Assessment and Utilization of Wind Power in Kenya – A Review

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ABSTRACT

Wind energy is one form of free renewable resource that is being vigorously pursued by many countries of the world including Kenya. It is a cheap, clean and non-polluting energy sources that may finally be used to replace the expensive fossil fuels. Any plans to develop wind energy must begin by understanding the wind resource of the region, which involves trying to determine sites with the best wind energy potential in the region. A national wind resource assessment and mapping should indicate whether or not a country has the potential to utilize the wind energy.

One of the crucial information needed when evaluating the wind energy potential of any given area or site is a reliable wind resource data, that is. surface wind speed and direction from a number of well distributed stations in the region. The data used in this study is hourly wind speed and direction for the period 1995 to 2000 over Kenya. The presentation given in this report is an attempt to provide an insight into the wind energy resource of Kenya. Maps of the spatial patterns of the average wind speeds and wind power densities, prevailing wind directions, frequency distribution of the wind speed including seasonal variability for some selected stations are presented. It is hoped that such information may be of benefit to a broad cross-section of users including government planners, private wind energy developers among many others. These products will therefore enable users to make informed decisions regarding the wind resource in Kenya.

1. INTRODUCTION

Kenya's energy sector comprises petroleum, electricity and the renewable energy subsectors. Kenya is a net importer of petroleum products, which constitute the dominant source of commercial energy in the country. Petroleum has, over the years, accounted for about 80% of the country's commercial energy requirements. The overall large hydropower potential in Kenya is estimated at about 2263 MW while the Small, Mini and Pico hydros are estimated at 3000 MW.

Kenya's installed capacity electric power generation by September 2001 stood at 1172 MW and corresponded to an effective generation capacity of about 1067.3MW of which hydropower accounts for 677.2MW equivalent to 63.4%, oil fired thermal 323.5MW or 30.3% and geothermal 57MW or 5.3%. Electricity is the third largest form of energy and the second ranked commercial energy in Kenya after biomass and petroleum.

Geothermal energy resources in Kenya are located within the Rift Valley and their potential for power generation is estimated at over 2000 MW out of which 57 MW has already been developed and connected to the grid. Another 100 MW is under development. Table 1 below gives a summary of the generating capacity by source between 1987 - 2001.

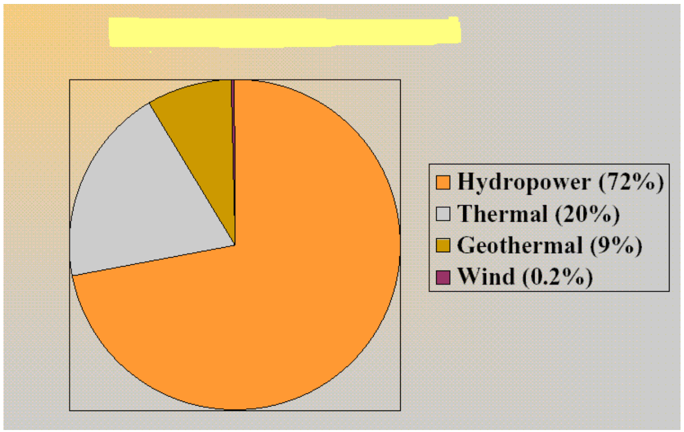

Figure 1: Pie chart presentation on domestic Power consumption in Kenya

It can be seen from the figure above that hydropower takes the lion's share in domestic power production. However, this poses a serious problem similar to that experienced in 1999 - 2000 drought. The drought had devastating effects in the overall economy of the country in which the hydro-generation capacity was reduced by more than 60% of the normal output. The intensity and scale of power rationing in 2000 was the worst ever in Kenya's history. Figure 2 shows the water levels in the Masinga Dam under normal climatic conditions while Figure 3 gives the opposite. This therefore calls for a search and promotion of other alternatives energy sources such as wind and solar energy resources.

Figure 2: Normal water levels in Masinga Dam during normal climatic conditions

Figure 3: Lowest water levels in Masinga Dam during the 1999-2000 Drought

2. CHARACTERISTICS OF THE WINDS OVER KENYA

Kenya's location within the equatorial region does not favour stronger winds like those experienced in the extra-tropical regions, which are usually strong and persist over a longer period of time. Nevertheless, there are however many locations in Kenya that possess relatively strong and persistent wind speeds with considerable wind power potential throughout the year.

Various studies have shown that complex topographical features and the varying nature of the surfaces and the existence of large inland lakes found in Kenya have marked influence in modifying the horizontal and vertical wind speed profiles thus making many locations to possess substantial wind energy potentials. The meso-scale circulations (Land/Sea breeze) generated by these large water bodies are known to have significant influence on both the wind flow and weather patterns of the surrounding areas (Findlater, 1969, Asnani and Kinuthia, 1984).

Other studies have also shown that the topographical features around Marsabit and Turkana regions have marked influence on the wind flow patterns over the region. A low-level jet known as the Turkana Jet has been observed over this region and is attributed to the orographic channeling effects of the surface wind speeds by the mountain ridges around this region. This ventury effect results in very strong and persistent winds over the Marsabit area. (Chipeta, 1976; Oludhe, 1987; Oludhe and Ogallo 1990a; Oludhe, 1992, Oludhe and Ogallo, 1996, Oludhe, 1998).

Table 1: Installed Electric Power Generating Capacity by Source (MW) for some selected years

HYDRO CAPACITY	1987	**1990**	**1993**	**1996**	**1999**	**2000**	**2001**
KenGen							
Tana	14.4	14.4	14.4	14.4	14.4	14.4	14.4
Wanjii	7.4	7.4	7.4	7.4	7.4	7.4	7.4
Kamburu	91.5	91.5	91.5	91.5	91.5	91.5	94.2
Gitaru	145.0	145.0	145.0	145.0	145.0	225.0	225.0
Kindaruma	44.0	44.0	44.0	44.0	44.0	44.0	44.0
Selbe Falls	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Mesco	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Ndula	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Sagana	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Gogo Falls	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Masinga	40.0	40.0	40.0	40.0	40.0	40.0	40.0
Kiambere	---	144.0	144.0	144.0	144.0	144.0	144.0
Turkwel	---	---	106.0	106.0	106.0	106.0	106.0
Sub-total Domestic	**348.5**	**492.5**	**598.5**	**594.5**	**594.5**	**674.5**	**677.2**
UEB Imports	30.0	30.0	30.0	30.0	30.0	30.0	30.0
Total Hydro	**378.5**	**522.5**	**628.5**	**624.5**	**624.5**	**704.5**	**707.2**
Effective Hydro	369.0	479.0	586.4	567.2	584.2	584.2	
Geothermal							
KenGen	45.0	45.0	45.0	45.0	45.0	45.0	45.0
IPPs	---	---	---	---	---	8.0	12.0
Sub-Total	45.0	45.0	45.0	45.0	45.0	53.0	57.0
Oil Fired Plant							
KenGen	168.1	168.1	144.3	144.3	122.8	110.4	227.8
REF	---	---	---	3.8	5.4	5.1	5.4
IPPs	---	---	---	---	87.5	87.5	99.5
Sub-Total	168.1	168.1	144.3	148.1	215.7	203.0	332.7
WIND							
KenGen				0.35	0.35	0.35	0.35
TOTAL CAPACITY	591.6	**735.6**	**817.8**	**817.95**	**885.55**	**1048.4**	**1097.2**
EFFECTIVE	**515.7**	**603.7**	**655.7**	**723.4**	**831.1**	**909.1**	**1000.2**
SYSTEM PEAK DE-	**430.0**	**520**	**596**	**648.0**	**734.0**	**734.0**	**720.0**

SOURCE: KPLC, 2001

KenGen – Kenya Electricity Generating Company

IPP – Independent Power Producers

The high mountains found in the country include Mts. Kenya (5199m), Elgon (4321 m) on the Kenya - Uganda border and Kilimanjaro (5895 m) on the Kenya - Tanzania border. There are also a number of small hills and flat plateau (Nyika/Yatta plateau) found in the country and which also do have marked influence on the general characteristics of the surface wind speeds over Kenya. **Figure 4** below presents the general topography of Kenya.

