# Wind Energy Development in the African Great Lakes Region to Supplement the Hydroelectricity in the Locality: A Case Study from Tanzania

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***Abstract*****—**The African Great Lakes Region refers to the zone around lakes Victoria, Tanganyika, Albert, Edward, Kivu, and Malawi. The main source of electricity in this region is hydropower whose systems are generally characterized by relatively weak, isolated power schemes, poor maintenance and technical deficiencies with limited electricity infrastructures. Most of the hydro sources are rain fed, and as such there is normally a deficiency of water during the dry seasons and extended droughts. In such calamities fossil fuels sources, in particular petroleum products and natural gas, are normally used to rescue the situation but apart from them being non-renewable, they also release huge amount of green house gases to our environment which in turn accelerates the global warming that has at present reached an amazing stage. Wind power is ample, renewable, widely distributed, clean, and free energy source that does not consume or pollute water. Wind generated electricity is one of the most practical and commercially viable option for grid quality and utility scale electricity production. However, the main shortcoming associated with electric wind power generation is fluctuation in its output both in space and time. Before making a decision to establish a wind park at a site, the wind speed features there should therefore be known thoroughly as well as local demand or transmission capacity. The main objective of this paper is to utilise monthly average wind speed data collected from one prospective site within the African Great Lakes Region to demonstrate that the available wind power there is high enough to generate electricity. The mean monthly values were calculated from records gathered on hourly basis for a period of 5 years (2001 to 2005) from a site in Tanzania. The documentations that were collected at a height of 2 m were projected to a height of 50 m which is the standard hub height of wind turbines. The overall monthly average wind speed was found to be 12.11 m/s whereas June to November was established to be the windy season as the wind speed during the session is above the overall monthly wind speed. The available wind power density corresponding to the overall mean monthly wind speed was evaluated to be 1072 W/m2, a potential that is worthwhile harvesting for the purpose of electric generation.

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***Keywords*****—**Hydro power, windy season, available wind power density.

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## I. Introduction

The Great Lakes of Africa are a series of lakes in and around the geographic Great Rift Valley formed by the action of the tectonic East African Rift. They include Lake Victoria, the second largest fresh water lake in the world in terms of surface area, and Lake Tanganyika, the world's second largest in terms of volume as well as the second deepest (See Appendix for more details) [1]. The others are Albert, Edward, Kivu, and Malawi. Some call only Lake Victoria, Lake Albert, and Lake Edward the Great Lakes as they are the only three that empty into the White Nile. Lake Tanganyika and Lake Kivu both empty into the Congo River system, while Lake Malawi is drained by the Shire River into the Zambezi [1].

The African Great Lakes Region refers to the region around these lakes. These include the entirety of the nations of Rwanda, Burundi, and Uganda as well as portions of the Democratic Republic of the Congo (DRC), Tanzania, and Kenya as shown in Figure 1. It is one of the most densely populated areas of the world, with an estimated 107 million people living in the Great Lakes region [1, 2]. Because of past volcanic activity this part of Africa contains some of the world's best farmland. Its altitude also gives it a rather temperate climate despite being right on the equator.

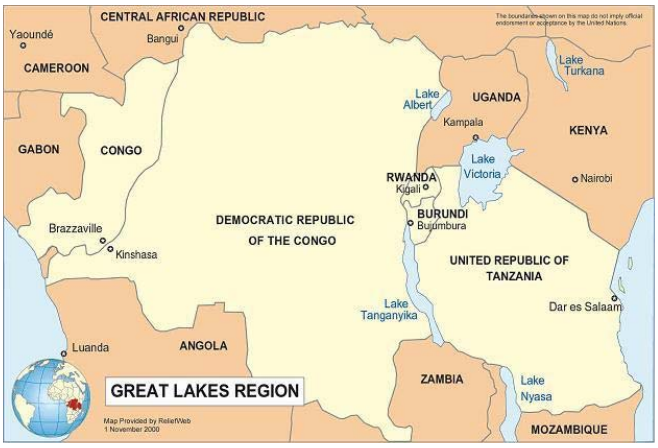


Fig. 1 Countries of the great lakes region [1]

The majority of the Great Lakes region population still relies on bio-fuel (wood, animal waste, etc.) as their primary fuel source. Commercial energy resources in the region include coal, natural gas (which is not yet being fully exploited), hydroelectricity, geothermal energy sources, and strong potential for oil. In 2001, 57 % of electricity in the region was generated through hydroelectricity and 43 % through thermal and geothermal sources [1, 2]. Oil prices in the region have a significant impact on local economies, because the area is heavily dependent on oil imports.

