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ORIGINAL RESEARCH PAPER

Economic assessment of renewable power generation based on wind speed and solar radiation in urban regions

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ABSTRACT: Economic evaluation of 12 MW grid-connected wind farms and PV power plants in two regions in Northern Cyprus for electricity generation was investigated. The wind speed, sunshine duration, and solar global radiation characteristics were analyzed using monthly data collected over 17 years (2000-2016) for Girne and nine years (2008-2016) for Lefkoşa, which were measured at various heights. The result showed that during 2000-2016, the mean wind speed at Girne was 2.505 m/s and during 2008-2016, the mean wind speed at Lefkoşa was 2.536 m/s. The result showed that both regions had annual mean wind speed greater than 2 m/s at 10 m height. Moreover, the annual mean sunshine duration and global solar radiation were higher than seven h/day and 15 MJ./m^2/day at a height of 2 m for all studied regions, respectively. In this study, eight distribution functions were used to analyze the wind speeds and global solar radiation data in each region. The results indicated that Weibull and Logistic were the best distributions for analyzing the wind speeds and global solar radiation data of the studied regions, respectively. Furthermore, the capacity factors of the selected regions ranged between 1.92% and 48.53%. Based on the renewable energy cost results, it is found that the generation costs of the wind farm were between 0.023 and 0.04 Euro/kWh, while the PV plant was between 0.08 and 0.098 Euro/kWh.

KEYWORD: *Distribution functions; Economic viability; Grid-connected; Northern Cyprus; PV power plant; Wind power farm.*

INTRODUCTION

Renewable energy resources such as wind and solar energy can be considered as essential factors for reducing air pollution and fossil fuel consumption (Jakariya and Islam 2017; Emran*et al*., 2015; Yang *et al*., 2017; Jimmy *et al*., 2017; Halabi*et al*., 2018).Wind energy is considered as a clean and environmental energy source (Kassem 2018; Kaplan 2015). It is one of the critical available sources that can be used for generating electricity via wind turbines. Nevertheless, it is necessary to investigate the wind characteristics (wind speed and wind direction) in detail in order to evaluate the wind power generation at the selected region (Ozay and Celiktas 2016; Dai *et al*., 2017). Consequently, analyzing the wind characteristics is considered as the primary concern before a wind farm is designed for the selected region (Ozay and Celiktas 2016; Dai *et al*., 2017; Bilir*et al*., 2015). Numerous studies have focused on the statistical analysis of wind characteristics and wind energy potential using many probability density functions

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(Bilir *et al*., 2015; Bagiorgas *et al*., 2007; Shata and Hanitsch 2006; Keyhani *et al*., 2010; Emami and Behbahani-Nia 2012; Aries *et al*., 2018).A solar photovoltaic (PV) system is an alternative clean source for generating electricity(Anwar *et al*., 2013). Investigation of the available solar irradiance in the selected region is the primary factor for the design, size, and performance of the solar power project (Ayodele and Ogunjuyigbe 2015).In general, the use of wind and solar energy as the primary power sources for producing electricity in several industries places shows the significance of these sources (Vogiatzis *et al*., 2004; Almorox *et al*., 2005; Sabzehparvar 2008; Weapon *et al*., 2014; Razak *et al*., 2010; Razmjoo *et al*., 2017).Meanwhile, in Northern Cyprus, the electricity is mainly produced by using fossil fuels, i.e., the electrical demand in Northern Cyprus is covered by using diesel power stations. Additionally, the growth of the population and other factors in Northern Cyprus has led to an increase in the demand for fossil fuels. Resultantly, alternative energy sources such as wind and solar energy can be considered as alternative energy resources for producing electricity. In this paper, the wind and solar power potential at two regions in Northern Cyprus (Girne and Lefkoşa) were investigated to determine whether a wind or solar source of 12 MW can be utilized economically based on the method of the present value of costs. Weather data (wind speed, wind direction, global solar radiation, sunshine, air temperature) was collected for a period of17 years (2000-2016) for Girne and nine years (2008-2016) for Lefkoşa. This analysis was divided into two parts. In the first part, statistical analysis of the wind characteristics of the studied regions using five distribution functions (Weibull, Gamma, Lognormal, Logistic and Log-Logistic) was described and compared. Also, the measured wind speed data have been extrapolated to heights of 30 and 50m, then the capacity factor of the selected wind turbine was estimated. Moreover, the performance of 12MW for electricity generation was assessed along with the estimation of the costs of wind energy production in Girne and Lefkoşa. In the second part, the global solar radiation characteristics were analyzed using four distribution functions (Normal. Logistic, Nakagami and Rician). Also, the characteristics of sunshine duration have been studied. A Photovoltaic Geographic Information System (PVGIS) was used to evaluate the performance of a 12MW power plant project in the studied regions. This study has been carried out in Northern Cyprus over a seventeen-year period of 2000-2016 for Girne and nine-year period of 2008-2016 for Lefkoşa.

MATERIALS AND METHODS

Probability distribution functions

Knowledge of weather data characteristics, such as the wind speed and solar radiation of the region, is required for renewable resource assessment. Several distribution functions have been used in the literature to present weather data for selected regions. In this paper, eight probability distribution functions are used to analyze the distributions of wind speed (v) and global solar radiation (G), as shown in Table 1. The most commonly used methods used to estimate the parameters of distribution functions are the graphical method, the method of moments, and the maximum likelihood method (Allouhi *et al*., 2017). In this study, the maximum likelihood method is used to estimate the parameter values for each distribution function. This estimation method is generally used in statistics (Allouhi *et al*., 2017). The fitting of the distribution parameters requires numerical iterations (Allouhi *et al*., 2017). Therefore, Matlab R2015a software, statistical assistant software, was used in order to get the parameters of the distribution functions in this study.

Wind speed variation with height

Estimation of the wind speed (v) at various heights(z)is important for any wind farm project. It can be determined using Eq. 1 (Kaabeche *et al.,* 2011; Ucar and Balo 2008).

$$\frac{v}{v_{10}} = \left(\frac{z}{z_{10}}\right)^{\alpha} \tag{1}$$

Where v_{10} is the wind speed at a height of 10m (z_{10}), and α is the coefficient of surface roughness, which depends on the characteristics of the region (Ozay and Celiktas 2016). The value of α can be obtained from the Eq. 2 (Irwanto *et al*., 2014; Mostafaeipour 2010).

$$\alpha = \frac{0.37 - 0.088ln(v_{10})}{1 - 0.088ln(z_{10}/10)} \tag{2}$$

Wind power density (WPD)

