Feasibility study of distributed wind energy generation in Jumla Nepal

Rabin Dhakal*, Bharosh Kumar Yadav**, Niwesh Koirala***, Binod Babu Kumal***, Hanna Moussa*‡

*Department of Mechanical Engineering, Texas Tech University, 2500 Broadway, Lubbock, TX 79409, USA

**Department of Mech. Engineering, Purwanchal Campus, Institute of Engineering, Tribhuvan University, Dharan, Nepal

***Vortex Energy Solution Pvt. Ltd., Bhaktapur, Nepal

‡ Corresponding Author; Postal address: Lubbock, TX, USA. 79409, Ph# +1-806-632-8141, Email: hanna.moussa@ttu.edu

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Abstract- Renewable energy production needs serious attention in highly traditional, inefficient, and energy-dependent countries like Nepal. Moreover, the option of an effective renewable energy technology that is economically feasible and environmentally acceptable is a topic of interest due to the availability of various types of renewable energy sources in Nepal. Among other renewable energy sources like micro hydro, solar, biogas etc, very few studies had been conducted on wind energy sources in Nepal and those few studies also focuses mostly on large scale wind farming. So, this study analyzes the suitability of distributed wind energy production in Tila village of Jumla district in the western part of Nepal. Five-year (2015-2019) wind speed data were examined to obtain wind power density and energy density. Two-parameter Weibull probability density function was used to evaluate these two quantities. The annual Weibull parameters k and c of 1.73 and 4.21 m/s were obtained to calculate 43.79 W/m^2 power density and 378.37 kWh/m^2 energy density. This study also provides the economic evaluation of a 100 kW distributed wind energy system, and the technical and economic aspects of the proposed system are compared with the corresponding characteristics of the existing renewable energy systems, i.e., micro hydropower and solar power. The study shows that when there is not enough sunlight for the solar PV system and not enough water flow coupled with maintenance problems in the micro hydropower system, the distributed wind energy system may function as a substitute system.

Keywords- distributed wind energy; site suitability; off-grid energy generation; electrification.

1. Introduction

The number of people around the world still lacking electricity has dropped to 860 million in this decade [1, 2]. Although almost every country in the world continued to make unprecedented progress toward the goal of universal access to electricity, this objective is difficult to attain because nearly 85% of such people live in remote rural areas [2]. The recent history has showcased economic growth and improvement of living standards of people who use electrical energy. This is especially observed in the case of rural communities. For the economic advancement of the people in this region, the exploitation of renewable energy resources needs serious attention. This increasing demand for electrical energy coupled with the need to reduce carbon emissions is one of the key factors that drive the pursuit of renewable resources such as solar photovoltaic, wind, and hydro power. Implementing steps to introduce renewable resources in rural areas will help local communities to be self-sustainable in terms of production they make and capital they own for their betterment [3].

Renewable energy is the third largest contributor to the global electricity supply. Renewable energy satisfies 18 percent of the energy demand in the world [4, 5]. Clean energy sources such as wind, hydro, solar, biomass, and geothermal have gained attention worldwide because they are almost non-pollutant [6]. Out of these technologies, the energy from wind is one of the major sources of electricity generation and is being actively pursued in many countries. Although deployment of wind energy started in the decade of 1970s [7], partially in response to the oil crisis and environmental and climate change problems, over the past decade more and more wind turbines are producing power. Wind turbine electricity generation has increased by more than 25% per year [8]. Furthermore, being third among other renewable energy sources, wind power produces approximately 13,500 MW of energy [5]. Theoretically, the potential supply of the Earth's wind energy substantially exceeds global energy demand. However, the irregular nature of wind resources is a major hurdle to exploit wind power [9].

The wind is the movement of air from a high-pressure region to a low-pressure area. Wind occurs since the Earth's surface is heated unevenly by the sun. With the rise of hot air, cooler air comes in to fill the vacuum. The wind will blow as the sun shines [8]. The first step to using wind energy in an area is to evaluate the capacity and feasibility[10], to know where, when and how much wind energy is available, as the wind energy has intermittent and variable structure[11], with the analysis of the meteorological parameter affecting wind turbine power generation such as wind speed, wind direction, pressure and air temperature[12]. Moreover, the maximum utilization of wind energy depends on the proper analysis of the wind data measured hourly, daily, weekly and monthly[13]. The energy capacity of wind turbines can be measured by averaging the energy of potential wind speeds over a period; therefore, the probability distribution of different wind speeds in the area is the main factor in computation. The Different distribution functions are available to evaluate the wind energy capacity and output of energy of any site, including Weibull distribution, Rayleigh distribution, Johnson distribution, Pearson distribution, and Chi-square distribution. Most of the published articles use Weibull distribution [5, 10] due to its good accuracy and simplicity.

Various studies have been carried out focusing on determining the viability of wind energy projects through the analysis of wind data in different locations in Nepal. It has been suggested that Jumla has the highest wind resource potential and is most economically viable compared to other potential sites studied [14]. Jumla is in Karnali state, which is in the mountainous region of Nepal. One research study has suggested that there is a potential for distributed wind energy generation in Jumla, but the site accessibility issues currently make it unfeasible for large-scale wind farming [15]. Hence, there are no site-specific detailed case studies has been done so far for distribute energy generation. It has been proposed that wind power projects are technically viable in this region but the compatibility evaluation of this technology with other possible technologies and detailed economic analysis have not been done so far. Therefore, the aim of this research is to assess the wind energy capacity for a village in Jumla district in the western part of Nepal. In this research, five years (from 2015 to 2019) of daily averaged wind speed data from the Department of Meteorology and Hydrology under the Government of Nepal is collected. The data is further processed to obtain wind power and energy density. Next, we analyze the suitability of small-scale 100 kW wind power projects for off-grid energy generation to complement the existing renewable energy projects.

