkably from one month to another. The monthly and yearly standard deviation values were between 1.00 and 1.49 m/s with only a few under 1.00 m/s. (range from 0.95 to 1.49) as shown in (Table 4.1).

From figure 4.3, it can be seen that the whole year wind speed had the lowest value in the month of June and the highest in the month of February ranging from 2.03 to 3.43 m/s with an annual average of 2.56 m/s. Only three months (January, February and March) experienced wind speeds above 2.5 m/s. Thus during these three months wind energy can be harnessed using small wind turbines since the cut in wind speed for any meaningful wind energy conversion is 2.5 m/s (Keyhani, 2010).

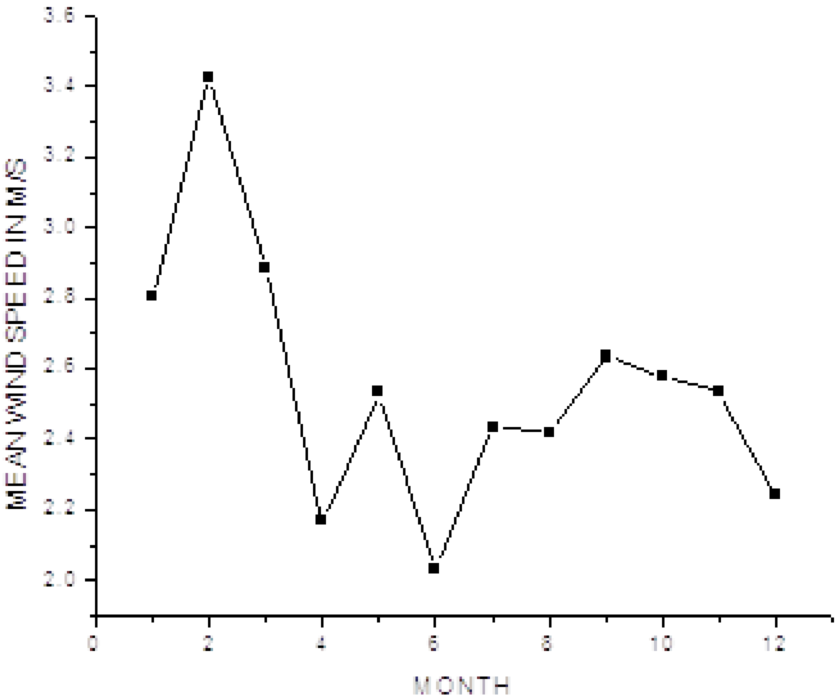


Figure 4.3: Monthly mean wind speed trend for Kisumu 2002 to 2012.

4.2.3 Vertical wind speed profile

The vertical wind profile was calculated from the wind speed of the known height of 10 m which is the standard height used in most Meteorological stations. This height is chosen due to less interference of wind speeds by topographical features and buildings. Extrapolating wind speeds was based on the relation:

$$v = v_o(h/ho)^{\alpha} \qquad \text{(C)}$$

Where $\propto$ = height exponent (0.14 – 0.4) 0.14 for calm sea, 0.3 for towns and cities and 0.4 for a rough terrain. (Nelson, Vaughn 2009)

v_o = wind speed at anemometer height (h_o)

h = height at which wind speed is measured

h_o = anemometer height (10 m)

The values of the wind speeds at different heights were determined and presented as shown in table 4.3 and the vertical wind speed profile for different hub heights illustrated in figure 4.4.

Table 4.3: Vertical wind profile for Kisumu for hub heights 10 m to 100 m.

Extrapolated wind speeds (m/s), height exponent α= 0.3										
Month	**10m**	**20m**	**30m**	**40m**	**50m**	**60m**	**70m**	**80m**	**90m**	**100m**
Jan	2.81	3.46	3.90	4.25	4.55	4.80	5.03	5.24	5.43	5.60
Feb	3.43	4.22	4.77	5.20	5.56	5.87	6.15	6.40	6.63	6.84
March	2.89	3.55	4.01	4.38	4.68	4.94	5.18	5.39	5.58	5.76
April	2.17	2.67	3.01	3.28	3.51	3.71	3.88	4.04	4.19	4.32
May	2.53	3.12	3.52	3.84	4.10	4.33	4.54	4.73	4.90	5.05
June	2.03	2.50	2.83	3.08	3.30	3.48	3.65	3.79	3.93	4.06
July	2.44	3.00	3.39	3.69	3.95	4.17	4.37	4.54	4.71	4.86
Aug	2.42	2.98	3.36	3.67	3.92	4.14	4.34	4.51	4.68	4.83
Sep	2.63	3.24	3.66	3.99	4.27	4.51	4.72	4.91	5.09	5.25
Oct	2.58	3.18	3.59	3.91	4.18	4.42	4.63	4.82	4.99	5.15
Nov	2.53	3.12	3.52	3.84	4.11	4.34	4.54	4.73	4.90	5.05
Dec	2.24	2.76	3.12	3.40	3.63	3.84	4.02	4.18	4.33	4.47
whole year	2.56	3.15	3.56	3.88	4.15	4.38	4.59	4.77	4.95	5.10

