

Determination of Yearly Wind Energy Potential and Extraction of Wind Energy Using Wind Turbine for Coastal Cities of Baluchistan, Pakistan

Muhammad Shoaib^{1*}, Imran Siddiqui², Saif Ur Rehman¹

¹Department of Physics, Federal Urdu University of Arts, Science and Technology, Karachi, Pakistan.

²Department of Physics, University of Karachi, Karachi-75270, Pakistan

*Email: profmshoaib@fuuast.edu.pk

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Abstract: Wind energy assessment of Ormara, Gwadar and Lasbela wind sites which are located in province Baluchistan is presented. The daily averaged wind speed data for the three sites is recorded for a period of four years from 2010-2013 at mast heights 7 m, 9.6 m and 23 m. Measured wind data are extrapolated to heights 60 m (Ormara), 80 m (Gwadar) and 60 m (Lasbela). Yearly averaged wind speeds are modeled using a two parameters Weibull function whose shape (k) and scale (c) parameters are computed using seven well known numerical iterative methods. Reliability of the fitting process is assessed by employing three goodness-of-fit test statistics, namely, RMSE, R^2 and χ^2 tests. Tests indicate that MLE, MLM and EPFM outperformed other Weibull parameter estimation methods for a better fit behavior. Yearly Weibull *pdf* and *cdf* are obtained and Weibull wind characteristics are determined. Wind turbines Ecotecnia 60/1.67 MW and Nordex S77 1500 kW are used to extract wind energy on yearly basis. Estimated yearly Weibull power densities are in the range 623.00 - 700.13 W/m², 276.04 - 307.55 W/m² and 66.85 - 75.93 W/m² for Ormara, Gwadar and Lasbela respectively. Extracted wind energy values for Ormara and Gwadar using wind turbines are reported as ca. 8623 kWh and ca. 4622 kWh, respectively.

Keywords: Wind energy, wind turbine, weibull, nordex, ecotecnia.

Introduction

In the past few decades a world-wide growth in utilization of renewable energy resources is witnessed. This is due to the fact that there has been a growing concern over the ill-effects of the conventional electricity generation processes on the environment and a rapid depletion of oil and gas reservoirs, forcing policy makers to explore alternative energy resources. The harmful effects associated with burning of fossil fuel for the generation of electricity increased the concentration of carbon monoxide, hydrocarbons, airborne particulate, ionizing radiation and trace elements (Kainkwa, 2000) in the environment. During the last ten years period, from 2008 to 2017, the global renewable power capacity has risen from 1057962 MW to 2179099 MW, which is an increase of more than 50% (IRENA, 2018). In comparison to nonrenewable energy sources, wind energy as the source of renewable energy is eco-friendly and cheap and is fastest growing source of energy (Jamdade, S. G. and Jamdade, P. G, 2012) which is economically viable and technically feasible for power generation. Wind is produced by the differential heating of the earth's surface and adjacent atmosphere.

Due to the economic and environmental effectiveness of wind energy, researchers all over the world to investigated wind data for different wind potential sites. This is useful in mapping wind characteristics (wind potential and direction) on a local scale and predictions of prevailing wind patterns for the site under investigation. Additionally, such local scale assessments provide an opportunity to plan feasibility

reports for investigated sites to construct a wind energy conversion system. The data points recorded are discrete in time intervals but in actuality show a continuous variability and has a diffuse wind speed distribution. Physically meaning full wind potential estimations require fitting of the recorded discrete wind speed points to a continuous mathematical function. Rehman et al. (1994); Rehman et al. (2012) approximated the measured wind speeds to a Weibull function and found good agreement. Bagiorgas et al. (2012); Bagiorgas et al. (2011) using Weibull function found a close agreement between Weibull function and measured wind speeds. Sulaiman et al. (2002) used a Weibull function to calculate wind energy potential for Oman. Authors used K-S test for the assessment of goodness-of-fit of modeled function. Sopian et al. (1995) determined wind power potential for Malaysia by using Weibull function. Garcia et al. (1998) used log-normal model to study wind speed data. Seguro et al. (2000) using Weibull functions to determine wind characteristics of the investigated site.