The wind characteristics necessary for wind energy assessment studies are the wind speed strength, its direction and more critical its reliability. Wind speeds are known to vary significantly in both space and time and therefore wind resource assessment requires a careful and detailed space-time evaluation of the wind speed characteristics.

The first step in a regional wind energy resource assessment is to determine the major wind flows contributing to the resource. These may include the westerly winds, the Monsoon winds which are seasonal winds caused by large annual temperature differences over land and sea areas. Mesoscale winds associated with topographical features, including physical and differential heating elements must all be taken into account when estimating the wind potential for a given region. The second step is to analyze the observed data to determine the magnitude and duration of winds for each scale of motion. Depending on the region, wind resources can vary from year to year, (seasonally), from day to day, (diurnally), and even from minute to minute (Turbulence). Long-term averages of wind speed and direction are most important for estimating power output at a given site. Seasonal and diurnal variations are important when considering peak demand and power supply.

Figure 4: Topography of Kenya (Macmillan, 1994)

3. STUDY AREA AND DATA

Kenya lies astride the equator and is situated between longitudes 34ºE to 42ºE and latitudes 5.5ºN to 5ºS. Uganda borders it to the west, Tanzania and the Indian Ocean to the south, Somali to the east, and Ethiopia and Sudan to the north. The total area of the country is about 582,646 Sq. Km. **Table 2** gives the position of the wind measuring locations in Kenya used for this study.

Table 2: Synoptic stations with wind data used in the wind project

No	Station	Latitu-	Longitu-	Abbrevia-
1	Dagoretti	-1.30	36.75	Dag
2	Eldoret	0.53	35.28	Eld
3	Embu	-0.50	37.45	Emb
4	Eastleigh	-1.31	36.82	Eas
5	Garissa	-0.48	39.63	Gar
6	JKIA	-1.32	36.92	Jkia
7	Kakame	0.28	34.77	Kak
8	Kericho	-0.48	35.18	Ker
9	Kisii	-0.68	34.78	Kisi
10	Kisumu	-0.10	34.75	Kisu
11	Kitale	1.02	34.98	Kit
12	Kabete	-1.25	36.73	Kab
13	Lamu	-2.27	40.90	Lam
14	Lodwar	3.12	35.62	Lod
15	Machako	-1.58	37.23	Mach
16	Makindu	-2.28	37.83	Mak
17	Malindi	-3.23	40.10	Mal
18	Mandera	3.93	41.87	Man
19	Marsabit	2.32	37.98	Mar
20	Meru	0.08	37.65	Mer
21	Momba-	-4.03	39.62	Mom
22	Moyale	3.53	39.05	Moy
23	Msabaha	-3.27	40.05	Msab
24	Mtwapa	-3.93	39.73	Mtw
25	Nanyuki	0.05	37.03	Nany
26	Nakuru	-0.28	36.07	Nak
27	Narok	-1.10	35.87	Nar
28	Nyahu-	-0.03	36.35	Nyah
29	Nyeri	-0.43	36.97	Nye
30	Thika	-1.02	37.10	Thi
31	Voi	-3.40	38.57	Voi
32	Wajir	1.75	40.07	Waj
33	Wilson	-1.32	36.82	Wil

The spatial distribution of these stations is given in **Figure 5** next page.

3.1 Fitting Weibull Frequency Distribution to the wind speeds over Kenya

The knowledge of the probability distribution of the wind speeds, $f(v)$, and its moments are important for estimating the mean available wind power of a site and the probability of wind speed being in certain intervals of interest. A typical distribution for use in wind speed analysis is called the Weibull Distribution and this distribution can give an indication as to the type of probabilities that can be expected for any given wind speeds(Oludhe, 1998; 1987). The Weibull distribution is a special and powerful frequency distribution that adequately describes the surface wind speed frequency data and may subsequently be used for wind power analysis.

The Weibull distribution is best described by the relation:

$$f(v) = (\frac{k}{c}) \cdot \left[(\frac{v - v_o}{c}) \right]^{k-1} \cdot \exp\left[(\frac{v - v_o}{c}) \right]^{k}$$

(1)

for $v \geq 0, c \geq 0, k \geq 0$ and $v_0 \geq 0.$ where c, k and v_0 are the scale, shape and location parameters respectively. The mean $E(v)$] and variance $Var(v)$] for this distribution may be given by the relations: $E(v) = \bar{v} = c \cdot \Gamma(1 + \frac{1}{k}) + v_0$ and $Var(v) = \sigma^2 = c^2 \cdot \left[\Gamma(1 + \frac{2}{k}) - \Gamma^2(1 + \frac{1}{k})\right]$ respectively

3.2 Estimation of the Wind Power using the Weibull Distribution

The power in the wind at any given moment is the result of a mass of air moving at some given speed in a particular direction. The available wind power at any given location, ($\mathrm{P_a}$), is given by the relation:

