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Wind Potential at Two Places (Hawke's Bay Mast and FFC Mast) of Karachi

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Abstract

Wind speed distribution and wind potential were studied at two places, that is, Fauji Fertilizer Company and Hawke's bay of Karachi. Weibull parameters (k and c) were determined by analyzing the daily wind speed data at Hawke's bay and FFC Mast for the years 2010 and 2007, respectively. The data was obtained from the website of Alternative Energy Development Board (AEDB), Pakistan. To find k and c, four methods (maximum likelihood, empirical method, method of moments, and energy pattern method) were used. The mean wind speed was also predicted by using these four methods.

Keywords: Weibull distribution, wind potential, wind speed

Introduction

Finding an alternate source of energy is the ultimate goal of the countries around the world. Unlike developed countries, Pakistan is facing sever energy shortage because of the lack of conventional sources of energy (fossil fuel). Pakistan is also searching for other options for the generation of electricity. Wind energy is one of the sources of alternate energy for which Pakistan has appreciable potential. Solar energy is the source of wind energy. Wind energy can be utilized to generate electricity. Wind turbines convert the wind's kinetic energy into mechanical energy, which in turn converts into electricity [1].

Fossil fuel is the conventional source of the generation of power. Unfortunately, Pakistan is not very rich in this resource. Pakistan is an underdeveloped country and has poor economic conditions which do not allow the import of fossil fuel. Being a developing country, most of population lives in backward areas and is still waiting for the electricity grid. To help these impoverished communities, especially to overcome the energy crises, Pakistan needs to increase its energy resources such as hydropower, solar and wind energy. The coastal line of Pakistan extends almost 1000 km in the south and in its north there are mountainous areas, both of these provide an excellent resource for the generation of electricity. This wind potential can be utilized to overcome the prevailing power crisis in the country [2].

1.1 Weibull Distribution

Weibull distribution / density function is the most common function used to determine the wind potential [3]. Weibull distribution has an important role in the description and prediction of wind power and its relevant distributions. We can easily apply it. Wind data is displayed in an almost similar manner as Weibull distribution, which has different mathematical formulae depending upon the number of parameters. Two parameter Weibull distribution is given in equation (1) and its parameters include scale parameter (k) and shape parameter (c) [4-5].

1.2 Probability Density Function (PDF)

A number of researchers have used Weibull Probability Density Function (PDF) for modeling wind speed data [6, 7, 8, 9, 10, 11, 12]. The wind speed distribution is a continuous probability distribution. Its PDF is given below by equation (1),

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

where 'k' is a shape factor or parameter which is a dimensionless quantity and 'c' is the scale factor which indicates the dimension of wind speed.

2. Determination of Parameters

Several different methods have been used to determine the parameters (k and c) of Weibull distribution. In this study, we used the following methods.

1. Maximum Likelihood Method (MLM)
2. Methods of Moments (MOM)
3. Energy Pattern Method (EPM)
4. Empirical Method (EM)

2.1 Maximum Likelihood Method (MLM)

Steven et al. suggested MLM for the determination of the parameters 'k' and 'c'. MLM utilized the following mathematical relation for determining these parameters [13],

$$k = \left[\frac{\sum_{i=1}^{n} {v_i}^k \ln(v_i)}{\sum_i^n v^k} - \sum_i^n \frac{\ln(v_i)}{n}\right] \quad (2)$$

$$c = \frac{\sum_i^n {v_i}^k}{n} \quad (3)$$

Due to the involvement of logarithm in shape parameter equation, special care was required in estimating Weibull parameters using MLM that included zero wind speed. Zero value of wind speed in wind speed data is not accounted for in this method because of the logarithm function in the above formula. The occurrence of zero makes the calculation indeterminate.