Ayush Parajuli (2016) investigated wind potential for Jumla, Nepal using Weibull and Rayleigh function. The study indicated superiority of Weibull function over Rayleigh function. Sarkar et al. (2017) assesses the suitability of various statistical models such as Weibull, Gamma and inverse Weibull function as fitting function for random variations of the recorded wind speeds. The study considered three classes of wind and found that low speed regime follows Weibull function whereas the mid speeds cannot be described by Weibull function. The study further revealed that wind speeds at tails follow extreme value distribution.

Odo et al. (2012) used 13 years of wind speed data recorded at Enugu, Nigeria to study the wind potential of the site. Dokur and Kurban (2015) studied wind potential of Bilecik region in Turkey. Vaishali et al. (2016) analyzed wind speed data from four locations around the world. The researchers did compare five different fit functions including Weibull function and found Weibull function showing best fit situation. Muhammad Shoaib et al. (2016); Muhammad Shoaib et al. (2017) extracted wind energy using wind turbine for Baburbund Sindh, Pakistan. Researchers fitted measured wind speeds to Weibull and maximum entropy function and extracted energy stored in wind using a wind turbine. A comparison between Maximum Entropy Principle (MEP) and Weibull function for the estimation of wind potential of Kati Bandar (Muhammad Shoaib et al. 2017) is given, with MEP outperforming Weibull function. Muhammad Shoaib et al. (2019) fitted wind speed data measured at Jhampir Sindh, Pakistan to a two parameter Weibull function and estimated function parameters using maximum likelihood method (MLM), modified maximum likelihood method (MMLM) and energy pattern factor method (EPFM). Annual and monthly Weibull function wind characteristics are also determined.

The present study is aimed at estimation of wind potential using four year daily averaged wind speed data obtained from three sites in Baluchistan namely, Ormara, Gawadar and Lasbela. Weibull function is used as a fitted function to obtain Weibull wind speed characteristics and wind energy potential. Fitted function parameters are computed using seven methods of estimations and goodness-of-fit is assessed using RMSE, R^2 and χ^2 tests. Probability density functions (*pdfs*) and cumulative distribution function (*cdf*) are also calculated.

Materials and Methods

Wind speeds are recorded intermittently and reliable estimates of wind potential and wind energy extraction using a wind turbine requires modeling of measured wind speeds to a continuous probability function. The modeled function gives probabilities of wind speeds within a narrow band. Weibull function, named after its inventor Waloddi Weibull (Weibull, 1951) is commonly used to assess the variability in wind speeds. Function is characterized by shape (k) and scale (c) parameters which are empirically determined using estimation methods. The scale parameter specifies the range of values present in the given data and the shape parameter describes the width of the given data set. A smaller shape parameter value is associated with a wider distribution of data with a correspondingly lower peak. This freedom in the estimation of parameters gives Weibull function its flexibility towards approximating different data distributions. Weibull function, $f(V)$, in terms of wind speeds, V , is expressed as (Akpınar and Akpınar, 2004),

$$f(V) = (k/c)(V/c)^{k-1} e^{-(V/c)^k} \quad (1)$$

Here shape parameter ' k ' is dimensionless and scale parameter ' c ' has the dimensions of speed. The cumulative Weibull distribution function, $F(V)$ is given as

$$F(V) = 1 - e^{-(V/c)^k} \quad (2)$$

The probability of wind speed ' V ' is expressed by the function $f(V)$ whereas $F(V)$ gives the probability that wind is lower than or is equal to ' V ' (Sathyajith et al. 2011). Mean wind speed, V_m , most probable wind speed, V_{mp} and wind power density, P_D , using Weibull function are obtained from following relations (Justus et al., 1978; Isaac, 2000; Barthelmie and Pryor, 2003; Tian, 2010),

$$V_m = c[\text{Gamma}(1+1/k)] \quad (3)$$

$$V_{mp} = c\left[\left((k-1)/k\right)^{1/k}\right] \quad (4)$$

$$P_D = \frac{\rho_a c}{2} \text{Gamma}(1+3/k) \quad (5)$$

$$P_A = \frac{1}{2} \rho_a V^3 \quad (6)$$

where V_{mp} is the frequently appearing wind speeds at the site under study and $\rho_a = 1.225 \text{ kg/m}^3$ is the air density and $\text{Gamma}()$ is the Gamma function. Equation (6) gives the actual wind power density obtained from the measured wind speed data.

