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Wind energy resource assessment for Kiribati with a comparison of different methods of determining Weibull parameters

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ABSTRACT

Wind energy resource assessments at two locations in Kiribati are carried out. The wind resource on the main atoll of Tarawa is analysed along with a nearby atoll Abaiang. Measurements of wind speed, direction, ambient temperature and pressure were performed and analysed. The Tarawa site has an average wind speed of 5.355 m/s at 34 m above ground level (AGL) and the Abaiang site has an average wind speed of 5.4575 m/s at 34 m AGL. The wind direction for both the sites is predominantly East-North-East. Average diurnal wind shear coefficient correlated well with the variation in temperature. The overall average turbulence intensity was about 10% at 34 m and about 13% at 20 m AGL for both the sites. The Weibull parameters were obtained for both the sites using seven methods and the most accurate method, which was found to be the Moments method, was used to find the Weibull parameters and the wind power density. The Weibull parameters were also obtained for the two seasons of Kiribati – the dry and the wet seasons. A high resolution wind resource map of both the sites is obtained using Wind Atlas Analysis and Application Program (WAsP). The WAsP analysis indicates reasonably good wind power development potential for the Tarawa and Abaiang atolls. Annual energy production with five Vergnet 275 kW turbines for both the locations is estimated and an economic analysis is performed, which showed a payback period of 5.42 years to 8.74 years.

1. Introduction

Kiribati is an island republic, located almost at the equator in the central Pacific Ocean. Encompassing three groups of islands, Kiribati is a small nation of land area 811 km^2; however, the country has a total of 33 atolls that cover 3.5 million km^2 of the ocean. The total population of Kiribati is about 110,000 and is facing a serious threat from rising sea level, as most of the land in Kiribati is less than 2 m above sea level. The isolated location of the Kiribati islands prevents tourism from flourishing and the country becoming a major business hub, although the weather is quite good.

The country generates most of its power from diesel generators. The first national energy resource assessment for Kiribati was carried out in 2004 where the possible applications of renewable energy technologies, based on the potential of different renewable energy resources available, were considered [1]. Solar and wind energies were found to have potential in Kiribati. A research by Tarakia [2] in one of the islands confirmed that there is indeed good potential for solar and wind energies with an annual wind energy output of 48018 kWh from a PGE 20/25 wind turbine (25 kW).

As climate change became a pressing issue around the globe, lots of research work dealing with the assessment of renewable energy resources is being done around the world. Confronting and responding to climate change is one of the foremost issues of our time especially for small islands nations like Kiribati. Utilization of renewable energy will lead to its sustainable development, as it will reduce the heavy dependence on imported fossil fuels which is the major import [1].

The wind energy resource is poorly understood in Kiribati and resource survey is needed to be carried out before any investment in wind power generation can be made [1].

Despite the ever increasing interest in wind energy, its uncertain nature makes the estimation of wind energy the most difficult and crucial part of wind energy development. Concerning the importance of identifying the potential for wind, it was recognized that the measured data is considered ideal for assessment otherwise the satellite wind data could be used as an option for regions where year-long time series data is unavailable [3].

The fact that wind energy has been proven matured in terms of current technology makes the methods and modeling tools for predicting the potential for wind well understood [4]. For simple terrain

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Nomenclature

A	scale factor, m/s
AEP	annual energy production
AGL	above ground level
C_{omr}	operational maintenance/repair costs
COE	coefficient of efficiency
EPF	energy pattern factor method
i	inflation rate
I	investment
IRERAS	integrated renewable energy assessment system
k	shape factor
LS	least squares method
MAE	mean absolute error
MAPE	mean absolute percentage error, %
ML	maximum likelihood method
MML	modified maximum likelihood method
MO	moments method
MQ	moments and quartiles method
N	number of observations
PVC	present value of costs
r	interest rate,%
RMSE	root mean square error, m/s
S	scrap value
t	lifetime of the turbine, years
TI	turbulence intensity, %
$\overline{U}$	mean wind speed, m/s
U_m	median wind speed, m/s
WAsP	wind atlas analysis and application program
WPD	wind power density, W/m^2
α	wind shear coefficient
Γ	gamma function
σ	standard deviation of wind speed, m/s

topography places like Kiribati, existing analysis tools could assess the potential with minimal uncertainties.

