Wind and Solar Resource Potential Assessment in Bhutan

Namgay Tenzin, R.P. Saini

Abstract*: Renewable energy sources have become important part of energy mix in the modern power grid because of limited non-renewable resources, increasing price of fossil fuels and environmental concern due to use of fossil fuels. Wind and solar power technologies are two most mature technologies today which can offset the use of fossil fuel-based power plants and decarbonize the electrical grid. Bhutan is generating renewable power by using its rivers in the run off river hydropower scheme, which is supplied across the whole country. Apart from hydropower small scale wind and standalone solar PV systems are currently operational; limited studies are available on solar and wind power potentials in Bhutan. Therefore, this paper discusses the assessment wind and solar resource potential of some of the selected sites of Bhutan using measured data from local weather stations and also NRELs climate data. The wind data is used to analyze the wind power density and wind power potential using Weibull distribution. Also, wind power potential at different heights are estimated after extrapolating wind speeds using wind log formulae. Wind power potential estimate analysis shows that valleys of Wangduephodrang, Tsirang and Trashiyangtse are found to have good potential for wind farm development. Solar PV system potential assessment using NREL's TMY data for solar power development Wangduephodrang and Paro valleys is found to have very good potential.

***Index Terms*: Solar, Wind, Wind power density, Weibull distribution**

I. INTRODUCTION

Renewable energy today constitute about 10.4% of the total energy consumption globally with annual growth rate of 5.4%[1]. Integration of variable renewable sources especially solar and wind into the grid has become important to reduce the dependency on fossil fuel based thermal power plants. Solar PV and wind power constitute 5.6% and 1.9% respectively from total global renewable electricity generation of 26.5%[1]. Among all the renewable energy sources solar and wind power are most developed technologies and widely used resource. The use of conventional resources especially fossil fuel based or coal based thermal power plants for power generation have led to environmental degradation ever since the industrial revolution. The power demand is increasing in developing countries at a faster rate than the developed ones; since the demand on conventional power plants in these countries are high there is a need to develop renewable power to reduce dependency on power plants which uses fossil fuels and its derivatives as fuel[1]. On top of that limited resources of conventional sources along with increased cost for extraction of resources has resulted in increased cost for per unit of energy generated
from these power plants have led to rise of renewable energy resources especially for power generation in the last few decades.

Bhutan is geographically blessed with mountains steep rugged terrain of the Himalayas with V shaped valleys with glaciers which are mostly snow fed makes Bhutan suitable for hydropower development. The total techno-economic potential for hydropower plant is estimated at 23,760 MW of 30000 MW potential where currently 1606 MW has been installed all run off river scheme [2,3]. Hydropower is one of the main drivers of economy in Bhutan which contributed to 19% of total revenue in 2015-2016. Alternative energy sources especially renewables is recognized for further development like solar and wind to diversify the energy mix and enhance the power security of the country [2]. Currently almost all the electricity demands are met by hydropower plants, 95% with grid connectivity and rest by standalone diesel generators (DG) and Solar Photovoltaic (SPV) systems; therefore development of renewable electricity is perceived very important to expand the electric grid and reduce dependency on hydropower [3]. Among all the renewable energy systems solar and wind power are most mature technologies which can be used for power generation. This paper aims to calculate the wind power potential for selected sites in Bhutan using measured data and Weibull distribution. The results may be used for power grid stability analysis with increased penetration of solar and wind power in the existing network. Wind energy potential assessment based on measured data for Jordan was studied by Bataineh and Dalalah [4] using Rayleigh and Weibull for estimation of wind power. To estimate wind power at practical hub heights wind speeds were extrapolated using power law. Mentis et.al [5] investigated the techno-economic assessment of wind power potential in India using geographical restrictions and found that untapped wind power could contribute to achieving 100% access to electricity. Rayleigh probability distribution was used to estimate wind speed due to limited availability data. Feasibility of the wind energy potential was investigated by Luankaeo and Tirawanichakul [6] for south Thailand using meteorological data. Weibull distribution was used to study the wind power density and logarithmic rule to extrapolate wind speed to desired heights. Waewsak, Kongruang and Gagnon [7] also investigated wind power potential for south Thailand using Windsim CFD modeling.

