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Data Correlation and Economic Analysis of Wind Regimes of Manga Hill in Nyamira County, Kenya

Kwamboka, J.O., Kamau, J.N., Saoke, C.O. and Ndeda, J.O.
Department of Physics
Jomo Kenyatta University of Agriculture and Technology, Juja, Kenya

Abstract:- Wind power is one of the fastest growing energy sources in the world. The Kenyan government has a new energy policy that directs its state-owned energy system, KenGen, as well as the country's independent power producers, to eliminate fossil fuel-powered generation. The country's energy plan outlines how the majority of the country's electricity will come from renewable sources at utility, commercial, industrial scale and Off-grid connections. An understanding of the characteristics of the wind is critical to all aspects of wind energy generation, from the identification of suitable sites to predictions of the economic viability of wind farm projects to the design of wind turbines themselves, all is dependent on the characteristic of wind. In this study, data from the Kisii meteorological station was used to make a comparison and correlation with the data obtained from the Manga Hill site, to determine how the data collected from the two sites tend to vary. In this correlation, the Pearson's Correlation Coefficient was found as 0.85. In addition, an economic evaluation of wind regimes of Manga Hill was done by making an analysis of three different wind turbines chosen to simulate the performance using their specific power curves. Bergey Excel-10 turbine model showed a better performance with high energy yield at minimum cost with increasing hub height. In order to utilize wind energy, installation of a 10 kW rated power horizontal axis wind turbine, with rotor diameter between 1 m and 7 m, at 30 m height would be economically viable for Manga Hill site for domestic power generation: for lighting and small house electrical applications as a supplement power to the grid connected electricity in the region.

***Keywords*:-** *Energy Potential, Economic Analysis, Energy Output, Power Curve.*

I. INTRODUCTION

Wind results from expansion and convection of air as solar radiation is absorbed on Earth. On a global scale these thermal effects combine with dynamic effects from the Earth's rotation to produce prevailing wind patterns [1].

The evaluation of wind power potential requires careful statistical analysis of mean wind speed and its frequency distribution [2]. To integrate wind power into the electric grid, wind's intermittency and persistence due to temporal and spatial variability in large range of scales becomes a big challenge [3].

There are high wind speeds in various parts of northern Kenya and other arid lands. Preliminary wind resource assessments show that wind regimes in certain parts of Kenya (such as Marsabit, Ngong and the Coastal region) can support commercial electricity generation as they enjoy wind speeds ranging from 8 m/s to 14 m/s. Specific areas that have been identified for wind power generation are Marsabit, Laisamis, Turkana and Samburu. These areas have potential to produce over 1,000 MW of wind power for sale to the national grid [4]. This preliminary assessment has been used to develop a wind map for the whole country. To facilitate decision-making in wind power generation investment, the government is undertaking wind data logging in high potential areas of Kenya. Kenya aims to generate 2,036 MW of wind power, or 9% of the country's total capacity, by 2030 [5].

The amount of energy that can be harvested from the wind depends on the size of the turbine and the length of the blades. The output of a wind turbine is proportional to the dimensions of the rotor and varies with the cube of the wind speed and every turbine has a unique power curve. With such a curve it is possible to predict the energy production of the turbine without considering the technical details of its various components [6]. The power curve therefore gives the electrical power output as a function of the hub height of the wind speed.

This paper presents an economic analysis through modeling of wind speeds collected and analyzed for Manga Hill by the simulation of three wind turbine models. Reference [7], collected and analyzed hourly wind speed data with their respective directions, daily temperatures and atmospheric pressure for Manga hill over a period of three months speed at 10 m and 15 m height for each of the three months and determined wind power energy for the site.

A. *Wind Power*

The power P, of the wind that flows at speed v, through a blade sweep area A, increases as the cube of its velocity and is given by [8];

$$P=\frac{1}{2}\rho A v^3 \tag{1}$$

where; ρ is the air density.

B. *The Variation of Speed with Height*

The wind speed increases with the height above the ground, due to the frictional drag of the ground, vegetation and buildings. The vertical variation of the wind speed (the wind speed profile), can be expressed by the power exponent function [9];

$$v_z = v_r \left[\frac{Z}{Z_r} \right]^{\alpha} \qquad (2)$$

where, Z is the height above ground level, v_r is the wind speed at the reference height r, above ground level, v_z is the wind speed at height Z, and α is an exponent which depends on the roughness of the terrain.

