FEASIBILITY STUDY OF MICRO-SCALE WIND POWER GENERATION FOR RURAL ELECTRIFICATION IN POLONNARUWA AREA

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Wind energy is one of the most promising alternative renewable energy technologies at present to sustain the increasing energy demand, whereas fossil fuels have negative effects on the environment. Moreover, the fossil is directly related to air pollution, land and water degradation. Despite significant progress made in power generation using large-scale wind turbines recently, domestic-scale wind turbines have received less attention, which have immense potential for standalone power generation. In this paper, micro-scale wind power generation in the Polonnaruwa area was investigated. The technical and economic feasibility of tower-mounted micro-scale standalone wind turbine installation was conducted. The potential of micro-scale wind power generation was statistically analyzed. The average wind speed data of a three-seasonal intervals of two years (2019 and 2020) was collected and analyzed to find the potential of wind power generation in the specified area. The Weibull probability distribution was applied to calculate the wind speed distribution at different heights. Therefore, the annual wind power potential of the area and the energy production of the selected wind turbine were estimated. Study results show that installation of the wind turbine at 10m hub height for this particular area gave better performance of annual energy production, capacity factor and, carbon savings. Therefore, a 500 W turbine with low cut- in wind speed of 2 m/s, was selected as the most appropriate micro scale wind turbine which can be installed at the site under study.

Keywords: annual energy production, capacity factor, wind turbine, weibull probability distribution, wind speed

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1. INTRODUCTION

Sri Lanka's electricity demand has grown steadily over the past fifteen years, with an average annual increase of 4.4% in energy demand and 2.6% in peak demand [1]. In response to the environmental and economic challenges posed by fossil fuel-based power generation, renewable energy has emerged as a viable alternative. Wind energy, in particular, offers a clean and sustainable solution, yet its application at the micro scale, especially for rural electrification, remains underexplored in Sri Lanka. The Ceylon Electricity Board's Long-Term Generation Expansion Plan (2022–2041) outlines a shift toward increased renewable energy penetration beyond 2030, reducing reliance on natural gas-based generation. Within this context, small-scale wind turbines (SWTs) have significant potential to contribute to decentralized, off-grid electricity solutions, particularly in remote and rural areas [2]. Globally, over 1.1 billion people still lack access to reliable electricity [3]. SWTs can complement solar and hydro systems, especially during nighttime or cloudy periods, offering flexibility and potential for local manufacturing and maintenance.

In Sri Lanka, most existing off-grid home power systems rely on solar PV, with limited deployment of wind-based solutions [1]. Given the favorable wind conditions and flat terrain in rural areas such as Polonnaruwa, this study investigates the feasibility of micro-scale wind power generation to meet household energy needs. The project evaluates different micro wind turbine models, analyzes wind speed patterns using historical data and the Weibull distribution, and estimates annual energy production.

2. METHODOLOGY

Figure 1 shows the overall research methodology followed for the research where key consideration is given to the selection of the type of SWT and wind power generation assessment using Weibull distribution.

2.1 Wind Data Acquisition

Wind data for this study was obtained from the Meteorological Department of Sri Lanka. Measurements were recorded at a hub height of 10 meters in Polonnaruwa over a one-year period. Data was collected twice daily and included wind speed and direction.

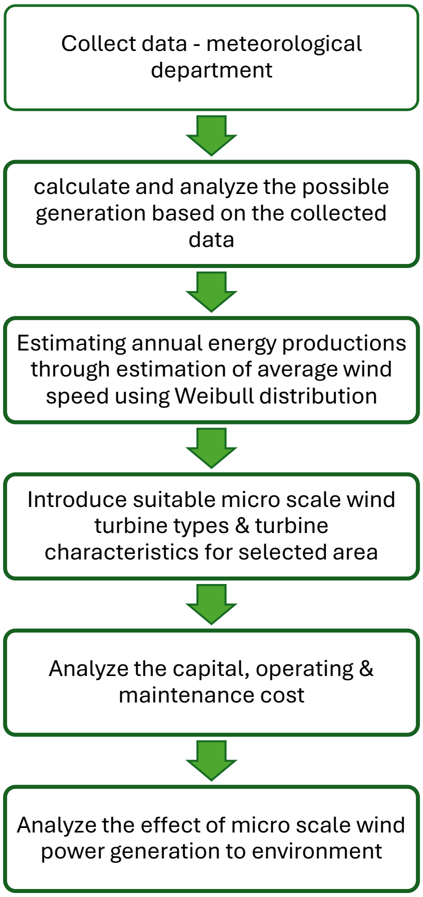

Figure 1: Overall research methodology flow chart

2.2 Wind Resource Assessment in Selected Area (Polonnaruwa)

The assessment focused on analyzing seasonal and annual wind speed trends along with predominant wind directions. The lowest speeds (1.48 m/s) were recorded between November 22 and December 13. An annual mean wind speed of 2.37 m/s was observed. These patterns were used to evaluate the site's suitability for small wind turbine installations [4].