2.2 Methods of Moments (MOM)

Jestus et al. introduced Methods of Moment (MOM) which is a very simple method as compared to MLM. The mean and standard deviation of wind speed data are used to calculate the parameters 'k' and 'c'. To calculate these parameters, the following equations (4) and (5) were used [13].

$$\bar{v} = c\gamma\left(1 + \frac{1}{k}\right) \quad (4)$$

$$\sigma = c\left[\gamma\left(1 + \frac{1}{k}\right) - \gamma^2\left(1 + \frac{1}{k}\right)\right]^{\frac{1}{2}} \quad (5)$$

2.3 Empirical Method (EM)

The determination of Weibull parameters using Empirical Method (EM) is carried out by calculating mean wind speed and its standard deviation. The following equations (6) and (7) are two moments required to calculate the values of 'k' and 'c' [13].

$$k = \left(\frac{\sigma}{v}\right)^{-k} \quad (6)$$

$$\bar{v} = c\gamma\left(1 + \frac{1}{K}\right) \quad (7)$$

2.4 Energy Pattern Method (EPM)

Power Density Method is an alternate name for the Energy Pattern Method. We can easily apply this method to determine Weibull parameters 'k' and 'c'. $\frac{\bar{v}^3}{(\bar{v})^3}$ is known as the Energy Pattern Factor (EPF) and is used to determine the scale factor. Like MOM, scale parameter is found via second moment about mean. The following equations were used to calculate Weibull parameters [13].

$$E = \frac{\bar{v}^3}{(\bar{v})^3} \quad (8)$$

$$K = 1 + \frac{3.69}{(E)2} \quad (9)$$

$$\bar{v} = c\gamma\left(1 + \frac{1}{k}\right) \quad (10)$$

3. Results and Discussion

Research in alternate energy resources is the right answer to today's increasing use of electricity. Wind energy is a good option of renewable energy. In this study, we investigated wind data of FFC (2007) and Hawke's bay (2010). Wind data was obtained from the onsite Karachi meteorological office. Weibull distribution with two parameters (k and c) was used to model and fit the wind data of FFC mast and Hawke's bay mast. The parameters of Weibull distribution were calculated using four methods (EPM, EM, MoM, MLM) and the corresponding curves were also drawn. The graphs in Figure 1 (for FFC mast from January 2007 to December 2007) and Figure 2 (for Hawke's bay mast from January 2010 to December 2010) show curves and histogram plotted on the base of the recorded wind data and the curves were plotted using 'k' and 'c' values obtained through the four methods described above. These values were used in the Weibull distribution formula to find the estimated values of distribution. The curves are good representation of recorded data as most of them overlap within the region of histogram. To check the goodness of fit (or uncertainties), mean square error was calculated. The chi square good fit test and Kolmogorov test were also used to verify the goodness of fit. Table 1 shows the values of uncertainties (MSE) in estimated values for January to December 2007 (for FFC). Table 2 shows the uncertainties measured by chi square good fit test and Kolmogorov test. The mean wind speed was also calculated and shown in the same table. All the methods employed gave almost the same value of mean wind speed for twelve months. The maximum mean wind speed of 12.3 approximately was found in August, whereas the minimum mean wind speed was 5.87 which occurred in February. The FFC is a good place to install wind mills as the potential of wind energy is great from April to September. The wind potential is also appreciable in other months. Table 3 shows the values of Weibull parameters (k & c) for FFC from January to December, 2007.

Table 1. Mean Wind Speed for FFC from January to December 2007 and Mean Square Error in Wind Speed

Months	Mean wind speed /(m/s)				Mean square error in mean speed			
	EPM	**EM**	**MOM**	**MLM**	**EPM**	**EM**	**MOM**	**MLM**
January	7.579256	7.574594	7.687325	7.459327	9.31E-05	9.88E-05	8.84E-05	8.63E-05
February	5.870208	5.868354	5.891656	5.964817	1.91E-04	1.95E-04	1.94E-04	2.12E-04
March	7.408941	7.405468	7.610447	7.384481	9.42E-05	9.81E-05	8.06E-05	1.01E-04
April	8.229305	8.232403	8.229815	8.215471	6.43E-05	5.78E-05	5.84E-05	5.16E-05
May	12.53782	12.43435	12.41723	12.46571	1.35E-05	7.32E-06	7.43E-06	8.21E-06
June	10.31624	10.31168	10.26513	10.33014	3.92E-05	3.53E-05	3.70E-05	3.54E-05
July	9.751203	9.729856	9.701502	9.771737	3.37E-05	2.71E-05	2.75E-05	2.66E-05
August	12.36801	12.27426	12.27075	12.34404	1.29E-05	7.36E-06	7.45E-06	7.26E-06
September	9.363626	9.282404	9.252301	9.283953	2.30E-05	1.24E-05	1.25E-05	1.26E-05
October	6.841908	6.840489	6.868236	6.824704	1.30E-04	1.24E-04	1.22E-04	1.22E-04
November	5.912426	5.912216	5.913717	5.929853	1.90E-04	1.88E-04	1.90E-04	1.89E-04
December	8.061929	8.05968	8.122297	8.026638	9.21E-05	1.05E-04	1.01E-04	1.79E-04

