ESTIMATION OF WIND POWER DENSITY USING WEIBULL PARAMETERS IN FIVE CITIES OF WEST BENGAL

Rahul SINGH[1], Om PRAKASH[2] & Richa PANDEY[3]

This study is aimed at estimation of the wind power density for electricity generation based on wind flow data got from RETScreen database of five cities in West Bengal, India. The probability density function and cumulative density function along with other statistical technique were used to estimate shape (μ) and scale (λ) characteristics of Weibull distribution. Two Weibull characteristics (λ and μ) were utilized to assess the wind power density (WPD) of all the five locations and are found to be 4.6136 W/m², 9.0438 W/m², 5.3178 W/m², 22.0605 W/m², and 9.8422 W/m², respectively for Kolkata, Durgapur, Kharagpur, Shiliguri, and Asansol. Therefore, a small-scale wind turbine is best suited and recommended to change the available energy of air into electricity as WPD are found to be less than 100 W/m² at a height of ten meters from the ground surface.

Keywords: Wind power density, Weibull characteristics, Wind energy, Wind speed

1. Introduction

Renewable energy technologies are essential to achieve environmental protection and sustainable economic development [1-3]. In recent years, wind energy is being increasingly used as an option in contrast to customary fossil fuel; in several countries, the rate of growth is in double digits [4]. This is because wind energy is the cleanest renewable energy with the potential to overcome global warming [5]. In recent years, India has also taken several steps to make modern energy accessible. Since the year 2000, India has accelerated rural electrification drive and succeeded in minimizing the number of families without the reach of electricity by more than half. Nonetheless, there are still about 240 million people, or around 20% of the population, that have no access to electricity [6]. In such a scenario, it is essential to consider wind power that can be used as a clean and indigenous source of power and can also create many jobs. The wind power industry in India is well developed and has enhanced manufacturing capacity. With its capability and experience, India's wind power industry can help meet its climate and energy security goals. This industry is approximately thirty years old and holds

[1] Assistant Professor, Department of Mechanical Engineering, Amity University Jharkhand, Ranchi, India. Email: rahul282828@gmail.com
[2] Professor, Department of Mechanical Engineering, National Institute of Technology Patna, Bihar, India. Email: dromprakash67@gmail.com
[3] Assistant Professor, Department of Mechanical Engineering, BIT MESRA, Ranchi, Jharkhand, India. Email: richapandey@bitmesra.ac.in

the 4th position globally with over 31 GW installations at the end of March 2017. Here, it should be noted that the country has a short-term target of 60 GW installations by the year 2022. In spite of ample wind energy potential, India lags to harvest its available wind resource completely due to inconsistent wind resource assessment at various places. The assessment of wind resource is decisive step to forecast the available wind power for electricity generation at a specified altitude.

A review of literature revealed that many countries do not sufficiently assess their wind resources; thus, they are unable to effectively use the available kinetic energy of wind by virtue of its velocity [7-8]. Like other states in India, the potential of wind energy is distributed unevenly in different cities of West Bengal. So, wind power density and further factors should be determined on a site by site basis so as to understand the distribution of wind energy across the country [9]. For five districts in the state of Jharkhand, Singh and Prakash recently measured the wind energy potential [10]. It has been reported that, in West Bengal, the demand for power is rapidly increasing; so, the state should shift its focus to alternative sources of renewable energy in order to decrease its dependence on fossil fuel resources that are limited in quantity [11]. According to the report of Economic Research India Pvt Ltd, the gross wind power potential of the state is 450 MW, but its installed capacity is only 2.5 MW as of March 2013 [12]. This could be because of no land acquisition policy that serves as a stumbling block to investment in West Bengal. The allocation of state-held land through competitive bidding is a major issue that prevents investments in the largest wind-farm project of the Eastern region [13]. For the first time exploration work aimed to examine the accessibility of wind resource for the generation of electric power at five diverse sites in West Bengal using small-scale or micro wind turbine are carried out at 10 m height. The authors too invested significant amount of time at the five chose areas of West Bengal to all the more likely comprehend the attainability of wind to power generation utilizing wind turbine using Weibull parameters. The Ministry of New and Renewable Energy (MNRE), a separate department of government of India, focused on renewable energy is actively encouraging and providing subsidy to wind energy project from planning to operation. The government is aggressively working to add 225GW renewable energy capacity by 2022.