2. Nepal and its Energy Outlook

The percentage of the population remaining to get connected to electricity has decreased from 35 % to 4.5 % in this decade. However, 1.3 million out of 29 million Nepalis still need to be connected to an electricity supply [16]. As most of this population lives in Karnali State, exploitation of renewable energy needs serious attention in this region as other energy sources are expensive and beyond reach. Choosing a suitable renewable energy technology that is economically feasible and environmentally acceptable is a topic of interest among researchers working in this field because of the availability of different kinds of renewable energy sources in the region. Researchers have argued that renewable energy technologies such as micro and mini hydropower, solar, wind, and biomass are not only technically feasible and financially viable solutions but also suitable energy sources for rural and remote areas in developing countries like Nepal [17]. Out of these technologies, Nepal has not yet achieved a significant progress in wind energy project development despite its theoretical potential being around 3000 MW [14]. However, Nepal's government is collecting wind data for detailed feasibility studies and also a subsidy policy has already addressed the need to develop wind energy technology [18, 19]. These policies put a high priority on collecting data, preparing wind maps, offering financial support to attract investors, and creating Wind Energy Master Plan for effective deployment of potential wind energy resources [7]. Given the policy support, wind resource endowment in Nepal is not being explored.

3. Methodology

3.1. Study location

Fig. 1. Location of the study on google earth map indicated by a yellow pin (yellow line is the boarder of Nepal with China and India)

For the site location, we have chosen Tila village of Jumla which is at elevation of 2718 meters, at 29.275 deg latitude and 82.184 deg longitude in Nepal as shown in Fig.1. The topography of Tila village is extremely varied, with a maximum change of elevation of 1000 meters. Moreover, within a range of 16 km, the elevation varies about 2464 meters, and within a range of 80 km, the difference is about 6302 meters. The village is covered mostly by cropland, trees, and grassland. Tila village has a total of 2626 households with 13,607 inhabitants who are mostly poor [20]. The electricity they currently receive from a micro hydro system is subsidized by the government but the villagers face load shedding of several hours every day. To alleviate this problem, they have rooftop solar power installed, but during the winter season when there is less daylight solar power is unreliable. Similarly, the micro hydro system is dependent on the snowy and rainy seasons. During those seasons, the canal experiences blockages and piping systems need significant maintenance. This is an opportunity for the government to invest in other renewable resources. For this to happen, we must study the availability of wind energy sources and their suitability for the village. We also need to find a suitable location for installing wind turbines based on topography, wind resources, road access, and security.

3.2. Data collection

To perform wind resource assessment, we need a lot of information related to the site. This information includes climate data such as wind speed, wind direction, temperature, pressure, humidity, and precipitation, and topographic data including elevation and roughness. The five-year wind data (from 2015 to 2019) have been obtained from the meteorological stations set up by the Department of Hydrology and Meteorology of the Government of Nepal. Nowadays, most of these data are also readily available from satellite sources [21]. Since the data are taken at a hub height of 10 m, we used Equation 12 to extrapolate the results for a hub height of 30 m. Fig.2 shows that there is a large variation of mean wind speed in the year 2017. Otherwise, there is less variation in wind speed throughout the year and less variation of the mean monthly wind speed between the years.