Calculation of Weibull Parameters

Weibull ' k ' and ' c ' parameters are computed using MLM, MMLM, MoM, MLE, EM, EPFM and PDM. MLE is a statistical method based on linear regression, in case of a discrete time series data MLM is used, MMLM is used when the given data set is in frequency distribution, MoM is determined using the law of large numbers, EM is a statistical method and is used when mean and standard deviation are given, EPFM is estimated based on the criteria of efficient energy extraction from wind and PDM is a variation of EPFM and is iteratively solved to obtain k . Mathematical representations for seven methods are given in Table 1.

Statistical Tests

The agreement between measured wind speeds and fitted function is tested using different goodness-of-fit criteria. In this study chi-squared (χ^2), Root mean square error (*RMSE*), and R^2 or coefficient of determination tests are used. R^2 gives a measure of variance between two (or more) variables and is given by the expression,

Table 1. Mathematical expression for estimating Weibull parameters.

Parameter Estimation Method	Mathematical Expression
MLE	$Y = \ln\{\ln(1/(1 - F(V)))\}, X = \ln V, a = -k \ln c, b = k$ $b = \frac{m \sum_{j=1}^m X_j Y_j - \sum_{j=1}^m X_j \sum_{j=1}^m Y_j}{m \sum_{j=1}^m X_j^2 - \left(\sum_{j=1}^m X_j\right)^2} \quad a = \frac{\sum_{j=1}^m X_j^2 \sum_{j=1}^m Y_j - \sum_{j=1}^m X_j \sum_{j=1}^m X_j Y_j}{m \sum_{j=1}^m X_j^2 - \left(\sum_{j=1}^m X_j\right)^2}$
MLM	$k = \left(\frac{\sum_{j=1}^m V_j^k \ln V_j}{\sum_{j=1}^m V_j^k} - \frac{1}{m} \sum_{j=1}^m \ln V_j \right)^{-1} \quad c = \left(\frac{1}{m} \sum_{j=1}^m V_j^k \right)^{1/k}$
MMLM	$k = \left(\frac{\sum_{j=1}^m V_j^k \ln(V_j) f(V_j)}{\sum_{j=1}^m V_j^k f(V_j)} - \frac{\sum_{j=1}^m \ln(V_j) f(V_j)}{f(V \geq 0)} \right)^{-1} \quad c = \left(\frac{1}{f(V \geq 0)} \sum_{j=1}^m V_j^k f(V_j) \right)^{1/k}$
MoM	$\bar{V} = c [\text{Gamma}(1 + 1/k)]$ $\sigma = c [\text{Gamma}(1 + 2/k) - \text{Gamma}^2(1 + 1/k)]^{1/2}$ $\bar{V} = \frac{1}{m} \sum_{j=1}^m V_j \quad \text{and} \quad \sigma = \left[\frac{1}{m-1} \sum_{j=1}^m (V_j - \bar{V})^2 \right]^{1/2}$
EM	$k = (\sigma / \bar{V})^{-1.086}, \quad c = \bar{V} / \text{Gamma}(1 + 1/k)$
EPFM	$E_{pf} = \frac{\frac{1}{m} \sum_{j=1}^m V_j^3}{\left(\frac{1}{m} \sum_{j=1}^m V_j \right)^3}$
PDM	$E_{pf} = \frac{\bar{V}^3}{V^3} = \frac{\text{Gamma}(1 + 3/k)}{\text{Gamma}^3(1 + 1/k)}, \quad c = \left(\frac{1}{m} \sum_{j=1}^m V_j^k \right)^{1/k}$

$$R^2 = \frac{\sum_{j=1}^m (y_j - z_{avg})^2 - \sum_{j=1}^m (y_{jc} - x_j)^2}{\sum_{i=1}^m (y_i - z_{avg})^2} \quad (7)$$