The electric power supply industry in the region is almost invariably government owned, highly centralized and politically regulated. Although the area has no shortage of the resource base for economic power generation and supply, there has been deterioration in the performance of the electric power utilities, and a depression of the electricity markets of

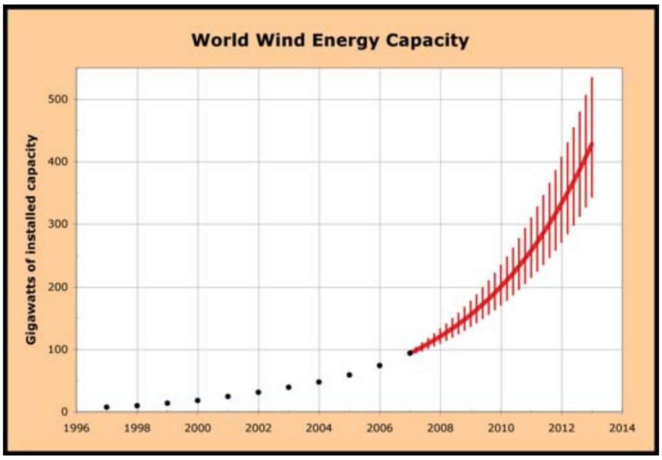


Fig. 2 Total world wind energy installed capacity (MW) and prediction 1997-2013 [3]

the region in the 1980s. The infrastructure is still largely characterized by isolated networks with little or no interconnection between countries, low fuel use efficiency, low capacity factors, and high distribution and transmission losses [2].

Hydropower, which is currently the main source of electricity in the great lakes region, relies on long rains, the later of which are not reliable. For consistency of hydropower on the rivers that are rain fed, dams are usually constructed to store water that can be used during the dry period and at the same time increase the head of the rivers. There are as well limits to the extent one can go with large hydro options and there are issues of submergence, social rehabilitation and risks of drought events. There is also a conflict over the water resources. The same water that is used for agriculture and human consumption by local communities is needed to generate hydropower. Consequently it is important that the region diversify its source of electricity to other renewable energy resources such as wind and solar instead of the current tendency of relying heavily on hydrological resources. Wind is a renewable energy source that is abundant in the area but its magnitude has not yet been examined thoroughly. Wind energy is in fact one of the most practical and commercially viable option for grid quality and utility scale electricity generation.

Wind power is ample, renewable, widely distributed, clean, and free energy source that does not consume or pollute water. Wind-based electricity does not have much adverse impacts tags except visual impact, noise and impacts on birds, which

TABLE I
. TOTAL INSTALLED WIND POWER CAPACITY NATION WISE FOR THE YEARS 2005 AND 2007 [3]