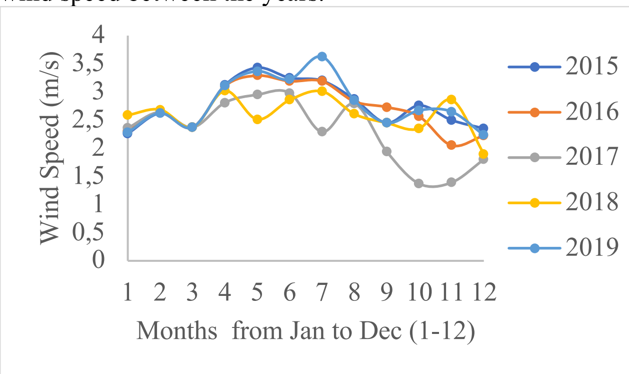

Fig. 2. Mean monthly wind speed in the period of 2015-2019 in Jumla

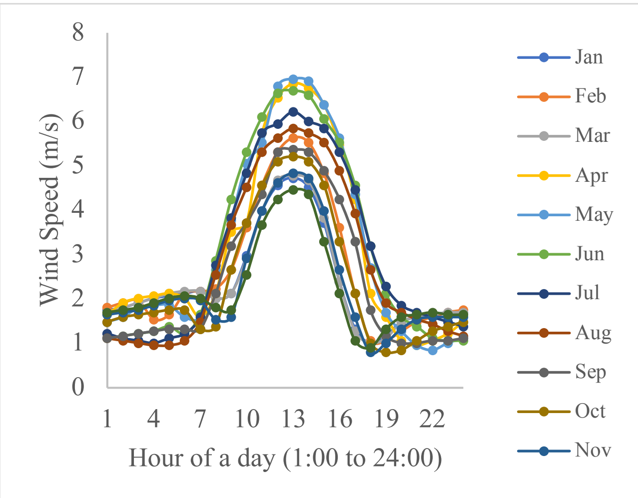

Fig. 3. Average hourly wind speed in each month

The annual average wind speed in Jumla varies from 2.25 to 2.88 m/s. At any place, the wind speed is largely based on the area's topography. The average hourly wind speed in Jumla during the whole year experiences moderate seasonal variability. February 15 to August 24 (about 6.3 months) is the windier part of the year. The less windy time of year lasts for 5.7 months from August 24 to February 15. As the average annual wind speed is low for the energy generation, it is necessary to view the hourly wind speed in the locality. Figure 3 represents the hourly average wind speed extrapolated to a hub height of 30 m (the data were originally taken at a hub height of 10 m). The average hourly wind speed in Jumla in January varies throughout the day. The windiest time of the day is around 1:00 pm, with an average hourly wind speed of 5.1 m/s, mostly staying between 4.4 m/s and 6.9 m/s. The wind speed starts to increase at around 8 am with value 1.8 m/s and keeps increasing till 1:30 pm to value 5.1 m/s. It decreases subsequently, and at 7 pm has almost the same value as at 8 am. Thus, the maximum energy will be extracted from 8 am to 7 pm. Night-time wind speed is not sufficient to produce wind energy.

Temperature also affects wind energy production because the density of air varies with the temperature. Moreover, the altitude also affects the density of air in Jumla. The average temperature is taken on the first day of each month for this research. The temperature varies from 50°F to 70°F throughout the year (see Fig. 4). The warmest period of the year is between 3rd May and 9th September (which is about 4.3 months). An average daily high temperature is above 68°F. The coldest period of the year is between 10th December and 27th February (about 2.6 months) with an average daily high temperature below 52°F.

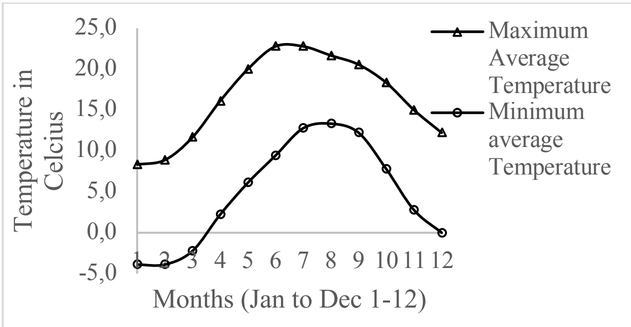

Fig. 4. Monthly average high and low temperature in Jumla

Rainfall also impacts wind power generation. Extreme seasonal rainfall variability occurs in Jumla. The rainy season lasts 8.2 months from 26th February to 23rd October, with at least 12.7 mm of monthly rainfall (see Fig. 5). The dry season lasts from 23rd October until 16th February for 3.8 months.

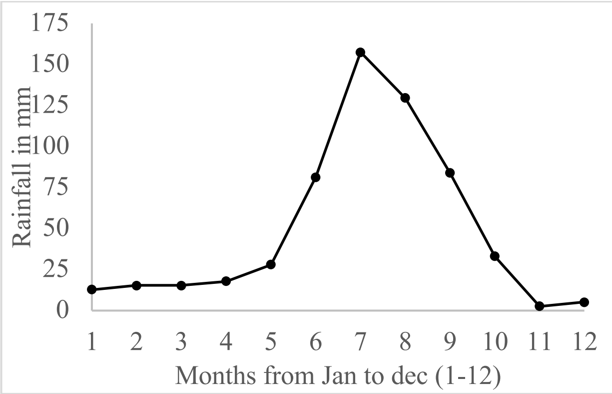

Fig. 5. Average monthly rainfall in Jumla

Wind power generation is also affected by the snowfall. Figure 6 shows the liquid-equivalent snowfall, which is between 5 to 10 times smaller than the actual snowfall amount assuming the frozen ground. Monthly liquid-equivalent snowfall is experiencing seasonal variability. The snowy period runs from 10th December until 9th March for 3 months.

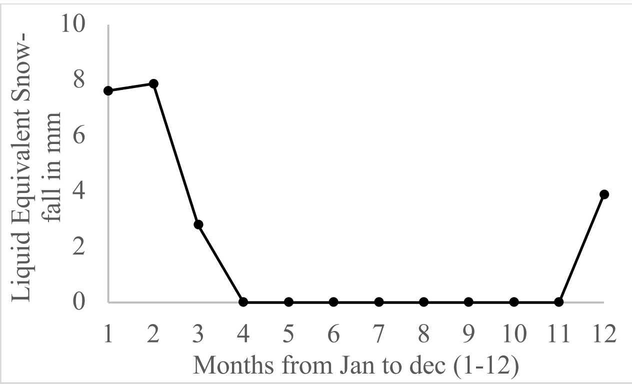

Fig. 6. Average monthly liquid-equivalent snowfall in Jumla

3.3. Data Analysis

Information about the wind speed distribution plays an important role in making wind energy resources feasible. The best method to explore the feasibility of the wind energy resource at any location is to calculate the wind power intensity based on the wind speed data from a local meteorological station. Several probability density functions can be used to match and define the wind velocity over time. These functions include Weibull, chi-squared, normal square root, generalized normal, log normal, three-parameter log-normal, inverse Gaussian, gamma, kappa, wake by, and hybrid distributions. The Weibull two-parameter distribution function is widely regarded as the best choice for the analysis of wind speed data because of its simplicity and high precision. Parajuli's study of Jumla also shows that the Weibull distribution is best suited to estimate wind speed [6].