Where y_j and y_{jc} are the measured and calculated wind speeds and z_{avg} is the average value of measured wind speeds. R^2 gives the square of correlation between values predicted by the fitted function and measured values. R^2 lies in the range 0 and 1, a good fit implies a value closer to 1. The residual between predicted and recorded wind speed values is obtained using *RMSE* given by the equation

$$RMSE = \left[\frac{1}{m} \sum_{j=1}^m (y_j - x_j)^2 \right]^{1/2} \quad (8)$$

Where 'm' is the total number of observation, 'y_j' is the observation frequency and 'x_j' is Weibull frequency. A lower value of *RMSE* points to a good fit. Another test for the assessment of goodness-of-fit of a function is an χ^2 test, developed by Karl Pearson. χ^2

test is given by:

$$\chi^2 = \sum_{j=1}^m \frac{1}{y_{jc}} (y_j - y_{jc})^2 \quad (9)$$

Wind Energy Extraction Using a Wind Turbine

The particular choice of a wind turbine for the extraction of wind energy relies on characteristic wind estimates determined by a model function, in this case the Weibull function. Using wind turbine the energy stored in wind is calculated by solving two integrals, one of which is an integral whose integrand is the product of Weibull *pdf* and power curve function (*P_c*) of the turbine and the other integral with integrand as the Weibull *pdf*. The integration is performed over turbine characteristic parameters, namely, cut-in (v_{cin}), cut-off (v_{co}) and rated wind speed (v_r). Integrals are solved numerically using 64 Point Gauss-Legendre algorithms, and they are expressed as;

$$E_{TA} = TP_r \int_{v_{cin}}^{v_r} P_c(k/c)(V/c)^{k-1} e^{-(V/c)^k} dV + TP_r \int_{v_r}^{v_{co}} (k/c)(V/c)^{k-1} e^{-(V/c)^k} dV \quad (10)$$

Where ' P_r ' is the turbine rated power and ' T ' is the time interval in which energy is extracted. Mathematical description and detail procedure for extraction of wind energy contained in wind is given in ref. Muhammad Shoib et al. 2016.

Data Description

Wind speed data for three sites in Baluchistan province, Pakistan, that is, Ormara, Gwadar and Lasbela is used. Wind speed data is taken from PMD (PMD, 2014; Muhammad Shoib, 2016) masts whose

Results and Discussion

Descriptive Statistics

Descriptive statistics is computed for the three investigated sites. Wind speed distribution in case of Ormara is skewed positive with skewness, $S = 0.42$, averaged yearly wind speed 9.61 m/sec. A high average wind speed resulted in a power density of 543.47 W/m². In contrast to Ormara, the recorded distribution for Gwadar is negatively skewed, with

Table 3. Yearly averaged descriptive statistics for Ormara, Gwadar and Lasbela for entire recorded wind speed data set (2010 – 2013).

SITE/Period	Heights (m)	# Data Points	Mean V_{avg} m/sec	σ m/sec	K	S	V_{min} m/sec	V_{max} m/sec	P_A (W/m ²)	C.V. %	C.I. (95.0%)
ORMARA/ 2010-2013 (Jan-Dec)	60	365	9.61	4.50	-0.16	0.42	1.66	23.20	543.47	46.78	0.46
GWADAR/ 2010-2013 (Jan-Dec)	80	365	7.14	2.18	-0.07	-0.27	0.83	13.20	222.65	30.49	0.22
LASBELA/ 2010-2013 (Jan-Dec)	60	365	4.03	2.03	-0.85	0.23	0.35	9.44	39.99	50.53	0.21

geographical location and coordinates are given in Table 2. Wind speeds in knots for 4 years during the period 2010 to 2013 are recorded daily at 12:00 noon and at 7 m, 9.6 m and 23 m mast heights for Ormara, Gwadar and Lasbela, respectively. Before analysis the obtained wind speed data is converted from knots to meter/second (m/sec). Moderate to high wind patterns prevail throughout the year at all three sites due to their location along the coast of Baluchistan, Pakistan. Application of wind turbines for energy extraction requires extrapolation of the measured wind speeds to heights at which wind turbines are available commercially. In this study measured wind speeds are extrapolated for heights 60 m and 80 m for Ormara and Lasbela and 80 m for Gwadar. After averaging, the four years data sets for all three sites are converted into a single data set of 365 data points for one complete year.

