Wind Power Generation Scenarios in Lebanon

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Abstract-Renewable energy in terms of solar and wind energy can be an essential part of Lebanon's strategies to add new capacity, increase energy security, address environmental concerns, and resolve the electricity crisis. In this regard, there is an urgent need to develop road maps in order to reduce the effect of global warming and enhance sustainable technological development for generating clean power in the country. Therefore, the present paper evaluates Lebanon's wind energy generation potential as an alternative solution to supply electricity to households in various locations distributed over Lebanon. In the present study, the measured data are used to evaluate the wind energy potential in Lebanon and to find suitable locations to install wind farms in the country. Accordingly, the results demonstrated that Ain ed Dabaa is the most suitable location for the installation of a wind farm. Moreover, the study aims to develop a wind energy cost analysis techno-economic model for eight conventional wind turbines and a Barber wind turbine, which was found to be very competitive. Consequently, this study showed that the implementation of a wind turbine could provide clean, economical, and continuous production of electricity in countries that suffer from daily blackouts.

Keywords-Lebanon; wind potential; conventional wind turbines; Barber wind turbine; techno-economic model

I. INTRODUCTION

Energy demand growth, global warming, climate change, and increasing consumption of fossil fuels has led to the transition from conventional fuels to renewable energy resources [1-3]. Moreover, the use of fossil fuels in the generation of electricity contributes significantly to Greenhouse Gas (GHG) emissions, which further contributes to climate change [4, 5]. According to [6], utilizing renewable energy as an alternative energy source will help reduce environmental problems, essentially GHG emissions and air pollution. The use of renewable energy, including wind and solar energy, is rapidly increasing because it is economically viable and has limited environmental impact [7]. During the recent years, many studies have evaluated wind and solar energy potential as clean power sources for electricity generation in various countries. For instance, authors in [8] analyzed the performance of a 5kW rooftop photovoltaic (PV) system in Northern India. The results indicated that the annual average capacity utilization factor was 16.39%. Authors in [9] evaluated the wind potential in Taza and Dakhla cities, Morocco using the Weibull distribution function. The results demonstrated that the value of wind power density is 435.96W/m^2 and 122.91W/m^2 in Dakhla and Taza respectively. Authors in [10] estimated the potential of rooftop PV electricity in Lethbridge, Canada using LiDAR data and ArcGIS. The results showed that the developed system has a huge potential to offset the energy demand of the city. Authors in [11] assessed the performance of the Aventa AV-7 wind turbine for electricity generation in Medina. It was found that the annual generation of energy from the selected turbine is 8648kWh.

A. *Electricity Situation in Lebanon*

Lebanon is located on the Eastern edge of the Mediterranean Sea, between 33.8547°N latitude and 35.8623°E longitude. At present, fossil fuels (97%) and hydropower (3%) are the main sources of electrical energy in Lebanon. Generally, the production capacity of electricity reaches 3600MW, while the actual production capacity currently does not exceed 2000MW. Currently, Lebanon has 7 thermal power plants, 6 hydroelectric plants, and 2 power ships operating to generate electricity. The electricity consumption has increased due to the growth of the population and the continuing demand for new large and small appliances as shown in Figure 1 [12]. Besides, only 70% of total generated power covered the energy needs in the country as shown in Figure 2.

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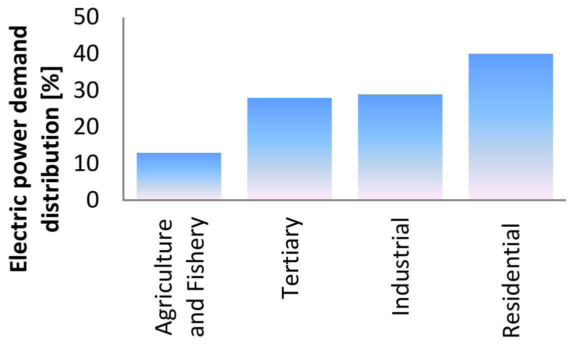

Fig. 1. Electrical power demand distribution [12].

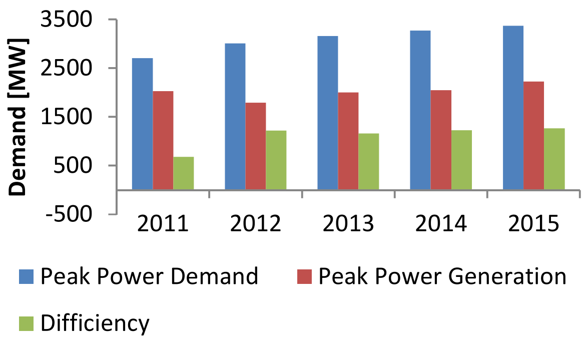

Fig. 2. Electrical power demand distribution [13].