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Similarly wind power availability of Batna, Algeria was studied based on measured data using Weibull and wind power law for estimating wind power potential and extrapolation of wind speeds respectively[8].

Solar and wind power potential of Iran was studied by Mohammadi, Mostafaeipour and Sabzpooshani for selected zones by using measured data. Weibull Distribution Function was employed to assess the wind power potential at different heights and changing Weibull shape factor [9]. Watts, Oses and Perez [10] investigated the wind energy potential for Chile to identify feasible locations for wind farm development with the help of open source data since wind data was not available. They studied power different wind turbine generators by varying air density which is not constant, varies with height of the hub along with economic analysis is discussed. Solar and wind energy synergy for Australia was examined by Prasad, Taylor and Kay [11] using MERRA (Modern Era Retrospective Analysis for Research and Applications) data spanning 36 years was used. It shows good synergy between wind and solar power located close by had high reliability of power compared to standalone systems but recommends further study to ascertain the claim and reduce intermittency issues with solar and wind. Similarly, solar and wind power assessment for Afghanistan studied by Ershad, Brecha and Hallinan [12] to increase the total electricity generation to meet the rising load demand of the country with the help of measured solar and wind data points that country has potential for development of renewable power. Wind and solar power models were modeled using NREL's System Advisor Model software which is one of the widely used software for estimation of renewable resources and sizing. Likewise, Turkey's wind power potential based on measured data was assessed by Ucar and Balo [13], by using Weibull distribution which has become most commonly used and accepted distribution to estimate wind power potential. So far there is very limited study conducted to ascertain wind and solar resource potential using measured data for electricity generation in Bhutan and this paper aims to estimate the wind and solar power potential assessment using the data available and most commonly used methods.

II. SITE DESCRIPTION

Bhutan is located in south Asia between Asian giants, India and China which has an area of 38394 sq.km adorned with mountains, Himalayas covering it with population of 0.7 million. Bhutan has achieved 95% of grid connected electricity from hydropower plants which are all run off river schemes [3]. A study carried out by NREL in 2009 pointed out that Bhutan has good potential for solar and wind power development with 1200MW and 761MW respectively. In the same report it is mentioned the wind power potential assessment needs further investigation [14]. Solar power potential for Paro (Longitude 89.4º E, latitude 27.4º N and elevation 2200m) and Wangduephodrang (Longitude 89.9º E, latitude 27.5º N and elevation 1180m) is estimated using NREL's TMY (Typical Meteorological Year) data using SAM software. For wind power potential assessment valleys of Wangduephodrang and Tsirang (Longitude 90.1º E, latitude 27º N and elevation 1520m) in the west; Trashiyangtse (Longitude 91.5º E, latitude 27.6º N and elevation), and Lhuntse (Longitude 91.2º E, latitude 27.6º N and elevation 1750m) in the east are chosen for wind power assessment.

III. DATA SOURCE AND METHODOLOGY

Renewable energy-based power is expensive compared to conventional power systems and also the power generation is intermittent, control and protection schemes employed makes it expensive; although the cost per unit of renewable energy has decreased significantly over the last decade. Therefore, renewable power potential assessment especially solar and wind power has become very important aspect of power system planning and design. The wind speed data from 2010 to 2017 was collected from National Center for Hydrology and Meteorology, Thimphu, Bhutan, nodal agency for weather and climate data services in Bhutan. The wind speed data were measured and recorded at a height of 2m and averaged daily. As in most under-developed and developing countries, solar radiation data is not measured in any of the weather monitoring stations across Bhutan. To estimate solar power NREL's TMY data is used which is one of the most widely accepted data set for solar radiation around the world.