2. Background

The assessments of wind potential in the literature were fundamentally done by analyzing the wind data. There have been numerous studies to assess the potential for wind energy at specific locations. Adaramola et al. [5] studied the annual and seasonal wind speed characteristics and Weibull parameters at a height of 12 m along the coast of Ghana. The annual wind speeds at the measurement sites were in the range of 3.88 m/s to 5.30 m/s. They concluded that wind turbines with cut-in wind speeds of less than 3 m/s and rated wind speed of 9–11 m/s will be appropriate for wind energy development along the coast of Ghana. Tizpar et al. [6] statistically analyzed the wind power potential at Mil-E Nader, Iran, based on 10 min measurements at three heights of 10 m, 30 m and 40 m; the eighteen months average wind speed at 30 m height was 6.84 m/s. They estimated the wind shear coefficient and also the turbulence intensities at the three heights. They obtained different Weibull parameters at the three different heights Boudia and Guerri [7] investigated the wind power potential at the coast in the north-west of Algeria by measuring the wind at a height of 10 m above ground level at three sites and analyzing with the Wind Atlas Analysis and Application Program (WAsP), which is now an industry standard tool for wind resource assessment [8]. They estimated the seasonal as well as annual Weibull parameters. They generated the resource grid for mean wind speed, estimated the annual energy production and also carried out a cost analysis of installing different wind turbines at those sites. Carrasco-Díaz et al. [9] performed an assessment of wind power potential along the coast of Tamaulipas in Mexico. Mean wind intensity field and the corresponding mean power density were modeled using WAsP.

Shu et al. [10] analyzed the wind characteristics and wind energy potential in Hong Kong statistically. Measurements were made at five locations that ranged in height from 74 m to 966 m above mean sea level. The mean wind speeds varied from 2.55 m/s to 9.04 m/s. They studied the monthly variation of wind speed and compared the monthly as well as seasonal Weibull probability density function distributions. They used three methods for obtaining Weibull parameters: the moments method, the maximum likelihood method and the power density method. Baseer et al. [11] studied the wind speed and power characteristics for Jubail industrial study in Saudi Arabia with the help of measured wind speed data at three heights above ground level. The local wind shear coefficient at three heights was studied in detail including its diurnal variation. For heights of 10 m and 50 m, the wind shear coefficient varied from 0.12 to 0.38. They obtained the Weibull parameters using maximum likelihood method. A preliminary assessment of wind power potential for the coastal region of Bheemunipatnam based on the wind data at a height of 10 m collected from NASA website was performed by Murthy and Rahi [12]. They extrapolated the wind speeds to heights of up to 150 m from the power law. They also obtained the Weibull probability functions at heights of 10 m to 150 m. The mean wind speed was 4.74 m/s at 10 m above ground level and was estimated to be 6.98 m/s at a height of 150 m. Solyali et al. [13] did a technical assessment of wind power potential for a site in northern Cyprus. The mean wind speed at a height of 30 m above ground level was in the range of 2.6–4.6 m/s at the six sites. Weibull parameters were obtained using the maximum likelihood method, least squares method and WAsP. The WAsP method had the highest R^2 (coefficient of determination) value. Using power law, they estimated the wind speeds at heights of 50 m, 80 m and 90 m. Goh et al. [14] assessed the wind energy potential in Malaysia based on the prediction of wind using Mycielski algorithm and K-mean clustering. They analyzed the predicted results using Weibull analysis to obtain the most probable wind speed. Weibull parameters were obtained for different years and the frequency distribution was compared using different methods. Asthine et al. [15] carried out an assessment of wind energy potential over Ontario and Great lakes in Canada for small wind turbine hub heights of 10 m and 30 m. The studied the stability of atmospheric boundary layer in summer and winter seasons. Li and Li [16] examined in detail the wind characteristics for the Waterloo region in Canada based on measured data at an elevation of 10 m above the ground level. They carried out a statistical analysis of the monthly as well seasonal wind speed distributions.

Fazelpour et al. [17] studied the wind energy potential at four locations in Iran. They carried out a detailed investigation of the Weibull parameters in different months and compared the R^2 value and a comparison of errors. During the recent years, there has been a significant increase in the assessment of wind energy resource with increased focus on comparison of Weibull parameters obtained using different methods. Wang et al. [18] carried out a detailed investigation of wind speed probability distribution and assessed the wind energy resource at four places in China. Mohammadi et al. [19] obtained the Weibull parameters using different methods and computed the power density at four stations in Alberta province of Canada.

Kumar and Prasad [20] carried out a wind resource analysis of the two major islands in Fiji using WAsP and compared the NASA data with measured data. Sharma and Ahmed [21] carried out wind resource assessment on the main island Tongatapu of Tonga using WAsP. An average wind speed of 4.5 m/s was measured at a height of 34 m above ground level. They also estimated the annual energy production for the site with the Bonus 300 kW Mk III wind turbine. Sharma and Ahmed