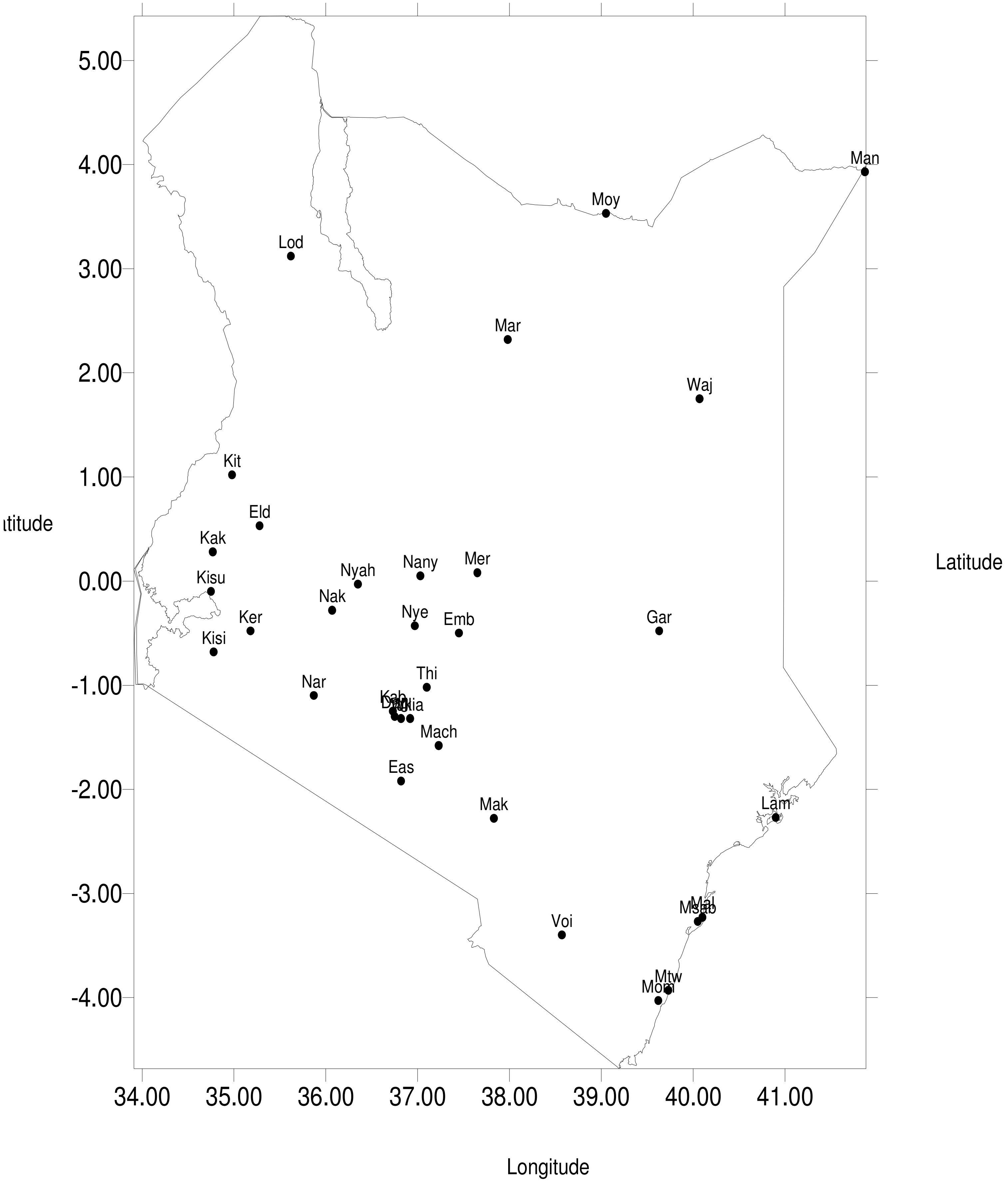

Figure 5: Spatial Distribution of the synoptic stations used in the Study

where ρ is the air density (Kg/m3), V is the undisturbed wind velocity (ms-1) and A is the area swept by the rotor blades (m2). A useful method for characterising the wind power density at various sites is to compute the average or expected available wind energy per unit rotor area $E(\mathrm{P_a})/A$, sometimes referred to as the wind power density. The estimation of surface wind power density at any given site can be obtained by incorporating the Weibull frequency distribution with equation (2) to yield the relation:

$$\frac{E(\mathrm{P_a})}{A} = \tfrac{1}{2}\cdot E(\rho)\cdot E(v)^3 \quad (\mathrm{Wm^{-2}})$$

(3)

The mean of the speed cubed, $E(v^3)$, may be determined exactly from the relation:

$$E(v^3) = \sigma^3\left[\sqrt{\beta_1} + 3\cdot(\tfrac{\mu}{\sigma}) + (\tfrac{\mu}{\sigma})^3\right]$$

so that

$$\frac{E(\mathrm{P_a})}{A} = \tfrac{1}{2}\cdot E(\rho)\cdot\sigma^3\cdot\left[\sqrt{\beta_1} + 3\cdot(\tfrac{\mu}{\sigma}) + (\tfrac{\mu}{\sigma})^3\right]$$

($\mathrm{Wm^{-2}}$) **(4)**

where μ, σ and $\sqrt{\beta_1}$ are the mean, standard deviation and skewness of the wind speed distribution respectively.

Equation (4) above was used to estimate the available surface wind power density (Wm-2) at each of the wind measuring sites in Kenya after correcting for the mean air density, $E(\rho)$ or $\overline{\rho}$ using the relation below:

$$E(\rho) = \overline{\rho} = 1.225\cdot(\tfrac{288.15}{T})\cdot(\tfrac{B}{1013.3})$$

(Kg.m-3) **(5)**

where T is the mean station temperature (K) and B is the site barometric pressure (mb).

4. RESULTS AND DISCUSSION

Figure 6a presents the spatial patterns of the observed mean and maximum wind speeds over Kenya. It can clearly be seen that the northeastern parts of the country have wind speed greater than 4.0ms^{-1} including the coastal areas of the country. Marsabit region has the highest wind speeds of more than 11.0ms^{-1}. Again, Marsabit region had the highest wind power of more than 1000Wm^{-2}.

Figure 7a presents the observed relative wind speed frequency distribution over Marsabit in year 2000. It shows that the most frequent wind speeds over the area are between 10.0 – 11.0ms^{-1} and these winds blow for more than 60% of the time. Figures 7b and 7c give examples of the fitted Weibull frequency distribution and estimates of the wind power densities for Marsabit, Eastleigh, Garissa and Malindi stations.

Figure 7d show the distribution of the wind direction (Wind Roses) for Marsabit, Eastleigh and Garissa stations. The predominant wind direction for Marsabit is South-easterlies while in Eastleigh they are North-Easterlies. The wind direction in Garissa is predominantly Southerly winds. Wind direction varies from one station to another in response to synoptic scale and mesoscale effects.

Figures 7e and 7f present the diurnal wind speed and wind power over Marsabit during the different months of the year. There is clear evidence of strong diurnal and seasonal variability for both the wind speeds and power potential over Marsabit.

5.0 HARNESSING WIND ENERGY IN KENYA

With the abundance of wind energy resources in many parts of the country, especially around Marsabit area and along the Kenyan coastline, electricity generation through wind energy provides a viable and environmental friendly option. There are currently 3 large wind generators of capacity 200 kW each operating in Marsabit and Ngong towns respectively. The Marsabit wind generator is a hybrid system that has been integrated with diesel power systems while the Ngong wind machines are interconnected with the grid. These wind generators are operated and maintained by the Kenya Electricity Generating Company (KenGen).

Similarly, there are over 200 wind pumps (Kijito) installed in the country of sizes of 12', 16', 20' and 24' rotor diameters mainly for pumping water for domestic use and for irrigation. A limited number of small wind generators of capacity 1 - 5 kW for use in remote missions, farms and rural health centres are also working in various places.