Solar power potential is assessed using SAM software with the help of TMY data, considering both beam and diffused radiation. Wind power is assessed by employing Weibull distribution function, changing shape parameter and scale factor to match the measured wind data. Theoretical, potential for a year is then calculated by multiplying wind power density and number of hours in a year.

IV. WIND SPEED FREQUENCY DISTRIBUTION

Wind profile is very important factor to be considered while estimating wind power potential. Weibull distribution is known to give very good estimates of wind power potential among other frequency distribution techniques such as Rayleigh, logo normal etc [13]. The simplified Weibull distribution equation used is given below

$$v_{mean} = c\,\Gamma(1 + 1/k) \qquad \textbf{1}$$

Where c is the Weibull scale parameter, k is the dimensionless Weibull shape parameter and Γ is gamma function. The wind speed extrapolation equation known as wind power law is

$$U_z = U_H\left(\frac{Z}{H}\right)^{\alpha} \qquad 2$$

Where U_z is height at which wind speed is to be estimated at Z m, U_H is the mean speed at reference height H m and α is the surface roughness coefficient. Wind speed increases with increase in height as per equation 2; the roughness coefficient for different surfaces varies from 0.1 for oceans and plains to 0.4 for tall structures like buildings in city area [15]. It is understood that offshore wind farms receive higher wind speeds than onshore farms due to this very reason. Modern wind turbines increasingly operate at higher heights to take advantage of higher wind speeds available at those heights.

Wind power density can be found using

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$$P_{wind} = \frac{1}{2}(\rho A_1)v^3 \quad (3)$$

Where cross-sectional area (A) is perpendicular to wind gust with wind speed v m/s and air density ρ=1.22 (kg/m^3).

V. RESULTS AND DISCUSSIONS

i. Wind Power Potential

Wind speed and direction are two important parameters for assessment of wind power potential of a given site to give clear understanding of prevailing wind speed with direction in the region.

Fig.2.1 describes the prevailing wind speed with direction with the help of wind rose diagram measured at a height of 2m from ground level from 2010 to 2017. From the wind rose it is shown that Wangduephodrang has good potential with wind speeds greater than 3m/s blowing from south to north west and same is true for Tsirang. In the eastern Bhutan Trashiyangtse shows good potential with winds blowing from east to south west consistently throughout the year with speeds greater than 3 m/s.

Wind speeds measured at 2m is extrapolated using equation 2 with roughness coefficient (α) of 0.2 considering at fairly an area with small trees and shrubs. Wind frequency distribution and wind power density curves are computed using extrapolated data.

Wind frequency distribution with Weibull distribution is computed for all the four sites at different hub heights; at a height of 50m the scale factor ranging from 1.0 to 1.5, shape factor 2.8 to 4.7 are used to match the wind speed data which are presented in Table 1, 2,3, and 4 respectively. The results show that at 50m hub height wind power densities are, 200.96 W/m^2 for Tsirang, Wangduephodrang 103.57 W/m^2, Trashiyangtse 119.62 W/m^2, and Tangmachu 129.75 W/m^2 respectively using data from 2010 to 2017.

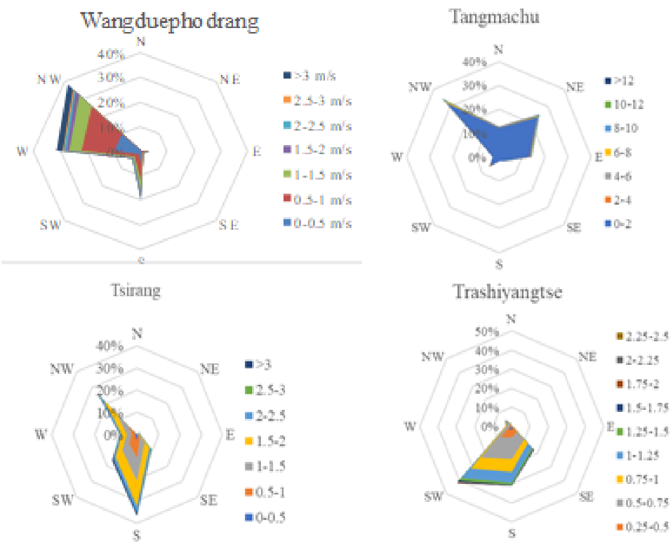

Fig. 1 Wind rose diagram for five selected sites at 2m.