For a given wind data at a height Z and a roughness length Z0 the velocity at length of ZR can be found using this logarithmic profile as given in Equation 1.

$$V(Z_R) = V(Z)\,\frac{\ln\left(Z_R/Z_o\right)}{\ln\left(Z/Z_o\right)} \qquad \text{.............................} \qquad \textbf{EQ (1)}$$

3. RESULTS AND DISCUSSION

This section presents the results of wind resource analysis and power production analysis of selected SWT types.

3.1 Estimation of wind speeds at different heights

The seasonal average values of wind speeds were applied to estimate the annual average wind speed at locations of different heights. Different types of landscapes and roughness lengths of the Polonnaruwa area are considered for estimating [5]. Those estimations are based on the logarithmic law of a wind shear formula as given in Equation 1.

3.2 Weibull distribution of wind speed

Wind speed distribution .is very crucial in assessing the wind potential and feasibility for the installation of a turbine at particular site location. Therefore, estimating the wind speed frequency distribution has been conducted using Weibull distribution as shown in Figure 2.

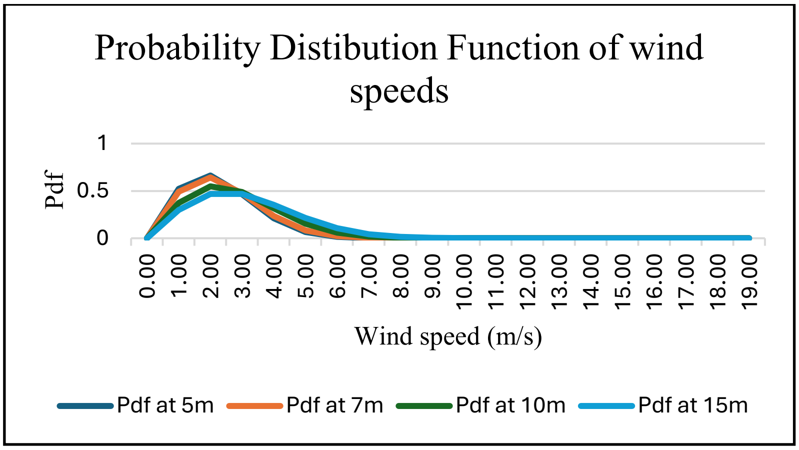

Figure 2: Wind speed distribution at different hub heights

3.3 Wind power and energy density calculations

To evaluate the wind resource available at the potential area for the heights of 5m, 7m, and 15m, the best way is to calculate the power density to indicate how much energy is available at the site to be converted into electricity by a wind turbine. The formula used for calculating wind power per unit area (P/A) or wind power density and the energy density are given in equations (2), (3) and (4).

$$\frac{P}{A} = \frac{1}{2}\rho V^3 \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Eq (2)}$$

$$\frac{E}{A} = \frac{P}{A}(n\,\Delta t) \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{Eq (3)}$$

Time availability =Probability Distribution×365×24 ………………Eq (4)

3.4 Wind Turbine's Performance Assessment

Key factors considered for wind turbine installation include hub height, low cut-in speed, rotor diameter, and noise impact on nearby receptors. . Selection was based on the average annual wind speed of 2.37 m/s and the lowest seasonal wind speed of 2.51 m/s in the Polonnaruwa district, along with the mentioned criteria. The energy produced at each wind speed by each turbine is calculated and included in Table 1 where specifications for each wind turbine are considered for calculations.