From the values obtained, it shows that the wind speeds increase with increase in hub height. This is because at higher heights the wind flow becomes steadier because of less interference from vegetation and other artificial structures. The mean wind speed at 50 m was 4.15 m/s which translates to a Wind power density of 43.78 W/m^2 whereas at 100 m the mean wind speed was 5.10 m/s which translates to a wind power density of 81.25 W/m^2. This implies that Kisumu falls in class I according to the wind energy classification at a hub height of 50 m (appendix V).

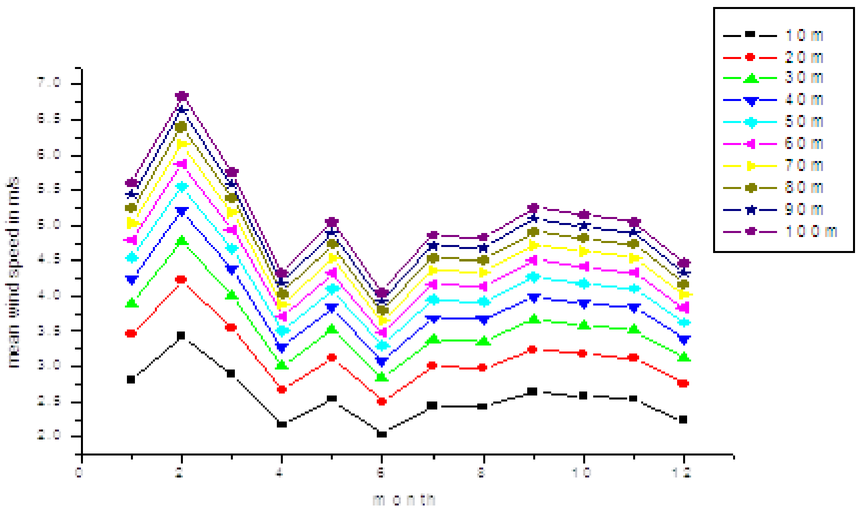


Figure 4.4: Vertical wind profile for Kisumu for different heights.

4.2.4 Annual and overall mean wind speeds

The yearly mean wind speeds was obtained by averaging all the available wind speeds in the year in Kisumu. The average values of wind speed for each year from 2002 to 2010 are presented in table 4.4. The results show that all the mean wind speeds were below 3.0 m/s with the highest mean wind speed obtained in 2002 and was 2.56 m/s and the lowest appearing in 2010 and was 2.187 m/s. The average mean wind speed for the period of study was 2.38 m/s. Based on the current wind energy conversion system, the average annual wind speed harnessed in Kisumu is below 2.5 m/s which is the cut in speed for any meaningful wind energy conversion and thus the region is not suitable for year round electricity generation at a hub height of 10 meters. However for small scale applications and with the development of wind turbine technology, the utilization of wind energy is still promising but only in a small scale.

4.2.5 Weibull distribution

Table 4.4 shows the mean yearly measured values of the two Weibull parameters, the scale parameter c (m/s) and the shape parameter k (dimensionless) calculated from (2002-2010) data of the site studied. The values of k and c were determined by using equations 2 and 3 respectively. From the table, it was observed that the yearly values of k ranged between 4.08 in 2010 to 4.855 in 2009 with an annual average of 4.51, whereas the lowest value of the scale parameter c was 2.41 m/s obtained in the year 2010 and the highest 2.80 m/s obtained in the year 2002 with the average being 2.10 m/s.

Monthly Weibull parameters c (m/s) scale parameter and k (dimensionless shape parameter) were calculated and presented in table 5. The parameters were distinctive for different months. This shows that the wind distribution in the site under study differed remarkably over the whole year.