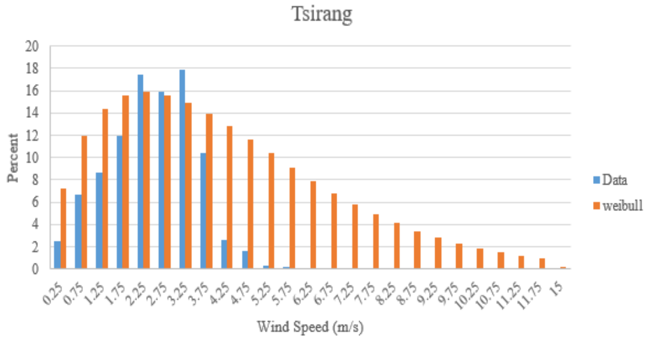

Fig. 2 Tsirang wind frequency distribution at 50m.

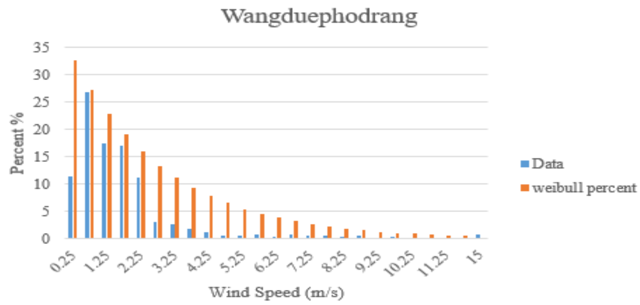

Fig. 3 Wangduephodrang wind frequency distribution at 50m.

Wind power density increases with wind tower hub height at which turbine is hoisted; therefore, wind power density at different hub heights of 50m, 80m and 100m are extrapolated using wind speeds measured at 2m. Table1 and Fig.7 clearly shows that with increase in hub height the wind power density increases but very little is known about the wind shear stresses on the turbine at extreme hub heights [15].

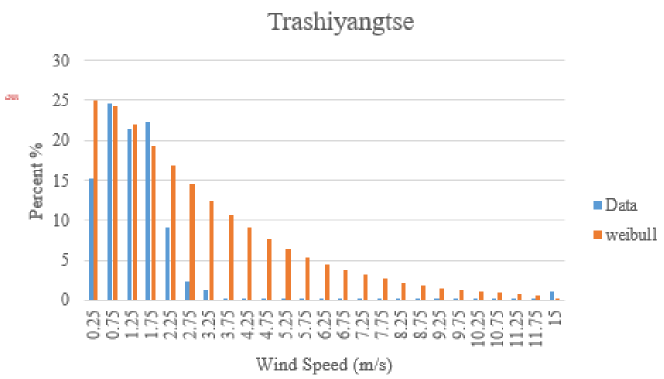

Fig. 4 Trashiyangtse wind frequency distribution at 50m.

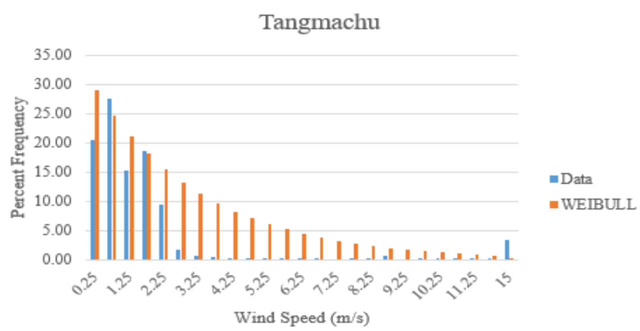

Fig. 5 Lhuntse wind frequency distribution at 50m.