The WPD model describes the distributions of

Table 1: Expressions of statistical distributions used in this study

Model	Distribution function	Probability distribution function	Parameter definition	References
v	Weibull	$f(v)=\left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1}e^{-\left(\frac{v}{c}\right)^{k}}$	k: shape parameter. c: scale parameter in m/s.	Dabbaghiyan *et al*., 2016; Osinowo *et al*., 2017
	Gamma	$f(v)=\frac{v^{\xi-1}}{\beta^{\xi}\Gamma(\xi)}e^{\left(-\frac{v}{\beta}\right)}$	β: shape parameter. ξ: scale parameter.	Branoet *al*., 2011
	Lognormal	$f(v)=\frac{1}{v\sigma\sqrt{2\pi}}e^{\left\{\frac{1}{2}\left(\frac{ln(v)-\mu}{\sigma}\right)^{2}\right\}}$	μ: location parameter. σ: scale parameter.	Sunderland *et al*., 2013
	Logistic	$f(v)=\frac{e^{\left(\frac{v-\mu}{\sigma}\right)}}{\sigma\left\{1+e^{\left(\frac{v-\mu}{\sigma}\right)}\right\}^{2}}$	μ: location parameter. σ: scale parameter.	Mohammadi *et al*., 2017
	Log-Logistic	$f(v)=\left(\left(\frac{\beta}{\alpha}\left(\frac{v}{\alpha}\right)^{\beta-1}\right)/\left(1+\frac{v}{\alpha}\right)^{\beta}\right)^{2}$	β: log location parameter. α: log scale parameter.	Mohammadi *et al*., 2017
G	Normal	$f(G)=\frac{Exp\left(-\frac{(G-\mu)^{2}}{2\sigma^{2}}\right)}{\sigma\sqrt{2\pi}}$	μ: mean in m/s. σ: standard deviation in m/s.	Mohammadi *et al*. 2017
	Logistic	$f(G)=\frac{e^{\left(\frac{G-\mu}{\sigma}\right)}}{\sigma\left\{1+e^{\left(\frac{G-\mu}{\sigma}\right)}\right\}^{2}}$	μ: location parameter. σ: scale parameter.	Mohammadi *et al*., 2017
	Nakagami	$f(G)=\frac{2m^{m}}{\Gamma(m)\Omega^{m}}G^{2m-1}e^{\left(-\frac{m}{\Omega}G^{2}\right)}$	m:shape parameter. Ω:scale parameter.	Mohammadi *et al*., 2017
	Rician	$f(G)=\frac{G}{\sigma^{2}}e^{-\frac{G^{2}+z^{2}}{2\sigma^{2}}}I_{0}\left(\frac{zG}{\sigma^{2}}\right)$	z : signal of interest. σ^2: variance of Gaussian corruption in complex data. I_0: modified zeroth order Bessel function of the first kind.	Kim and Suh, 2007

wind energy at various wind speed values. For a period measurement, the WPD can be calculated by the measured values as Eq. 3 (Irwanto *et al.,* 2014) and by *f(v)*values as Eq. 4 (Mohammadi *et al.,* 2017).

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

Were, $\bar{v}$ is the mean wind speed, ρ is the density of air at the region (kg/m^3), and A is the swept area of the rotor blades (m^2)

$$P(v)=\frac{1}{2}\rho Av^{3}f(v) \tag{4}$$

Where, *P(v)*is WPD distribution for a particular *(v)*.

Capacity factor and output energy of the wind turbine

The power curve of the wind turbines and wind speed characteristics are the mean parameters used to calculate approximately the energy of the wind turbine, E_{wt} (Gökçek and Genç 2009).The expression as Eq. 5 is used to determine the total output power of the wind turbine.

$$E_{wt}=\sum_{i=1}^{n}P_{wt\,(i)}\,t \tag{5}$$

Where, t is the period (generating unit). The output power of the wind turbine, $P_{wt(i)}$, can be calculated as given in Eq. 6 (Pallabazzer, 2003).

$$P_{wt\,(i)}=\begin{cases}P_r\frac{v_i^2-v_{ci}^2}{v_r^2-v_{ci}^2}(v_{ci}\le v_i\le v_r)\\ \frac{1}{2}\rho AC_p v_r^2(v_r\le v_i\le v_{co})\\ 0\qquad (v_i\le v_{ci}\ and\ v_i\ge v_{co})\end{cases} \tag{6}$$

Where, v_i is the wind speed at a specific region in m/s, P_r is the turbine rated power in W, v_r is the wind speed rated in m/s, v_{ci} and v_{co} are the cut-in and cut-off wind speeds in m/s, respectively and C_p is the performance coefficient of the turbine, which can be calculated using Eq. 7 (Nouni *et al*., 2007).

$$C_p=2\frac{P_r}{\rho Av_r^3} \tag{7}$$

The capacity factor is a key factory used to estimate the production of the wind turbine and can be expressed as Eq. 8 (Wang *et al.,* 2016).

$$CF = \frac{E_{wt}}{P_r . t} \tag{8}$$

Renewable energy cost

In general, the cost of electricity depends on three main factors

i. capital and investment cost
ii. operating and maintenance cost
iii. fuel cost

In this study, the Benchmark and Production Tax Credit Present Value was used to evaluate the economic feasibility of the wind farm project. These economic measures are explained briefly below.

a. Net Present Value (NPV)

The time flow of the money, all cash flow estimates, and the salvage value of the investment are important factors for the Net Present Value (NPV) (Katsigiannis and Stavrakakis, 2014). Generally, NPV regarding net cash flow (C_t), discount rate (i), capital investments (I_{cap}) and the expected lifetime of the project (PL) can be calculated from Eq. 9 (Katsigiannis and Stavrakakis, 2014).

$$NPV = \sum_{t=1}^{PL} C_t . (1+i)^{-t} - I_{cap} \tag{9}$$

b. Internal rate of return (IRR)

The internal rate of return (IRR) of any wind project is the discount rate where the NPV of a project becomes zero. It can be calculated by Eq. 10 (Katsigiannis and Stavrakakis, 2014).

$$0 = I_{cap} + \sum_{t=1}^{PL} \frac{C_t}{(1+IRR)^t} + \frac{S_{PL}}{(1+IRR)^{PL}} \tag{10}$$

Where, S_{PL} is the remaining value of the project.

c. Levelized cost of energy (LCOE)

LCOE is the average total value of the project cost (capital costs and O&M cost) during working life of the plant divided by the total power generated of the project over that lifetime. It is expressed as given in Eq. (11) (Bruck *et al.,* 2018).

$$\mathrm{LCOE} = \frac{\left(\sum_{t=-N}^{t=-1} \frac{I_t}{(1+i)^t}\right)_{construction} + \left(\sum_{t=0}^{t=n-1} \frac{F_t + O\&M_t - D_t + T_t}{(1+i)^t}\right)_{production}}{\left(\sum_{t=0}^{t=n-1} \frac{G_t}{(1+i)^t}\right)_{production}} \tag{11}$$

Where, LCOE is levelized cost of energy in \$/kWh or \$/MWh, I_t is investment made in the period in \$, $O\&M_t$ is Operation and Maintenance in period in %, D_t is depreciation credit in \$, T_t is the tax levy in \$, F_t is fuel cost, which is zero in wind and solar power generation and i is discount rate.