The electricity crisis is one of the most important issues affecting the daily lives of citizens, shop owners, and small businesses in Lebanon for years. The electricity crisis in Lebanon is not new and the electricity sector has suffered from decades of mismanagement, weak policies, and the absence of proper planning. The country has been suffering from a severe shortage of energy due to the dilapidation of old power stations that were accompanied by sabotage operations during the past years. As a result, duration of power cuts for citizens increased to more than 20 hours a day. For this reason, citizens rely on domestic power generators or small home generators, both of them adding great financial burdens. According to [14, 15], private generators are utilized in all the country to meet the energy demand, and they are considered the third main source of production of electricity.

B. The Renewable Energy Situation in Lebanon

According to [14, 16], the power sector in the country contributes about 58% of total CO_2 emissions, of which 25% come from private generators. Consequently, utilizing renewable energy would reduce the consumption of fossil fuels and could be a clean source for electricity generation in the country. Authors in [17] concluded that wind power systems could be alternative sources to fulfill the electrical power required and reduce the CO_2 emissions. Moreover, according to [17], standalone wind turbines are privately utilized for the generation of electricity for homes and small private companies. Approximately 2.06% of wind power is currently used for electric power generation in Lebanon [18]. Authors in [19] found that wind energy could be utilized in the country for electricity generation during the night. Authors in [20] concluded that the utilization of small-scale wind systems could be used for the generation of electricity from wind energy in Beirut, Sidon, and Tripoli. Authors in [21] concluded that wind turbine systems could be installed to complement the main grid with electric power during the peak hours.

Numerous researchers have investigated the potential of renewable energy, particularly wind energy in different locations in Lebanon [16, 19-25]. For instance, authors in [25] investigated the wind potential in 9 locations in Lebanon. The author concluded that a small-scale wind system could be more profitably used for these areas. Authors in [23] studied the characteristics of wind energy in five locations in Lebanon. Their results showed that the wind energy system can be an alternative solution and more cost-effective than conventional power sources. Authors in [24] assessed the wind energy potential in 8 locations in the Northern Lebanon. The results showed that wind power system can be utilized to reduce the energy shortage in the country. According to [16, 19-25], it can be concluded that:

- The utilization of wind power systems in Lebanon is limited.
- Renewable energy systems can solve the electricity crisis and reduce CO_2 emissions.
- Only a few studies investigated the wind turbine performance for generating electricity in Lebanon.

According to the literature review, no studies evaluated the potential and variability assessment of wind energy over Lebanon considering various climate conditions.

C. The Importance of the Current Study

Globally, wind energy and its associated technologies are essential to support electricity consumption and supply power in order to mitigate the electricity crisis. Besides, as an ongoing study on the assessment of renewable energy systems, primarily wind and solar energy in different locations, the present study aims to investigate the wind potential in various locations distributed over Lebanon. To achieve this, measured data for the period 2010-2017 were collected from meteorological agencies. Consequently, the Weibull distribution function was used to evaluate the characteristics of wind speed in the selected locations. The distribution parameters were estimated using the maximum likelihood method. The power density was calculated and was used to evaluate the potential of wind energy in each location. Additionally, the Power-Law exponent method was utilized to estimate the wind speed at various hub heights. Based on the literature, wind power is low and unsustainable in many regions in Lebanon. Consequently, this study aims to evaluate the techno-economic performance of the Ferris wheel-based Barber wind turbine, which is a new wind turbine technology, at low wind speed locations. Furthermore, the performance of the selected wind turbine is compared with conventional wind turbines under the same economic conditions.

II. MATERIALS AND METHODS

The proposed methodology aims to assess the wind energy potential in 12 locations in Lebanon in order to identify suitable locations for future wind power systems. Then, the economic viability of wind systems is evaluated. Figure 3 illustrates the proposed methodology used in this study.

A. Study Area and Dataset

This examination was undertaken to identify the best location for installing wind power systems among the chosen locations in Lebanon. Table I summarizes the geographic information of the selected locations.

TABLE I. THE SELECTED LOCATIONS

Location	Latitude [°N]	Longitude [°E]	Elevation [m]
Younine	34.0776	36.2750	1198
Birket Aarous	34.2911	36.1456	2766
Ain ed Dabaa	34.4431	35.8992	296
Mqaybleh	34.6460	36.3577	330
Ras Ouadi Ed Darje	34.2533	36.5775	1555
Kfardebian	34.0017	35.8349	1670
Qaraoun	33.5669	35.7193	913
Khartoum	33.4079	35.3751	305
Iskandarounah	33.1550	35.1685	53
Beirut	33.8938	35.5018	40
Khiam	33.3294	35.6148	697
Hekr El Dahri	34.6306	36.0237	10

B. Wind Speed Distribution

The correct determination of the probability distribution of wind speed is a prominent factor in evaluating the wind energy potential in a region. Thus, knowing the wind speed distribution at a specific location is necessary for determining its potential. A 2-parameter Weibull distribution is commonly utilized to study the characteristics of wind speed. The Weibull Probability Density Function (PDF) $f(v)$ and the cumulative distribution function $F(v)$ expressions are [26]:

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

$$F(v) = 1 - exp\left(-\left(\frac{v}{c}\right)^{k}\right) \quad (2)$$

where v is the mean wind speed (m/s), k is the shape parameter, and c is the scale parameter of the Weibull distribution.