2. Methodology

Five cities, namely, Kolkata, Durgapur, Kharagpur, Siliguri, and Asansol, of West Bengal were chosen for the investigation in light of the fact that there has been a quick pace of development in these urban areas that will require inexhaustible energy source later on. The electricity produced will not only full fill the void of electricity demand but also boost the socio-economic growth of approximately five million peoples of five districts of West Bengal, India. The area maps of the five urban locations have appeared in Fig. 1.

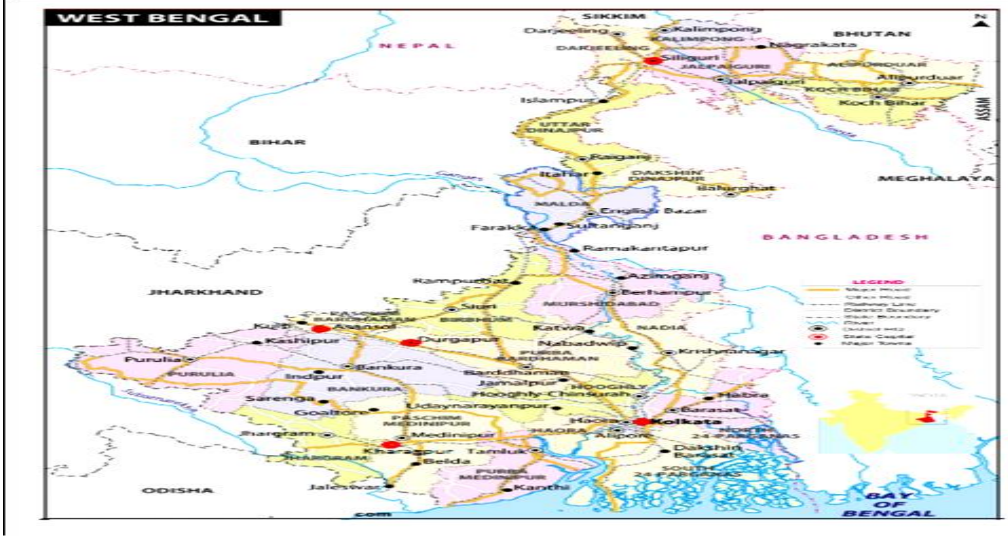

Fig. 1. Area maps of the five urban locations under study in West Bengal [highlighted by red dots] (Source: locations on google map)

Twenty-two years of wind data in between 1983 to 2004, at an altitude of ten meters above the surface was gathered from the RETScreen database (ground stations) so as to examine the energy potential of these locations [14]. In most part of the globe, the standard altitude above the nearby vegetation for measuring wind speed is 10 m [15]. With advancement in wind blade design and blade materials, even we can generate considerable wind power at 10 m height. Table 1 presents the air density, geographical location, and elevation of the selected cities of West Bengal, India.

Table 1

Location co-ordinates of five cities of West Bengal.

Place	Kolkata	Durgapur	Kharagpur	Siliguri	Asansol
Density of air	1.158 kgm^{-3}	1.155 kgm^{-3}	1.157 kgm^{-3}	1.069 kgm^{-3}	1.141 kgm^{-3}
Altitude	6.0 m	61.0 m	26.0 m	198.0 m	205.0 m
Longitude(E)	88.3	87.3	87.3	88.4	87.0
Latitude(N)	22.5	23.5	22.3	26.7	23.7

2.1 Weibull Distribution

Weibull distribution was used as data analysis tool to investigate wind speed data and examine the energy available from wind to produce electricity in the five cities of West Bengal, India. The wind energy practitioners and engineers generally use Weibull distribution as it is more accurate, precise and reliable than compared to other wind assessment techniques [15]. Two important energy conversion characteristics, i.e., Weibull shape factor "μ" and Weibull scale factor "λ" were defined by means of probability density function f(x) and the cumulative distribution function or Weibull function F(x). In addition to the two-parameter Weibull characteristics (μ and λ) additional statistical tools, was also applied to examine the monthly average wind speed data [16]. Table 2 presents the average data of monthly as well as seasonal wind speed for the five selected cities of West Bengal throughout the twenty-two years duration.