It can be generally given as follows (Mohammadi *et al.,* 2018).

$$\mathrm{LCOE} = \frac{\text{sum of cost over lifetime}}{\text{sum of electricity generated over lifetime}} \tag{12}$$

Renewable energy in Cyprus

Cyprus is located in the Eastern Mediterranean and has a typical Mediterranean climate. Cyprus is located at latitude 35° North and longitude 33° E. Generally, the power generation in Cyprus is based exclusively on conventional fossil fuel energy, as shown in Fig. 1. In recent years, the growth of the population and other factors of Northern Cyprus have led to increasing energy demands, which are supplied by fossil fuels. Furthermore, electrical energy in Northern Cyprus is currently produced by fossil fuels and photovoltaic power plant, which installed in Serhatköy. The power generation in Northern Cyprus is around 212MW for the diesel generator and 1.27MW for the photovoltaic power plant, i.e., the total power generation in Northern Cyprus is around 300 MW (Ercan *et al.*, 2013; Yenen and Fahrioglu 2013). In the southern part of Cyprus on the other hand, there is a PV and wind power plant that accounts for a 4.9% share of the total power generation. Additionally, there are wind power plants installed in critical regions of the southern part of Cyprus, which have a total capacity of 188 MW (Wind-Power 2018).

Data measurements

In the present study, the measurement data including wind speed, wind direction, sunshine duration, air temperature and global solar radiation were recorded at two regions (Girne and Lefkoşa) in Northern Cyprus. The measurement data were collected from the Meteorological service in Northern Cyprus located in Lefkoşa. The geographic information details of the studied regions are illustrated in Fig. 2 and tabulated in Table 2. A cup anemometer and thermometer devices are installed at a height of 10m above the ground for measuring wind speeds and air temperature at the selected region, while an actinograph device is used for measuring the global solar radiation and sunshine duration data, which is placed at a height of 2m above the ground.

RESULTS AND DISCUSSION

Wind speed characteristics selected regions

Monthly and annual wind speed

Fig. 3 shows the mean monthly wind speed variations throughout the years selected. It is found that the mean monthly wind speed value for both regions (Girne and Lefkoşa) is approximately 2.5m/s. Also, the mean monthly wind speeds ranged from 1.1 and 4.6 m/s for Girne and from1.5 to 3.5 m/s for Lefkoşa. The maximum wind speed occurred in 2003-February and 2009-June at Girne and Lefkoşa, respectively. Moreover, it is noticed that the mean annual wind speeds were 2.505 and 2.536 m/s for Girne and Lefkoşa, respectively. In general, it can be concluded that Girne and Lefkoşa have low wind speeds.

Wind speed direction

The rose frequency diagram shows the annual wind speed distribution directions at a height of

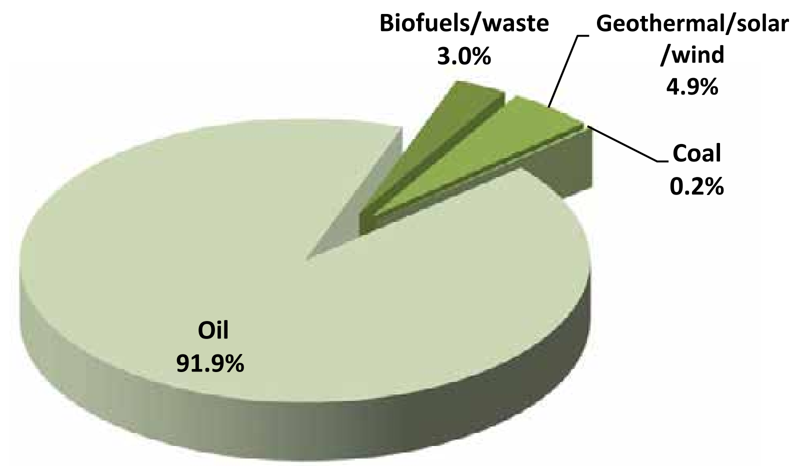

Fig. 1: Share of total primary energy supply in 2015 for Cyprus (IEA, 2015)

Fig. 2: The geographic location of the study area in Cyprus

Table 2: Details of each station used in the analysis

Region name	Coordinates		Measuring Height[m]	Period records	Year	Characteristics of the station
	Latitude [°N]	Longitude [°E]				
Girne	35° 20’ 25	33° 19’ 08	10 and 2	2000-2016	17	Coastal
Lefkoşa	35° 10’ 08	33° 21’ 33	10 and 2	2008-2016	9	Surrounded by buildings