To determine the distribution parameter, the Maximum Likelihood (ML) method is used to determine k and c [27]:

$$k = \left(\frac{\sum_1^n v_i^k ln(v_i)}{\sum_1^n v_i^k} - \frac{\sum_1^n ln(v_i)}{n}\right)^{-1} \quad (3)$$

$$c = \left(\frac{1}{n}\sum_1^n v_i^k\right)^{1/k} \quad (4)$$

Following the Weibull distribution, (5) and (6) are utilized to estimate the average wind speed and the standard deviation of the wind speed respectively.

$$v_m = c\Gamma\left(1+\frac{1}{k}\right) \quad (5)$$

$$\sigma = \sqrt{c^2\left[\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right]} \quad (6)$$

C. Wind Power Density

To assess the potential of wind energy, (7) is utilized to determine the Wind Power Density (WPD) at a specific location:

$$\left(\frac{P}{A}\right)_W = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{3}{k}\right) \quad (7)$$

The average value of WPD can be estimated by [21]:

$$\frac{P}{A} = \frac{1}{2}\rho v^3 \quad (8)$$

$$\frac{P}{A} = \frac{1}{2}\rho v^3 f(v) \quad (9)$$

$$\frac{\bar{P}}{A} = \frac{1}{2}\rho \bar{v}^3 \quad (10)$$

where P is wind power density (W), $\bar{P}$ is the mean wind power density (W), A is the swept area (m^2), ρ is the air density (kg/m^3), $f(v)$ is the PDF, and $\bar{v}$ is the mean wind speed (m/s).

D. Wind Speed Data Extrapolation at Different Hub Heights

Generally, wind speed measurements are carried out at a height of 10m above the ground. To obtain energy from wind turbines, it is necessary to estimate wind speeds at various hub heights using (11) [28]:

$$\frac{v}{v_{10}} = \left(\frac{z}{z_{10}}\right)^{\frac{0.37-0.088ln(v_{10})}{1-0.088ln(z_{10}/10)}} \quad (11)$$

where v is the wind speed at the wind turbine hub height z, v_{10} is the wind speed at the original height z_{10}.

E. Energy Output of a Wind Turbine

The produced energy by the wind turbine E_{out} can be estimated by [28]:

$$E_{out} = \sum_{i=1}^{n} \mathrm{P_{out}}\, t \quad (12)$$

where t is time and P_{out} is determined by:

$$P_{out} = \begin{cases} 0 & \text{when } v < v_{ci} \\ \frac{P_R v_{ci}^k}{v_{ci}^k - v_R^k} + \left(\frac{P_R}{v_R^k - v_{ci}^k}\right) v^k & \text{when } v_{ci} \le v \le v_R \\ P_R & \text{when } v_R \le v \le v_{co} \\ 0 & \text{when } v > v_{co} \end{cases} \quad (13)$$

where P_R is the rated power of the wind turbine, v_{ci} the turbine's cut-in speed, v_{co} turbine's cut-off speed, and v_R is its rated wind speed.

The average power generation of the turbine can be expressed as [29]:

$$P_{out} = P_R\left[\frac{exp\left[-\left(\frac{v_{ci}}{c}\right)^k\right] - exp\left[-\left(\frac{v_R}{c}\right)^k\right]}{\left(\frac{v_R}{c}\right)^k - \left(\frac{v_{ci}}{c}\right)^k} - exp\left[-\left(\frac{v_{co}}{c}\right)^k\right]\right] \quad (14)$$