Table 2. Results of Kolmogorov and Chi Square Tests for Wind Speed Calculated for FFC

Months	Kgtest				Chi			
	EPM	EM	MOM	MLM	EPM	EM	MOM	MLM
Jan	0.009162	0.008217	0.007796	0.004499	0.033304	0.034572	0.036338	0.045758
Feb	0.009292	0.008889	0.008992	0.010771	0.028999	0.029606	0.028154	0.029419
March	0.011899	0.011586	0.011905	0.011497	0.034043	0.034451	0.032094	0.034819
April	0.007361	0.007953	0.007901	0.008748	0.022946	0.021905	0.022007	0.021148
May	0.002802	0.005628	0.005705	0.006121	0.018633	0.018514	0.019137	0.023714
June	0.0075	0.008126	0.007965	0.008053	0.022503	0.021568	0.022015	0.021558
July	0.005097	0.006337	0.006315	0.006311	0.021069	0.019813	0.019952	0.019616
Aug	0.003114	0.005805	0.005894	0.005744	0.018354	0.017595	0.018123	0.01723
Sep	0.002675	0.006738	0.006814	0.006973	0.020145	0.017493	0.017796	0.018267
Oct	0.010564	0.011115	0.011067	0.011455	0.030486	0.030233	0.029998	0.03029
Nov	0.018577	0.018806	0.018565	0.018424	0.039363	0.039487	0.039342	0.039088
Dec	0.009162	0.008217	0.00821	0.00495	0.033304	0.034572	0.033878	0.044249

Table 3. Values of 'K' and 'C' Calculated Using Four Methods from January to December 2007 for FFC

Months	K				C			
	EPM	EM	MOM	MLM	EPM	EM	MOM	MLM
January	2.519408	2.4423	2.399	2.153183	8.12212	8.128039	8.047583	8.176807
February	2.405513	2.373304	2.399	2.503693	7.730428	7.732284	7.856176	7.576004
March	2.364306	2.339493	2.399	2.328818	7.545239	7.546452	7.767611	7.524856
April	2.847658	2.904257	2.899	2.980595	8.383571	8.376897	8.374878	8.345284
May	3.648411	4.46937	4.499	4.685309	12.60041	12.45604	12.43786	12.48305
June	2.701103	2.771493	2.749	2.764655	10.35752	10.34805	10.30141	10.36756
July	3.034102	3.206041	3.199	3.207548	9.764269	9.739116	9.710586	9.78142
August	3.59668	4.336539	4.369	4.321225	12.42671	12.29629	12.29186	12.36791
September	3.517446	4.184578	4.199	4.234286	9.377059	9.286664	9.256297	9.287902
October	2.516474	2.550424	2.549	2.570686	6.855935	6.853513	6.881826	6.836899
November	2.449541	2.463464	2.449	2.443318	5.931315	5.930574	5.932665	5.9495
December	2.519408	2.4423	2.449	2.187136	8.12212	8.128039	8.19422	8.129326

Table 4. Mean Wind Speed for Hawke's Bay from January To December 2010 And Mean Square Error in Wind Speed