From the results obtained the value of c was minimal in June (2.14 m/s) and the wind speeds were in the lowest speed range (2.03 m/s), February had the highest value of c (3.16 m/s) and thus the wind speed value had the highest speed range (3.43 m/s). The yearly mean value of c was 2.61m/s and the annual mean wind speed was 2.38 m/s. From this observation it can be inferred that the scale parameter c (m/s) is always close to the mean wind speed of a given site and therefore is a useful parameter used to assess the wind potential of the regime.

The shape parameter k (dimensionless) is also a very important Weibull parameter. This parameter denotes the peakedness of the wind speed distribution. A higher k value means that the wind speeds are highly peaked around the average wind speed. A higher k value implies that the wind speeds are fairly steady and conversely the smaller k value denotes a sparse wind distribution. Thus for Kisumu although the mean wind speed was low, the distribution was steady because the regime had a higher shape parameter k= 4.51.

Table 4.4: Yearly Weibull parameters and characteristic speeds for Kisumu.

Year	k(-)	c (m/s)	v_{mp}	v_{maxE}	v(m/s)(measured)	v(m/s)(predicted)
2002	4.605	2.801	2.616	3.083	2.558	2.560
2003	4.450	2.621	2.467	2.859	2.392	2.390
2004	4.597	2.599	2.458	2.819	2.374	2.375
2005	4.647	2.639	2.485	2.876	2.412	2.413
2006	4.616	2.595	2.453	2.817	2.372	2.372
2007	4.324	2.472	2.317	2.710	2.251	2.251
2008	4.414	2.602	2.447	2.844	2.373	2.372
2009	4.855	2.749	2.602	2.979	2.520	2.520
2010	4.078	2.410	2.238	2.673	2.187	2.187
whole year	4.510	2.610	2.454	2.851	2.382	2.382

Table 4.5: Monthly Weibull parameters and characteristic wind speeds in Kisumu.

Month	v(m/s)	k (-)	c(m/s)	v_{mp}(m/s)	v_{op}(m/s)	WPD(W/m^2)	WED(kWh/m^2/Month)
Jan	2.806	4.913	2.951	2.792	3.197	14.791	11.004
Feb	3.429	5.464	3.176	3.045	3.383	18.228	12.342
Mar	2.887	4.986	3.060	2.915	3.289	16.610	12.358
April	2.167	3.775	2.377	2.185	2.668	7.780	5.646
May	2.532	3.652	2.150	1.935	2.469	6.327	4.707
June	2.033	3.828	2.143	1.973	2.400	5.722	4.120
July	2.435	4.333	2.362	2.211	2.593	7.618	5.668
Aug	2.419	4.259	2.589	2.426	2.840	9.826	7.311
Sept	2.633	4.743	2.687	2.551	2.903	10.782	7.763
Oct	2.581	4.844	2.539	2.406	2.748	9.302	6.921
Nov	2.533	4.418	2.530	2.384	2.758	9.170	6.603
Dec	2.242	4.902	2.757	2.624	2.967	11.839	8.808
Whole Year	2.558	4.510	2.610	2.454	2.851	10.666	7.771

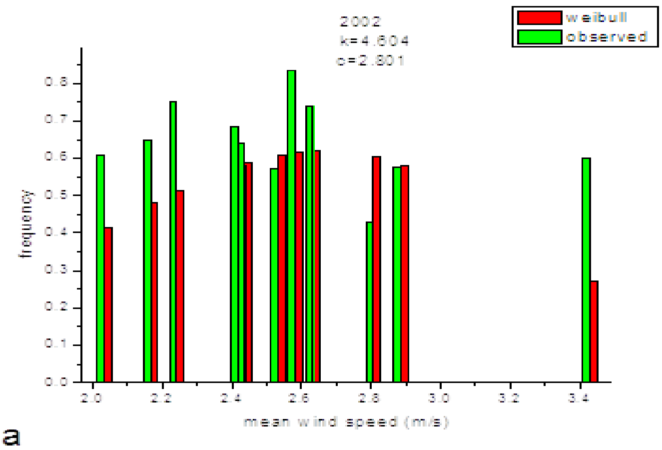
Tables 4.6 and 4.7 were used to plot the wind speed distribution frequencies as shown in figures 4.5 (a-b) and figures 4.6 (c-d) to compare the observed wind speed frequencies with the Weibull wind speed frequencies. As it can be seen, the Weibull distribution function fits well with the observed wind distribution. The peak of the density function indicates the most frequent velocity and it shows the fraction of time for which the wind speed possibly prevails at a location (Oyedepo *et al.* 2012).