The Capacity Factor (CF) is estimated [29, 30]:

$$CF = \frac{E_{out}}{8760 P_R} \quad (15)$$

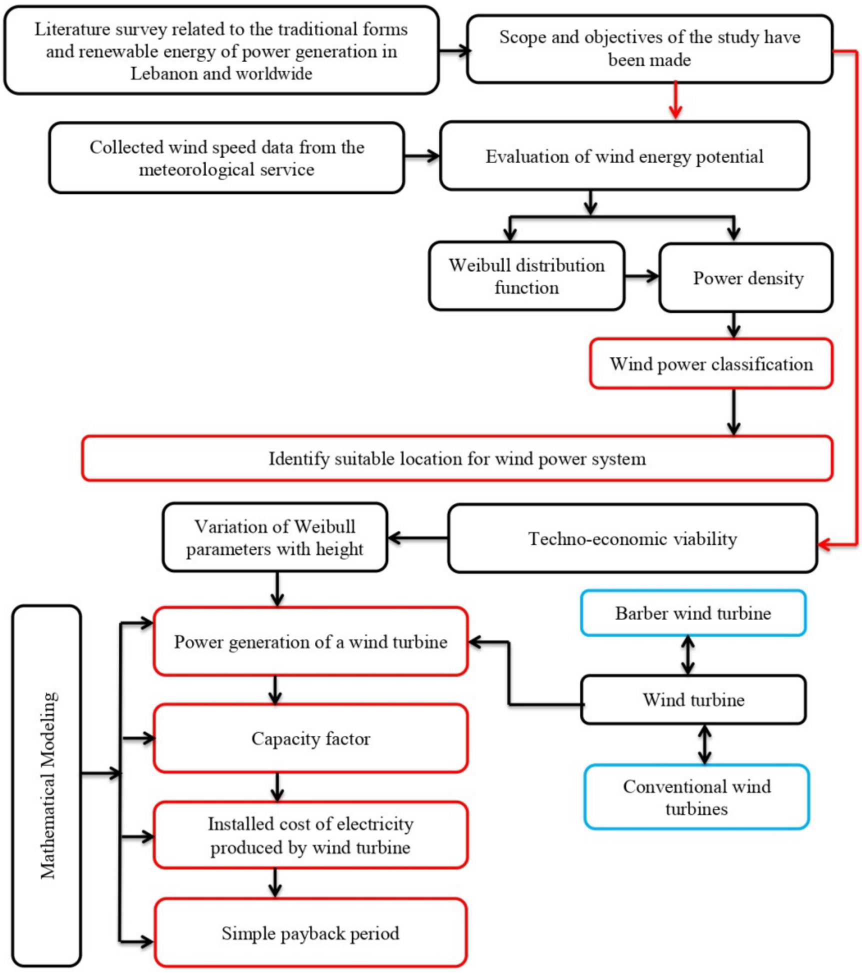

Fig. 3. Flowchart of the proposed methodology.

In this study, various wind turbines assumed the load profile for all months of the year. Nine wind turbines (Table II) with various characteristics including the Capital Cost of acquisition (CC) and O&M Cost (OMC) are selected as shown in Tables II-III. Generally, Conventional Wind Turbines (CWTs) are designed to generate electricity at high wind speeds. The cut-in speed and rated wind speed for these turbines are within the range of 3-5m/s and 12-15m/s respectively [30, 31]. CWTs are heavy and expensive to buy, install, and maintain. Therefore, the performance of the Ferris Wheel Wind Turbine (FWWT) is compared with the selected CWTs due to its advantages, such as its light design, lower weight to power ratios, etc. [32].

TABLE II. SELECTED WIND TURBINES

Model No.	Wind turbine model	Manufacture
Model#1	Enercon E5	Enercon GmbH
Model#2	Enercon E44	Enercon GmbH
Model#3	EWT DW61	Emergya Wind Technologies B.V.
Model#4	GE SLE 1.5	Winergy/Eickhoff/Bosch.
Model#5	AN Bonus 1 MW/54	Siemens Wind Power A/S
Model#6	DEWIND-62-91.5 m	DeWind
Model#7	Neg-Micon	NEG Micon A/S
Model#8	Vestas-V66	Vestas Wind Systems A/S
Model#9	Barber wind turbine	BarberWind Turbines

TABLE III. CHARACTERISTICS AND SPECIFICATIONS

Model No.	HH [m]	P_R [kW]	v_{ci} [m/s]	v_R [m/s]	v_{co} [m/s]	CC [USD]	OMC [USD/y]
Model#1	76	800	3	13	25	1750000	51250
Model#2	55	900	3	16.5	34	2337500	51250
Model#3	69	900	2.5	10	25	1918770	57158
Model#4	85	1500	3	14	25	3375000	57158
Model#5	50	1000	3	15	25	863530	25043
Model#6	91.5	1000	2.5	11.5	23	1124758	32618
Model#7	70	1000	4	14	20	1162460	33711
Model#8	67	1650	4	16	25	1768000	51272
Model#9	70	800	3	9.6	20	1400000	42000

F. Economic Viability of a Wind System

The wind energy farm's viability is dependent on its ability to generate energy at low operating cost. In this paper, the Levelized Cost Of Electricity (LCOE) is utilized to calculate the Electricity Generated Cost (EGC) of the wind turbine [32]:

$$LCOE = \left(\frac{\frac{i(1+i)^n}{(1+i)^n-1}}{8760f(v)\left[\frac{1}{2}\rho A v^3 C_p\right]}\right)\left[1+\frac{C_{om}}{i-e}\left[1-\left(\frac{1+e}{1+i}\right)^n\right]\right] \quad (16)$$

where ρ=1.23kg/m^3 is air's density, A is the swept area (m^2), C_p is the Betz limit power coefficient (theoretical value C_p =0.59), e is the escalation rate of operation and maintenance, i is the interest rate, n is the useful lifetime of the turbine in years, and C_{om} is the operation and maintenance costs during the first year.