Table 2. Geographical locations and coordinates for investigated site

Site	District	Geographical Coordinates
Ormara	District Gwadar, Makran coastal region	25°13' N and 64°37' E
Gwadar	Gwadar district along the coast of Arabian sea	25°8' N and 62°20' E
Lasbela	Lasbela coastal district	26°14' N and 66°19' E

skewness of $S = -0.27$ and yearly averaged wind speed of 7.14 m/sec. This gives a value of power density 222.65 W/m² for Gwadar. Low wind speeds are measured for Lasbela with an yearly average of 4.03 m/sec and with a positively skewed ($S = 0.23$) distribution. At such low yearly averaged wind speed, Lasbela has a power density value of 39.99 W/m². Table 3 gives descriptive statistics and moments for the three investigated wind sites.

Weibull Parameters Estimation

Assessment of wind potential at the sites under investigation, a continuous Weibull distribution function is fitted to recorded wind speed data for these sites. In order to determine Weibull shape (k) and scale (c) parameters, seven different estimation methods (Table 1) are used in this study. Tables 4, 5 & 6 list the Weibull wind characteristics for Ormara, Gwadar and Lasbela by fitting wind speed data at extrapolated heights of 60 m, 80 m and 60 m, respectively. Larger values of k for Ormara and Gwadar (3.01 - 3.42 and 3.31 - 3.99) suggest smaller variation in wind speeds, whereas for Lasbela, a smaller value of k (1.98 - 2.20) suggests larger variation in wind speeds; see Figs. 1-3. This is consistent with the observed wind speeds. Yearly averaged Weibull probability distribution plots for the study sites are shown in Figs. 1-3 using k and c parameters numerically determined using methods listed in Table 1. Reliability of the fitted function is assessed by using R^2 , $RMSE$ and χ^2

Table 4. Yearly averaged Weibull wind Characteristics and *k* and *c* values of Ormara.

Estimation Methods	# Of Hours	<i>k</i>	<i>c</i> (m/sec)	<i>V_m</i> (m/sec)	<i>V_{mp}</i> (m/sec)	<i>P_D</i> (W/m ²)	R ²	χ ² (10 ⁻⁰⁵)	RMSE (10 ⁻⁰³)
MLE	364	3.37	10.23	9.10	9.22	623.00	0.996	6.06	7.78
MLM	364	3.28	10.24	9.09	9.16	629.86	0.996	3.80	6.16
MMLM	364	3.30	10.62	9.43	9.52	700.13	0.996	3.02	5.49
MoM	364	3.42	10.34	9.20	9.34	639.58	0.996	5.48	7.39
EM	364	3.21	10.37	9.19	9.23	658.51	0.996	3.35	5.78
EPFM	364	3.01	10.40	9.20	9.10	681.45	0.996	2.06	4.54
PDM	364	3.36	10.30	9.16	9.27	635.61	0.996	3.85	6.19

Table 5. Yearly averaged Weibull wind Characteristics and *k* and *c* values of Gwadar.

Estimation Methods	# Of Hours	<i>k</i>	<i>c</i> (m/sec)	<i>V_m</i> (m/sec)	<i>V_{mp}</i> (m/sec)	<i>P_D</i> (W/m ²)	R ²	χ ² (10 ⁻⁰⁴)	RMSE (10 ⁻⁰²)
MLE	364	3.43	7.99	7.11	7.22	294.86	0.992	1.85	1.36
MLM	364	3.76	7.88	7.04	7.26	276.04	0.992	2.71	1.64
MMLM	364	3.94	8.19	7.35	7.61	307.55	0.992	1.82	1.35
MoM	364	3.99	7.97	7.15	7.42	282.95	0.992	2.52	1.59
EM	364	3.64	8.00	7.14	7.33	291.82	0.992	1.65	1.28
EPFM	364	3.31	8.06	7.15	7.22	305.84	0.992	0.81	0.90
PDM	364	3.95	7.94	7.12	7.38	279.82	0.992	3.18	1.78

Table 6. Yearly averaged Weibull wind Characteristics and *k* and *c* values of Lasbela.