Months	**Mean wind speed/(m/s)**				**Mean square error in mean wind speed**			
	EPM	**EM**	**MOM**	**MLM**	**EPM**	**EM**	**MOM**	**MLM**
January	5.43738	5.435883	5.472605	5.377427	2.51E-04	2.62E-04	2.58E-04	3.27E-04
February	5.507083	5.504171	5.511319	5.502853	2.10E-04	1.91E-04	1.93E-04	0.000201
March	5.931259	5.928967	5.948696	5.920141	1.71E-04	1.61E-04	1.59E-04	0.000161
April	7.197758	7.194171	7.210744	7.187204	1.06E-04	9.79E-05	9.75E-05	9.80E-05
May	8.845345	8.818252	8.809858	8.80488	3.42E-05	2.27E-05	2.26E-05	2.32E-05
June	7.753371	7.753358	7.736677	7.751392	9.58E-05	9.66E-05	1.00E-04	9.36E-05
July	7.686606	7.690552	7.664624	7.547262	8.62E-05	7.34E-05	7.75E-05	5.30E-05
August	6.178993	6.160818	6.132884	6.136957	8.97E-05	7.06E-05	7.26E-05	7.64E-05
September	6.169124	6.154108	6.159794	6.1062	8.97E-05	7.06E-05	7.01E-05	7.20E-05
October	5.31715	5.318153	5.324052	5.293761	0.000284	0.000278	0.000285	0.000273
November	5.053796	5.05214	5.093396	5.026755	2.58E-04	2.46E-04	2.35E-04	2.52E-04
December	5.873388	5.874375	5.936262	5.866686	2.29E-04	2.19E-04	2.08E-04	2.11E-04

Table 5. Results of Kolmogorov and Chi Square Tests for Wind Speed Calculated for Hawke's Bay

Months	Kgtest				Chi			
	EPM	EM	MOM	MLM	EPM	EM	MOM	MLM
January	2.51E-04	2.62E-04	2.58E-04	3.27E-04	0.015363	0.014792	0.014537	0.012917
February	0.012307	0.013402	0.013243	0.012853	0.035989	0.035121	0.035129	0.035516
March	0.017303	0.018274	0.018196	0.018349	0.035875	0.035862	0.035643	0.035973
April	0.010709	1.16E-02	1.15E-02	1.16E-02	0.03418	0.033801	0.033695	0.033848
May	0.004836	0.007667	0.007736	0.007433	0.025278	0.021122	0.021157	0.021159
June	0.012675	0.012598	0.01238	0.012908	0.025383	0.025396	0.025639	0.025396
July	0.00496	0.006113	0.005804	0.009828	0.029248	0.026652	0.027395	0.023093
August	0.006056	0.00829	0.008079	0.007576	0.028101	0.026813	0.026978	0.027002
September	0.006056	0.00829	0.008367	0.008363	0.028101	0.026813	0.026787	0.027174
October	0.013984	0.01438	0.013873	0.014977	0.032335	0.032118	0.03233	0.032142
November	0.00963	0.010463	0.010755	0.010287	0.032805	0.03234	0.031733	0.032728
December	0.006672	0.007296	0.007665	0.007853	0.031157	0.030484	0.029802	0.029994

Table 6. Values of 'K' and 'C' Calculated Using four Methods from January to December 2010 for Hawke's Bay

Months	K				C			
	EPM	EM	MOM	MLM	EPM	EM	MOM	MLM
January	2.156744	2.124111	2.119	2.004712	5.454145	5.453935	5.49199	5.399252
February	2.517219	2.587641	2.579	2.551363	5.515377	5.511219	5.518599	5.510477
March	2.558407	2.620561	2.619	2.623818	5.946886	5.94272	5.962938	5.933611
April	2.574963	2.652783	2.649	2.65463	7.217911	7.211391	7.228478	7.204204
May	3.175717	3.520284	3.529	3.487768	8.894706	8.848269	8.839251	8.835789
June	2.505826	2.499456	2.479	2.524915	7.797839	7.79833	7.782471	7.794289
July	2.643485	2.718787	2.699	2.98229	7.806677	7.799369	7.773539	7.612877
August	2.904638	3.114194	3.099	3.046049	6.1809	6.161919	6.133961	6.138194
September	2.904638	3.114194	3.119	3.119665	6.1809	6.161919	6.167613	6.113312
October	2.053459	2.068088	2.049	2.091396	5.33474	5.335156	5.342037	5.309181
November	2.552588	2.587248	2.599	2.580082	5.056871	5.054945	5.096379	5.029454
December	2.217822	2.241606	2.249	2.263825	5.902073	5.901712	5.9657	5.892497