Table 2

Seasonal variation of wind data of 22 years duration of five cities of West Bengal

Season		**Mean Wind Speed(m/s)**				
		Kolkata	**Durgapur**	**Kharagpur**	**Siliguri**	**Asansol**
Winter	Dec.	0.8	1.3	1.0	3.1	1.5
	Jan.	0.8	1.4	1.0	3.1	1.6
	Feb.	1.1	1.7	1.3	3.4	1.9
Spring	Mar.	1.4	1.8	1.5	3.5	2.0
	Apr.	2.2	2.5	2.3	3.5	2.6
	May.	2.2	2.7	2.4	3.2	2.8
Summer	Jun.	1.9	2.5	2.1	3.0	2.7
	Jul.	1.7	2.2	1.9	2.7	2.3
	Aug.	1.4	1.9	1.6	2.5	2.0
Autumn	Sep.	1.4	1.8	1.5	2.4	1.9
	Oct.	0.8	1.3	1.0	2.7	1.4
	Nov.	0.8	1.3	1.0	3.1	1.5

"The probability density function f(u) and cumulative density function F(u) are presented by relations (1) and (2), respectively, in terms of wind speed, scale, and shape parameter" [17].

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

$$F(u)=1-\exp\left[-\left(\frac{u}{\lambda}\right)^{\mu}\right] \quad (2)$$

where, μ (dimensionless) denotes Weibull shape, and λ (m/s) denotes scale parameters.

For the selected sites, the average (u_m) wind speed was determined from equation (3) while the variances (σ^2) of wind speed data was determined from equation (4) [17].

$$u_m=\frac{1}{n}\sum_{i=1}^{n} u_i \quad (3)$$

$$\sigma^2=\frac{1}{n-1}\sum_{i=1}^{n}(u_i-u_m)^2 \quad (4)$$

Where, the symbol i refers to the monthly wind data, while n denotes the total number of wind data used for the specific year.

The two Weibull distribution parameters were calculated as shown in relations (5) and (6), separately [17].

$$\mu=\left(\frac{\sigma}{u_m}\right)^{-1.086} \quad (5)$$

$$\lambda = \frac{u_m}{\Gamma\left(1+\frac{1}{\mu}\right)} \quad (6)$$

The notation u_m refers to average wind speed, σ refers to the standard deviation of wind speed data, and Γ denotes the gamma function.

The wind energy potential of a region can be estimated using the maximum energy carrying wind speed ($u_{Emax.}$) and the most probable wind speed (u_{mp}) data. Equation (7) presents the correlation among the most probable wind speed and the Weibull characteristics (μ and λ). Equation (8) presents the interconnection between the Weibull characteristics (μ and λ) and the maximum energy carrying wind speed [18].

$$u_{mp}=C\left(\frac{\mu-1}{\mu}\right)^{1/\mu} \tag{7}$$

$$u_{Emax.}=C\left(\frac{\mu+2}{\mu}\right)^{1/\mu} \tag{8}$$

2.2 Wind Power Density (WPD)

The wind power density is more effective in determining the potential of kinetic energy available from wind for generation of electric current in a particular region. As shown in equation (9) below, the two Weibull characteristics are used to determine the wind power density, WPD, for any place [19]:

$$WPD = 0.5\rho\lambda^3\left(1+\frac{3}{\mu}\right) \tag{9}$$

3. Result and Discussion

Table 2 display the wind data on the monthly and seasonal basis for the past 22 years of five selected cities of West Bengal. Also, the monthly comparison of wind data of past 22 years for five cities of West Bengal is indicated in Figure 2.

It was found that the wind speed was 0.8 m/s to 3.5 m/s. We found that Shiliguri offers the peak monthly average wind speed of 2.4 to 3.5 m/s. This was followed by Asansol having a monthly average wind speed of 1.4 to 2.8 m/s, Durgapur 1.3 to 2.7 m/s, Kharagpur 1.0 to 2.4 m/s, and Kolkata 0.8 to 2.2 m/s. Figure 3 shows the seasonal variation in wind speed in the five cities.