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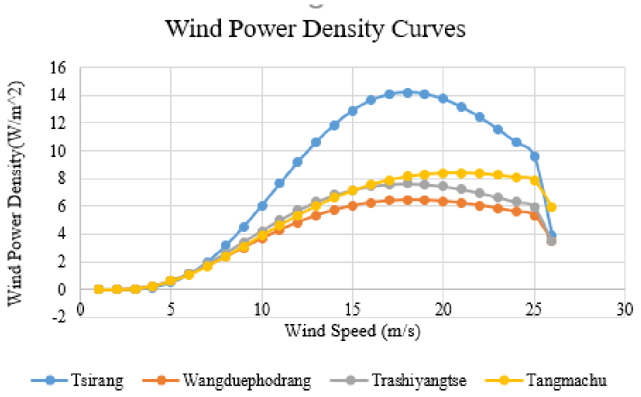

Fig. 6 Wind power density at 50m for four sites.

Table 1 Wind power density at different hub heights.

Hub ht	Tsirang	Wangdi	Tyangtse	Lhuntse
2	65.01113	50.31825	50.31825	44.91983
50	200.6907	103.5711	119.6235	129.7595
80	303.5356	251.1423	284.9989	250.1172
100	342.0238	271.0254	315.7371	273.8307

A graph showing effect of hub height and wind power density clearly shows that wind speeds are higher at greater hub heights therefore efforts are being made to utilize wind energy available at increased hub heights which is techno economically feasible.

i. Solar Power Potential

The global horizontal solar radiation received at Wangduephodrang is about 4.16 $kWh/m^2/day$ with 2.89 $kWh/m^2/day$ beam solar radiation and 2.30 $kWh/m^2/day$ as diffused solar radiation at an average temperature of 6.8^o C as shown in Fig. 9. Similarly, at Paro the global horizontal solar radiation received is 5.91 $kWh/m^2/day$ with 5.83 $kWh/m^2/day$ as beam radiation and 1.98 $kWh/m^2/day$ as diffused solar radiation with an average temperature of 11.9^o C which is shown in Fig.8.

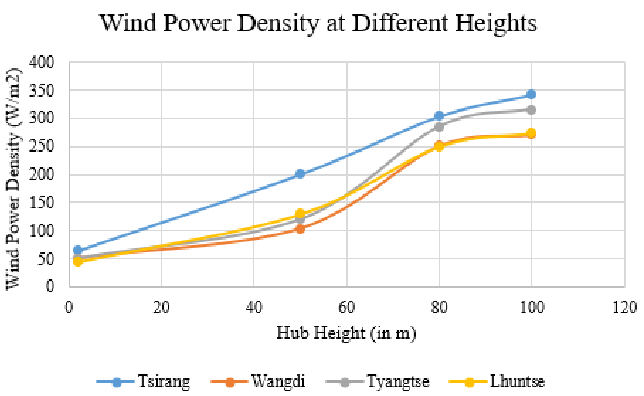

Fig. 7 Graph showing wind power density at different hub heights.

NREL's System Advisor Model (SAM 2017.9.5) software is used to estimate the output from PV array with Nominal Operating Cell Temperature (NOCT) method. The PV module with maximum power output of 350.056 W_{dc} is at 47.6 V_{dc} open circuit voltage with cell efficiency of 18.026% is chosen, tilted at an angle equal to the latitude of both the locations.

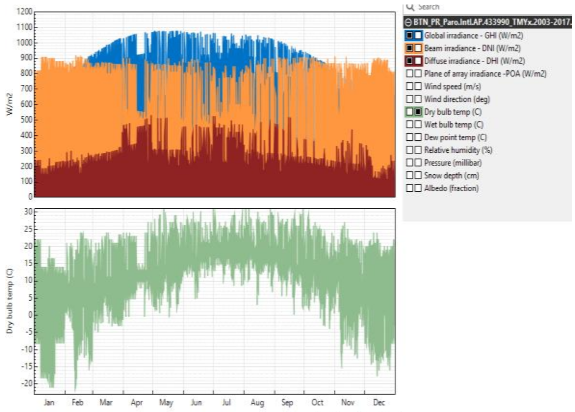

Fig. 8 Plot of Global, Beam and Diffused irradiance with dry bulb temperature for Paro, Bhutan.