| Installed wind power capacity (MW) | | | | |
|---|---|---|---|---|
| Rank | Nation | 2005 | 2006 | 2007 |
| 1 | Germany | 18,415 | 20,622 | 22,247 |
| 2 | United States | 9,149 | 11,603 | 16,818 |
| 3 | Spain | 10,028 | 11,615 | 15,145 |
| 4 | India | 4,430 | 6,270 | 8,000 |
| 5 | China | 1,260 | 2,604 | 6,050 |
| 6 | Denmark (& Faeroe Islands) | 3,136 | 3,140 | 3,129 |
| 7 | Italy | 1,718 | 2,123 | 2,726 |
| 8 | France | 757 | 1,567 | 2,454 |
| 9 | United Kingdom | 1,332 | 1,963 | 2,389 |
| 10 | Portugal | 1,022 | 1,716 | 2,150 |
| 11 | Canada | 683 | 1,459 | 1,856 |
| 12 | Netherlands | 1,219 | 1,560 | 1,747 |
| 13 | Japan | 1,061 | 1,394 | 1,538 |
| 14 | Austria | 819 | 965 | 982 |
| 15 | Greece | 573 | 746 | 871 |
| 16 | Australia | 708 | 817 | 824 |
| 17 | Ireland | 496 | 745 | 805 |
| 18 | Sweden | 510 | 572 | 788 |
| 19 | Norway | 267 | 314 | 333 |
| 20 | New Zealand | 169 | 171 | 322 |
| 21 | Egypt | 145 | 230 | 310 |
| 22 | Belgium | 167 | 193 | 287 |
| 23 | Taiwan | 104 | 188 | 282 |
| 24 | Poland | 83 | 153 | 276 |
| 25 | Brazil | 29 | 237 | 247 |
| 26 | South Korea | 98 | 173 | 191 |
| 27 | Turkey | 20 | 51 | 146 |
| 28 | Czech Republic | 28 | 50 | 116 |
| 29 | Morocco | 64 | 124 | 114 |
| 30 | Finland | 82 | 86 | 110 |
| 31 | Ukraine | 77 | 86 | 89 |
| 32 | Mexico | 3 | 88 | 87 |
| 33 | Costa Rica | 71 | 74 | 74 |
| 34 | Bulgaria | 6 | 36 | 70 |
| 35 | Iran | 23 | 48 | 66 |
| 36 | Hungary | 18 | 61 | 65 |
| | Rest of Europe | 129 | 163 | |
| | Rest of Americas | 109 | 109 | |
| | Rest of Asia | 38 | 38 | |
| | Rest of Africa & Middle | 31 | 31 | |
| | Rest of Oceania | 12 | 12 | |
| | World total (MW) | 59,091 | 74,223 | 93,849 |

compared to adverse impacts of other options is insignificant. However, the main shortcoming associated with electric wind power generation is fluctuation in its output both in space and time. Therefore, before one can decide to harvest the wind energy resource that is home grown, systematic investigation of its characteristics needs to be done. The main objective of this paper is to analyze wind speed data collected at Makambako (a site located in the southern highlands of Tanzania) to establish the fact that wind energy potential at the site is sufficiently high to generate electricity. Wind data,

Fig. 3 Picture showing foreign trees that are deformed by the strong winds existing in the prospective site

of most common time interval of one hour simulation for a continuous period of five years (2001 to 2005), is used as the primary information.

## II. Worldwide Wind Power Capacity

According to World Wind Energy Association (WWEA) modern wind industry with global installed capacity of about 100 000 MW, generates nowadays more than 200 bln kWh per year, equalling 1.3% of the global electricity consumption, while in some countries wind energy contributes to 40% and more as shown in Tables 1 and 2. The wind industry employs today 350,000 people worldwide [3]. There have been a very dynamic international wind energy markets that had an annual growth rate of 25 % in the past ten years.

At the end of 2007, worldwide capacity of wind-powered generators was 93,849 GW as detailed in Table 1. Although wind produces about 1 % of world-wide electricity use it accounts for approximately 19 % of electricity production in Denmark, 9 % in Spain and Portugal, and 6 % in Germany and the Republic of Ireland ad detailed in Table 2. Globally, wind power generation increased more than fivefold between 2000 and 2007 as depicted in Figure 2.

## III. Wind Resource at the Prospective Site

For wind energy to be economically competitive with other energy reserves there is a need for quick and cheap techniques for identifying areas of persistently strong winds. Certain indirect indicators of wind energy such as meteorological and topographical assessments, vegetation features as well as Aeolian land forms may aid to give some light on the features of wind resource [4]. Biological wind prospecting provides techniques for using the natural indicators around us as a guide to the strength, speed, frequency and direction of the wind. For the site-specific analysis the mean wind speed and the mean wind direction can be estimated from the degree of deformation of wind flagged trees. The trees by their shape can provide valuable indicator of wind shear and flow separation. Because of frictional effects, the winds near the ground are less strong and the trees show less deformation, whereas further up the crowns are strongly flagged as depicted in Figure 3.