Estimation Methods	# Of Hours	<i>k</i>	<i>c</i> (m/sec)	<i>V_m</i> (m/sec)	<i>V_{mp}</i> (m/sec)	<i>P_D</i> (W/m ²)	R ²	χ ² (10 ⁻⁰⁵)	RMSE (10 ⁻⁰³)
MLE	364	2.02	4.56	4.00	3.25	75.93	0.984	3.60	5.99
MLM	364	2.10	4.53	3.97	3.33	71.45	0.984	4.55	6.73
MMLM	364	1.98	4.35	3.81	3.05	66.85	0.984	16.0	12.8
MoM	364	2.16	4.60	4.04	3.45	73.11	0.984	5.27	7.25
EM	364	2.10	4.60	4.03	3.38	74.56	0.984	6.46	8.03
EPFM	364	2.16	4.60	4.04	3.45	73.02	0.984	5.08	7.11
PDM	364	2.20	4.58	4.01	3.47	70.51	0.984	5.92	7.68

goodness-of-fit tests. The test results indicate a good fit of the function to the measured wind speed data distribution for the three investigated sites.

Wind Power Densities

Yearly wind power density histograms for Ormara, Gwadar and Lasbela are shown in Figs. 4, 5 & 6. Figures show comparison between Weibull power density values estimated using Weibull function and actual power density values (*P_A*) determined using measured wind speeds. Weibull parameters '*k*' and '*c*' are determined using seven methods of estimation. Power density values determined using Weibull function are comparable to each other but are higher than actual power densities for all three sites. Actual power density values for the three sites are 543.47 W/m², 222.65 W/m², and 39.99 W/m². Whereas Weibull power densities obtained for 3 sites lie in the range 623.00 W/m² - 700.13 W/m², 276.04 W/m² - 307.55 W/m², and 66.85 W/m² - 75.93 W/m² for Ormara, Gwadar and Lasbela, respectively.

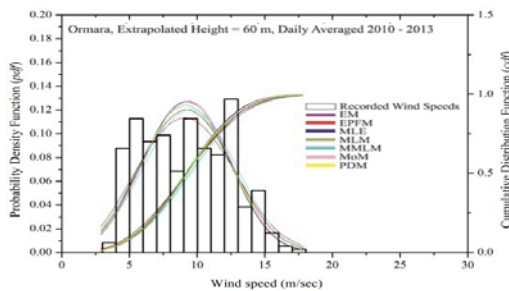


Fig. 1 Weibull pdf curves and histogram for Ormara

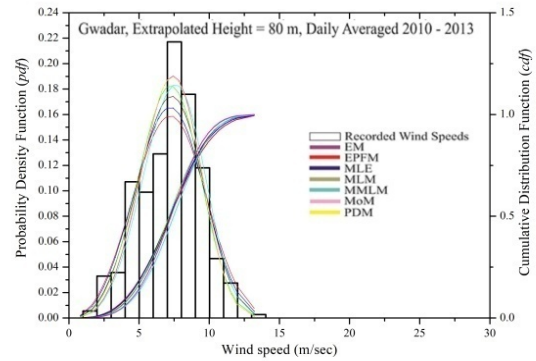


Fig. 2 Weibull pdf curves and histogram for Gwadar.

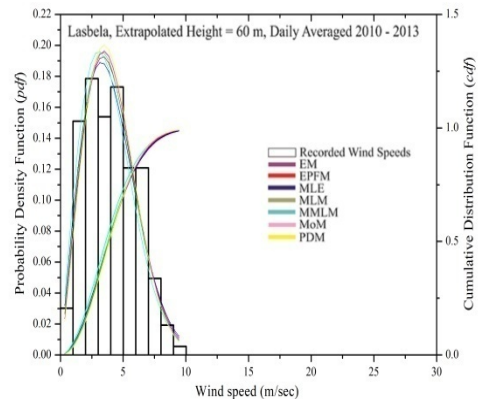


Fig. 3 Weibull pdf curves and histogram Lasbela

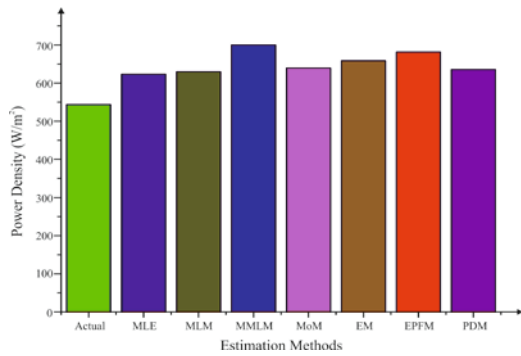


Fig. 4 Yearly averaged wind power density bars for Ormara.

