minimum wind speed values are recorded in July and October with a value of 4.31 m/s and 6.04 m/s , respectivily.

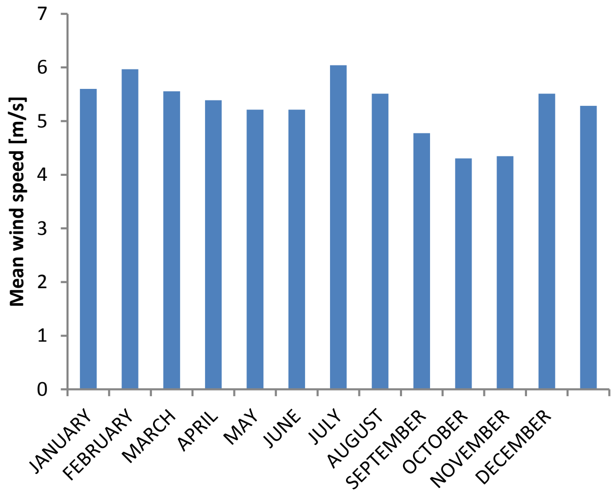

Figure 2. Monthly variation of mean wind speed in Tobruk, Libya

In order to know if the area is suitable for insullation of a wind turbine, the most probable wind speed (Vmp) and the maximum energy carrying wind speed (VmaxE) were calculated using Eqs. (16) and (17). Figure 3 shows the monthly variation of mean, Vmp and VmaxE. It is observed that monthly varition of Vmp and VmaxE are varied between 4.41-6.39 m/s and 5.50-8.57 m/s, respectively.

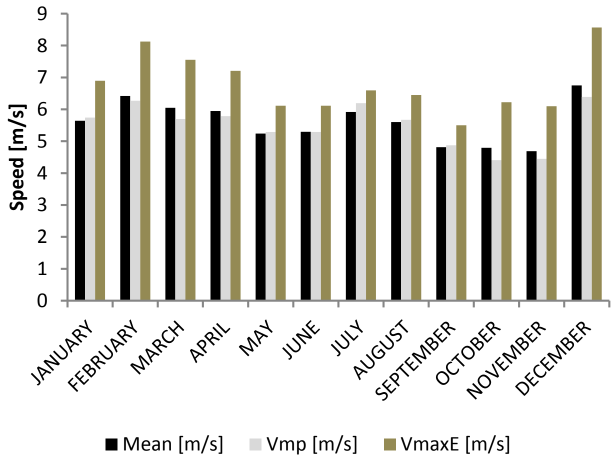

Figure 3. Monthly variation of Vmp and V maxE in Tobruk, Libya

4.2 Mean air density of Tobruk

Table 2 is tabulated the average air temperature and atmospheric pressure of the studied area. Assuming that air is an ideal gas, average yearly air density (ρ) values were calculated using Eq. (24) [33] or Eq. (25) [34]. Therefore, the averaged monthly air density was also tabulated in Table 2. In the current study, the air density at 10m height is assumed constant for other heights as there will be no significant difference.

$$\rho(z) = \frac{353.049}{T} e^{\left(-0.034\frac{z}{T}\right)} \quad (24)$$

$$\rho(z) = \frac{P}{RT} e^{\left(-\frac{gh}{RT}\right)} \quad (25)$$

P is the atmospheric pressure (hPa), R is the molar gas constant (287.05 J/(K mol)), T is the air temperature (K), g is the gravitational constant (9.81 m/s^2), and z is the considered height(s)

Table 2. Mean monthly air temperature, atomospheric pressure and air density at 10m height

Month	Air temperature [K]	Atomospheric pressure [hPa]	Air density [kg/m^3]
J	287.0	1021	1.229
F	288.0	1019	1.224
M	290.0	1017	1.216
A	292.0	1014	1.208
M	294.0	1014	1.199
J	297.0	1014	1.187
J	299.0	1014	1.179
A	300.0	1014	1.175
S	299.0	1015	1.179
O	296.0	1017	1.191
N	292.0	1018	1.208
D	288.0	1020	1.224
Averaged	293.5	1016.4	1.202