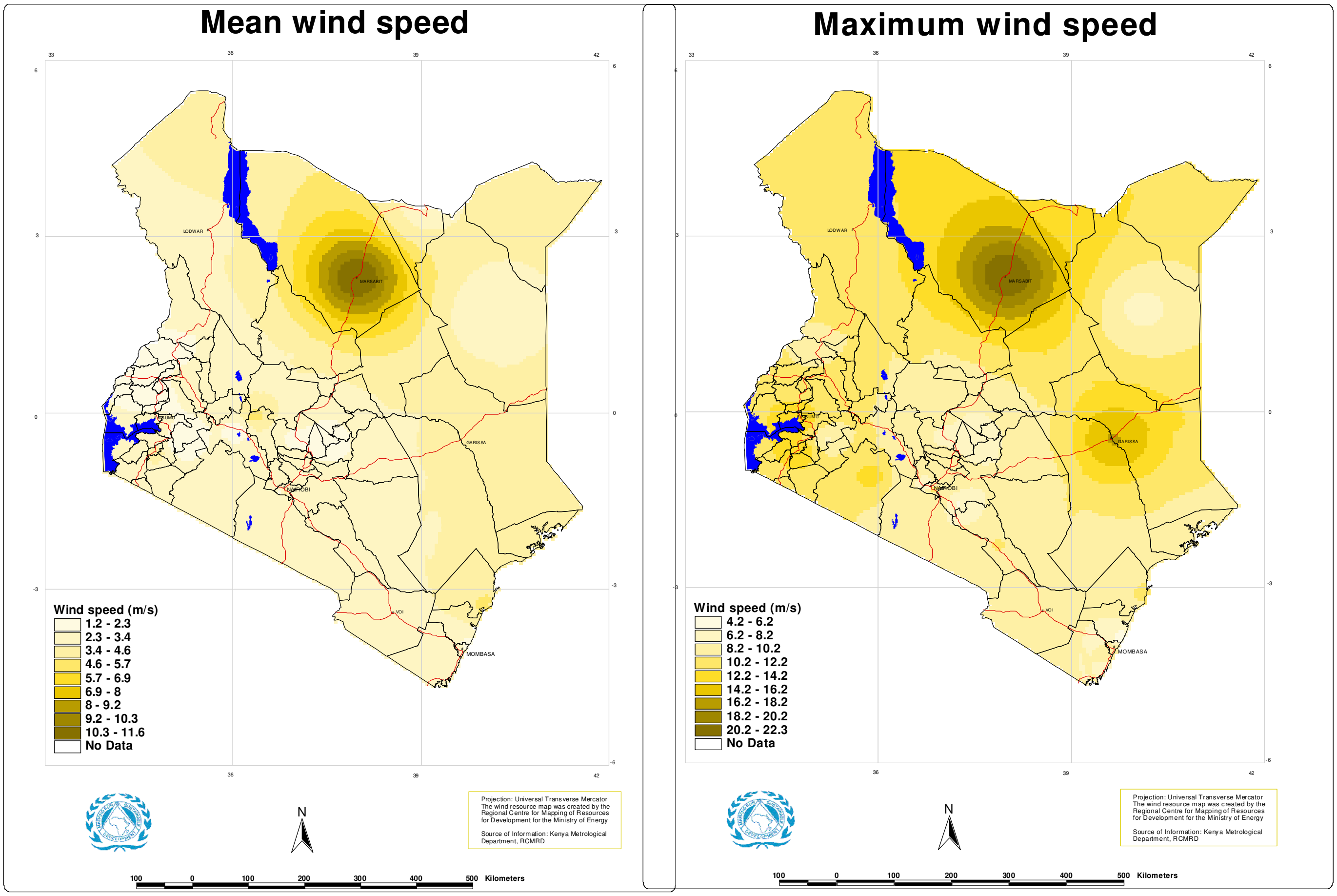

Figure 6a: Spatial patterns of the mean and maximum wind speeds (ms^{-1}) over Kenya
Source: Ministry of Energy, Wind Atlas for Kenya, 2004

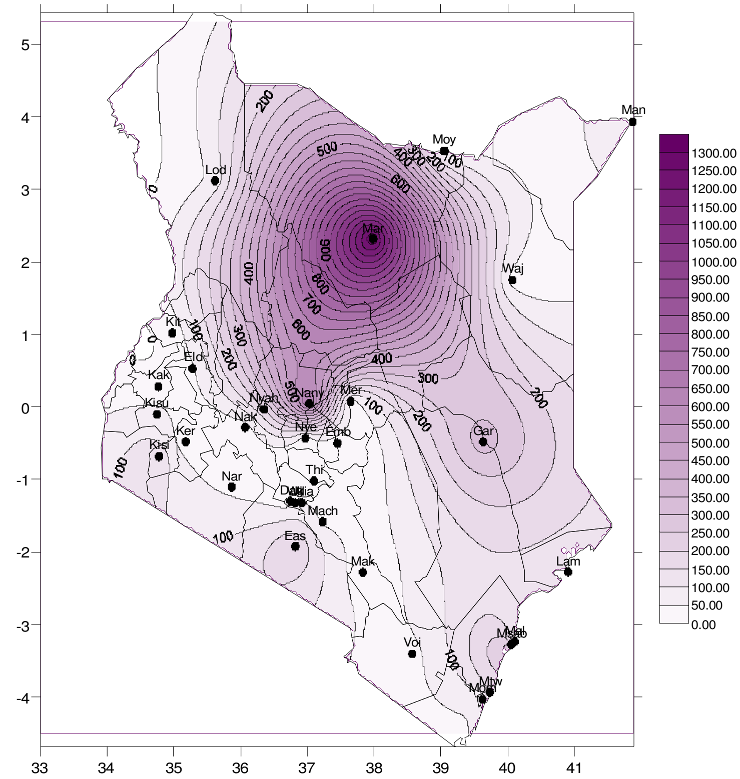

Figure 6b: Spatial patterns of the wind power density (Wm^{-2}) over Kenya

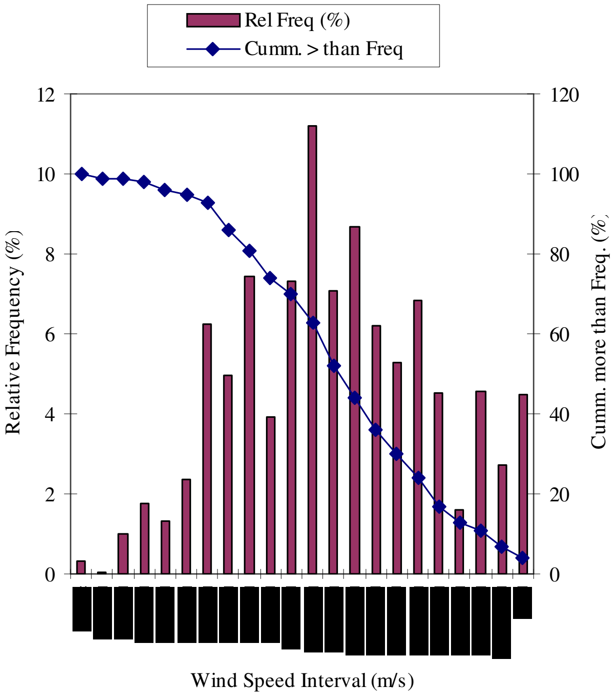

Figure 7a: Relative Frequency Distribution of the wind speeds over Marsabit

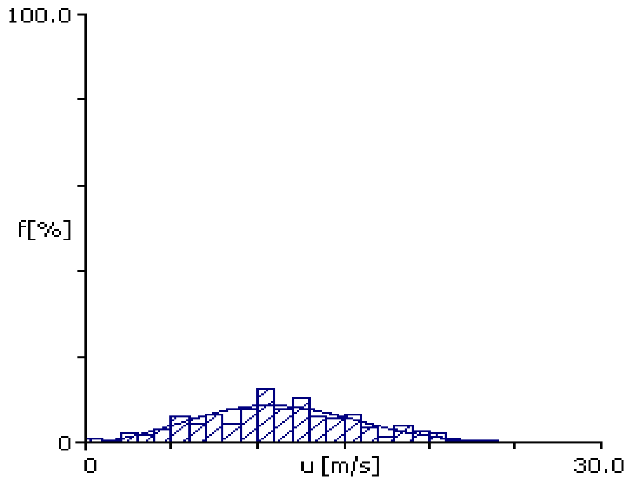

Figure 7b: Fitted Weibull Frequency Distribution of the wind speeds over Marsabit