Table 4 shows the values of uncertainties (MSE) in estimated values for January to December, 2010 (for Hawke's bay). Table 5 shows the uncertainties measured by chi square good fit test and Kolmogorov test. The mean wind speed was also calculated and shown in the same table. All the methods employed gave almost same value of mean wind speed for twelve months. The maximum mean wind speed of 8.84 approximately was found in May, whereas the minimum mean wind speed was 5.03 which occurred in November. The Hawke's bay is good place to install wind mills as the potential of wind energy is great from April to September. The wind potential is also appreciable in other months. Table 6 shows the values of Weibull parameters (k and c) for Hawke's bay from January to December, 2010.

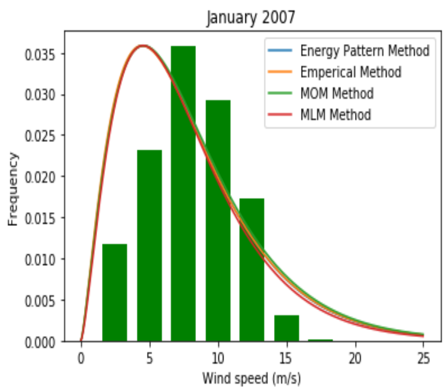

Figure 1a. January 2007 (FFC)

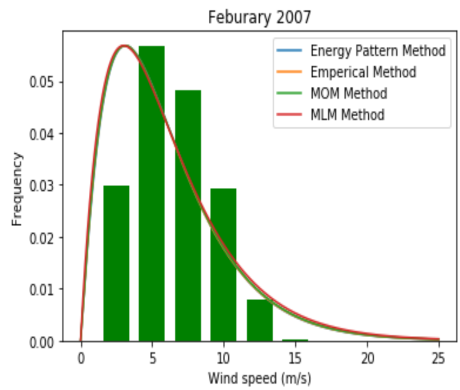

Figure 1b. February 2007 (FFC)

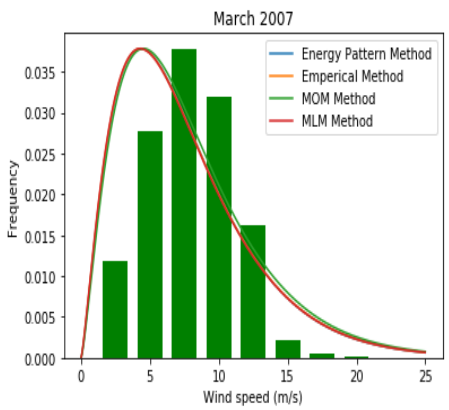

Figure 1c. March 2007 (FFC)

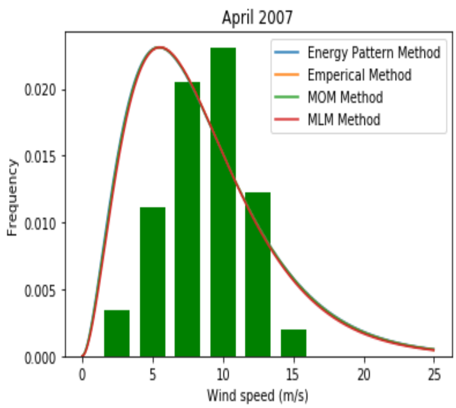

Figure 1d. April 2007 (FFC)

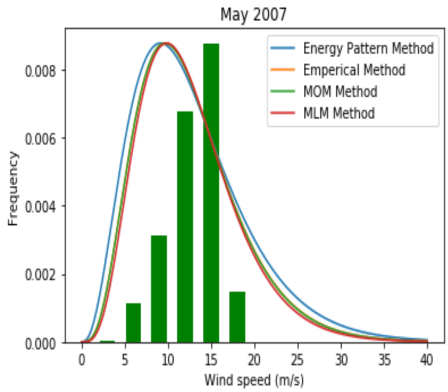

Figure 1e. May 2007 (FFC)