The wind regimes at the site is quite high as can be demonstrated by the trees that have been deformed as a result of strong winds that are existing in that area (See Figure 3).

TABLE II

Table 2. The Ratio of Annual Wind Power Generation (TWh) to the Total Electricity Consumption (TWh) for Nine High Ranked Nations (Source: [3])

| Annual Wind Power Generation (TWh) / Total electricity consumption(TWh) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Nation | 2005 | | | 2006 | | | 2007 | | |
| | | Wind Power | % | Total Power | Wind Power | % | Total Power | Wind Power | % | Total Power |
| 1 | Germany | 27.2 | 5.1 | 533.7 | 30.7 | 5.4 | 569.9 | 39.5 | 6.8 | 585.0 |
| 2 | United States | | | 4049.8 | 26.3 | 0.6 | 4105.0 | | | 4189.0 |
| 3 | Spain | 23.2 | 9.1 | 254.9 | 29.8 | 10.1 | 294.6 | | | 303.8 |
| 4 | India | | | 679.2 | | | 726.7 | 14.7 | 1.9 | 774.7 |
| 5 | China | | | 2474.7 | 2.7 | 0.1 | 2834.4 | | | 3255.9 |
| 6 | Denmark (& Faeroe Islands) | 6.6 | 19.3 | 34.3 | 7.4 | 16.8 | 44.24 | | | 37.276 |
| 7 | France | | | 547.8 | 2.3 | 0.4 | 550.1 | | | 545.3 |
| 8 | United Kingdom | 1.0 | 0.2 | 407.4 | | | 383.9 | | | 379.8 |
| 9 | Portugal | | | 35 | 4.7 | 9.7 | 48.9 | | | |
| | World total (TWh) | | | 15,746.54 | | | 16,790 | | | |

The trees usually get flagged toward the wind direction. The trees shown in the picture are non- indigenous and that is why they suffer such a big deformation. It is worthwhile noting that native trees usually adapt themselves to the high wind load and the degree of the deformation is usual less that the foreign ones. The flagged trees gave a rough idea about the strong winds in the site and this fact lead us decide to perform direct wind measurement in the prospective sites.

Fig. 4 The portable weather station that was installed at the experimental site

## IV. Equipment Used

Wind speed and direction were measured, respectively, by anemometer (type AN1) and windvane (type WD1) both Fig.3 supplied by DELTA-T-DEVICES. The two wind sensors were positioned 2 m above the ground level as shown in Figure 4. Wind measuring devices were part of the other sensors of the portable weather station. The data were recorded on hourly basis and the one that is used in this article covered the period from 1st January 2001 to 31st December 2005.

## V. Methods of Data Analysis

The wind speed data, $V_r$, that were collected at a reference height of $Z_r$=2 m were extrapolated to a height $Z_X$ = 50 m, that corresponds to the hub height of standard wind turbines, using the relation:

$$V_X = \frac{\ln \frac{Z_X}{Z_o}}{\ln \frac{Z_r}{Z_o}} V_r \tag{1}$$

in which, $V_x$, corresponding speed at 50 m and $Z_o$ is the roughness length of the area that was taken to be 0.25 m. This value of the roughness length matches with the vegetation features of the area that was composed of isolated trees with some grass and is also in agreement with standard values given in [4].

The available wind power density ($Wm^{-2}$) can be evaluated from the relation:

$$P = \frac{1}{2}\rho \overline{V}^3 \tag{2}$$

where ρ is the air density, whose value was taken as 1.207 $kg/m^3$ in this analysis and $\overline{V}$ is the overall monthly mean wind speed for the entire period under consideration. The available wind power density on monthly basis can also be calculated by using Equation 2 and $\overline{V}$ replaced by the average monthly wind speed.