3.3.1. Weibull Distribution Function Weibull Distribution Function

The Weibull probability density function is a two-parameter distribution with a dimensionless shape parameter k and a velocity scale parameter c in m/s [22].

$$f(u) = \frac{k}{c}\left(\frac{u}{c}\right)^{k-1} \exp\left[-\left(\frac{u}{c}\right)^{k}\right] \quad (1)$$

where *f(u)* denotes the probability distribution of wind speed *u*. The quality of wind resources can be evaluated from the parameters *c* and *k*. The parameter *c* is proportional to the wind speed and *k* characterizes the shape of the Weibull distribution. A smaller value of *k* describes variable wind whereas a larger value corresponds to constant wind. Typical values of *k* are between 1 and 3 [23]. Weibull parameters can be obtained using various methods such as graphical method, method of moments, maximum likelihood method, standard deviation method, modified maximum likelihood method, power density method, equivalent energy method, etc. In this research, Weibull parameters are obtained by the standard deviation method using the following relations [6] :

$$k = \left(\frac{0.9874}{\frac{\sigma}{u'}}\right)^{1.0983} \quad (2)$$

$$c = \frac{u'}{\Gamma\,(1+\frac{1}{k})} \quad (3)$$

where u' is the mean wind speed and σ is the variance of the data. The mean wind speed and variance are calculated from the expressions below [6] [22].

$$u' = \frac{1}{n}\sum_{i}^{n} u_i \quad (4)$$

$$\sigma = \sqrt{\left[\frac{1}{n-1}\sum_{i=1}^{n}(u_i - u')^2\right]} \quad (5)$$

The quantities u' and σ can also be expressed in terms of the Weibull distribution function as follows [6] [22]:

$$u' = \int_0^{\infty} u f_w(u)du = c\ \Gamma\left(1+\frac{1}{k}\right) \quad (6)$$

$$\rho = \sqrt{c^2\left\{\Gamma\ \left(1+\frac{2}{k}\right) - \left[\Gamma\ \left(1+\frac{1}{k}\right)^2\right]\right\}} \quad (7)$$

Here gamma function $\Gamma(x)$ is given by the relation [6] [22]:

$$\Gamma(x) = \int_0^{\infty} \exp(-u)\,(u)^{x-1}dx \quad (8)$$

3.4. Wind Power Density

The wind power density describes the wind resource available at a site, i.e., the capacity of a specific site for the wind energy production. It can be calculated using the relation [6]:

$$P = \frac{1}{2}\rho\, u^3 \ \ (\text{W/m}^2) \quad (9)$$

where P is the wind power per unit area (A). Equation 9 can also be expressed as follows [10]:

$$\frac{P}{A} = \frac{1}{2}\rho \int_0^{\infty} u^3 f(u)d(u) = \frac{1}{2}\rho\, c^3 \Gamma\left(1+\frac{3}{k}\right) \quad (10)$$

where ρ is the density of air at 15°C and pressure of 1 atm. Air density decreases as elevation and temperature rise [24]. Literature shows that there is no significant difference between the standard air density and the air density at the elevation where the wind turbine is to be installed [6]. Therefore, the standard air density is used in this study (ρ=1.225 kg/m^3). After obtaining the wind power density, we evaluate the wind energy density E for a specific period T using the following relation [22]:

$$E = PT \quad (11)$$

3.5. *Wind Energy Extrapolation*

The wind speed taken from the meteorological stations was measured at a hub height of 10m. Wind speed increases with height in the majority of locations and is related mainly to mixing in the atmosphere and rough topography [6]. To determine the overall wind energy capacity for the actual installation of the wind turbine, the estimated surface wind speed must be adjusted for the real installation hub height and the estimation is performed using power law [25]:

$$\frac{u_2}{u_1} = \frac{ln\left(\frac{h_2}{n}\right)}{ln\left(\frac{h_1}{n}\right)} \quad (12)$$

Where h_1 and h_2 are height above ground level for the wind speed of u_1 and u_2 respectively, and n is the roughness length in the current wind direction; in our study, we take n = 0.03 suitable for Tila village with open agricultural area without fences and hedgerows, very scattered buildings and only softly rounded hills [25].

3.6. *Economic Analysis*

After the evaluation of the wind energy density and energy potential, annual energy production will be calculated using the Weibull wind speed probability distribution f and power curve of a 100 kW turbine selected based on the wind energy distribution [10]:

$$AEP = \sum_{u=1}^{n} P_u * f(u) * 8760 \quad kWhs \quad (13)$$

Here u is the wind speed of the turbine, varying from 1 to the cut-out wind speed of the turbine, which is specified by the manufacturer in the power curve. P_u is the power that can be produced by the turbine at speed u. Usually, the cut-in speed of the wind turbine is above 2-3 m/s and the power produced below it is zero. $f(u)$ is the Weibull distribution function and is given by using equation 1.

The revenue generation (R) will be calculated based on the tariff rate (TR) of electricity provided in the guidelines of Alternative Energy Promotion centre in Nepal. Assuming the energy produced will be fully consumed in the locality, the revenue generated is calculated as follows:

$$R = AEP * TR \quad (14)$$

The cost of the project is estimated based on the cost of turbines available on the international market and on other costs such as installation, maintenance, etc. described in literature on international practice. After the economic evaluation of the project is performed, we calculate the subsidy that the government must provide to run the project. First, we determine the net present value (NPV), which is the contrast between the present value of cash inflows over time and the present value of cash outflows; NPV is used to assess the viability of a planned expenditure or project in capital budgeting and investment planning [26].

$$NPV = \sum_{i=1}^{n} \frac{0.97*R}{(1+r)^i} - I \quad (15)$$

Where i varies from 1 to the total project duration taken for financial calculation (usually it is equal to 20 years). I is the capital investment and r is the discount rate (usually in the range of 8-12%).