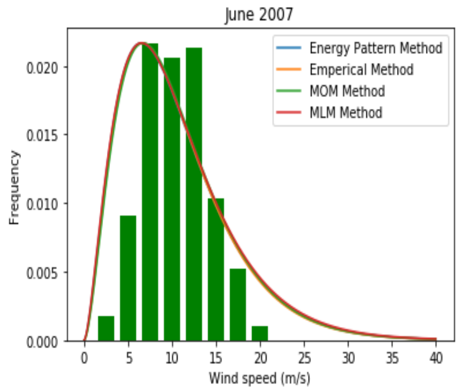

Figure 1f. June 2007 (FFC)

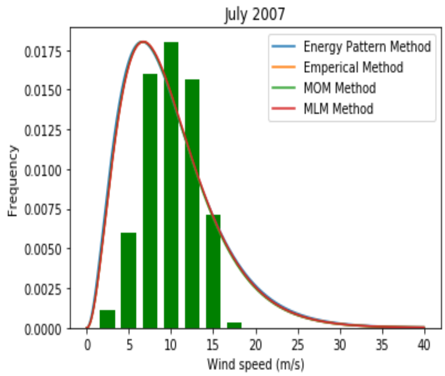

Figure 1g. July 2007 (FFC)

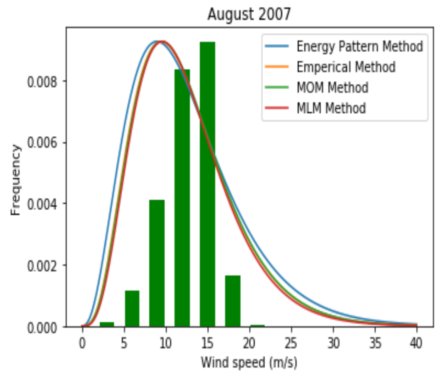

Figure 1h. August 2007 (FFC)

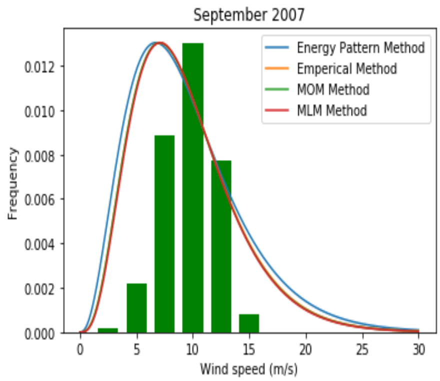

Figure 1i. September 2007 (FFC)

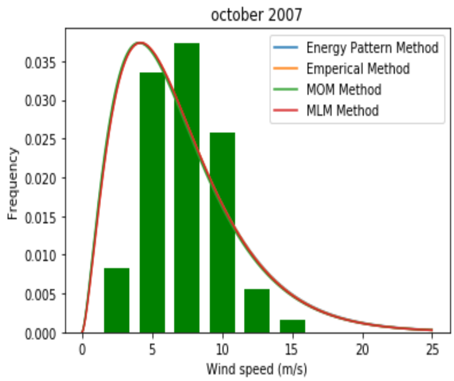

Figure 1j. October 2007 (FFC)

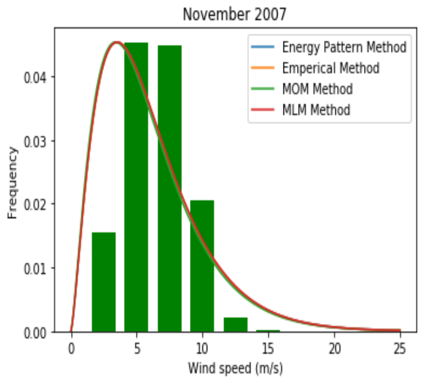

Figure 1k. November 2007 (FFC)

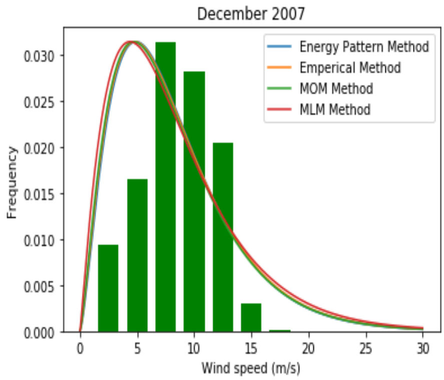

Figure 1l. December 2007 (FFC)