4.3 Analysis of Weibull parameters, power and energy densities

The monthly values of the Weibull distribution parameters are presented in Table 3. The distribution paramters values were calculated using Eqs. (4) and (6). In addition, the wind power dnesity and energy are determined using Eqs. (9) and (10), respectively. It is found that the monthly shape paramters are ranged between 2.822 and 6.740. In addition, the scale paramters are with the rang of 5.117-7.270m/s. Moreover, it is found that the lowest wind power density is achived in November (61.864 W/m^2) and the highest value is obtained in December (184.792 W/m^2) as shown in Table 3.

Table 3. Monthly Weibull parameters, power density and energy density.

Month	k	c [m/s]	WPD [W/m^2]	E [kWh/m^2]
J	3.887	6.199	107.921	945.390
F	3.257	7.014	158.815	1391.223
M	3.123	6.445	132.871	1163.948
A	3.547	6.351	126.330	1106.651
M	4.39	5.611	86.476	757.531
J	4.39	5.611	89.170	781.133
J	6.74	6.345	124.605	1091.539
A	4.657	5.972	105.677	925.732
S	4.813	5.117	66.988	586.815
O	2.822	5.148	66.188	579.807
N	2.949	5.118	61.864	541.925
D	3.064	7.27	184.792	1618.778

4.4 Extrapolation of wind speed and parameters Weibull at different hub height

During the investigation period, the mean annual wind speed at Tobruk area is 5.29 m/s at 10m height. The monthly averaged wind speed at various heights is estimated using Eq. (11) and presented in Figure 4. It is observed that the maximum and minimum wind speeds occurred in July and October, respectively. In addition, it is observed that the monthly variations of wind speed at various heights share a similar pattern as shown in Figure 4.

The Weibull parameters values at various heights are calculated at various heights using Eqs. (13)-(15) and tabulated in Table 4. It is observed that the Weibull paramters (k and c) are increased with the hub heights, which indicated that the wind speed of Nalut is constant. The wind power density and the wind speed at various height are shown in Figure 5. It is noticed that the wind power density is increased with the increased of altitude.

It can be concluded that there is a good correlations between wind speed and Weibull parameters because they are function of heights as shown in Figure 5 and Table 4.

Table 4. Weibull parameters extrapolated at various heights

Month	30 m		50 m		70 m	
	k	c [m/s]	k	c [m/s]	k	c [m/s]
J	3.887	7.877	3.907	8.805	3.917	9.475
F	3.257	8.913	3.267	9.963	3.277	10.720
M	3.123	8.189	3.143	9.154	3.143	9.851
A	3.547	8.070	3.567	9.021	3.577	9.707
M	4.390	7.129	4.410	7.969	4.420	8.575
J	4.390	7.129	4.410	7.969	4.420	8.575
J	6.740	8.062	6.760	9.012	6.770	9.697
A	4.657	7.588	4.677	8.482	4.687	9.127
S	4.813	6.502	4.823	7.268	4.833	7.821
O	2.822	6.541	2.842	7.312	2.852	7.868
N	2.949	6.503	2.969	7.269	2.979	7.822
D	3.064	9.238	3.084	10.330	3.094	11.110