To qualify for a subsidy, the project is supposed to be just sustainable, i.e., without any profit or loss. As we mentioned, the project life is 20 years (n =20) and the net present value should be zero at the end of the project life. The capital investment is divided among the local level investment *(C)*, and the subsidy from the government *(S),* the subsidy amount is calculated as follows:

$$S = \sum_{i=1}^{n} \frac{0.97*R}{(1+r)^i} - C \quad (16)$$

The percentage of Total Capital Investment (TCI) can be calculated as:

$$TCI = \frac{S}{I} 100\,\% \quad (17)$$

The statistical analysis of the proposed system is presented in the next section. Then we provide the economic evaluation of the system and compare it with the existing renewable energy systems, i.e., micro hydro and solar power. The comparison is based on different technical and economic parameters such as efficiency, capacity factor, electrical components, cost, other components, and maintenance.

4. Statistical Analysis

4.1. *Analysis of Weibull Parameters*

The Weibull density function is used to describe the variability of wind speeds. This is a statistical method generally recognized as a standard approach for assessing local wind probabilities. To evaluate Weibull parameters, yearly average wind speed and standard deviation were calculated using Equations (2) and (3) and tabulated in Table 1.

Table 1. Monthly wind speed and standard deviation

Months	Parameter	2015	2016	2017	2018	2019	Average
Jan	u'	2.26	2.31	2.37	2.58	2.28	2.36
	σ	1.23	1.17	1.10	0.85	1.20	1.11
Feb	u'	2.62	2.63	2.65	2.68	2.62	2.64
	σ	1.46	1.47	1.47	1.54	1.46	1.48
Mar	u'	2.37	2.37	2.38	2.36	2.37	2.37
	σ	1.14	1.15	1.19	1.13	1.14	1.15
Apr	u'	3.12	3.11	2.81	3.30	3.11	3.09
	σ	1.87	1.97	2.45	2.10	1.91	2.06
May	u'	3.43	3.29	2.95	2.71	3.37	3.15
	σ	2.10	2.14	2.63	1.91	2.12	2.18
June	u'	3.25	3.19	2.98	3.01	3.22	3.13
	σ	1.80	2.00	3.37	1.94	1.89	2.20
July	u'	3.20	3.31	2.29	3.02	3.33	3.03
	σ	1.80	1.89	1.50	1.80	1.84	1.97
Aug	u'	2.87	2.83	2.79	2.61	2.85	2.79
	σ	1.64	1.76	2.94	1.32	1.69	1.87
Sept	u'	2.48	2.73	1.94	2.65	2.45	2.45
	σ	1.83	1.74	1.65	1.24	1.79	1.65
Oct	u'	2.76	2.57	1.37	2.48	2.67	2.37
	σ	1.64	1.57	1.50	1.18	1.61	1.50
Nov	u'	2.50	2.05	1.39	2.86	2.65	2.29
	σ	1.32	1.27	1.22	0.99	1.30	1.22
Dec	u'	2.35	2.23	1.80	1.90	2.23	2.21
	σ	1.21	1.12	1.02	0.59	1.17	1.02
Yearly	u'	2.77	2.72	2.31	2.68	2.76	2.66
	σ	1.59	1.60	1.84	1.38	1.59	1.62

To determine power density and energy density, Equations (10) and (11) were used. Table 2 presents yearly Weibull parameters and average Weibull parameters for five years.

Table 2. Yearly Weibull Parameters, Wind Power Density (WPD), and Wind Energy Density (WED)

Year	u (m/s)	σ	k	c (m/s)	WPD (W/m^2)	WED (kWh/m^2)
2015	2.77	1.59	1.81	4.30	36.62	316.40
2016	2.72	1.60	1.77	4.26	35.09	303.21
2017	2.31	1.92	1.21	4.22	79.40	686.02
2018	2.68	1.38	2.04	3.99	31.56	272.66
2019	2.76	1.59	1.81	4.29	36.29	313.54
Average	2.65	1.62	1.73	4.21	43.79	378.37

While the shape factor varies between 1.21 and 2.04, the scale factor ranges from 3.99 to 4.29 m/s. The 5-year mean values of the scale factor and shape factor are 1.73 and 4.21 m/s, respectively. The greatest and smallest values of wind power, 79.40 W/m^2 and 31.56 W/m^2, occur in the year 2017 and 2018, respectively. The wind energy density value ranges from 272.66 kWh/m^2 in the year 2018 to 686.02 kWh/m^2 in the year 2017.

The monthly average wind speed is based on the hourly average for each day. Table 3 presents that the shape and scale parameters are in the range of 1.45–2.31 and 3.17-5.29 m/s, respectively. Moreover, the largest and the smallest values of wind power density equal to 178.28 W/m^2 in May and 16.98 W/m^2 in December. The wind energy density value ranges from 12.63 kWh/m^2 in December to 132.64 kWh/m^2 in May.

Table 3. Monthly Weibull Parameters, Wind Power Density (WPD), and Wind Energy Density (WED).

Year	u (m/s)	σ	k	c (m/s)	WPD (W/m^2)	WED (kWh/m^2)
Jan	2.36	1.11	2.25	3.40	20.70	15.40
Feb	2.64	1.48	1.85	4.06	31.25	23.25
Mar	2.37	1.15	2.18	3.45	21.28	15.84
Apr	3.09	2.06	1.54	5.10	55.24	41.10
May	3.15	2.18	1.47	5.28	178.28	132.64
Jun	3.13	2.20	1.45	5.29	177.55	132.09
Jul	3.03	1.97	1.59	4.94	51.27	38.14
Aug	2.79	1.87	1.53	4.61	40.62	30.22
Sep	2.45	1.65	1.52	4.06	27.59	20.53
Oct	2.37	1.50	1.63	3.83	24.14	17.96
Nov	2.29	1.22	1.97	3.45	19.87	14.78
Dec	2.21	1.02	2.31	3.17	16.98	12.63
Average	2.66	1.62	1.78	4.22	34.25	25.48