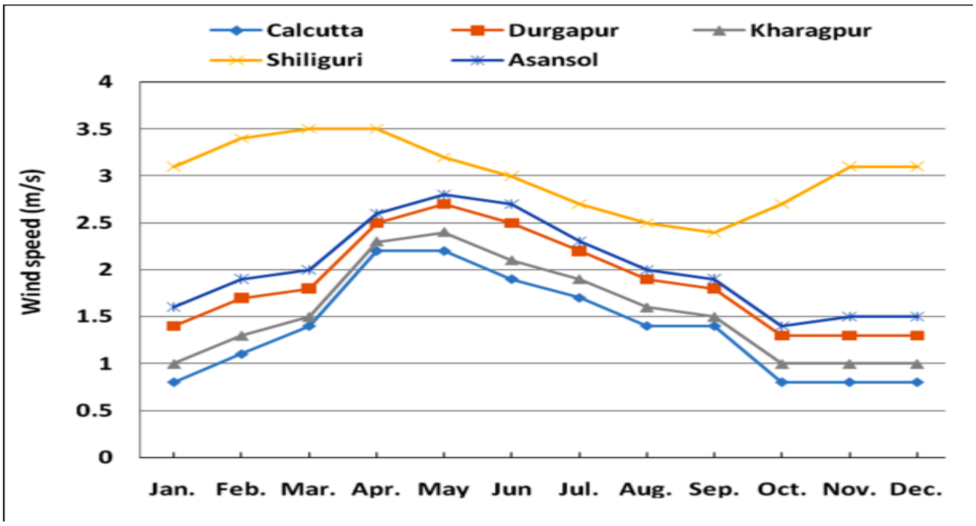

Fig. 2. Comparison of wind data among five cities of West Bengal during 12 months.

Moving further, the average wind speed is the maximum in spring (March to May) for all the cities. The seasonal average wind speed fluctuates from 0.9 m/s for Kolkata in winter (December to February) to 3.4 m/s for Siliguri in spring (March to May). The variation in wind speed indicates that none of the selected cities have consistent wind speed throughout a year. The annual average wind speeds of the five cities are displayed in Figure 4.