Table 4.6: Wind speed distribution frequencies for Kisumu (2002 and 2003).

	Year					
	2002			2003		
Month	**Mean wind speed (m/s)**	**Weibull**	**Observed**	**Mean wind speed (m/s)**	**Weibull**	**Observed**
January	2.806	0.604	0.429	2.629	0.622	0.752
February	3.429	0.270	0.599	3.304	0.229	0.543
March	2.887	0.581	0.578	3.387	0.180	0.532
April	2.167	0.479	0.648	2.333	0.626	0.619
May	2.532	0.610	0.325	1.806	0.388	0.750
June	2.033	0.412	0.608	1.833	0.404	0.746
July	2.435	0.587	0.639	1.839	0.407	0.691
August	2.419	0.583	0.684	2.387	0.636	0.554
September	2.633	0.620	0.740	2.267	0.609	0.659
October	2.581	0.616	0.833	2.129	0.557	0.531
November	2.533	0.610	0.575	2.367	0.633	0.598
December	2.242	0.515	0.750	2.419	0.639	0.772

Table 4.7: Wind speed distribution frequencies for Kisumu (2009 and 2010).

	Year					
	2002			2003		
Month	**Mean wind speed (m/s)**	**Weibull**	**Observed**	**Mean wind speed (m/s)**	**Weibull**	**Observed**
January	3.226	0.372	0.591	2.065	0.617	0.494
February	2.893	0.597	0.896	2.339	0.637	0.647
March	3.242	0.360	0.716	2.048	0.613	0.694
April	2.217	0.542	0.525	1.833	0.525	0.746
May	1.871	0.343	0.617	1.806	0.512	0.607
June	2.200	0.533	0.565	2.000	0.597	0.784
July	2.403	0.625	0.678	2.210	0.642	0.807
August	2.516	0.655	0.696	2.403	0.624	0.567
September	2.683	0.661	0.650	2.350	0.635	0.582
October	2.065	0.457	0.608	2.323	0.639	0.657
November	2.583	0.663	0.585	2.283	0.642	0.628
December	2.339	0.600	0.660	2.581	0.557	0.516



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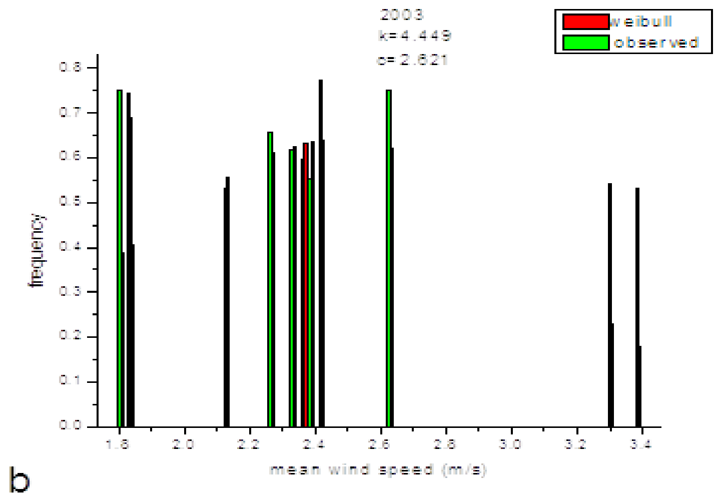