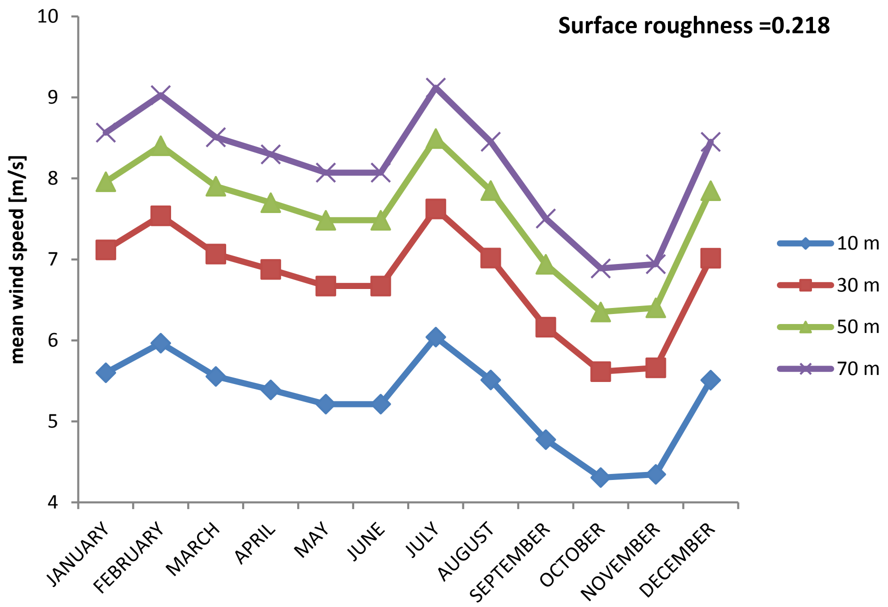

Figure 4. Monthly averaged wind speed at various heights

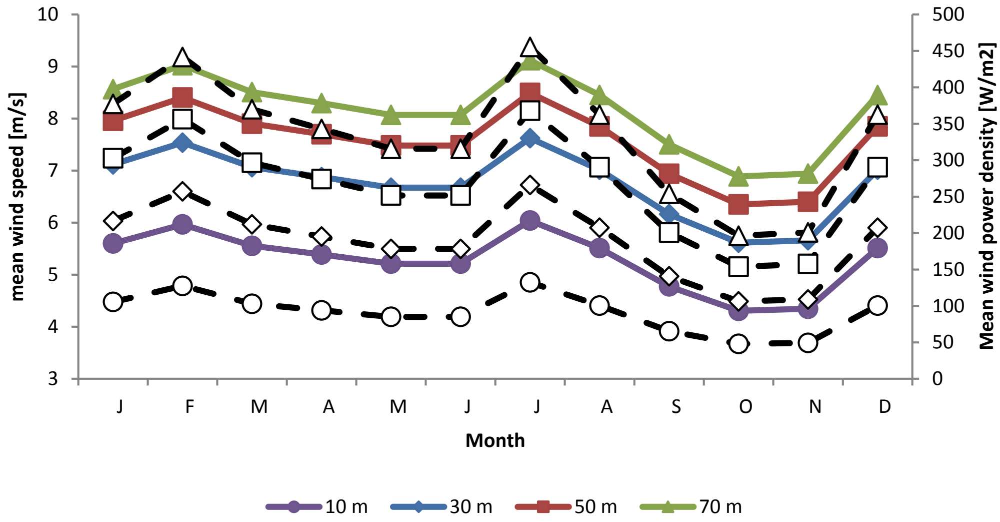

Figure 5. Monthly variation of wind power density and wind speed in Tobruk, Libya at verious height (wind speed: solid line; wind power density: dashed line)

4.5 Performance selected wind turbines

The selected wind turbines that satisfy the estimated annual energy for the selected location are shown in Table 5. In this study, seven wind turbine models with the different are used in the present work. Selection of these wind turbines were made after an overall comparison between different types of wind turbines.

In order to evaluate the cost of kWh of the energy produced by the turbine at the selected area, the following assumption had been taken.

1). The interest rate (r) and inflation rate (i) were taken to be 8% and 6%, respectively [35].
2). Machine life (n) is 20 years [36].
3). Operation and maintenance cost C_{omr} is assumed 7% of the initial capital cost of the wind turbine installation system (system price/life time) [37].
4). Scrap value (S) was assumed 10% of the turbine price and civil work.
5). Investment (I) is the summation of the turbine price and other initial cost which varied from country to other country [37, 38]. In the present study, Investment (I) is assumed to be 68%.