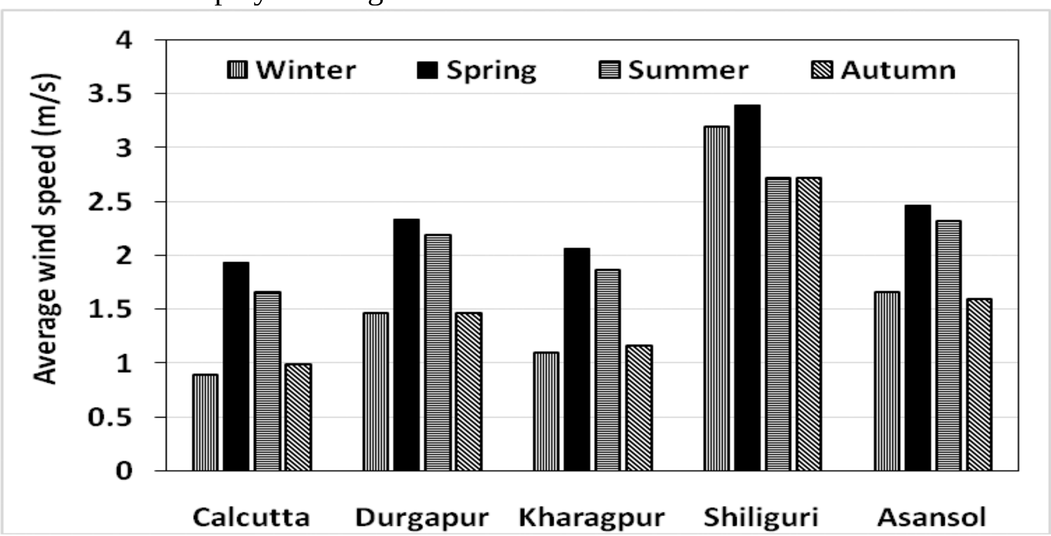

Fig. 3. Seasonal variation of wind data in five cities of West Bengal

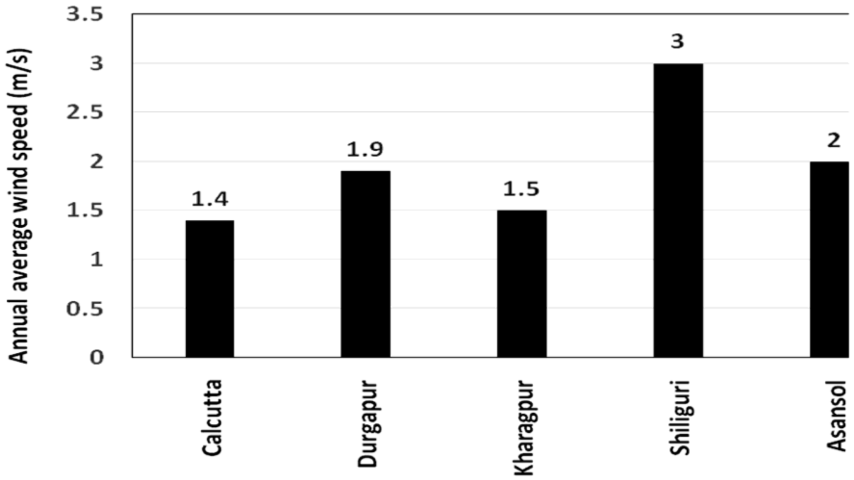

Fig. 4. Annual average wind speed of five cities of West Bengal.

They have also reported that the speed at which the wind is flowing as well as its direction primarily depend on height along with geographical and climatic condition of the site and vary accordingly [20]. Since the power available from the wind flow at any region varies directly to the change in wind speed, henceforth a marginal deviation in speed of wind will noticeably increase the wind power [21]. Table 3 presents the statistical and Weibull parameters calculated for the five cities.

Table 3

Outcome of Weibull statistical analysis

Place	Kolkata	Durgapur	Kharagpur	Siliguri	Asansol
u_m	1.4	1.9	1.5	3.0	2.0
σ	0.5345	0.5069	0.5214	0.3713	0.4872
u_{max}	1.9	2.7	2.4	3.5	2.8
μ	2.8454	4.1993	3.1505	9.6701	4.6351
λ	1.5712	2.0904	1.6761	3.1582	2.1879
u_{mp}	1.3494	1.9592	1.4847	3.1227	2.0761
u_{Emax}	1.8944	2.2935	1.9591	3.2201	2.3639
WPD	4.6136	9.0438	5.3178	22.0605	9.8422

In Weibull distribution, the shape parameter (μ) was 2.8454≤μ≤9.6701, whereas the scale parameter (λ) was 1.5712≤λ≤3.1582. The calculated Weibull parameters for the selected cities are shown in Figure 5. The most probable wind speed (u_{mp}) values for Kolkata, Durgapur, Kharagpur, Shiliguri, and Asansol were 1.3494, 1.9592, 1.4847, 3.1227, and 2.0761 m/s while the yearly values of wind speed carrying maximum energy ($u_{Emax.}$) were 1.8944, 2.2935, 1.9591, 3.2201 and 2.3639 m/s, respectively.

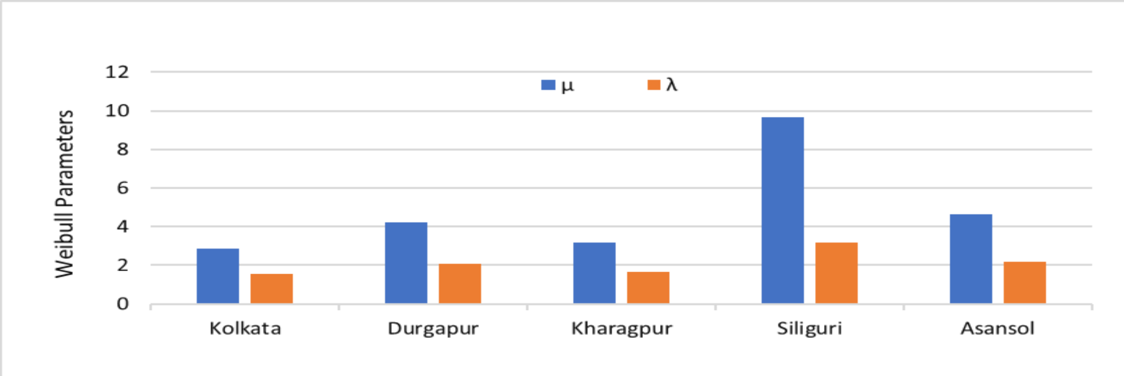

Fig. 5. Weibull characteristics (μ and λ) of five cities of West Bengal

With respect to probable wind speed, Shiliguri showed the highest value, followed by Asansol, Durgapur, Kharagpur, and Kolkata. With respect to the yearly values of wind speed carrying maximum energy, Asansol showed the maximum value, followed by Durgapur, Kharagpur, and Kolkata. Among the five cities, Kolkata showed the lowest wind speed carrying maximum energy and probable wind speed. The wind power densities WPD of Kolkata, Durgapur, Kharagpur, Shiliguri, and Asansol were 4.6136 W/m^2, 9.0438 W/m^2, 5.3178 W/m^2, 22.0605 W/m^2, and 9.8422 W/m^2, respectively. Siliguri had the highest wind power density.