C. *Economic Analysis Methods*

The cost of renewable energy technologies varies by technology, country and project, based on the renewable energy resource, capital and operating costs, and on both the efficiency and performance of the technology in use [10]. For a preliminary estimation of a wind energy system's feasibility, determination of its relative economic benefit is done by two methods: the simple pay back analysis and cost of energy analysis [6]. In this study cost of energy has been employed to determine the unit cost to produce energy.

The cost of energy (COE) analysis is the unit cost to produce energy from the wind system. It is expressed as a fraction of the total costs on energy produced, thus:

$$COE = \frac{C_c xFCR + C_{O\&M}}{E_a} \qquad (3)$$

Where, C_c x FCR +$C_{O\&M}$ constitute total cost, C_c is the installed capital cost, $C_{O\&M}$ is the average operation and maintenance costs, FCR is the fixed charge rate and E_a is the energy produced [6].

II. MATERIALS AND METHODS

A. *Data Correlation*

The wind data measured at the Manga hill site was correlated with wind data obtained from the Kisii meteorological station in order to determine how the data collected from the two sites tend to vary. The 2 m hub height data obtained from Kisii meteorological station was extrapolated to a height of 10 m by using the power exponent equation 2 and wind shear exponent value of 0.3. The obtained wind speeds were compared with the 10 m height data from Manga Hill to determine the variation.

B. *Average Wind Speed*

An earlier study carried out for the site showed the during the period of study, all the three months depicted medium mean wind speeds between 3.4 m/s and 7.46m/s for the 10 m height and mean wind speeds between 3.6 m/s and 8.1 m/s for the 15 m height. Wind speed distribution differed quite remarkably from month to month since different months have different weather characteristics, whereby some days in the months had lower temperatures while others had higher temperatures which influence the wind patterns [7].

C. *The Wind Power Density*

The wind power density per unit area for the Manga Hill site based on the Weibull PDF was determined as 142.57 W/m^2 from three months averages and thus the extractable power obtained from the Beltz criterion was calculated as 84.49 W/m^2 [7].

D. *Wind Turbine Simulations*

Using the data collected in the study above at Manga Hill, three small sized Bergey model wind turbines with power rates 1 kW, 6 kW and 10 kW were chosen to simulate their performance at the Manga Hill. The three turbines are up wind, horizontal axis, with three blades. The technical specification and cost for the three turbine models are as shown in Table 1 [11].

Turbine Model	Rated Power(kW)	Turbine Cost (US$)
BGXL1	1	5000
BG6	6	21995
BG10	10	32000

Table 1:- Technical Specifications of Wind Turbines Considered for the Study

The turbine cost in Table 1 includes charge controller, volt alternator and stop run box with alternator diodes. Obtaining the capital cost estimation, in addition to the turbine cost, the following costs were incurred to acquire locally, a turbine for domestic wind power installation.

- Mast with a fixed charge of $ 700 and $83.33 for every meter. This includes the tower sections and associated hardware, wires and anchors.
- Transportation $ 200.
- Labour $ 2200.
- Miscellaneous costs are 10% of turbine cost [11].

The unit cost to produce energy was calculated by relating the capital cost of various wind turbines with their respective output and the result obtained from this relation were compared with the cost of the grid connected electricity.

E. *Power Curves*

The specific power curves for the three turbine models used for the study generated from the monthly kilowatt-hours energy output are illustrated in Fig. 1 and 2 [11]