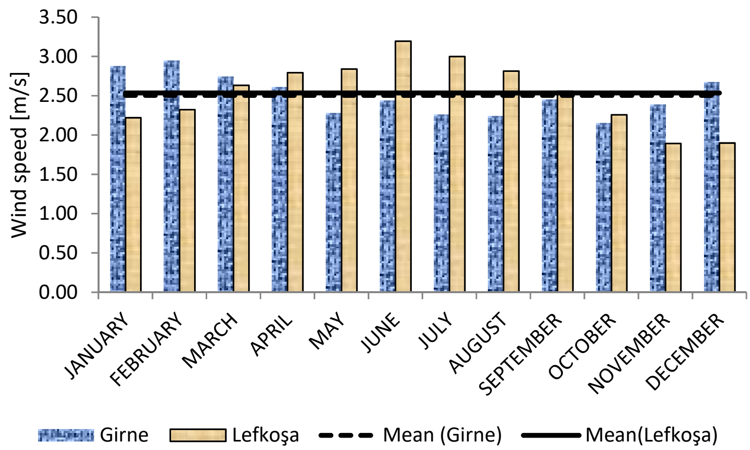

Fig. 3: Monthly mean wind speed in m/s for all years

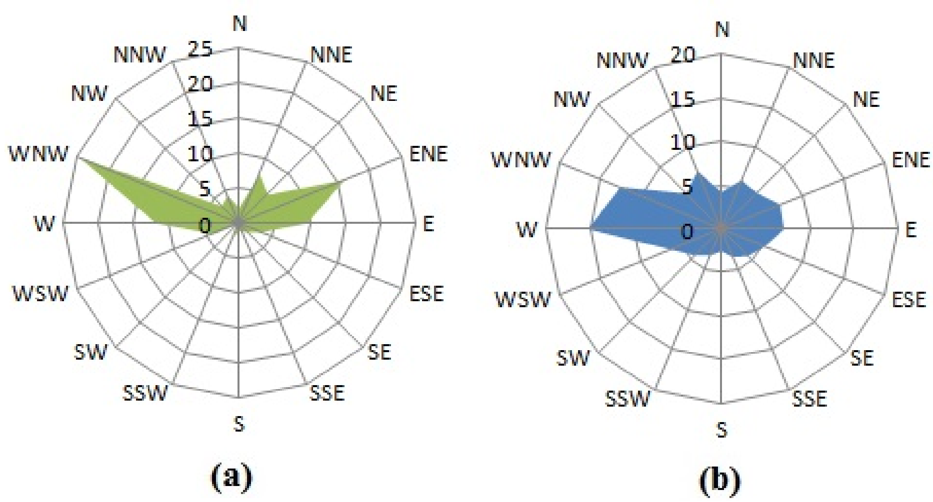

Fig. 4: Annual wind speed distribution direction in %; (a) Girne and (b) Lefkoşa

10mdiagram (Fig. 4). It is observed that the dominant direction of the wind for Girne was found to be WNW with a frequency value of almost 24.7%, whereas, in Lefkoşa, the direction was W with a frequency value of almost 15.3%. Furthermore, ENE and WNW were considered as the most probable second wind directions, with frequencies of 16.3% and 12.5% for Girne and Lefkoşa, respectively.

Hourly wind speed

The wind speed variation during the day is quite important for the integration of wind power into the overall energy supply. The mean hourly wind speeds vary within a 24h period for both regions in Northern Cyprus, as shown in Fig. 5. It is observed that the hourly variations of wind speed at Girne and Lefkoşa share a similar pattern. Moreover, it is revealed that the mean wind speed slowly decreases during the morning time from 1 to 6 am and rebounds afterward. The mean wind speed increases sharply after 8 am and reaches the peak point at around 2 pm.

Global solar radiation and sunshine duration characteristics of the selected regions

Monthly and annual global solar radiation and sunshine duration

Fig. 6 shows the mean monthly global solar radiation and sunshine duration variations for all years at Girne and Lefkoşa. It is observed from Fig. 6(a) that the monthly average solar radiation values range from 4.7 to 29.9 MJ/m^2/day for Girne and 8 to 29.5MJ/m^2/day for Lefkoşa. During the period of measurement, the highest mean monthly global solar radiation occurred in summer (June, July, and August) at both selected regions, while the minimum occurred in winter (December, January, and February). It is also observed that Lefkoşa has a higher annual global solar radiation compared to Girne, with values of 19.051 and 16.845 MJ/m^2/day, respectively, as shown in Fig. 6(a). The mean monthly sunshine duration varies from 4.43to 11.60 h/day in Girne and 5.26 to 11.43 h/day in Lefkoşa, as shown in Fig. 6(b). It is also found that the mean monthly sunshine duration for both regions (Girne and Lefkoşa) is approximately8h/day. Moreover, it can be seen that the annual sunshine duration for the studied regions ranged between 7.914 h/day and 8.393 h/day for Girne and Lefkoşa, respectively, as shown in Fig. 6(b).

Determination parameters of distribution functions

Wind speed distributions

In this section, the aim is to determine the best statistical model that describes the wind regime in the selected regions. The best model provides vital information for the assessment of wind energy potential. Table 3 shows the mean wind speed, the distribution parameters throughout the years and the R-squared value for each mode. Furthermore, Fig. 7 shows the proper probability density function (pdf) model for the observed wind speed data for each region. From Table 3 and Fig. 7, it is observed that the

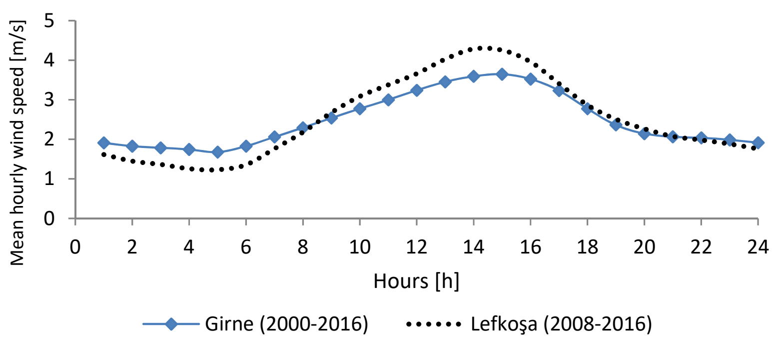

Fig. 5: Mean hourly wind speed in m/s for whole years

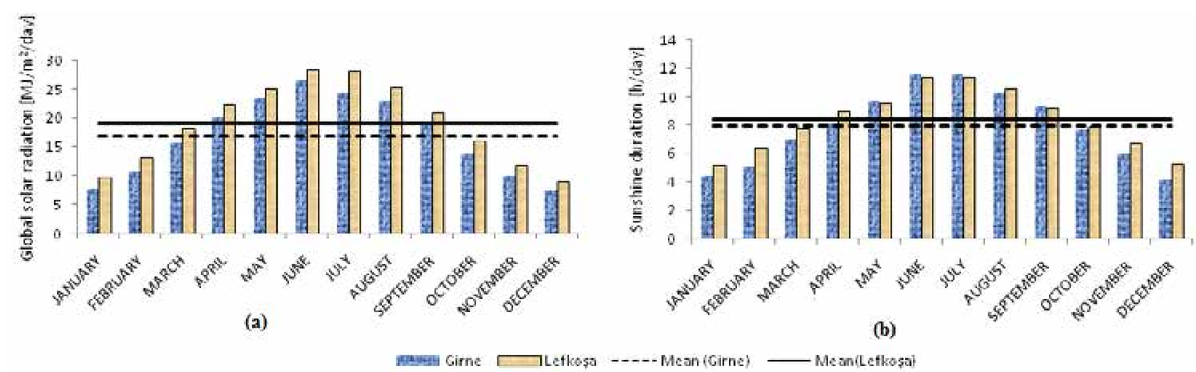

Fig. 6: Monthly (a) global solar radiation in MJ/m^2/day and (b) sunshine duration in h/day for whole years

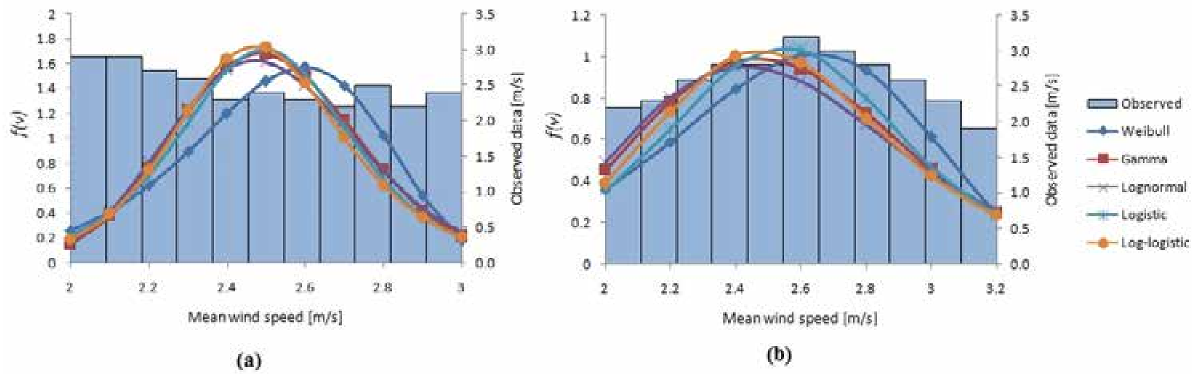

Fig. 7: Fitting pdf to the wind speed data; (a) Girne and (b) Lefkoşa

Table 3: Wind speed distribution parameters for the selected regions throughout the investigation period and the selected distribution (**in bold**) for each region using the maximum likelihood method.