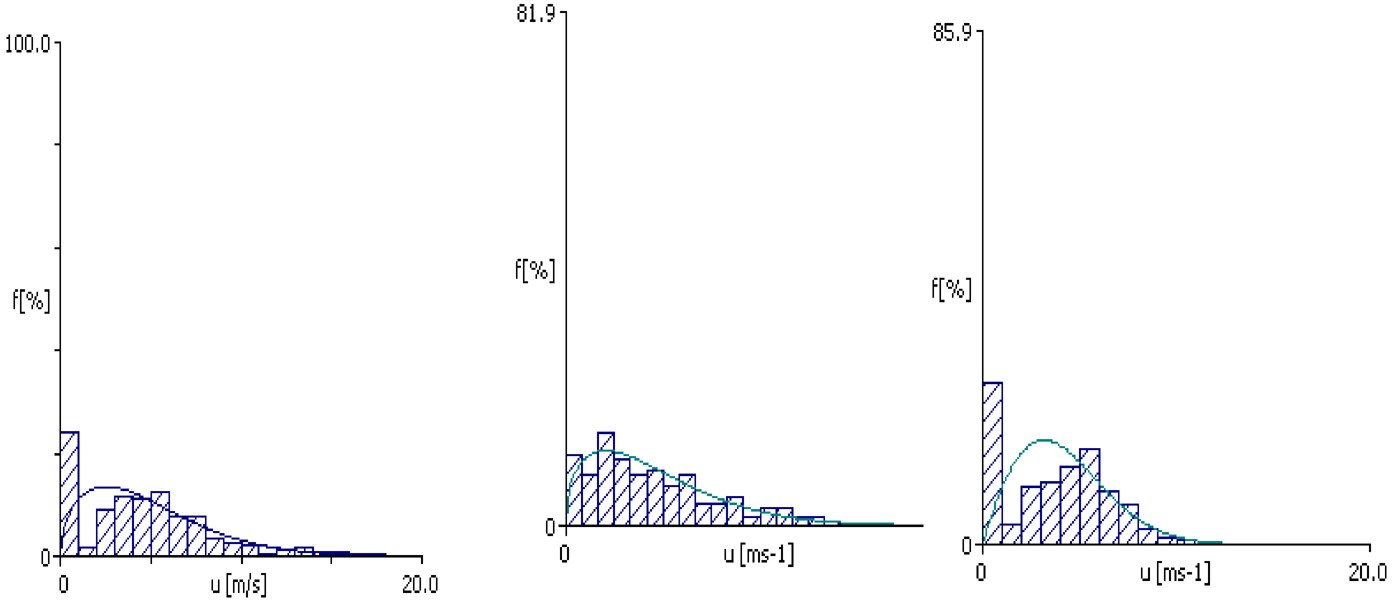

Figure 7c: Fitted Weibull Frequency Distribution of the wind speeds over Eastleigh, Garissa and Malindi

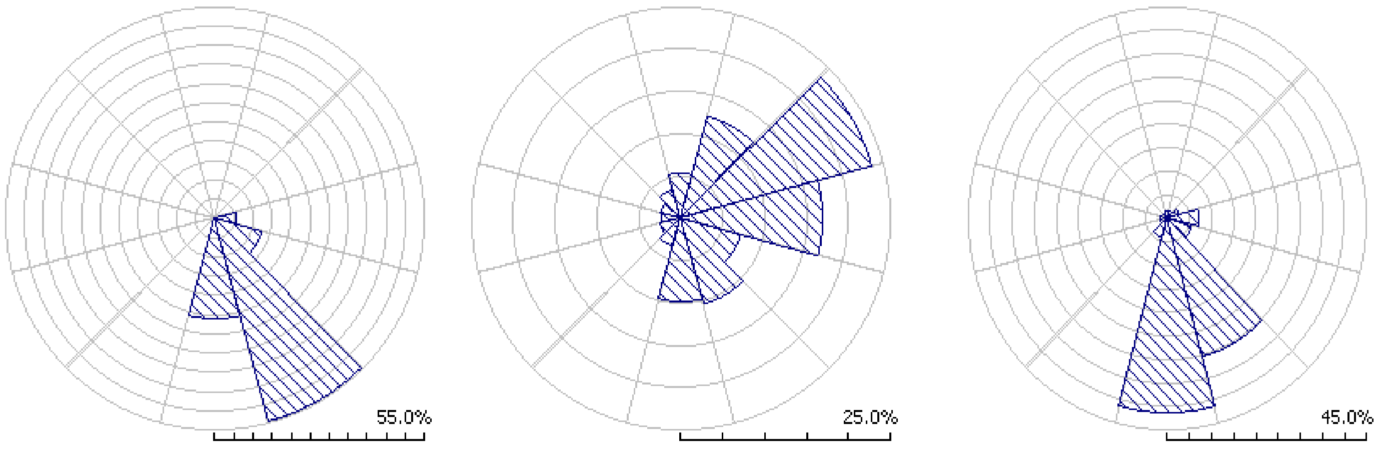

Figure 7d: Wind Rose Frequency Distribution for the winds over Marsabit, Eastleigh and Garissa