Table 5. Characteristics of the selected wind turbines

Characteristics	Bonus -33	Bonus -54	Vestas - 80	YDF-1500-87	EWT DW52	Suzlon-S52	Vestas - V47
Hub height [m]	30	50	67	75	75	75	55
Rated power [kW]	300	1000	2000	1500	500	600	660
Rotor diameter [m]	33.4	54.2	80	87	51.5	52	47
Cut-in wind speed [m/s]	3	3	4	3	3	4.5	4
Rated wind speed [m/s]	14	15	16	10.2	10	14	15
Cut-off wind speed [m/s]	25	25	25	25	25	25	25

The monthly capacity factor of the selected wind turbine is shown in Figure 6. It is found that EWT DW52 has the maximum capacity factor compared to other models. In addition, it is observed that the maximum monthly capacity factor is recorded in July with a approximately value of 57.60%. In addition, the electricity-generated cost per kWh of wind turbine with capacity of 1500kW is the lowest compared to other models as shown in Figure 7. The annual capacity factor and the electricity-generated cost per kWh of selected wind turbine are tabulated in Table 6.

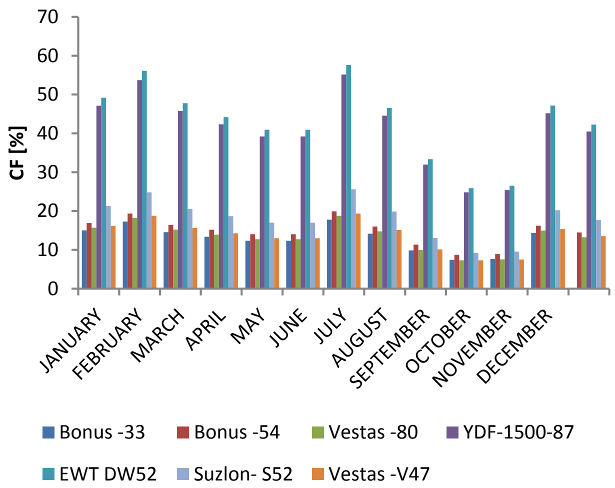

Figure 6. Monthly variation of capacity factor for for Tobruk, Libya

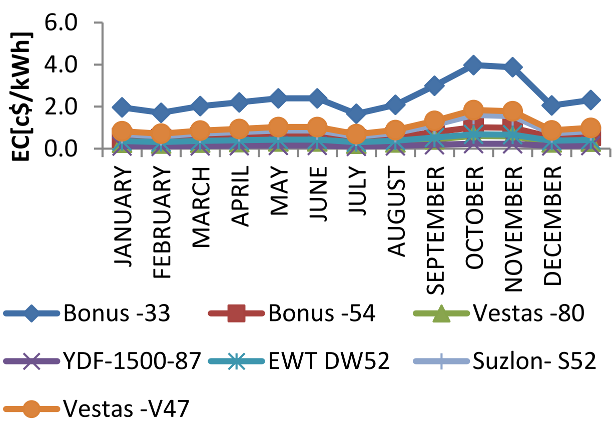

Figure 7. Monthly variation of electricity generated cost per kWh (EC) for for Tobruk, Libya

Table 6. Annual energy production for studied area

Models	Total energy power [MWh]	CF [%]	EC [c$/kWh]
Bonus -33	13.96	12.75	2.3121
Bonus -54	52.83	14.47	0.6109
Vestas -80	96.48	13.22	0.3345
YDF-1500-87	221.50	40.46	0.1457
EWT DW52	77.11	42.25	0.4185
Suzlon- S52	38.70	17.67	0.8340
Vestas -V47	32.55	13.51	0.9916
Bonus -33	13.96	12.75	2.3121
Bonus -54	52.83	14.47	0.6109
Vestas -80	96.48	13.22	0.3345

5. CONCLUSIONS

In this study, the evaluation of wind potential at Tobruk in Libya was investigated. Moreover, the capabilities of three selected wind turbine to generate power at the selected area were examined and compared. It is found that the mean wind speed was ranged from 4.31 to 6.04 m/s at 10 m height. Moreover, the values of wind power density were ranged from 61.864W/m^2 to 184.792 W/m^2. The result demonstrated that the win potential at the selected area could be considered as Marginal (class 2) according to wind power classification. In comparison, it was found that YDF-1500-87 has the lowest energy cost per KWh and maximum energy power compared to other models.

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