An inverter with maximum AC power of 60000W; efficiency of 98.427% with output voltage of 480V_{ac} is selected for DC to AC power conversion. A single array size of 420kW_{dc} is designed with DC to AC conversion ratio of 1.2 with 8.2% DC power losses, system degradation rate of 0.5% per year.

The total energy generated in a year theoretically is 531392 kWh with a capacity factor of 14.6% in the first year for Wangduephodrang. Similarly, for Paro the total energy that can be generated theoretically is 785815 kWh with a capacity factor of 21.5%.

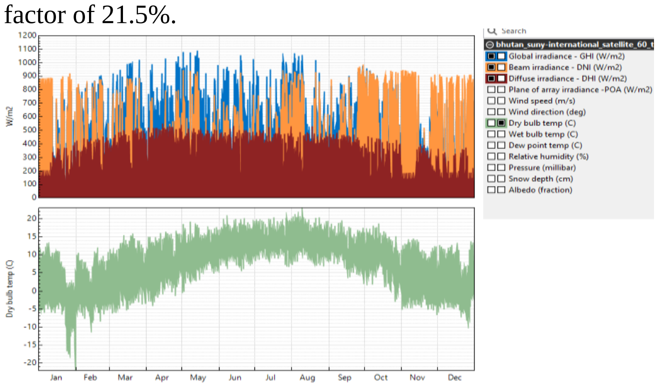

Fig. 9 Plot of Global, Beam and Diffused irradiance with dry bulb temperature for Wangduephodrang, Bhutan.

VI. CONCLUSIONS

The results obtained from this study on solar and wind power potential assessment for selected locations in Bhutan were compared with the similar study conducted by NREL in 2009 on Solar and Wind Power assessment for Bhutan.

Gilman, Heimiller and Cowlin in 2009 [14] concluded that in several valleys of Bhutan there was good potential for wind power development with wind power density of class 3, class 4 and class 5 respectively based on geo-spatial data set with error of about 12%. In terms of solar power development, the northern regions of Bhutan were found to have good solar power potential. This study finds that the wind power density estimated by NREL in 2009 is quite high and does not match with the analysis carried out in this study with measured data over a period of 8 years. However, it is observed that all the potential sites identified then was found to have marginal to moderate wind power density at a hub height of 50m. Some of the key conclusions are

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i. Tsirang valley in the south western Bhutan was found to have wind power density of about 200W/m^2 with winds blowing consistently from south to north west.
ii. Wangduephodrang in the western Bhutan, Tangmachu and Trashiyangtse in the east, is found to have wind power density of about 104 W/m^2, 120W/m^2 and 130W/m^2 respectively.
iii. Increasing hub height to 80m was found to increase the wind power density by more than 50% in most cases.

It is seen that Tsirang and Wangduephodrang valleys may be the most feasible sites for wind farm development since it has access to good road network and high-tension transmission lines currently. Trashiyangtse and Tangmachu sites possess good potential for wind power development in near future.

In case of solar power, both the selected locations Wangduephodrang and Paro have good potential for development of solar PV power systems.

Solar and wind are variable sources which varies with time; for power potential assessments to be reliable and accurate a good data set is required; the data available is of daily averaged with limited data sets, there is a need to measure wind speed for shorter intervals like 1 minute or 5-minute data to improve the data which in turn improves the data quality and the resource estimation outputs.

The results from this study may be useful to size the solar and wind power system for the mentioned locations and used for stability analysis of integrated grid with solar and wind power in Bhutan.

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