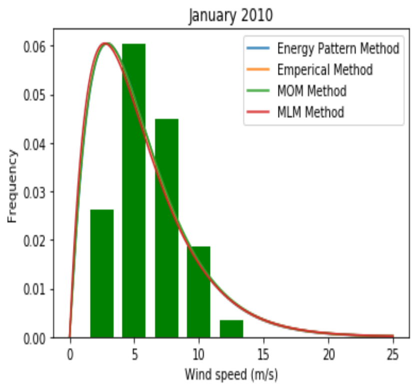

Figure 2a. January 2010 (Hawke's bay)

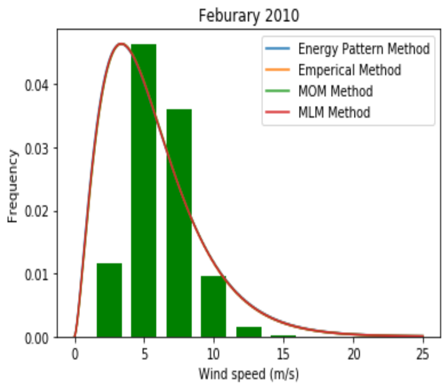

Figure 2b. Febuary2010 (Hawke's bay)

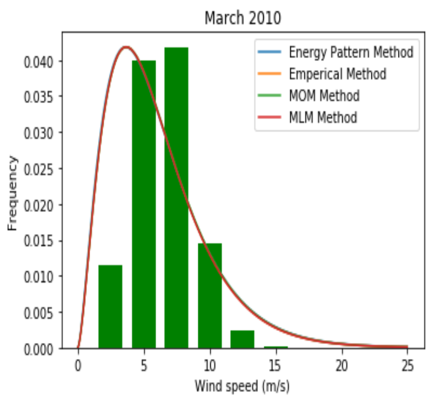

Figure 2c. March 2010 (Hawke's bay)

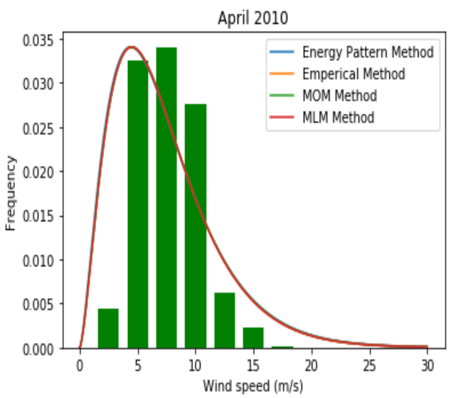

Figure 2d. April 2010 (Hawke's bay)

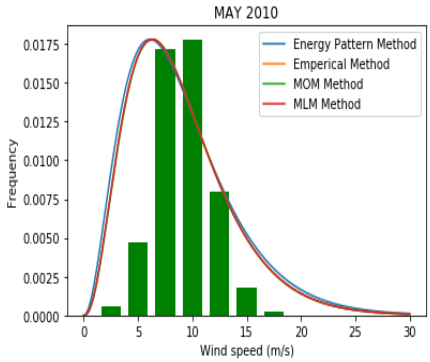

Figure 2e. May 2010 (Hawke's bay)

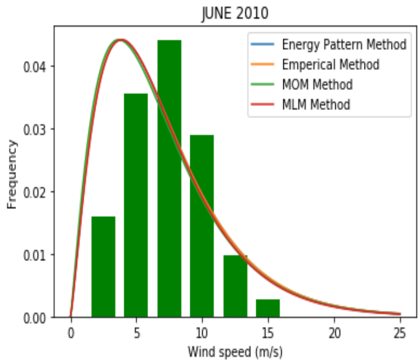

Figure 2f. June 2010 (Hawke's bay)

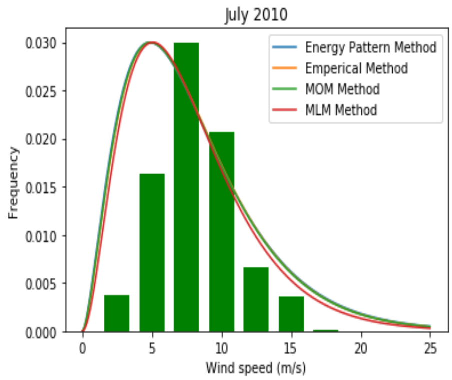

Figure 2g. July 2010 (Hawke's bay)