A location/site having WPD greater than 700 W/m^2 is very good for the generation of electricity from wind. If WPD value is between 300 to 700 W/m^2, then the site is considered to be good; WPD between 100 to 300 W/m^2 denotes fairly good site and that below 100 W/m^2 denotes a poor site [22-23].

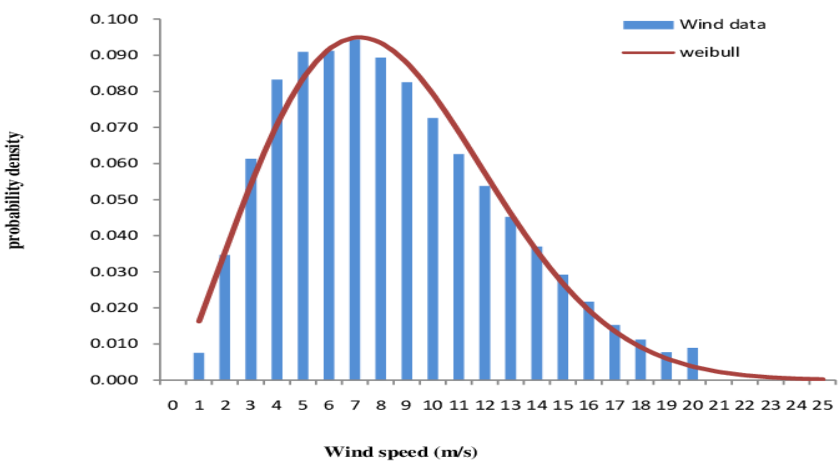

Fig. 6. Validation of Weibull distribution for wind speeds [24]

Different researchers have examined the potential of various locations in different parts of the world for electricity generation from wind power using the globally adopted Weibull 2 (two) parameters as represented and validated by figure 6 [24]. The above results obtained justify the wind power density for the range of wind speed for our five selected locations of West Bengal.

4. Conclusion

The current investigation did an evaluation for estimating the capability of wind power for generation of electric flow at ten-meter height for five urban areas of West Bengal, to be specific Kolkata, Durgapur, Kharagpur, Siliguri, and Asansol from the wind flow information got from ground stations of recent twenty-two years from RETScreen atmosphere database. The point of the examination is to profit the lives of more than five million individuals residing in these five urban communities of West Bengal, India by making use of the plentiful energy accessible from wind to change it into power with the assistance of wind turbines. The average monthly, seasonal and annual wind speeds were statistically analyzed thoroughly for five cities and the calculation of Weibull parameters (μ and λ) were done. The outcomes acquired from Weibull investigation alongside two attributes μ and λ were presented in Table 3 for decision making and feasibility of wind energy-based power generation. In view of the results, we confirmed that none of the five urban communities are proper for enormous scope of power produced from wind energy as WPD are found to be less than 100 W/m^2. Be that as it may, the low speed wind in these areas can be astutely used to produce power utilizing miniaturized scale wind turbine at a height of ten meters or above starting from the earliest stage. With the advancement in wind turbine technology, wind resource assessment is prerequisite to select the best required wind turbine for power generation. At the moment, focus is given more on to the development of micro or roof top wind turbine for electricity generation in urban areas.

R E F E R E N C E S

[1] *Feretic, D., Tomsic, Z. and Cavlina, N.*, Feasibility Analysis of Wind-Energy Utilization in Croatia. Energy, **24**, 239-246. (1999)

[2] *Adami, L., Castagna, G., Magaril, E., Giurea, R., Ferronato, N., Ruggieri, G., Torretta, V., Rada, E.C.*, Criticalities and potentialities of local renewable sources of energy, WIT Transactions on Ecology and the Environment, **222**, 103-115, (2019)

[3] *Hansen, U.E., Nygaard, I., Morris, M., Robbins, G.*, The effects of local content requirements in auction schemes for renewable energy in developing countries: A literature review, Renewable and Sustainable Energy Reviews, **127**, (2020)