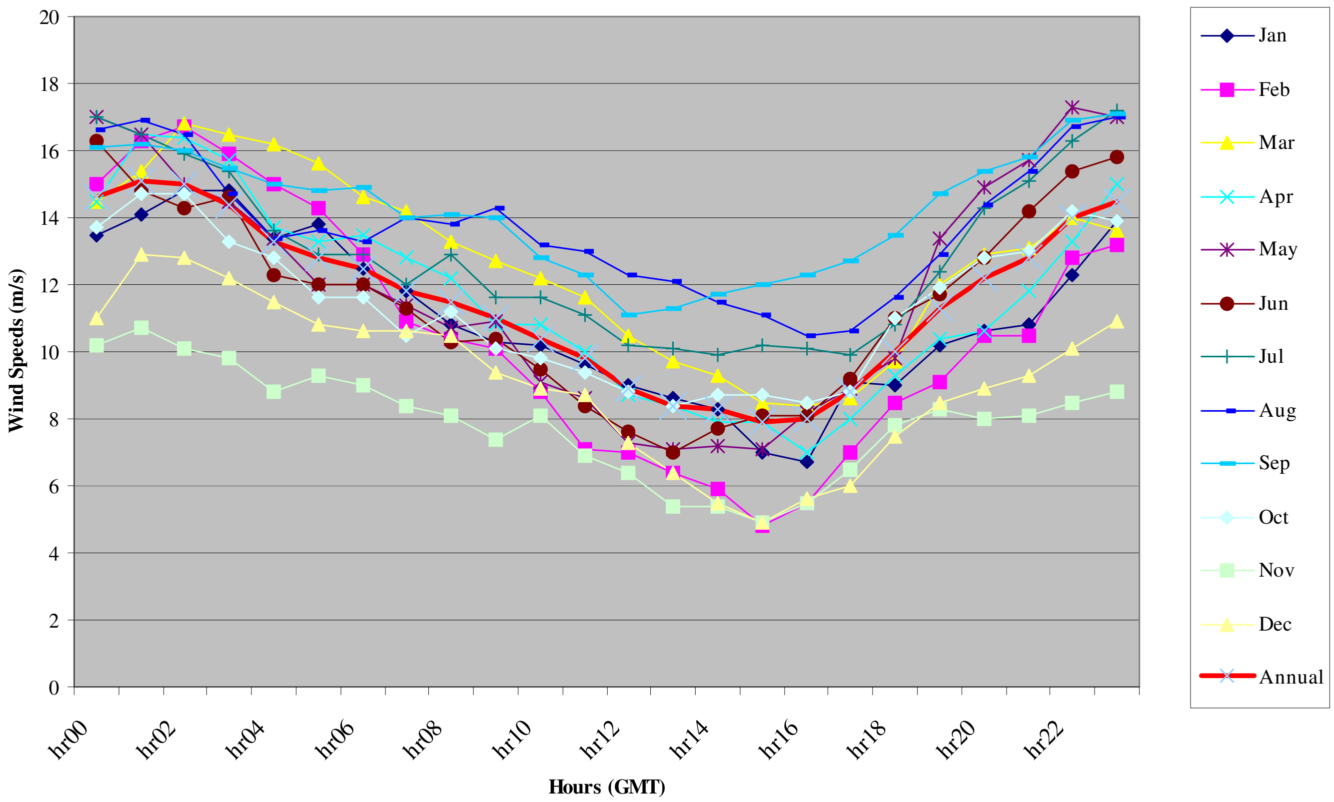

Figure 7e: Diurnal wind speed variation over Marsabit

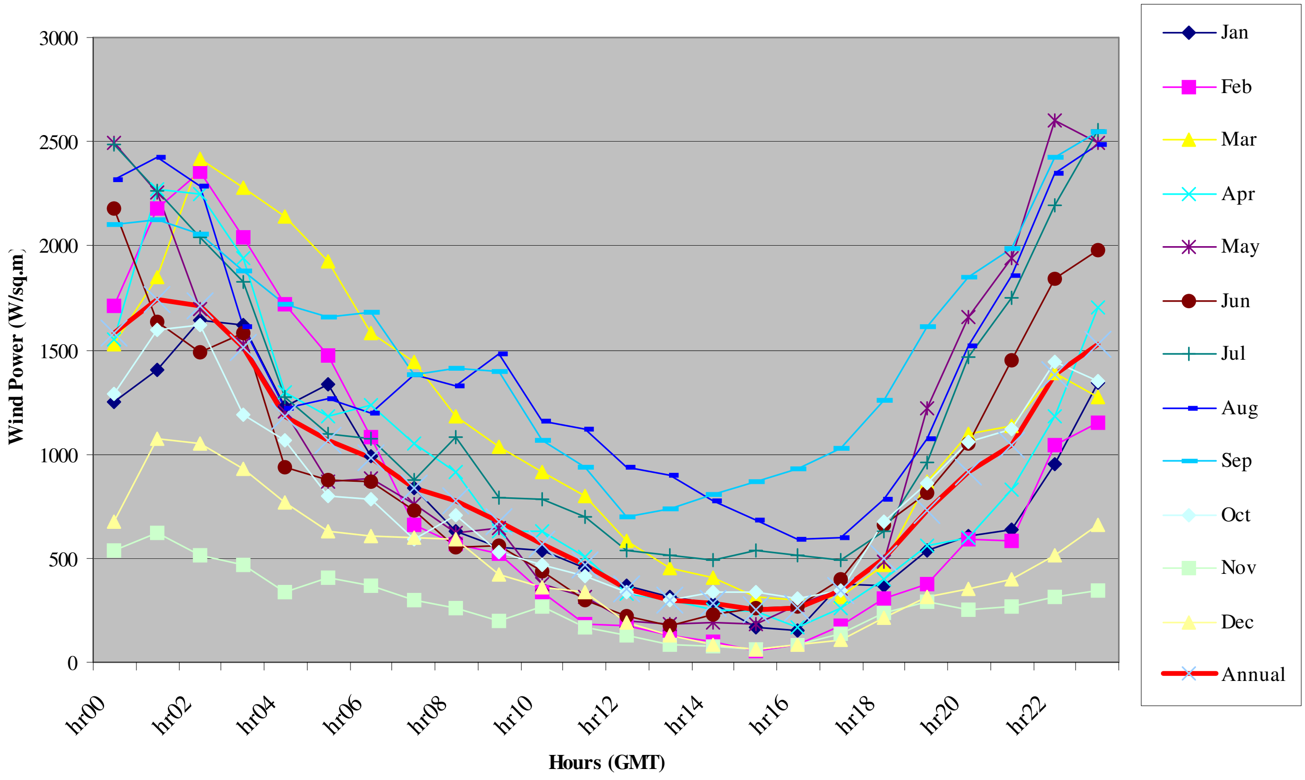

Figure 7f: Diurnal variation of the wind power variation over Marsabit

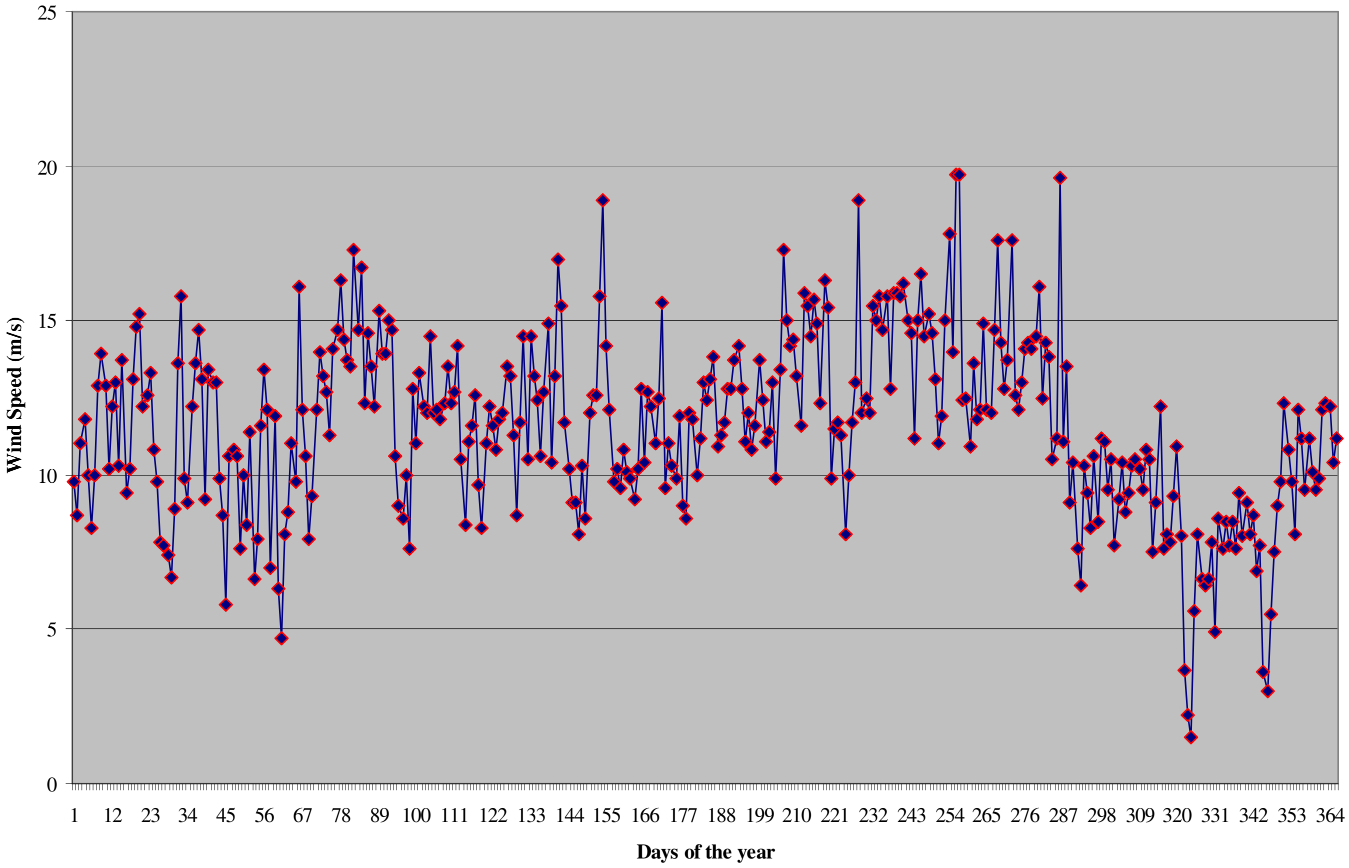

Figure 7g: Daily wind speed variation over Marsabit