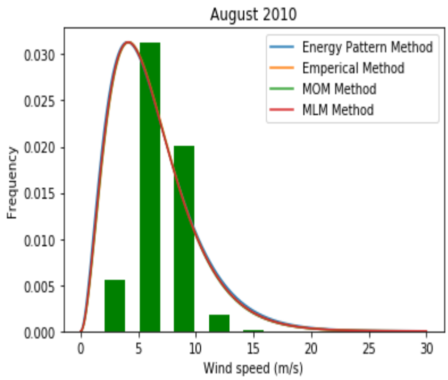

Figure 2h. August 2010 (Hawke's bay)

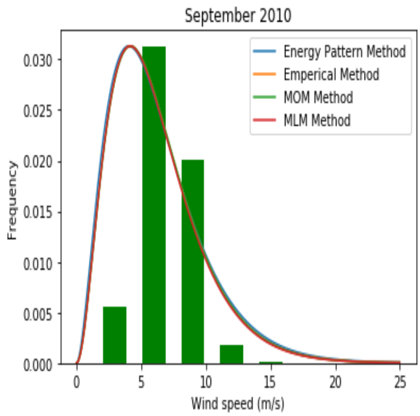

Figure 2i. September 2010 (Hawks bay)

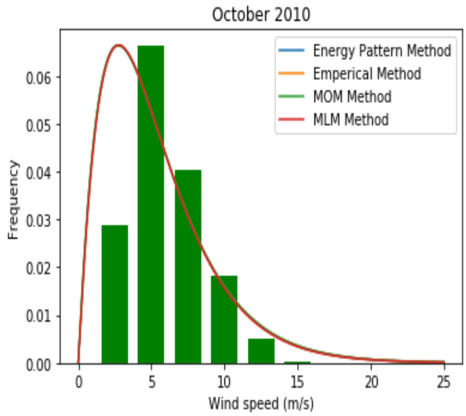

Figure 2j. October 2010 (Hawks bay)

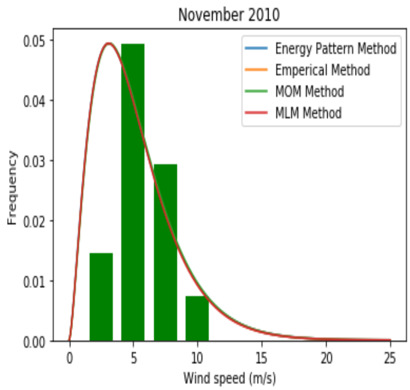

Figure 2k. November 2010 (Hawke's bay)

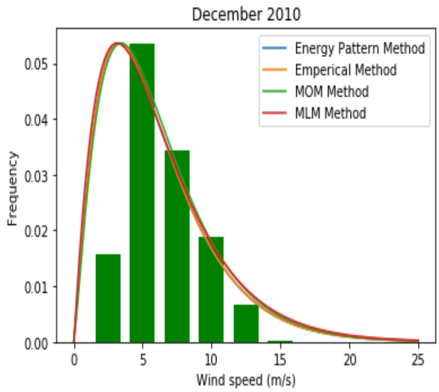

Figure 2l. December 2010 (Hawke's bay)

Figures. 1 and 2 show curves drawn by 'k' and 'c' values and the histogram of the recorded data.

4. Conclusion

Weibull distribution was used to model and analyze the wind potential of two places, that is, FFC and Hawke's bay of Karachi city. The Weibull distribution parameters were calculated using four different methods. The Weibull Probability Density Function (PDF) was drawn for each of these methods. It was found that each method produced the same distribution curves. Figures 1a-1j and 2a-2j show that curves obtained by different methods overlap and a histogram was also drawn from the recorded wind speed data. These figures also show that Weibull distribution curves are a good representation of the recorded wind speed data. The maximum wind potential was found during the month of August for FFC and during the month of May for Hawke's bay. FFC has more wind potential than Hawks bay.

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