Additionally, (17) is used to determine the simple payback period (SPP) [32]:

$$\mathrm{SPP} = \frac{I}{8760 f(v)\left[\frac{1}{2}\rho A v^3 C_p\right] P_e} \quad (17)$$

where I is the installed capital cost of the wind turbine plus the costs of civil works and P_e is the price of electricity ($/kWh).

III. RESULTS AND DISCUSSION

A. Characteristics of the Wind Speed at 10m Height

The statistical description of monthly wind speed includes mean value, Standard Deviation (SD), Coefficient of Variation (CV), Minimum (Min.), Maximum (Max.), Kurtosis (K), and Skewness (S) as summarized in Table IV for all selected locations. According to the findings, it is noticed that the maximum mean monthly wind speed of 4.90m/s is recorded in Ain ed Dabaa, while the minimum of 2.81 is recorded in Khiam and Khartoum. The monthly wind speeds for Ain ed Dabaa and Khartoum are illustrated in Figure 4. It is observed that the maximum value of monthly wind speed of 5.82m/s is recorded in January. The highest value of 3.03m/s for Khartoum is recorded in June as shown in Figure 4. It can be seen that the CV values are moderately low, ranging from 6.52% to 17.25%. Additionally, all S values for most of the selected locations are negative, indicating that all distributions are left skewed.

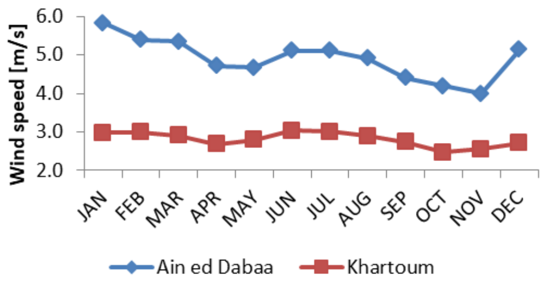

Fig. 4. Mean monthly wind speed at a height of 10m.

TABLE IV. STATISTICAL ESTIMATORS OF MONTHLY WIND SPEED

Variable	Younine	Birket Aarous	Ain ed Dabaa	Mqaybleh	Ras Ouadi Ed Darje	Khiam
Mean	2.90	3.01	4.90	2.91	3.19	2.81
SD	0.45	0.31	0.53	0.30	0.45	0.18
CV	15.37	10.14	10.79	10.14	14.05	6.52
Min.	2.32	2.44	4.00	2.36	2.54	2.47
Max.	3.51	3.45	5.82	3.34	4.03	3.03
S	0.03	-0.56	-0.15	-0.56	0.52	-0.54
K	-1.46	-0.26	-0.41	-0.26	-0.19	-0.81
Variable	**Kfardebian**	**Qaraoun**	**Khartoum**	**Iskandarounah**	**Beirut**	**Hekr El Dahri**
Mean	3.48	2.86	2.81	3.32	3.48	2.91
SD	0.41	0.19	0.18	0.57	0.41	0.30
CV	11.66	6.52	6.52	17.25	11.66	10.14
Min.	3.04	2.51	2.47	2.72	3.04	2.36
Max.	4.22	3.08	3.03	4.27	4.22	3.34
S	0.82	-0.54	-0.54	0.42	0.82	-0.56
K	-0.75	-0.81	-0.81	-1.46	-0.75	-0.26

B. Determination of Weibull Parameters

The Weibull distribution parameters for the selected locations using monthly wind speed data were determined using the ML approach. The calculated shape k and scale c parameters of all selected locations at 10m height are shown in Figure 5. The value of k ranged from 5.99 to 15.45 with an average value of 10.49. The annual value of c range was 2.88-5.04m/s with an average value of 3.32m/s. Moreover, the average wind speed and its SD were calculated using from (5) and (6) and are shown in Figure 5. It is observed that the mean wind speed and SD are within the range of 2.78-4.8m/s and 0.22-0.63m/s respectively. Moreover, the PDF indicates the frequency of different levels of speed. It can be utilized to estimate which level of wind speed is prevalent in the location. The wind speed where the distribution curve peaks are the most frequently observed wind speed for the location. Figure 6 illustrates the PDF of all selected locations.