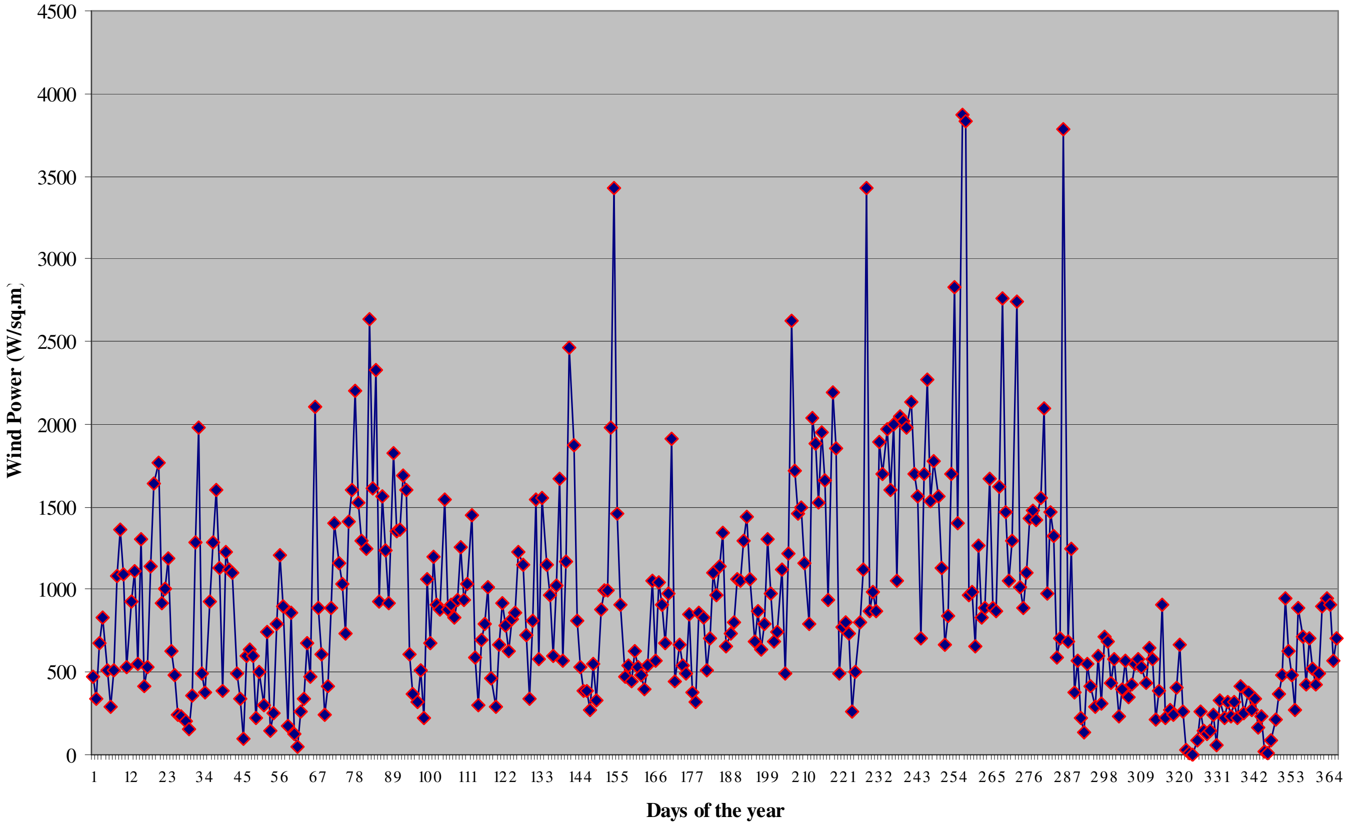

Figure 7h: Daily wind power variation over Marsabit

Figure 8 below shows a typical components of a wind pump as well as an example of a Kijito wind pump installed in Kajiado. Many of these windpumps are being used to pump water at many locations in Kenya.