4.2. *Annual Energy Production*

The annual energy production can be calculated after analysing the power curve of the turbine and wind energy distribution throughout the whole year. To get the power curve, one must choose a specific turbine that will be installed on a specific site. Once the wind statistics are analysed, the wind turbine generators are selected and apply the wind statistics in our calculations. The wind turbine is a mechanical structure that converts the kinetic energy of the wind into mechanical energy through the induced rotation of airfoil shaped rotors. Such a rotational force on the rotor drives the generator to produce energy for consumption [27]. The electricity production by the wind turbine generator depends upon several factors of which cut-in, rated, and cut-out wind speed parameters are most important. A wind turbine does not generate electricity below cut-in speed and above cut-out wind speed. The power output of the wind turbine generator system increases with the wind speed between cut-in speed and rated wind speed [28]. Comparing the wind velocity distribution shown in Fig. 7 with the turbine power curve depicted in Fig. 8, we find that the wind speed in Jumla is in the lower range of the velocity needed for power generation. Therefore, for this site, a low-speed wind turbine is needed.

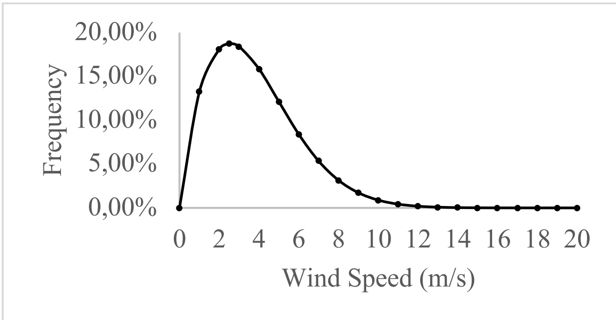

Fig. 7. Weibull distribution of wind speed in Jumla

There are different types of wind turbines commercially available on the market with power rating from a few kW to more than 5MW. The selection of the turbine for wind power generation is vital to get the maximum energy output for an area of installation. Turbine selection depends on two factors: one is the customer's perspective, which includes cost, operational reliability, availability, operation, and maintenance, and the other is the technical perspective, which ensures the maximal annual energy production and hence includes capacity factor, size of the rotor, and wind power curve [29]. In addition, a suitable site with a good average wind speed, wind direction, and elevation plays a vital role in getting maximum rated output from the turbine. A list of turbines with their specifications is discussed below

Table 4. Wind Turbines and their specifications

Maker	Rated Power	Rotor Diameter	Cut in Speed	Weight
Hummer	100 kW	25 m	2.5 m/s	2200 kg
Aeolos	100 kW	24.5 m	3 m/s	8350 kg
Danish	100 kW	20.6 m	3 m/s	ungiven
Polaris	100 kW	25 m	2.7 m/s	ungiven

First a comparison is made between four different turbines that are most suitable for our site. Hummer H25.0-100KW is selected because our site requires a low cut-in wind speed with reasonable power production. The weight and size of the turbine is another factor in selection as roadways by which the turbine should be transported are steep and have many turns. The direct drive makes the cost of the turbine reasonable, and the turbine will be easy to maintain and install. Moreover, the Hummer brand is one of the leading low-speed manufacturers in the world so it can provide lifelong service. The power curve of Hummer H25.0-100KW is presented in Fig. 8; the data was taken from the manufacturer's website. A turbine can only generate power when it reaches the cut-in speed and stops generating electricity when it reaches the cut-out speed. The power curve shows energy generation at different wind speeds.

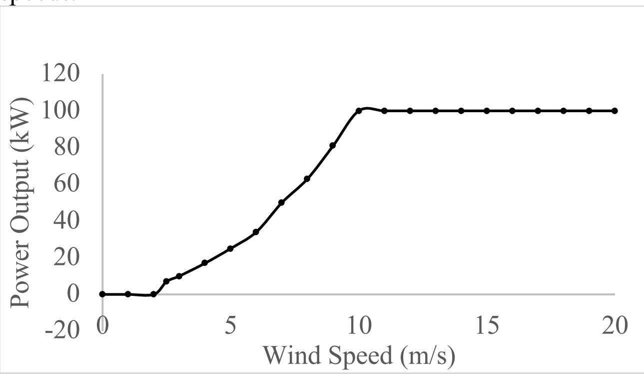

Fig. 8. Power Curve of Hummer H25.0-100KW [30]

Based on the generated wind statistics, the annual energy production was calculated for a wind farm with a Hummer H25.0-100KW turbine at the hub height of 30m. For the calculation of the AEP, 8760 hrs. per year was assumed in this research, neglecting turbine downtime, and the result is 170.268 MWhs.

5. Economic Evaluation

In this research, the economic evaluation is based not only on the cost of Hummer H25.0-100KW turbine but also on the cost of installation of distributed wind energy sources discussed in literature and other associated costs. In an article from Windustry, it is mentioned that wind turbines under 100 kilowatts cost roughly $3,000 to $8,000 per kilowatt of capacity and a 10-kilowatt machine (the size needed to power a large home) might have an installed cost of $50,000-$80,000 (or more) [31]. In a report published by the U.S. Department of Energy in 2016 about the market of distributed wind energy sources, the total cost of the project considered is between $3500/kW and $7200/kW [32]. According to the 2005-2014 data in the report, the costs of small wind turbines were mostly increasing because of various factors, although they are now trending downward. These factors include changes in hardware costs, soft costs, and the marketplace. The overall wind energy market saw turbine costs increase from 2002 through 2008 and then decline as a result of domestic and global changes in labor costs, warranty provisions, manufacturer profitability, turbine scaling, raw material prices, energy prices, and foreign exchange rates.