Figure 4.5: Observed and calculated wind speed frequencies for Kisumu

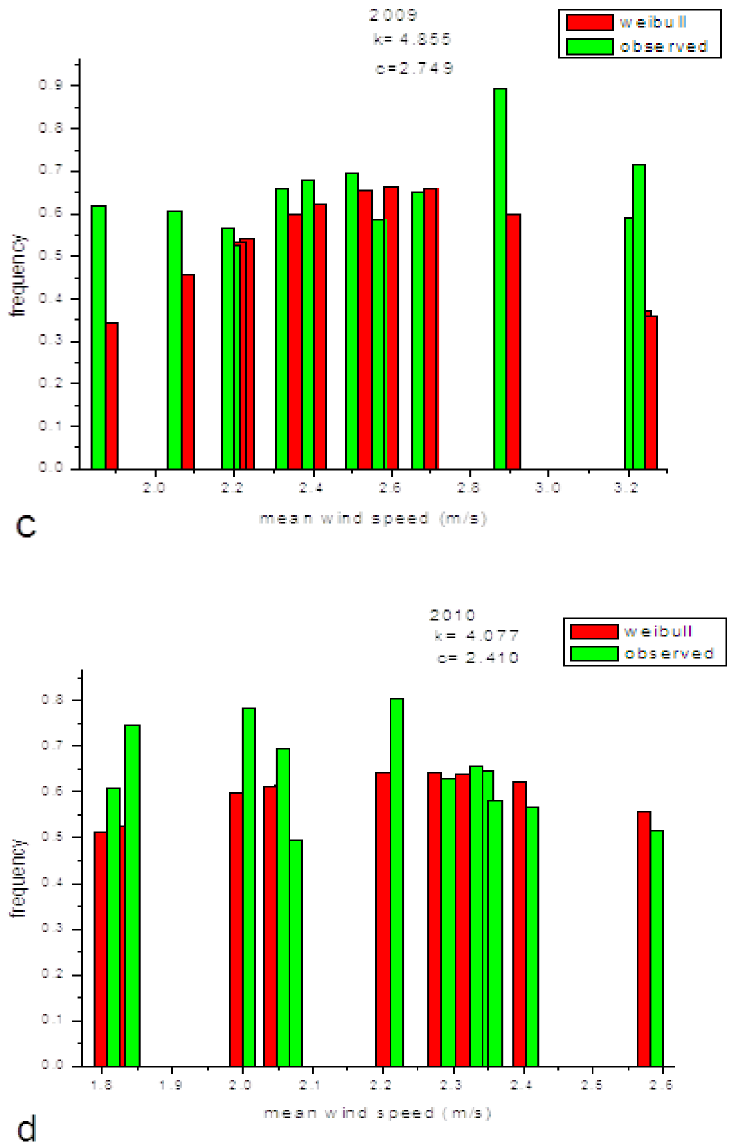

Figure 4.6: Observed and calculated wind speed frequencies for Kisumu.

4.2.6 Calculation of wind power density and energy

The monthly wind power density and wind energy density were calculated using equations (13) and (14) respectively and presented in table 4.8. The monthly variation of the wind power density is illustrated as shown in figure 4.7. It can be observed that there were dramatic monthly changes in wind power density with a maximum value of 18.22 W/m^2 in February. This shows that the maximum wind power density was 3.18 times the minimum wind power density 5.72 W/m^2.

Such considerable difference in the wind power density may be accounted for by the fact that the wind power is proportional to the cube of the wind speed. Thus a small change in mean wind speed amounts into a drastic change in wind power density. The monthly changes in wind power density shows the importance of distinguishing different months of the year when a wind power project is assessed or being designed. Based on the monthly trend of the wind power density, higher WPD were experienced in the months of December, January February and March thus in such months wind energy can be harvested using small wind turbines for domestic use to supplement the grid power.

The results showed some oddness in the WPD experienced in Kisumu for example though the mean wind speed experienced in December (2.24 m/s) was lower than in May (2.53 m/s) , higher wind power density was experienced in December. This can be accounted by the differences in the standard deviations of the wind distribution in these months (standard deviation in May was 1.55 with wind power density 6.33 W/m^2 compared to standard deviation in December of 0.946 with a wind power density of 11.84 W/m^2. This can be accounted for since a month with the same mean wind speed but higher standard deviation will have more potential to experience higher wind speeds and the WPD is proportional to the cube of the wind speed so more wind power may be harnessed in such occasions (Keyhan *et al., 2010*).

With the current existing wind turbine technology, the maximum extractable power from a wind machine according to Betz relation is given by 0.593x18.23 w/m^2 x A (swept area of the turbine).

The annual wind power density and wind energy density were determined using equations (13) and (14) and presented as shown in table 8. From the table it is observed that the highest value of the wind power density was 157.63 W/m^2 in 2002 followed by 147.62 W/m^2 in 2009 while the lowest was obtained in 2010 (97. 63W/m^2). The annual mean power density for the period studied was 128.00 W/m^2. The wind energy density ranged between 114.38kWh/year in 2010 to 71.46kWh/year in 2002.