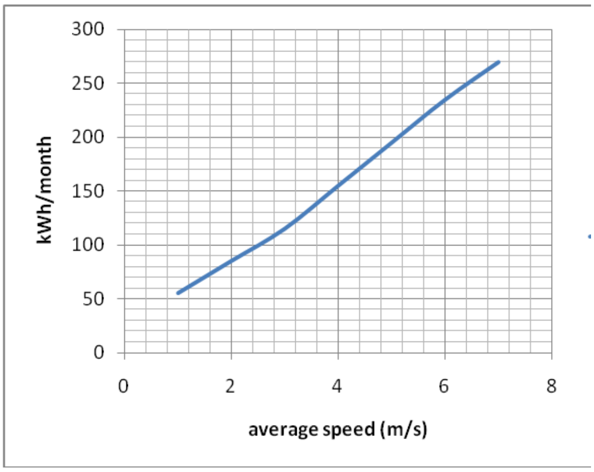

Fig 1:- Power Curve for Bergey Excel 1 Model

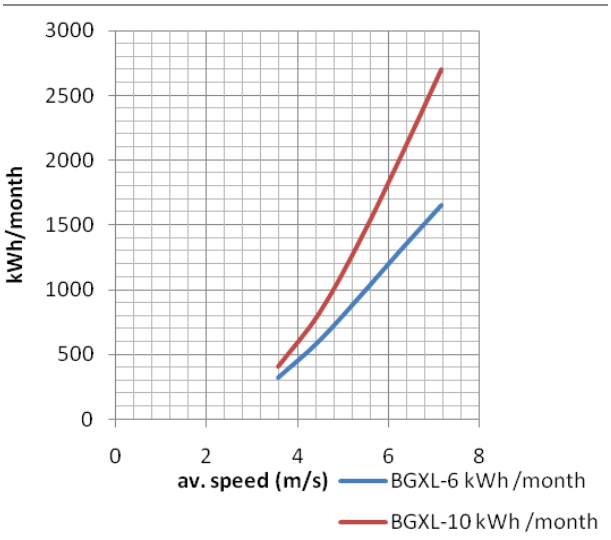

Fig 2:- Power Curves for Bergey Excel 6 and 10 Models

The power curves presented in Fig. 1 and 2 were used to match the mean wind speeds with the output to obtain the annual energy yields for the turbines for the site.

III. RESULTS AND DISCUSSION

A. Data Correlation

During the study period Manga experienced wind speed which are NW direction oriented, Kisii meteorological station experiencing E and SE oriented winds. A graph obtained from the comparison is shown in Fig. 3.

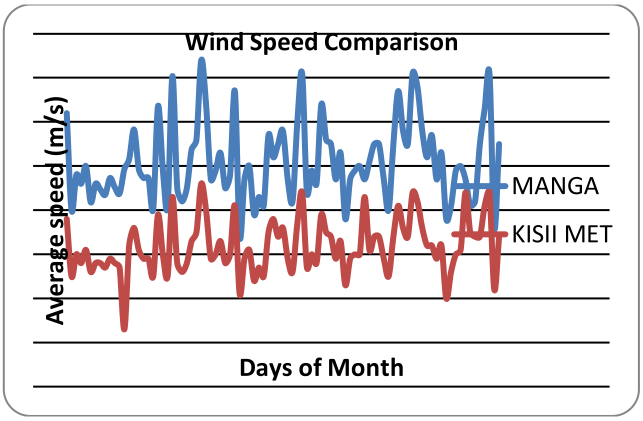

Fig 3:- Comparing Wind Speeds for the Two Sites

The Kisii meteorological station is on the altitude of 1700 m above sea level while Manga is on the altitude of 1983 m above sea level; this explains the variation in the values of the wind speed. The mean wind speed for the Manga Hill data has been calculated as 5.1 m/s and that from Kisii meteorological station at 10 m height as 3.2 m/s, indicating that the mean wind speeds for the two sites has a large difference between them. The differences in the wind directions and speed could have come up because of the topographical differences of the two locations. Owing to the hilly nature of the Manga site, the hill tops of the surrounding hills influence the wind patterns. Since hills have a significant influence on wind patterns, whereby causing acceleration of the wind and make the wind speed up while flowing towards the hill tops which are exposed to strong winds.

The correlation graph generated from the data from the two stations is shown in Fig. 4.

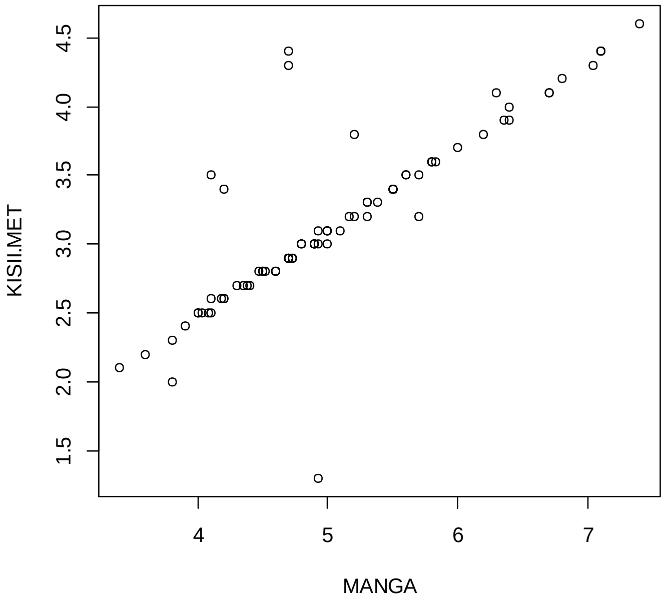

Fig 4:- Correlation Chart for Data from Manga Hill with Kisii Met Station

The Fig. 4 shows a correlation graph obtained from the Manga hill and recorded data from the Kisii meteorological station made simultaneously. The Pearson r coefficient for the data was found to be 0.85 which indicate that the data from the two stations strongly tend to vary together and hence a high correlation. The data from the Kisii meteorological station can therefore be used to model the wind patterns for the Manga site.