Region	Observed data [m/s]	Weibull			Gamma			Log-normal		
		Mean [m/s]	k	c [m/s]	Mean [m/s]	**β**	**ξ**	Mean [m/s]	**μ**	**σ**
Girne	2.505	2.504	10.560	2.622	2.508	100.600	0.025	2.509	0.914	0.104
R-squared [%]	-		99.198			99.164			99.136	
Lefkoşa	2.536	2.535	2.703	7.375	2.533	38.925	0.065	2.537	0.917	0.170
R-squared [%]	-		93.995			93.792			93.689	

Region	Observed data [m/s]	Logistic			Log-Logistic		
		Mean [m/s]	**μ**	**σ**	Mean [m/s]	**β**	**α**
Girne	2.505	2.495	2.491	0.152	2.502	0.910	0.060
R-squared [%]	-		97.044			97.940	
Lefkoşa	2.536	2.545	2.545	0.239	2.565	0.927	0.097
R-squared [%]	-		89.772			90.589	

Weibull, Gamma, and Lognormal models can provide a reasonable approximation of the observed wind speed data in each region. Moreover, it is noticed that the Weibull distribution model has a maximum R-squared compared to other models, which means that it can be considered as the best model for studying the wind speed of the regions.

Wind power density at various heights

In this paper, the roughness surface (α) value of the studied region was calculated using Eq. (2), then the annual wind speeds were determined at various heights using Eq. 1. The roughness surface values of the selected regions are 0.289 and 0.287 for Girne and Lefkoşa, respectively.

As mentioned before, Weibull distribution provided the best fit to the actual wind data for the regions. Therefore, in this paper, the wind power density (WPD) (W/m^2) and mean wind speed (m/s) regarding Weibull parameters can be estimated using Eqs. 11and 12 (Solyali *et al*., 2016).

$$\bar{v} = c\Gamma\left(1+\frac{1}{k}\right) \tag{13}$$

$$WPD = \frac{1}{2}\rho c^3 \Gamma\left(1+\frac{1}{k}\right) \tag{14}$$

Where ρ = air density at the site. The air density is calculated using Eq. 13 (Sathyajith, 2014).

$$\rho = \frac{353.049}{T} e^{\left(-0.034\frac{z}{T}\right)} \tag{15}$$

Where, z is the elevation in [m], and T is the temperature at a considered site in [K].

The mean annual air density, which is calculated using Eq. 15, is illustrated in Fig. 8. It is observed that the annual density valuesare1.199 and 1.205 kg/m³ for Girne and Lefkoşa, respectively. In this work, in the studied region, the seasonal changes are small, justifying the assumption of a constant air density for the calculation of the mean wind power density at different heights (30m and 50m).

Table 4 tabulates the Weibull parameters of annual wind speed and WPD at different regions and heights. These heights were selected based on the hub height of the wind turbine models. Using Eq. (14), the maximum observed power density values are 38.92 W/m² for Girne and 40.23W/m² for Lefkoşa at a height of 50 m. According to wind power classification (Mohammadi and Mostafaeipour, 2013), the wind energy sources in these selected regions is classified to be poor i.e., the wind power at a height of 10m is less than 100 W/m² or the wind power at a height of 30m is less than 160W/m² (Mohammadi and Mostafaeipour, 2013). It can be concluded that wind turbines with low capacity are suitable to be used for generating electricity in these regions.

Global solar radiation distributions

The frequency of the global solar radiation measurements of the studied regions and the distribution probability density curves are given in Fig. 9. Also, it shows a comparison between four distribution functions, described by its pdf, versus the mean annual global solar radiation, for data collected on an annual basis from 2000-2016 for Girne and 2008-2016 for Lefkoşa based on parameters calculated using the maximum likelihood method. The R-squared value was calculated to find the best distribution function that provides the best wind speed data fit. It is observed that the Logistic distribution provides the better fit for the global solar radiation data from Girne and Lefkoşa, because it has the maximum R-squared value, as shown in Table 5.

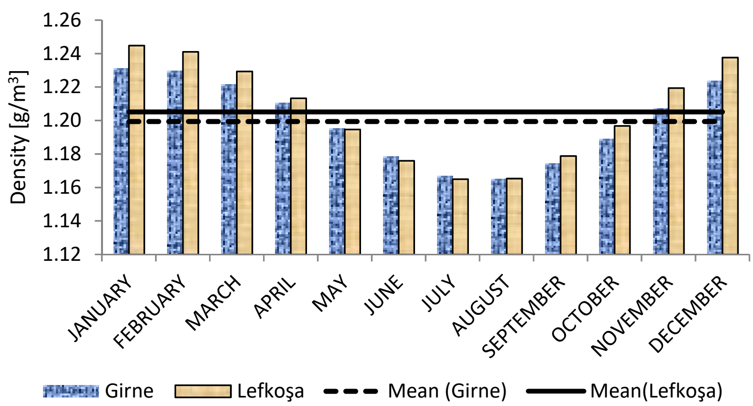

Fig. 8: Annual mean density at studied regions over the investigation period at 10m height (assumed constant)

Table 4: Distribution parameters and WPD at different regions

Region	Investigation period	Parameters	Height [m] 10	30	50	R^2
Girne	2000-2016	K	10.88	10.88	10.88	99.158
		c [m/s]	2.62	3.6	4.17	
		Mean [m/s]	2.50	3.44	3.98	
		WPD [W/m²]	9.93	25.76	40.04	
		Observed mean [/s]	2.51	3.44	3.99	
		Observed $\bar{P}(v)$ [W/m²]	9.69	24.93	38.92	
Lefkoşa	2008-2016	K	7.58	7.58	7.58	93.935
		c [m/s]	2.69	3.7	4.297	
		Mean [m/s]	2.57	3.53	4.04	
		WPD [W/m²]	10.75	27.97	43.13	
		Observed mean [/s]	2.53	3.48	4.03	
		Observed $\bar{P}(v)$ [W/m²]	9.92	25.81	40.23	