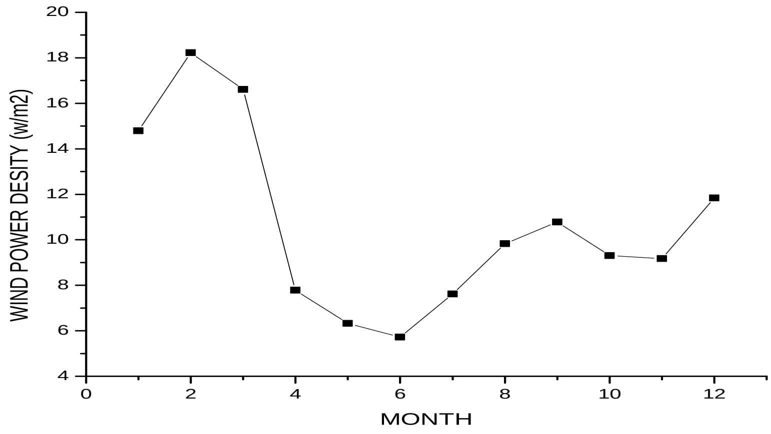

Figure 4.7: Monthly variation of the wind power density in Kisumu.

Table 4.8: Maximum wind power and annual energy production in Kisumu Meteorological

Year	Wind Power Density P/A (W/m^2)	Wind Energy Density E/A (kWh/m^2/Year)
2002	157.632	114.380
2003	134.706	97.629
2004	123.163	90.297
2005	132.271	96.230
2006	124.688	90.649
2007	105.047	76.654
2008	128.923	94.291
2009	147.621	107.648
2010	97.907	71.465
Whole year	127.995	93.249

Chapter Five: Conclusion And Recommendations

5.1 Conclusions

In the present study, a three-hour daily measured long term wind speed data of Kisumu were statistically analysed. The Weibull probability density function was fitted to the measured probability distribution on a yearly basis. The wind energy potential of the regime was analysed based on the Weibull model. The most important outcomes of the study can be summarized as follows:

1. Kisumu has marginal potential because the chances of having wind speeds less than 3 m/s are higher. However from the extrapolated wind profile, Kisumu had a mean wind speed

of 4.15 m/s at 50 m and 5.10 m/s at 100 m. This implies that Kisumu has a potential for grid connected applications at a hub height of 100 m. However for wind systems to be installed at such greater hub heights, the cost of constructing such wind towers against the total value of the amount of energy harnessed must be taken into account for the viability of the project.

2. The Weibull distribution presented here indicated a good agreement with the data obtained from actual measurements for the regime under study.
3. For Kisumu only February had the highest average wind speed above 3 m/s. the rest had wind speeds below 3 m/s
4. The yearly mean wind speeds were found to range between 2.2 and 2.6 m/s for most years considered with the maximum yearly mean wind speed of 2.56 m/s experienced in 2002 and a minimum of 2.19 m/s experienced in 2010. The annual mean being 2.38 m/s for the whole period of study
5. The data also showed that for Kisumu the maximum monthly wind speed occurred in the month of February while June showed the minimum wind speed with the most probable wind speed being 2.45 m/s. while the wind speed carrying maximum energy was 2.85 m/s. Thus small scale wind turbines rated 2.85 m/s will be recommended for Kisumu (Keyhani 2010).
6. The yearly average wind power density ranged from 157.63 to 97.91W/m^2 which may not be adequate for grid connected electrical but can be utilized for mechanical applications. It is however worth noting that such amount of energy harnessed in the two sites is adequate to supplement the grid energy where intermittent power is required like wind pumps and mechanical applications like sugarcane milling since the two areas are agriculturally productive areas. Households in the two regimes can also harness wind energy by using small stand alone wind turbines for battery charging and lighting applications.

Since the mean wind speeds in the two regions are less than 5–6 m/s required for grid connected applications, small scale wind turbines can be recommended based on the annual wind speeds available in the two regimes under study.

5.2 Recommendations

It should be recommended that a hybrid system that combines both the solar and wind energy application be explored. At the end, it is worth mentioning that the current work is only a preliminary study in order to estimate the wind energy potential analysis of the site under study, in order to have a comprehensive wind data base and obtain good predictions prior to construction and installation of wind energy conversion system. In assessing the wind power potential or choosing the suitable type of wind turbine, not only the wind data but also the site circumstances (terrain, different referred height, etc) should be considered that this issue can be addressed for application of new wind energy generation technology in future studies.

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