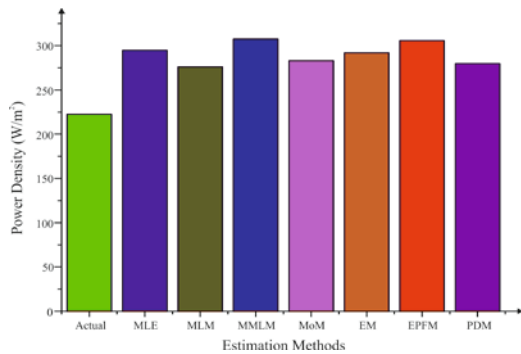


Fig. 5 Yearly averaged wind power density bars for Gwadar.

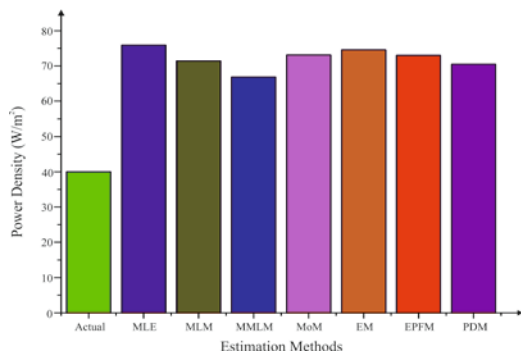


Fig. 6 Yearly averaged wind power density bars for Lasbela.

Wind Energy Estimation Using Wind Turbines

Due to high wind potentials of Ormara (623.00 W/m² - 700.13 W/m²) and Gwadar (276.04 W/m² - 307.55 W/m²) compared to Lasbela (66.85 W/m² - 75.93 W/m²), suitable wind turbines are used to extract wind energy at Ormara and Gwadar. Lasbela has a low wind potential therefore in this case wind turbine is not fitted to the modeled function for extracting energy. In case of Ormara and Gwadar, a cubic polynomial is fitted to the power curve of the selected turbines for these sites. Table 7 lists the coefficients of the fitted cubic polynomial for the chosen turbines. Figs. 7 & 9 are curves of cubic polynomial overlaid on turbine power curves showing reliable approximation. Figs. 8 & 10 are wind turbine curves overlaid on Weibull pdf

showing better part of turbine curves matching with Weibull pdf. The wind energy yields at extrapolated heights for Ormara and Gwadar using Weibull function and wind turbine are ca. 8623 kWh and ca. 4622 kWh using cubic polynomial as a fit function for wind turbine power curve, see Table 8. Capacity factors of wind turbines are estimated as ca. 58 % and ca. 35.18 % for Ormara and Gwadar, respectively (see Table 8).

Table 7. Wind turbines and fit parameters for cubic polynomials.

Fit Parameters	Ormara Ecotecnia 60/1.67 MW	Gwadar Nordex S77 1500 kW
Cubic Term P ₁	-0.002831	-0.002693
Square Term P ₂	0.07282	0.07007
Linear Term P ₃	-0.4553	-0.4455
Constant Term C	0.8645	0.8788
Sum of Squares Error SSE	0.006281	0.002127
R ²	0.9953	0.9983

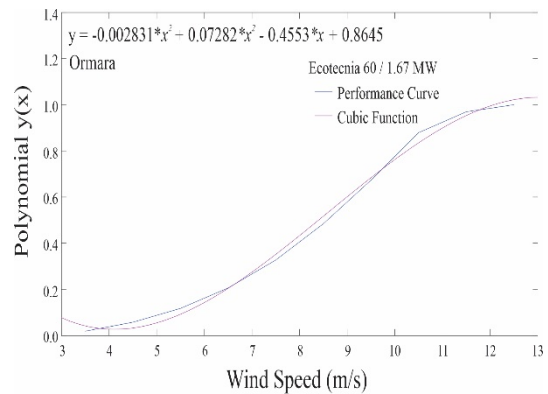


Fig. 7 Ecotecnia 60/1.67 MW turbine performance curve overlaid on cubic function curve.