C. Wind Power Density

To evaluate the wind potential in the selected locations, the annual WPD is computed from (7). The value of WPD for each location is tabulated in Figure 7. It is found that the value of WPD ranged from 13.18W/m^2 to 67.44W/m^2 with an average value of 21.03W/m^2. Based on these values, the wind energy generation potential of these locations is classified as class 1 (Poor) as shown in Table V. Therefore, small-scale wind turbines are suitable to be used in the selected regions for exploiting the available wind energy potential. Furthermore, it can be concluded that high-capacity wind turbines (MWs) with a height of 90m and above can be suitable for gathering the wind energy potential in the selected locations. This is investigated using the power-law method, i.e., the collected data at 10m height is synthesized to the 90m height at which most of the 1MW or above capacity wind turbine height is.

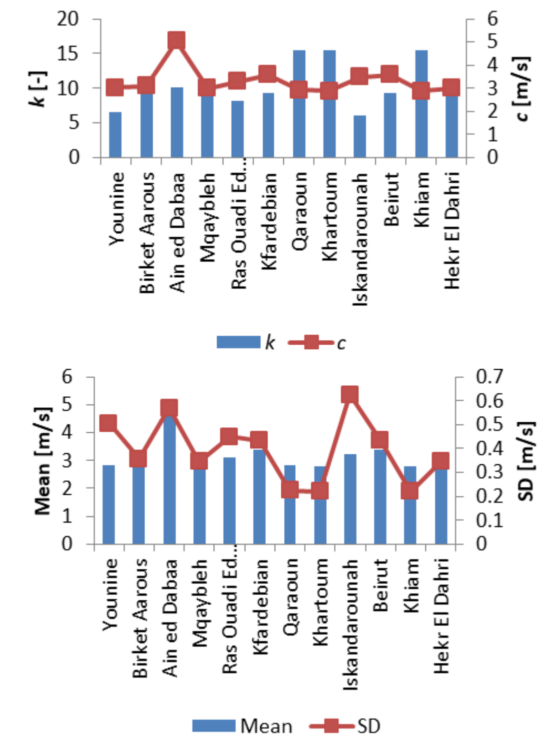

Fig. 5. Weibull parameters for all selected locations at a height of 10m.

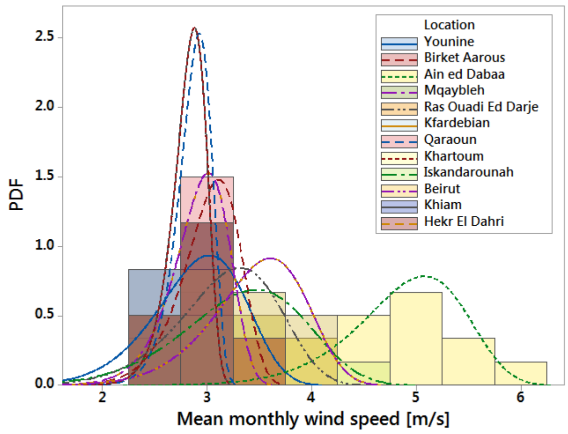

Fig. 6. The probability density function for all selected locations.

TABLE I. WIND POWER CLASSIFICATION AT 10m HEIGHT

Power class	$\bar{P}$[W/m^2]
1 (Poor)	≤100
2 (Marginal)	≤150
3 (Moderate)	≤200
4 (Good)	≤250
5 (Excellent)	≤300
6 (Excellent)	≤400
7 (Excellent)	≤1000

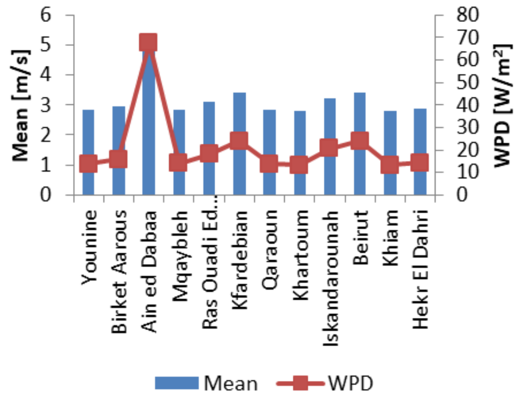

Fig. 7. The annual value of wind power density for all selected locations.

D. Techno-Economic Model

As mentioned above, 9 wind turbines with various characteristics were selected and the wind speed at various hub heights was calculated using (11). For instance, Figure 8 illustrates the monthly variation of wind speed at various hub heights for 3 selected locations. It can be seen that the value of wind speed increases with the increasing hub height of the wind turbine.