[4] *Lehmann, P., Söderholm, P.*, Can Technology-Specific Deployment Policies Be Cost-Effective? The Case of Renewable Energy Support Schemes, Environmental and Resource Economics, **71(2)**, 475-505, (2018)

[5] *Samuel Perkin, Deon Garrett, and Pall Jensson*, "Optimal wind turbine selection methodology: A case-study for Búrfell, Iceland". Renewable Energy, **75**, 165-172. (2015)

[6] *Mathew, S., Pandey, K.P. and Kumar, A.V.* Analysis of Wind Regimes for Energy Estimation. Renewable Energy, **25**, 381-399. (2002)
[7] *Malinowski, M., Milczarek, A., Kot, R., Goryca, Z., Szuster, J.T.,*.Optimized Energy-Conversion Systems for Small Wind Turbines: Renewable energy sources in modern distributed power generation systems, IEEE Power Electronics Magazine, **2(3)**, 16-30, (2015)
[8] *Ionescu, R.D., Ragazzi, M., Battisti, L., Rada, E.C., Ionescu, G.,* Potential of electricity generation from renewable energy sources in standard domestic houses, WIT Transactions on Ecology and the Environment, **176**, 245-253, (2013)
[9] *Sulaiman, M.Y., Akaak, A.M., Abd. Wahab, M., Zakaria, A., Sulaiman, Z.A. and Suradi*, J. Wind Characteristic of Oman. Energy, **27**, 35-46. (2002)
[10] *Singh, R., and Prakash, O.* Wind energy potential evaluation for power generation in selected districts of Jharkhand, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, Vol. 40, Iss**.** **6**, 673-679. (2018). DOI: 10.1080/15567036.2018.1454548.
[11] West Bengal Renewable Energy Development Agency. Accessed March 29, 2020. http://www.wbreda.org/
[12] Economic Research India Pvt Ltd report 2013. Accessed March 29, 2020. https://www.projectstoday.com/news/west-bengal-to-set-up-wind-power-station.
[13] The Hindu report, April 7, 2013. Accessed March 29, 2020.
[14] RETScreen Database, www.retscreen.net. Accessed March 29, 2020.
[15] *Oztopal, A. Sahin, A.D. Akgun, N. and Sen, Z.* On the Regional Wind Energy Potential of Turkey. Energy, **25**,189-200. (2000).
[16] *Albadi, M.H., El-Saadany, E.F. and Albadi, H.A.* Wind to Power a New City in Oman. Energy, **34**, 1579-1586. (2009).
[17] *Singh, R., and Prakash, O.* Assessment of wind energy potential in four cities of Gujrat, India, U.P.B. Sci. Bull., Series D, Vol. 81, Iss. **1**, 207-2016. (2019).
[18] *Ajayi, O.O., Fagbenle, R.O. and Katende, J.* Assessment of Wind Power Potential and Wind Electricity Generation Using WECS of Two Sites in South West, Nigeria. International Journal of Energy Science, **1**, 78-92. (2011).
[19] *Ilinca, A., McCarthy, E., Chaumel, J.-L. and Retiveau, J.-L*Wind Potential Assessment of Quebec Province. Renewable Energy, **28**, 1881-1897. (2003)
[20] *B.R. Karthikeya, Prabal S. Negi, N. Srikanth* Wind resource assessment for urban renewable energy application in Singapore Renewable Energy, **87,** Part 1, 403-414. (March 2016)
[21] *Ahmed, S.A.* Wind Energy as a Potential Generation Source at Ras Benas, Egypt. Renewable and Sustainable Energy Reviews, **14**, 2167-2177. (2010)
[22] *Seguro JV, Lambert TW*. Modern estimation of the parameters of the Weibull wind speed distribution for wind energy analysis. J Wind Eng Ind Aerodyn, **85**, 75–84. (2000)
[23] *Pashardes S, Christofides C*. Statistical analysis of wind speed and direction in Cyprus. Sol Energy, **55(5)**, 405–14. (1995)
[24] *Argungu, G.M., Bala, E.J., Momoh, M., Musa, M., Dabai, K.A., Zangina, U. and Maiyama, B.A.* Statistical Analysis of Wind Energy Resource Potentials for Power Generation in Jos, Nigeria, Based on Weibull Distribution Function. The International Journal of Engineering and Science (IJES), **2**, 22-31. (2013)