Table 1: Energy produced at each wind speed at 10m hub height by each turbine

Wind speed (m/s)	f(v) pdf	Time availability at 10m (hr.)	Fetcoi Vertical		Fichiouy		Dyna - Living		Lantern		Pikasola	
			Power (W)	Energy (kWh)	Power (W)	Energy (kWh)	Power (W)	Energy (kWh)	Power (W)	Energy (kWh)	Power (W)	Energy (kWh)
0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1.00	0.2	504.0	0.0	0.0	0.3	0.2	0.0	0.0	0.0	0.0	0.1	0.1
2.00	0.45	2940.0	1.4	4.1	2.6	7.6	6.5	19.1	3.1	9.2	0.8	2.4
3.00	0.5	3060.0	4.7	14.3	8.7	26.7	22.0	67.2	10.5	32.2	2.7	8.4
4.00	0.3	1750.0	11.1	19.4	20.7	36.2	52.0	91.1	24.9	43.6	6.5	11.4
5.00	0.1	348.0	21.6	7.5	40.4	14.1	101.6	35.4	48.7	17.0	12.7	4.4
6.00	0.0151	105.0	37.4	3.9	69.9	7.3	175.6	18.4	84.2	8.8	22.0	2.3
7.00	0.0024	51.2	59.4	3.0	111	5.7	279	14.3	133.7	6.8	35	1.8
8.00	0.0002	1.8	88.7	0.2	166	0.3	416	0.7	200	0.4	52	0.1
9.00	0.0	0.0	126.2	0.0	236	0.0	500	0.0	284	0.0	74	0.0
10.00	0.0	0.0	173.2	0.0	300	0.0	500	0.0	390	0.0	102	0.0
11.00	0.0	0.0	230.5	0.0	300	0.0	500	0.0	519	0.0	135	0.0
12.00	0.0	0.0	299.3	0.0	300	0.0	500	0.0	600	0.0	176	0.0
13.00	0.0	0.0	380.5	0.0	300	0.0	500	0.0	600	0.0	224	0.0
14.00	0.0	0.0	400	0.0	300	0.0	500	0.0	600	0.0	279	0.0
15.00	0.0	0.0	400	0.0	300	0.0	500	0.0	600	0.0	344	0.0
16.00	0.0	0.0	400	0.0	300	0.0	500	0.0	600	0.0	400	0.0
17.00	0.0	0.0	400	0.0	300	0.0	500	0.0	600	0.0	400	0.0
18.00	0.0	0.0	400	0.0	300	0.0	500	0.0	600	0.0	400	0.0
19.00	0.0	0.0	400	0.0	300	0.0	500	0.0	600	0.0	400	0.0
			Total generated energy	18.4	Total generated energy	34.5	Total generated energy	86.3	Total generated energy	41.4	Total generated energy	10.9

The results from table 1 shows that turbine "Dyna – Living" (500W) gives the best Annual Energy Production (AEP) than the four comparative potential wind turbines listed. The wind turbines' performance was analyzed in terms of Energy Produced, capacity factor and carbon saving for the potential wind turbines.

3.5 Estimation of capacity factor

The capacity factors and CO_2 savings of the selected wind turbines were calculated and are presented in Table 2, which shows that the Dyna-Living wind turbine achieves the highest capacity factor of 0.22 at a hub height of 10 m compared to the other turbines considered. CO_2 savings for each selected wind turbine, shown were estimated using the calculated annual energy production and a displacement factor of 0.03 kg CO_2/kWh [6]. Dyna-Living 500W wind turbine gives the most significant carbon savings from the other potential wind turbines at 10m hub height. It can reduce nearly 0.69% of carbon emission from using electricity for different activities. Hence, installation can be seen as a promotion of micro-scale renewable energy sources for rural areas.

Table 2: Capacity factors and CO2 savings

Micro wind turbine	Annual Energy Production(kWh)	% of CO_2 saved at 10m	Capacity factor value at 10m (%)

Fetcoi Vertical	18.4	0.15	0.12
Fichiouy Horizontal	34.5	0.27	0.16
Dyna - Living	86.3	0.69	0.22
Lantern	41.4	0.33	0.10
Pikasola	10.9	0.09	0.18

4. CONCLUSIONS/RECOMMENDATIONS

This study evaluated the technical, environmental, and economic feasibility of a micro-scale standalone wind turbine installation in the Polonnaruwa area as a representative rural case, identifying a 500 W low cut-in speed turbine as suitable for low-to-moderate wind conditions. The results emphasizing that both physical factors such as wind resource and installation environment, and financial factors including capital, operation and maintenance costs, variable demand, and interest rates, are crucial for optimal system performance and integration into the future energy mix.

REFERENCES

Narayana, M. (2006). Micrositing of Small-Scale Wind Turbines is Economically Viable for Rural Electrification in Sri Lanka. *In The International Technical Conference, 8th German Wind Energy Conference*.

Leary, J., To, L. S., Alsop, A., Latoufis, K., van Dam, E., Rivas, J., & Odongo, F. W. (2018). Is there still a role for small wind in rural electrification programs. *LCEDN. Loughborough, UK: Low Carbon Energy for Development Network & Wind Empowerment.*

WEO, I. (2017). Special report: Energy access outlook. IEA *WEO: Paris, France.*

Sunderland, K. M., Narayana, M., Putrus, G., Conlon, M. F., & McDonald, S. (2016). The cost of energy associated with micro wind generation: International case studies of rural and urban installations. *Energy*, *109*, 818-829.

Loganathan, B., Chowdhury, H., Mustary, I., Rana, M. M., & Alam, F. (2019). Design of a micro wind turbine and its economic feasibility study for residential power generation in built-up areas. *Energy Procedia*, *160*, 812-819.

Gebrelibanos, K. G. (2013). Feasibility Study of Small Scale Standalone Wind Turbine for Urban Area: Case Study: KTH Main Campus.

Sunderland, K. M., Narayana, M., Putrus, G., Conlon, M. F., & McDonald, S. (2016). The cost of energy associated with micro wind generation: International case studies of rural and urban installations. *Energy*, *109*, 818-829.

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