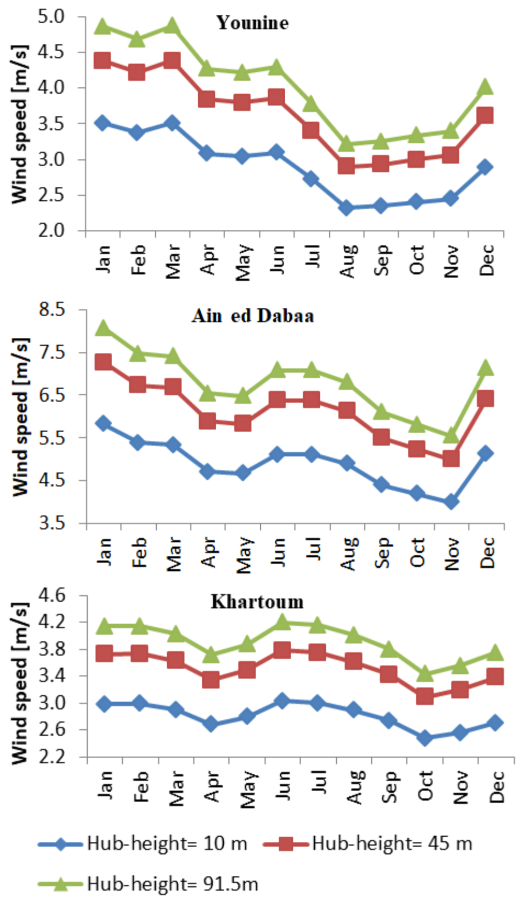

Fig. 8. Monthly average wind speed for 3 selected locations at various hub heights.

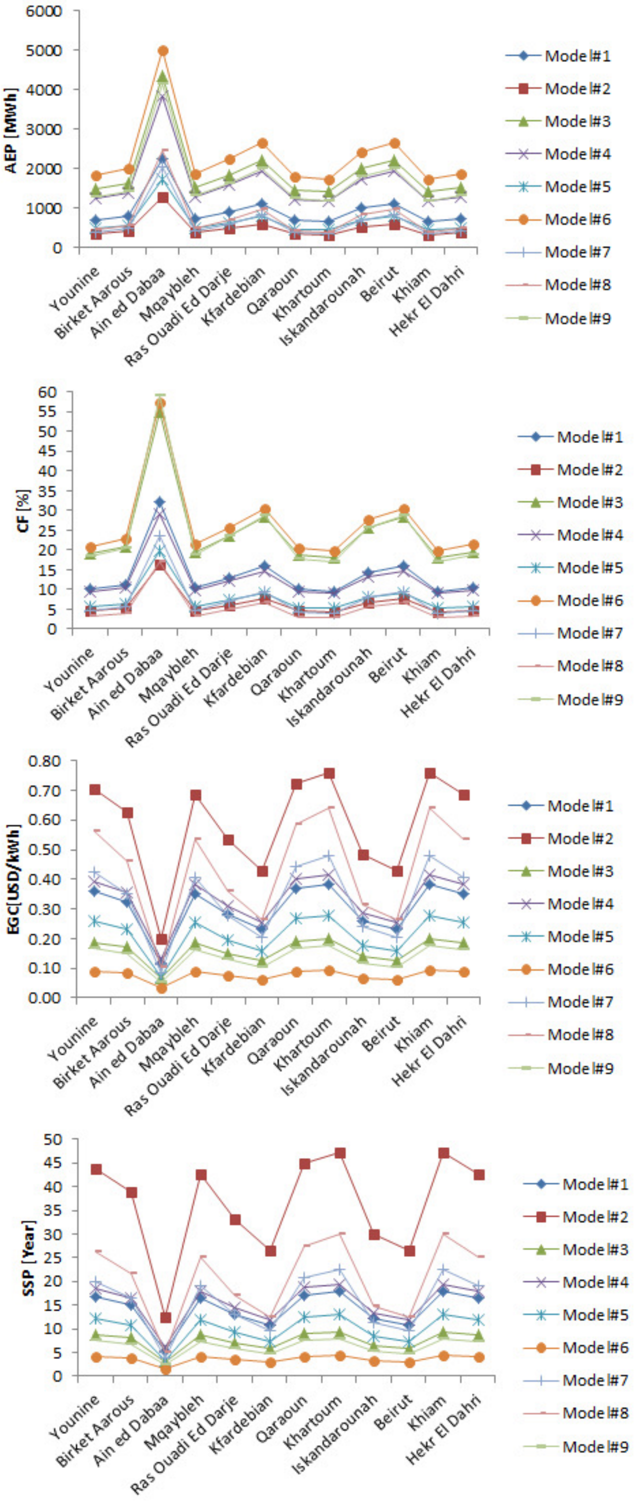

Fig. 9. The estimated results in terms of AEP, CF, EGC, and SPP.