Technical-economic analysis

Wind turbine farm projects: a Case study

Wind energy conversion systems are important for assessing any wind farm. The generating power (using wind energy conversion system connected to the grid) can be supplied to plants, schools, or community houses using a power inverter and electrical meter, which will change the type of current to alternating current (*AC*). Thus, Table 6 summarizes the technical specifications of the chosen turbine with various rated powers (300 and 1000 kW) and hub heights (30m and 50 m) (Ohunakin and Akinnawonu, 2012). Additionally, the hub of the turbine is chosen based on maximum generation times. The performance of the turbine can be evaluated by the capacity factor. Furthermore, Table 6 presents the capacity factors in percentages at the turbine hub height for all studied regions over the studied period. Additionally, it shows the effect of climate on the capacity factor of both turbines. It is observed that the highest capacity factor was obtained in 2003 for Girne and in 2013 for Lefkoşa, while the lowest were in 2002 and 2012 for Girne and Lefkoşa, respectively.

Economic feasibility of the wind farm

The main factors that affect the price of electricity produced by a wind energy farm are the turbine capacity and size of the wind power project (Ertürk, 2012). During lifetime project and O&M, approximately 70% of the total cost of the project is related to the wind turbine cost and grid-connection among other factors (Blanco, 2009). Lifetime project and O&M are considered as the main components for any wind farm project. Furthermore, taxes paid to local and federal authorities and payments for electricity used are considered as components of the electricity cost in wind power generation. In this section, Benchmark and Production Tax Credit wind turbine present value cost based on various assumptions (Table 7) are used to examine the economics of wind energy and the

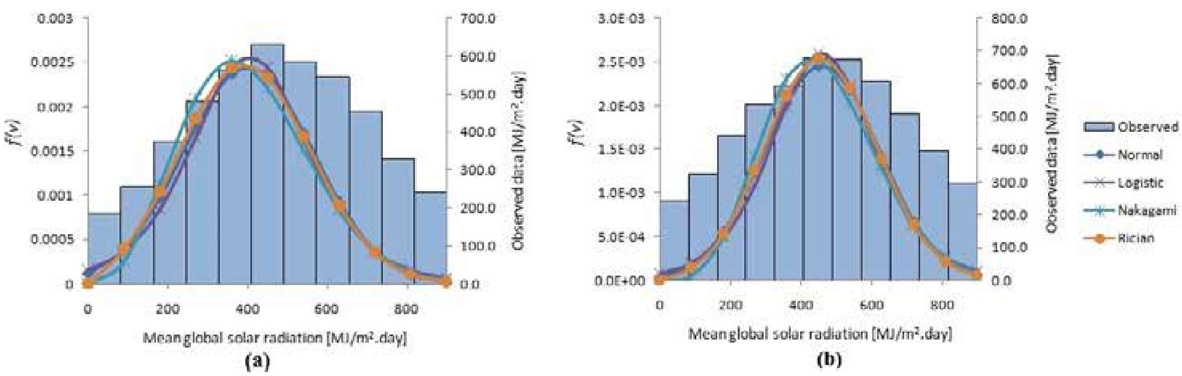

Fig. 9: Fitting pdf to the global solar radiation data; (a) Girne and (b) Lefkoşa

Table 5: Global solar radiation distribution parameters for selected regions throughout the period and the selected distribution (**in bold**) for each station

Region	Observed data [MJ/m²/day]	Normal			Logistic		
		Mean [MJ/m²/day]	***μ***	***σ***	Mean [MJ/m²/day]	***μ***	***σ***
Girne	402.317	402.317	402.317	162.994	404.492	404.492	96.829
R-squared [%]	-	96.951			97.531		
Lefkoşa	460.2	460.200	460.200	162.278	462.731	462.731	95.813
R-squared [%]	-	98.230			**98.624**		
Region	Observed data [m/s]	Nakagami			Rician		
		Mean [MJ/m²/day]	M	**Ω**	Mean [MJ. m²/day]	z	***σ***
Girne	402.317	401.868	1.733	186212	401.926	358.268	170.082
R-squared [%]	-	96.056			96.932		
Lefkoşa	460.2	459.830	2.264	235924	460.196	427.650	162.849
R-squared [%]	-	97.656			98.224		

Table 6: Technical specification and the capacity factor of the selected wind turbine based on hub height

Technical specification				
Wind turbine model	AN Bonus 300 kW/33		AN Bonus 1 MW/54	
z [m]	30		50	
P_r [kW]	300		1000	
v_r [m/s]	14		15	
v_{ci} [m/s]	3		3	
v_{co} [m/s]	25		25	
Rotor diameter [m]	33.4		54.2	
Capacity factor [%]				
year	Girne		Lefkoşa	
	30m height	50m height	30m height	50m height
2000	13.4	35.55	-	-
2001	8	25.1	-	-
2002	1.92	12.61	-	-
2003	19.62	48.53	-	-
2004	17.27	44.55	-	-
2005	16.06	43.01	-	-
2006	14.26	39.86	-	-
2007	7.64	27.2	-	-
2008	10.7	32.01	17.17	32.01
2009	9.74	30.38	13.09	30.38
2010	9.32	27.61	12.16	27.61
2011	6.79	25.12	6.15	25.12
2012	6.63	22.35	5.43	22.35
2013	13.53	37.57	14.68	37.57
2014	9.76	30.54	8.88	30.54
2015	12.25	35.28	8.18	35.28
2016	10.54	31.47	9.68	31.47
Annual	9.53	31.15	10.94	31.15

Table 7: Values and assumptions for the economics of wind energy

Particular	Value		Assumptions
	Girne	Lefkoşa	
Region area [km^2]	690	502	
wind turbine capacity [kW]	300/1000	300/1000	
Number of Turbine	40/12	40/12	
Turbine hub height [m]	30/60	30/60	
Wind farm Capacity [MW]	12	12	
Lifetime of project [year]	20	20	Based on literature (Vardar and Çetin, 2007; Ertürk, 2012)
Period of depreciation [years]	20	20	It is assumed to be equal to the economic lifetime (Ertürk, 2012)
Annual capacity factor [%]	10/31*	10/31*	See Table 9
Generation time [h]	12/19	12/19	Based on the annual hourly wind speed (Fig.5)
Salvage/Scrap value [%]	20	20	Salvage value assumed to be 20% of original capital cost based on the assumption of IEA(IEA 2015)
Wind Turbine Cost Share [%]	71	71	It is assumed based on Ref. (Ertürk, 2012)
Grid connection Cost Share [%]	12	12	It is assumed based on Ref. (Ertürk, 2012)
Civil work Cost Share [%]	9	9	It is assumed based on Ref. (Ertürk, 2012)
Other Capital Cost Share [%]	8	8	It is assumed based on Ref. (Ertürk, 2012)
O & M cost [%]	1.5	1.5	It is assumed
Tax rate [%]	20	20	The prevailing corporate tax rate in Turkey of 20% is used (Ertürk, 2012)
Interest rate [%]	8	8	
Production tax credit [Euro/kWh]	1.5	1.5	It is assumed
Price of electricity [Euro/kW.h]	0.04	0.04	The price of electricity values range from 0.03 to 0.5 Euro/kWh (IRENA, 2018)

* Annual capacity factor of all regions

feasibility of the project. The estimation of the present value cost analysis for the cost electricity based on Benchmark and Production Tax Credit method is described by Ragheb, 2017. Resultantly, the economic analysis is examined for two wind farms with a capacity of 12MW with different turbine numbers, namely a high and low capacity wind turbine.