After getting information about the total project cost, the next step is to calculate the total subsidy the government must provide to implement and run the project smoothly. The operation and maintenance costs are supposed to be 3% based on guidelines for the implementation of renewable energy technologies of the Alternative Energy Promotion Center. Thus, according to the economic evaluation of the 100-kW project in Tila village, based on the capital investment range from $3500/kW to $7200/kW, the subsidy the government has to provide to run the project without loss is calculated using Equations 16 and 17, which gives the range from 59 % to 80 %.

6. Comparison with Other Renewable Energy Sources

6.1. Micro Hydropower

Micro hydropower plants (MHPPs) are small-scale hydropower plants whose capacity ranges from 5 kW to 100kW [33] [34]. Such systems can be easily designed and developed for electricity loads varying from a single home to a small building and industry [35]. Generally, micro hydropower systems do not require large dams or reservoirs, with water from a river partially transferred through an intake channel to a forebay tank and then fed to a lower elevation via a penstock. The water turbine, usually located in a powerhouse, converts the energy in the water flow into electrical energy, with energy efficiency of up to 90 percent [36]. The history of micro hydropower starts in Nepal with enthusiasm to improve water mills to generate electricity of nominal capacity. With successful results, the enthusiasts started to look for a wider range of options. MHPPs are being installed in Nepal by different governmental and non-governmental organizations such as the Remote Area Development Committee under the Ministry of Local Development, GIZ, and private entrepreneurs [37]. The use of micro hydro technology has been a success story for Nepal for the past several years. Micro hydro technology has been providing energy to the people living in 55 hilly and mountainous districts out of a total of 76 districts across the country with inhabitants who live in off-grid remote areas. Around 3300 MHPPs of capacity of up to 100 kW have been installed so far and around 350,000 households rely on electricity at least for light [38]. Nepal's success in micro hydropower has been taken as an example by the neighbouring countries and some African countries [39]. In later years, the development of micro hydropower has decreased, due to the development of mega projects in Nepal and the extension of the national grid to many remote places.

The cost of installation of micro hydropower systems in Nepal depends on the site location. Several factors affect the installation cost including civil works required at the intake and for the canal, the length and type of penstock, the complexity of the turbine design, the distance to the distribution area, and the number of connected households [40]. Dhakal *et al.* and Acharya *et al.* provide the cost per kilowatt of micro hydro installations with different capacities at different site locations within Nepal. The cost varies from \$2000/kW to \$5000/kW with an average of \$3500/kW [41, 42]. The research demonstrates that there is very little change in the cost per kilowatt with the change in the system capacity, indicating that as the size increases, the fixed costs also increase. The cost breakdown for the Nepalese micro hydro sector shows electrical components 40%, civil components 30%, mechanical components 23%, and transportation 7% [43].

6.2. Solar Power

Nepal, with mean solar radiation of 4.7 kWh/m^2 per day and a surface area of 147,516 km^2, is the region in South East Asia with a tremendous amount of solar energy potential [44, 45]. The country is mainly divided into three geographical regions: Himalayan, Hilly, and Terai. With a total width of 193 km from south to north, Nepal consists of areas with altitude varying from 70 meters to 8848 meters [46]. Tila village of Jumla, located in the western mountainous region of Nepal, is in state number 6. As the Himalayan region has a lower potential for solar energy due to climate and the Terai region is connected almost entirely to the national grid, it is the western mountainous region where connection to the grid is difficult due to topography and the potential for the production seems fair. A major portion (about 55%) of the capital cost of the solar power plant consists of the cost of the Photovoltaic (PV) module and inverters [47], and the cost of the PV module decreased from 90\$/Wp in 1968 to 0.49\$/Wp in 2014 (Here, Wp is the solar installation power expressed in watt peak, it is the maximum electrical energy that the solar cell can generate in an ideal environment , i.e. solar collector in a cloudless sky)[48]. The capital cost has fallen from 2.4 million Dollar in 2009-10 to 0.9 million Dollar in 2015-16 per MW of the solar power plant.

6.3. Comparison of Technical Aspects

The distributed wind energy source and the micro hydropower energy source are quite similar in terms of their operation as both use turbines for the generation of electricity. Along with the micro hydropower system comparison is also made with solar PV system.

6.3.1. Efficiency

The efficiency of a wind turbine is about 50% and the overall distributed wind energy system has an efficiency range from 32% to 50% [49]. The efficiency of a distributed wind source is between the solar and micro hydro systems. The most efficient solar panels on the market today have efficiency ratings as high as 22.8%, whereas most panels range from 15% to 17% efficiency rating [49]. The battery of the solar system has the efficiency of about 70-90 % [50] and the overall solar PV system has the efficiency of 15 % [51]. With 50-60% efficiency, the micro hydro system has a higher efficiency than wind and solar systems.

6.3.2. Capacity Factor

The capacity factor is the amount of energy produced by a system divided by what it could produce if it functioned at peak capacity all the time. Wind, hydro, and solar capacity factors tend to vary with location and seasons since they depend on the speed of the wind, flow of water, and sunlight. According to the U.S. Energy Information Administration data provided in 2016, the wind energy system has a capacity factor of 34.7% whereas the hydropower system has 38%. The solar PV system has a capacity factor of 10-20 %.