To investigate the performance of wind energy, 9 wind turbines with various rated powers were considered. The aim is to select the turbine that best matches the wind regime at the selected locations. The electricity cost per kWh in Lebanon, the annual interest rate, the capital cost of acquisition, operation, and maintenance costs of wind turbines, and the life of the wind turbines are required for economic viability. These data were obtained from previous studies, trading economics, and global petrol prices. The Annual Energy Produced (AEP) and CF for the selected turbines were determined by (12) and (15) respectively. EGC and SPP were determined by (16) and (17). Figure 9 illustrates the estimated results in terms of AEP, CF, EGC, and SPP for all selected locations. It is found that the APE values ranged from 339.55MWh to 5017.35MWh with an average value of 1241.875MWh. The maximum and minimum values of APE are recorded in Ain ed Dabaa and Khartoum for a hub height of 91.5m (Model#6) and 55m (Model#2) respectively. The highest and lowest CF values are 59.23% (Ain ed Dabaa) and 2.79% (Khiam) respectively with an average value of 14.28%. Furthermore, the EGC values are within the range of 0.033-0.761USD/kWh with an average value of 0.287USD/kWh. Furthermore, the shortest payback period of 1.54 years is observed at Ain ed Dabaa for a hub height of 91.5m (Model#6).

Other researchers who analyzed the performance of a wind farm system in terms of CF, SPP, and EGC support these observations [30, 33-39]. For instance, authors in [35] found CF values within the range of 31.1-49% and 37.3-56.6% for 50m and 75m hub-height turbines. Authors in [30] found that the BWT 61m–800kW wind turbine has a payback period of 1.9-27.3 years and its EGC values were within the range of 0.04-0.43USD/kWh. In [36], it was found that the payback period for different wind farms with a capacity of 100MW ranged from 6.34 to 19.9 years. Authors in [33] found that the values of CF and EGC produced by various wind turbines were within the range of 32-38% and 0.255-0.306 USD/kWh respectively. Authors in [37] found that the CF values varied from 6.8% to 47.6% using various wind turbines with various characteristics. According to the finding of [34], the CF values of different wind turbines are estimated to be within the range of 22.9-50.6%. It should be noted that when the value of SPP exceeds the assumed lifetime of the wind turbine, it means that installing the wind turbines in locations is not economically viable for energy production for the selected wind turbine model. Moreover, according to [30, 31, 38], the SPP value for small and medium-scale wind turbines is within the range of 5-12 years. Therefore, more than 50% of the selected cities fall within the range of SPP. Based on these results, it can be concluded that:

- The results demonstrate the competitiveness of BWTs for operation compared to CWTs, especially at locations with low wind conditions.
- Although Model#6 has a lower EGC in all selected locations, Model#9 has a robust design and a wider range of applications for all classes of wind resources. Thus, model#9 would have a lower cost in the long run.
- FWWT technology is a strong candidate to increase the availability of economic, green, and sustainable energy in Lebanon.

The EGC values obtained from the current study are compared with the current electricity prices in Lebanon in

Figure 10. It is clear that the price of the electricity generated by wind turbine systems is less than the one from conventional systems. It can be concluded that the developed systems ensure the economic feasibility of the project for all locations. Wind energy will be able to solve the problem of a chronic lack of electricity and reduce the electricity bills in Lebanon.

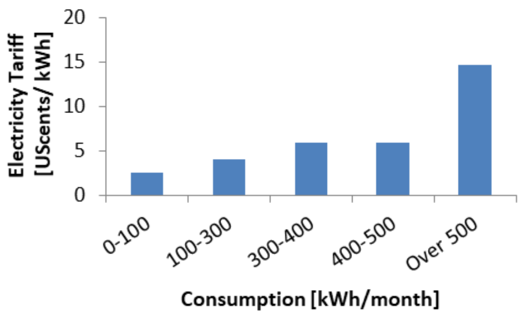

Fig. 10. Monthly average wind speed for some selected locations and various hub heights.

IV. CONCLUSIONS

Lebanon is experiencing a serious water and electricity crisis. The growing challenges faced by the population and energy sectors are outpacing the government's efforts to provide high-quality, affordable, and accessible electricity. In this context, utilizing wind energy is considered an alternative solution to supply electricity to households, reduce the effect of global warming, and enhance sustainable technological development. Therefore, there is an urgent need to develop road maps for the exploitation of renewable energy sources.

In this regard, the techno-economic model for the assessment of wind energy in selected locations in Lebanon is presented in this research. In this study, the techno-economic performance of new technology of wind turbine, the Barber wind turbine (Model#9), is compared to conventional wind turbines under the same economic conditions.

The results showed that the Barber wind turbine (Model#9) is very competitive to 8 known commercial wind turbines for low wind speed conditions. Consequently, the current study may encourage stakeholders in the renewable energy sector to provide support mechanisms for the adoption of large-scale and small-scale wind systems in the country.

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