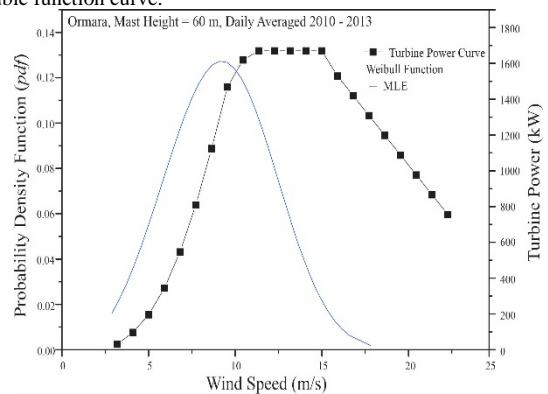


Fig. 8 Comparison of Weibull pdf for Ormara and turbine power curve.

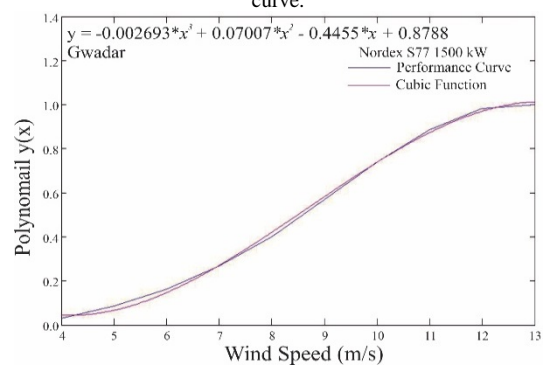


Fig. 9 Nordex S77 1500 kW turbine performance curve overlaid on cubic function curve.

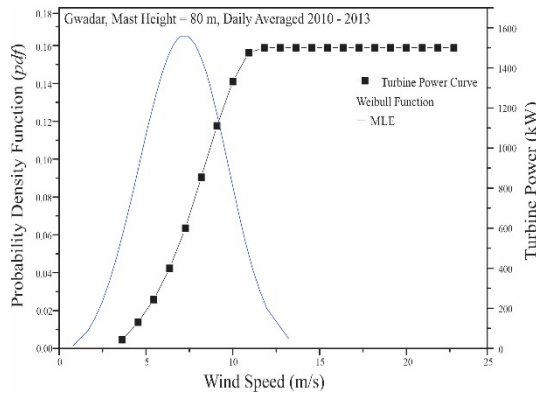


Fig. 10 Comparison of Weibull pdf for Gwadar and turbine power curve.

Table 8. Estimated of wind energy for Ormara and Gwadar using MLE. A degree 3 polynomial is fitted to the selected turbines power curves. (Availability (Σ_F), Efficiency (ϵ), Capacity Factor (C_F)).

Height (m)	Hours	P_D (W/m ²)	Mean Energy Density (kWh/m ²)	Ideal Wind Energy (kWh)	Actual Wind Energy (kWh)	Σ_F (%)	ϵ (%)	C_F (%)
60	8760	623.00	5457.510	23499.137	8623.920	98.42	36.70	58.95
80	8760	294.86	2583.014	12086.775	4622.295	96.58	38.24	35.18

Conclusion

The present paper investigates wind speed data distribution for three sites, namely, Ormara, Gwadar and Lasbela in Baluchistan province. Hourly wind speeds are recorded at 12:00 noon for four years i.e. 2010 – 2013 and at extrapolated heights 60 m (Ormara), 80 m (Gwadar) and 60 m (Lasbela). Initially, raw wind speed data set of four years is converted into a data set of one year duration. Descriptive statistics for the sites under study are determined. Wind energy potential is calculated using the processed data by using the Weibull function for the investigated sites. Fitted function parameters are numerically determined by solving seven estimation methods, listed in Table 1. Based on goodness-of-fit tests for all three sites the estimation methods MLE, MLM and EPFM performed better than other methods of calculating shape and scale parameters (see section Statistical Tests). Although fit results suggest good fitting of Weibull function to observed wind speed data distribution despite the fact that the calculated Weibull wind power density values are higher than wind power density values obtained directly from the observed wind speed data. Such a discrepancy is explained by realizing that calculated Weibull power densities are strongly weighted over higher wind speeds. This explanation is more consistent in case of Ormara ($V_{mp} = 9.10 - 9.52$ m/s) and Gwadar ($V_{mp} = 7.22 - 7.61$ m/s). In order to extract stored wind energy, wind turbines are fitted to wind power density for Ormara and Gwadar. The extracted wind energy for Ormara is 8623 kWh and for Gwadar is ca. 4622 kWh. The study reveals that Ormara appears to be a better choice for constructing a wind farm.

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