6.3.3. Electrical System

The modern wind power generation system uses a three-bladed horizontal axis wind turbine (HAWT) in combination with various types of generators with or without gear drive. The most popular generators are squirrel cage induction generator (SCIG), doubly fed induction generator (DFIG), electrically excited synchronous generator (EESG), and permanent magnet synchronous generator (PMSG). The squirrel cage induction generator is mainly used for fixed speed wind power generation in the small-scale power range, whereas the other three types of generators are used with variable speed wind power generation with maximum power point tracking (MPPT) technology. The small-scale wind power generation system also uses a conventional synchronous generator (SG). The power generated is fed to the load via a power electronic converter stage or sent to the micro-grid or power grid by a step-up power transformer for transmission and distribution purposes [52].

The wind power is a highly intermittent kind of energy source. Its reliability can be increased using either the battery energy storage system or the micro hydropower generation system. Because the micro hydropower (MHP) generation is not as intermittent as the wind power generation, the two renewable resources can be combined to increase the reliability of the energy system. In MHP generation, the constant flow of water is discharged through the water turbine-generator system. The same types of generators are used in the MHP system; the most common ones are the self-excited induction generator and traditional synchronous generator because of a lower cost and simpler maintenance. The generated power is connected to an isolated load, keeping the voltage and frequency constant. The voltage and frequency are made constant with the help of a simple to advanced electronic load converter [53]. Such a simple technique cannot be applied in wind power generation control system; complex power electronic converter stages such as a rectifier, DC-DC converter, and inverters for the power balance and frequency management are needed in this case.

Another type of renewable energy for supplying the off-grid demand is the solar PV power. The PV systems are used with or without a battery energy storage system. In PV power generation, the solar irradiance is incident on the solar panel or module, which converts the photons of energy into the electricity, and solar panels are connected in series and in parallel to make a solar array so that the required demand can be met at a suitable voltage and necessary current. The produced electricity is then fed to the DC-DC boost converter, mostly implementing MPPT technology, as in the case of wind power generation, and the boosted DC voltage is sent to the pulse width modulated (PWM) inverter to convert the DC power into AC power required by the consumer load. Also, the DC-link voltage between the DC-DC boost converter and the PWM rectifier can be connected to the battery energy storage system via a bidirectional DC-DC converter [54]. Although the battery storage system in PV power generation increases the overall cost of the solar plant, it also improves the power supply reliability for stand-alone consumer loads. Therefore, this is the best technology for areas like Jumla. Because of the rapid reduction in the cost of solar panels, the solar PV system has become an easy and fast power installation solution to supply isolated loads in comparison with the micro hydropower generation.

6.3.4. Components and Maintenance

Many components of a distributed wind energy system are less robust than those of a hydropower system. Moreover, hilly and winding roads make transportation of large wind turbine blades challenging, but the distributed wind energy system usually has smaller blades. On the other hand, the hydropower system consists of more civil components than the wind power system. The only civil components in the wind power system are the foundation and the tower while in the micro hydropower system, there are many civil components such as a weir structure, reservoir, canal, desilting basin, intake, machine foundation for the turbine and generator, etc. Therefore, there are fewer maintenance problems in the distributed wind energy system than in the micro hydropower system. Due to maintenance problems, people in Jumla face power cuts in the rainy season, and there are also other power outages arising from failure of different civil components of the system. The third type of the alternative energy sources has its disadvantages as well. Although the solar panel does not need much maintenance, in the solar PV system there is a huge cost associated with frequent battery replacement.

6.4. Comparison of Economic Aspects

Although micro-scale energy generation is not economical, the government of Nepal is promoting such projects because 4.5 % of people still lack electricity and no national grid has reached them. Therefore, the Ministry of Energy with Alternative Energy Promotion Center in Nepal subsidizes microscale projects to electrify communities [38]. Looking at the capital investment in the wind, micro hydro, and solar power, we find that distributed wind energy systems need more investment than the other two. The micro hydro system requires about \$2500/kW to \$5500/kW whereas a distributed wind energy system requires about \$3000/kW to \$7200/kW. The community usually participates in the construction of a micro hydro system, and the capital cost of the project is reduced, but for the distributed wind energy system, there is not much cost that can be reduced by community participation. Thus, the distributed wind energy system is less economical than the micro hydropower system. The cost of installation of the solar PV system is around \$2000 to \$4000 per kW, but its battery needs to be replaced every 2-5 years, so the actual cost may vary. Most of the solar PV systems are installed in single households in Tila so the cost associated with individual small systems may be greater than that of a bigger system. Since the solar system does not work at night and during the days with less sunshine in the winter season, this system is not much more effective for Tila village of Jumla. A distributed wind energy system, on the other hand, does not produce electricity when the wind speed is below the cut-in speed but, overall, it has a longer generation time than a solar PV system.

7. Conclusions

In Tila village of Jumla the average hourly wind speed varies from 1.5 m/s to 4.6 m/s at a hub height of 30 m. Yearly Weibull parameters k and c are 1.73 and 4.21 m/s. The wind power density of 43.79 W/m^2 and energy density of 378.37 kWhr/m^2 were obtained based on the Weibull distribution. Using the energy density, the total power generation of 170.268 MWhr/year is calculated from a 100kW distributed wind energy system. The proposed system can be run smoothly without loss if the government provides a subsidy of about 59% to 80% of the total investment of the project. Although the distributed wind energy system is not economical compared to micro hydro and solar power, this system can be introduced in Tila village through Nepal's subsidy policy as another renewable energy system because solar and micro hydro power do not satisfy the energy demand in the village. This system may act as a substitute system when there is not enough sunlight for the solar PV system and not enough water flow coupled with maintenance problems in a micro hydropower system. Moreover, the study of energy scenario after integration of wind and solar or wind and micro hydro systems can be done in future for proper utilization of available renewable energy sources in Jumla.

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