Based on the NPV analysis (Table 8), it is found that NPV is a positive value and it is in the range of between approximately 36 and 193 million Euros, with a various percent yearly net real rate of return in 20 years of 7.42% and 48.42%, respectively, which depends on the location and method of analysis used.

Table 8: Benchmark and production tax credit wind turbine present value cost analysis

AN Bonus 300 kW/33				
Particular	Benchmark		Production tax credit	
	Girne	Lefkoşa	Girne	Lefkoşa
Investment				
Wind turbines cost [Euro]	12200000	12200000	12200000	12200000
Wind Turbines Cost Share [Euro]	8540000	8662000	8540000	8662000
Grid connection Cost Share [Euro]	1464000	1464000	1464000	1464000
Civil work Cost Share [Euro]	1220000	1220000	1220000	1220000
Other Capital Cost Share [Euro]	976000	976000	976000	976000
Total turbines cost [Euro]	24400000	24522000	24400000	24522000
O & M cost [Euro]	183000	183000	183000	183000
Payment				
Total expenditure [Euro]	28060000	28182000	28182000	28182000
Current income				
Energy produced [kW/year]	77760000	73440000	77760000	73440000
Revenue from sales of electricity [Euro/year]	3888000	3672000	3888000	3672000
Yearly income (over ten years project)	-	-	1166400	1101600
Stream of net income [Euro/year]	3705000	3489000	3705000	3489000
Stream of net income per year(first ten years) [Euro]	-	-	4871400	4590600
Stream of net income per year(next ten years) [Euro]	-	-	3705000	3489000
Net present value [Euro]	36376236	43480652	60708411	57209023
Production tax credit [%]	-	-	47.57	44.92
Gross income stream [USD]	77760000	73440000	77760000	73440000
Yearly net real rate of return [%/year]	7.42	8.87	12.38	11.66
Present value of electricity [Euro/kWh]	0.0234	0.0296	0.039	0.0389
AN Bonus 1 MW/54				
Particular	Benchmark		Production tax credit	
	Girne	Lefkoşa	Girne	Lefkoşa
Investment				
Wind turbines cost [Euro]	9936000	9936000	9936000	9936000
Wind Turbines Cost Share [Euro]	7054560	7054560	7054560	7054560
Grid connection Cost Share [Euro]	1192320	1192320	1192320	1192320
Civil work Cost Share [Euro]	993600	993600	993600	993600
Other Capital Cost Share [Euro]	794880	794880	794880	794880
Total turbines cost [Euro]	19971360	19971360	19971360	19971360
O & M cost [Euro]	149040	149040	149040	149040
Payment				
Total expenditure [Euro]	22952160	22952160	22952160	22952160
Current income				
Energy produced [kW/year]	241056000	227664000	241056000	227664000
Revenue from sales of electricity [Euro/year]	12052800	11383200	12052800	11383200
Yearly income (over ten years project)	-	-	3615840	3414960
Stream of net income [Euro/year]	11903760	11234160	11903760	11234160
Stream of net income per year(first ten years) [Euro]	-	-	15519600	14649120
Stream of net income per year(next ten years) [Euro]	-	-	11903760	11234160
Net present value [Euro]	116872870	140002465	193408520	182560415
Production tax credit [%]	-	-	181.05	170.99
Gross income stream [USD]	241056000	227664000	241056000	227664000
Yearly net real rate of return [%/year]	29.26	35.05	48.42	45.71
Present value of electricity [Euro/kWh]	0.0242	0.0307	0.04	0.04

Consequently, the wind farm project is suitable and feasible for further consideration.

Solar plant projects: a Case study

The 12MW PV power plants are located at two regions in Northern Cyprus, namely Girne and Lefkoşa. In this study, PVGIS, which was developed by Joint Research Centre of the European Commission (Šúri *et al*., 2007; Simón-Martín *et al*., 2014; Huld *et al*., 2012), is used to evaluate the performance of a12 MW peak grid-connected solar PV system. The technical and economic specifications of two PV power plants with a capacity of 12MW and a total area of 29 km^2in both studied regions are summarized in Table 9.

Solar modules are used to absorb the solar irradiance and then converted to useful power. Therefore, power output depends on the type and location of the solar modules. Table 10 tabulates the mean monthly electricity production and global irradiation data over the given period (2007-2016) at the studied regions. The results show the effects of global irradiation, mounting position, period, and month on the power output of the system. For example, Fig. 10 clearly shows the effect of these factors on the power output of the system. The power output increases when the global solar radiation increases. Additionally, the highest annual power generation of the power plant occurred in the summer season (June, July, and August) during the period of 2007 to 2016.

Moreover, the mean monthly electricity production and irradiation of the PV plants over the period 2007-2016 for the various modules position are shown in

Table 9: General specification of the all PV power plants and assumptions for the economics of solar energy

Specification	Value	Specification	Value
Plant capacity [MW]	12	Capital cost [Euro]	1238000[a]
Total area [km^2]	0.29	System losses [%]	14[b]
Total panels	51280	Interest rate [%]	8[c]
Mounting position	Free-standing/Building integrated	Project lifetime [year]	25[d]

[a] It is assumed based on the type of PV panel type, PV module, and inverters (Kumar and Sudhakar, 2015; Bano and Rao, 2016; Mohammadi *et al.*, 2018)

[b]System losses assumed 14 % based on the assumption of PVGIS (PVGIS, 2016)

[c] It is assumed based on the assumption of Ref. (Bean *et al.*,2017)

[d] It is assumed based on the assumption of Ref. (Mohammadi *et al.*, 2018)

Table 10: Economic performance and electricity production by 12 MW PV system at the selected regions