B. *Cost Estimation for Energy Output*

Using the cost information illustrated in section II(D) and cost of energy in (3), details showing total capital cost for the different hub heights are shown in Table 2.

Turbine Model	**Turbine cost**	**Total capital cost based on hub heights (US $)**				
		10 m	**15 m**	**20 m**	**25 m**	**30 m**
BGXL-1	5000	9433	9850	10267	10683.3	11099.9
BGXL-6	21995	28128	28545	28961	29377.8	29794.4
BGXL-10	32000	39133	39550	39967	40383.3	40799.9

Table 2:- Total Capital Cost Based on Hub Heights

C. *Annual Energy Yields*

The annual energy yields were obtained from the power curves of the three turbine models illustrated in section II(E). From the power curves, the average mean wind speeds for the three months at various heights were used and their output for the site matched from the graph. The annual energy yields at different hub heights obtained from the curves are presented in Table 3.

Turbine Model	**Annual Energy Yield per kWh**				
	Hub Height (m)				
	10	**15**	**20**	**25**	**30**
BGXL-1	2049	2502	2843	3128	3371
BGXL-6	10820	13167	14934	16410	17672
BGXL-10	16247	20277	23310	25843	28011

Table 3:- Annual Energy Yields at Different Hub Heights for the Site

The wind energy yield showed an increase with increasing hub heights and size of the model as expected from the power law (1). The BGXL-10 models showed a better performance for the energy yield with increasing height while BGXL-1 showed a poor energy yield, however, the energy yield for BGXL-1, though low, increases with increase in height.

D. *Cost of Energy Based on Capital and Hub Height*

The capital cost of each of the wind turbines has been compared with their output to obtain the unit cost to produce energy at the different heights. The unit cost is presented in Table 4.

Turbine Model	**COE ($/kWh) with Hub Height**				
	10 m	**15 m**	**20 m**	**25 m**	**30 m**
BGXL-1	4.604	3.937	3.611	3.415	3.293
BGXL-6	2.6	2.168	1.939	1.79	1.686
BGXL-10	2.4089	1.95	1.715	1.563	1.457

Table 4:- COE Based on Capital and Hub Height for the Site

From Table 4, the cost of energy showed a decreasing trend with increasing hub heights for all the turbines considered for the study. The minimum cost of energy was obtained using BGXL-10 model while the Maximum cost is obtained using BGXL-1 model. This is advantageous since the BGXL-10 model with 10 kW rated power generates the highest power and is the most economical wind turbine model.

As per June 2018, the purchase tariff per year for the on grid supplied electricity supplied in Kenya for domestic users is approximately 2.73$/kWh [12]. Comparing the obtained result in Table 4, installation of BGXL-10 model with 10 kW rated power, with rotor diameter between 1 m and 7 m, at 30 m height, is economically viable for Manga Hill for domestic electricity generation. This can serve as an alternative source of power for domestic power generation in lighting and other house appliances.

IV. CONCLUSION

In making a correlation of wind speed data from the two stations considered in the study, the Pearson r coefficient for the data was found to be 0.85 which indicate that the data from the two stations strongly tend to vary together and hence a high correlation. The data from the Kisii meteorological station can therefore be used to model the wind patterns for the Manga site.

BGXL-10 turbine model showed a better performance with an annual energy yield of 28011 kWh compared to BGXL-1 turbine model yielding 3371 kWh at 30 m hub height. BGXL-10 turbine model has a minimum cost with increasing hub height, costing 1.457$/kWh compared to BGXL-1 turbine model costing 3.293$/kWh at the same hub height. Wind energy can be adapted for Manga area for a turbine height of 30 m as a complementary domestic energy source and this model can be used for places with similar wind regimes. This can be far much beneficial since power from the wind can be obtained at a fixed price over a long period of time and being a renewable source, it can mitigate the price uncertainty that fuel costs adds to the other sources of energy.

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