## VI. Results

### A. Monthly average wind speed

TABLE III
Mean monthly wind speed (m/s) at a height of 50 m for the years 2001 to 2005

| Month | 2001 | 2002 | 2003 | 2004 | 2005 | MEAN MONTHLY |
|---|---|---|---|---|---|---|
| Jan | 5.85 | 4.17 | 6.78 | 6.57 | 5.52 | 5.78 |
| Feb | 6.57 | 4.83 | 7.23 | 6.06 | 6.87 | 6.31 |
| Mar | 9.36 | 7.17 | 8.82 | 8.46 | 6.69 | 8.10 |
| Apr | 10.41 | 10.83 | 8.73 | 9.03 | 10.20 | 9.84 |
| May | 12.51 | 13.17 | 11.79 | 13.65 | 11.37 | 12.50 |
| Jun | 13.71 | 12.87 | 12.57 | 17.91 | 13.17 | 14.05 |
| Jul | 12.99 | 13.65 | 12.63 | 17.85 | 12.39 | 13.90 |
| Aug | 13.23 | 14.58 | 14.31 | 19.68 | 13.23 | 15.01 |
| Sep | 15.87 | 15.03 | 14.46 | 18.18 | 15.42 | 15.79 |
| Oct | 16.32 | 16.71 | 15.45 | 20.79 | 16.11 | 17.08 |
| Nov | 18.24 | 15.51 | 13.68 | 19.44 | 18.33 | 17.04 |
| Dec | 9.48 | 9.57 | 9.81 | 11.34 | 9.57 | 9.95 |
| Mean | 12.05 | 11.51 | 11.36 | 14.08 | 11.57 | 12.11 |
| STD | 3.83 | 4.22 | 2.98 | 5.53 | 3.99 | 4.11 |

Table 3 shows the monthly average wind speed at a height of 50 m and the corresponding overall monthly wind speed for the period under consideration. The entire monthly average wind speed for the whole period is 12.11 m/s. The period from June to November is the windy season in the site because the speed is above the entire mean wind speed. The calm period is from November to April as the speed is below the whole mean value.

*B. Available Wind Power density*

The overall available wind power density is as depicted in Figure 5. Series 1 stands for the average monthly value while Series 2 portrays the overall mean value speed for the period under investigation. The figure demonstrates that the power density is above entire mean from June to November while from December to May the power density is below the overall mean value. The overall mean wind speed which was 12.11 m/s was used to calculate the corresponding available wind power density using Equation 2 and it was found to be 1072 W/m$^2$.

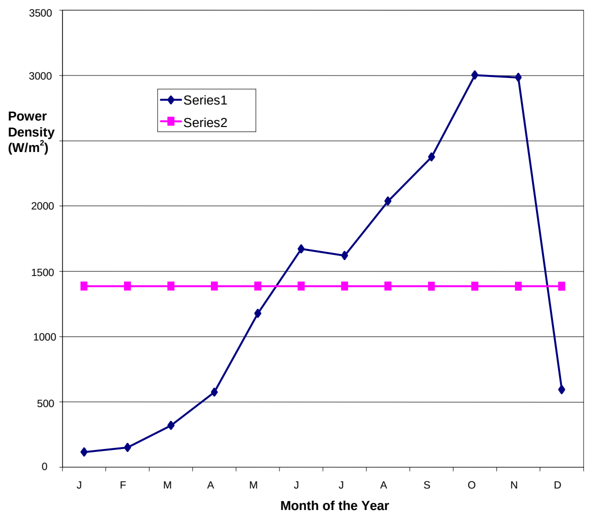


Fig. 5 Monthly Wind Power Density Against Month (2001-2005)

## VII. Discussions and Conclusions

The overall mean monthly wind speed of 12.11 m/s shows that the wind climate at this site is high enough to generate electricity. The windy season in the prospective site coincides with the dry season in many parts of the region under consideration. If the available wind energy is utilized to generate electricity, the wind-generated electricity could be used to supplement of shortage of electricity that prevails during the dry season in the locality. It is also recommended that other sites within the region should be investigated to explore their wind energy potential for the possibility of generating electricity from wind. The opportunities for Great Lake Region to emerge as a rising star in the growing renewable energy markets are enormous. The region has vast, latent potential for wind and solar power generation. Recent studies show strong potential for wind power generation, in Kenya, Burundi and Tanzania. In-depth evaluations are still pending for countries such as Tanzania and Kenya, where offshore wind currents are expected to be highly suitable for wind farming [5].

## References

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