Mounting position		J	F	M	A	M	J	J	A	S	O	N	D
Girne													
Free-Standing	E_m	102	112	157	163	165	169	174	175	164	148	124	100
	H_m	124	138	197	210	217	227	238	237	219	193	156	123
Building-Integrated	E_m	98.2	108	150	156	157	162	166	166	156	142	119	96.5
	H_m	127	138	197	210	217	228	238	238	219	193	156	122
Lefkoşa													
Free-Standing	E_m	80.5	88.8	134	145	149	156	163	158	131	116	105	78.2
	H_m	96.9	108	166	184	193	205	219	221	174	150	130	95.1
Building-Integrated	E_m	77.6	85.3	128	139	143	149	156	150	125	111	100	75.3
	H_m	96.7	108	166	184	193	206	219	211	173	150	129	94.9

Particular	Free-Standing		Building-Integrated	
	Girne	Lefkoşa	Girne	Lefkoşa
Optimum slope angle [°]	31	28	31	28
Optimum azimuth angle [°]	-5	13	-5	14
Yearly PV energy production [MWh]	1750	1500	1680	1400
Yearly in-plane irradiation [kWh/m^2]	2280	1930	2280	1930
Change in output due to				
1 Angle of incidence [%]	-2.6	-2.6	-2.4	-2.4
2 Spectral effects [%]	0.3	0.3	0.5	0.5
3 Temperature and low irradiance [%]	-8.5	-12.5	-11.7	-7.8
Total loss [%]	23	-22.2	-26.4	-25.5
PV electricity cost [Euro/kWh]	0.08	0.094	0.084	0.098

E_m[MWh]	Mean monthly electricity production
H_m[kWh/m^2]	Mean monthly global solar radiation

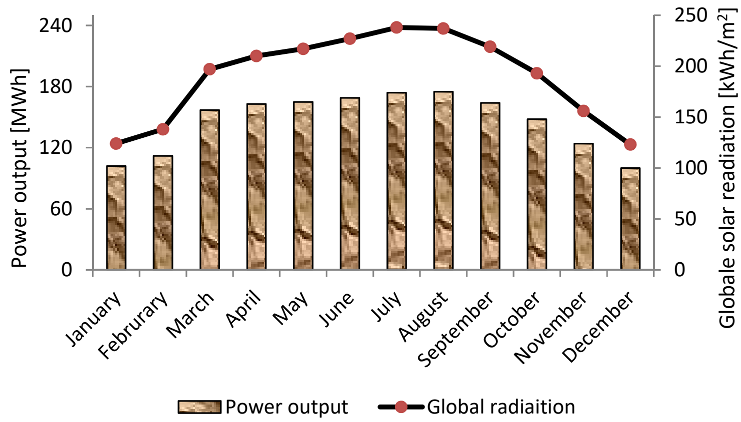

Fig. 10: Power output vs. global solar radiation for Girne

Table 10, in addition to the PV electricity for each position. It is observed that when the modules are mounted on a rack with air flowing freely behind the modules, this represents the most economical option for regions because the PV electricity cost of the Free-Standings module is lower compared to building an integrated mounting position

CONCLUSIONS

In this paper, wind and solar energy assessments and economic analysis of 12MW grid-connected wind farm and PV power plants in Girne and Lefkoşa in Northern Cyprus were conducted. Eight different distribution functions were used to analyze the wind speeds and global solar radiation characteristics. Additionally, the Net Positive Value method was used to evaluate the economic feasibility of the12 MW wind farm. PVGIS was used to study the PV power plant performance and estimate the electric cost for the studied regions. The following conclusions can be given from the obtained results

- The annual mean wind speeds for the studied regions range from 1.1 to4.6 m/s at a height of 10m.
- Based on the wind rose diagram, WNW was the prevailing wind directions for Girne and Lefkoşa with a frequency value of almost 25% and W with a frequency value of almost 16%, respectively.
- It is observed that the average monthly solar radiation values range from 4.7 to 29.9 MJ/m^2/day for Girne and 8 to 29.5 MJ/m^2/day for Lefkoşa.
- The results indicated that Weibull and Logistic distributions generally provided the best fit to the wind speed and global solar for studied regions, respectively. The obtained results demonstrated that even with the assumptions proposed in this study, the proposed wind power farms are still economically feasible in all selected regions
- The research finds that the generation costs of the wind farm are between 0.023 and 0.04 Euro/kWh, whereas for the PV plant, they are between 0.08 and 0.098 Euro/kWh.
- The proposed projects with a capacity of 48MW can be one of the alternative energy sources for generation electricity in Northern Cyprus, which significantly reduce the demand of conventional energy resources by 22% annually. Therefore, it can be concluded that the proposed systems beneficial for generating electricity in Northern Cyprus.
- The selected regions in Northern Cyprus have a huge solar potential and actual market opportunities for investors to develop grid-connected PV projects compared to wind farm projects.
- The application of the proposed method has been demonstrated by a case study that involves wind speed and global solar radiation data from two regions in Northern Cyprus.

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CONFLICT OF INTEREST

The author declares that there is no conflict of interest regarding the publication of this manuscript.

ABBREVIATIONS

A	Swept area
AC	Alternating current
c	Weibull scale parameter
CF	Capacity factor
C_p	Performance coefficient of the turbine
C_t	Net cash flow
E_m	Mean monthly electricity production
E_{wt}	The energy of the wind turbine
$f(v)$	Probability distribution function
G	Global solar radiation
H_m	Mean monthly global solar radiation
i	Discount rate
I_{cap}	Capital investments
IRR	An internal rate of return
I_0	Modified zeroth order Bessel function of the first kind
k	Weibull shape parameter
$LCOE$	Levelized cost of energy
m	Nakagami location parameter
NPV	Net Positive Value
pdf	Probability density function
PL	Expected lifetime of the project
P_r	Rated power of the turbine
$\bar{P}(v)$	Actual wind power density
$P(v)$	Wind power density distribution for a specified distribution function $f(v)$
PV	Photovoltaic
$PVGIS$	Photovoltaic Geographic Information System
$P_{wt(i)}$	The output power of the wind turbine
S_{PL}	The remaining value of the project
t	Period (generating unit)
T	Air temperature
v	Wind speed
v_{ci}	Cut-in wind speed
v_{co}	Cut-out wind speed
v_i	Wind speed at a specific region
v_r	Wind speed rated
$\bar{v}$	Mean wind speed
v_{10}	Wind speed at a 10m height
WPD	Wind power density
z	Height
z	Signal of interest
z_{10}	Reference height (10 m height above the ground)
α	Log-logistic log scale parameter
α	Surface roughness coefficient
β	Gamma shape parameter
β	Log-logistic location parameter
Γ	Gamma function
μ	Logistic location parameter
μ	Lognormal location parameter
μ	Mean speed
ξ	Gamma scale parameter
ρ	Air density
σ	Logistic scale parameter
σ	Lognormal scale parameter
σ	Standard deviation
σ^2	Variance of Gaussian corruption in complex data
Ω	Nakagami scale parameter

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