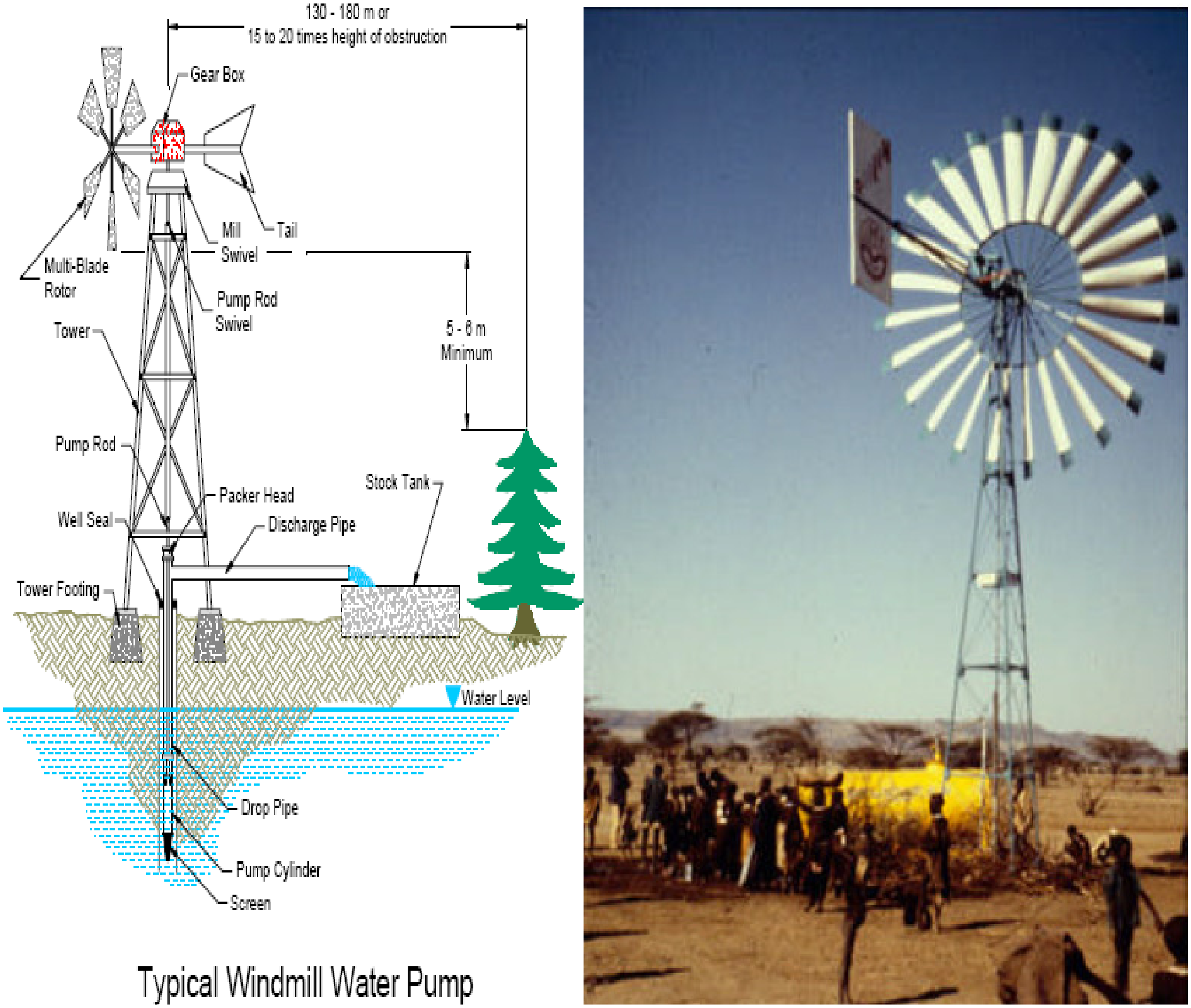

Figure 8: Examples of Installed Kijito wind pumps in Kenya.

Figure 9 next page shows some of the location of the wind pumps and wind generators in the country. A number of these windmills are still operational at many locations in Kenya. Details concerning these machines, their costs, performance and reliability may be obtained from Zieröth and Hüth, (1984), Kenna, (1986), GWEP, (1987) or IBRD, (1993). Studies carried out on the performance of the Kijito windmills have indicated that they are more reliable, better designed and robust to harsh exposure conditions.

6.0 CONCLUSIONS

It is apparent that most parts in Kenya (for example Marsabit, Garissa, Coast, etc) have good wind speed capable of driving large wind energy machines for purposes of wind energy utilization. Harnessing of Wind energy for various applications is therefore one sure way of achieving some of the Millennium Development Goals (MDGs) such as achieving environmental sustainability and poverty reduction among others.

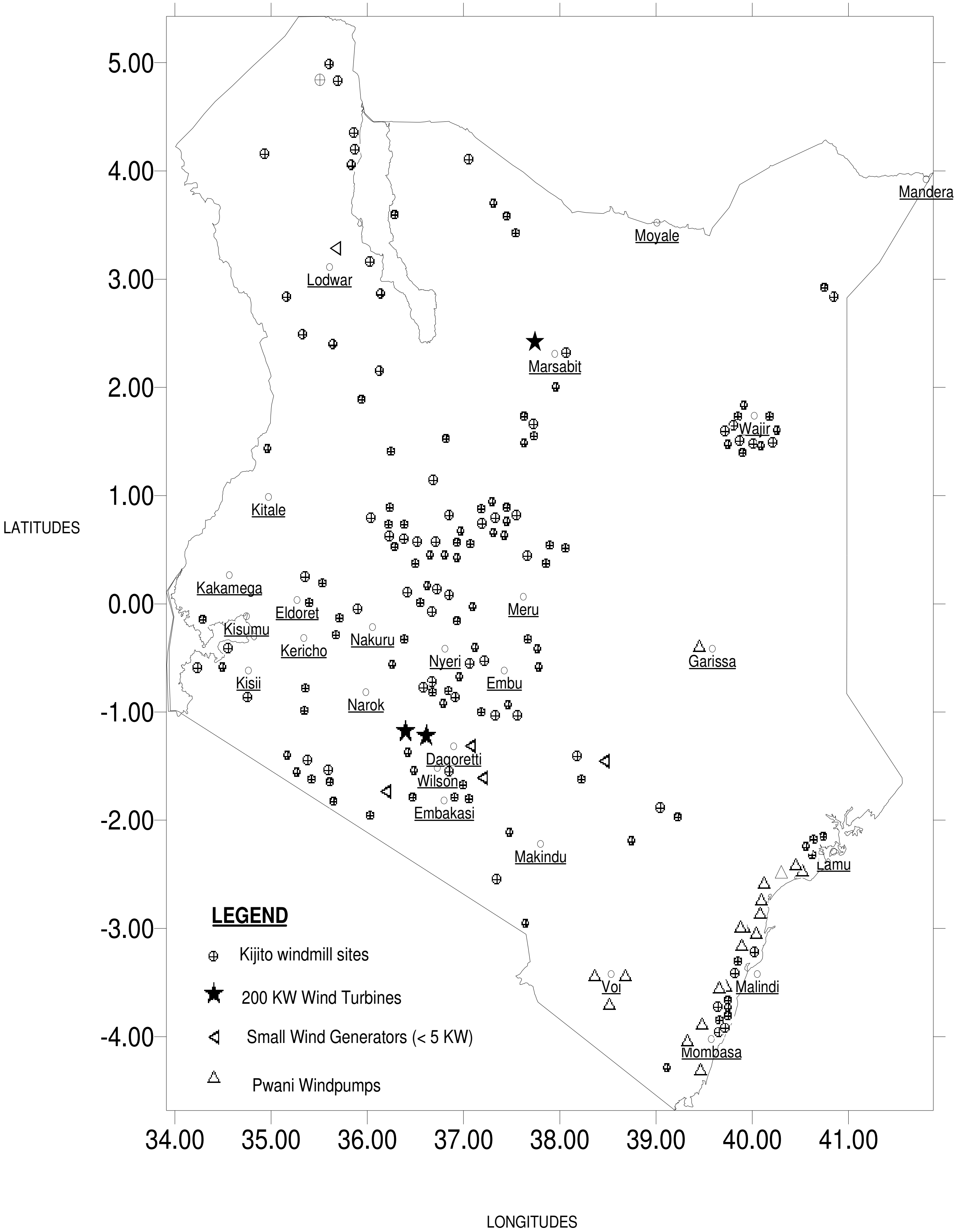

Figure 9: Locations of the Installed Kijito wind pumps and some wind generators in Kenya. (Source, IBRD, 1993)

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