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Economic analysis of large-scale wind energy conversion systems in central anatolian Turkey

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1. Introduction

A political, economical and technological development is influenced by social events in all world. Increasing of industrial production and raising competitiveness is possible by development of technology. Countries which fail to develop a technology will be difficult to survive in the new world order and they will take place in the class of very populated, poor countries whose revenues do not increase. Today, the developing countries make research their own energy sources, particularly renewable and clean energy sources and develops their own technologies about energy conversion systems because of difficulties on energy in all over the world.

Not only the converting most efficiently an energy source into useable energy but also it is extremely important that this source is clean and sustainable energy. Clean and renewable energies obtaining from sunlight, wind or water around the earth do not make a net contribution of carbon dioxide to the atmosphere. Therefore, these energy sources should be used to protect our world, because of global warming and the injurious effects of carbon emissions.

Pressure and temperature differences occurring in the atmosphere because of solar energy, and the earth's rotation, and different forms of the earth's surface create wind. People has been used the wind for various purposes such as windmill, water pumping, etc. for centuries. Not only wind energy can be used as mechanical power but also mechanical energy of the wind through a generator can be converted into electrical energy. But, interest in wind energy have always been tied to oil prices. In the 1970s, oil prices raised suddenly and both this rising and the injurious effects of carbon emissions pushed people to seek alternative, clean and renewable energy sources.

Due to the fact that wind energy is a fuel-free, inexhaustible, and pollution-free source, the role of wind energy in electricity generation increased in the United States, Asia and Europe. In the past 25 years, use of wind energy in U.S.A. increased, and the wind energy price was 80 cents/kWh in 1980 and this price decreased to 4 cents/kWh in 2002 (Kakac, 2006). Although wind produces only about 1.5% of worldwide electricity use, it is growing rapidly, having doubled in the three years between 2005 and 2009 (World Wind Energy Association, 2010). In several countries it has a distribution, accounting for about 19% of electricity production in Denmark, 10% in Spain and Portugal, and 7% in Germany and the Republic of Ireland in 2008. And Turkey is rather unsuccessful in using its potential and has 1002.35 MW installed capacity (Electricity Market Regulatory Authority, 2010). Cumulative variation of installed

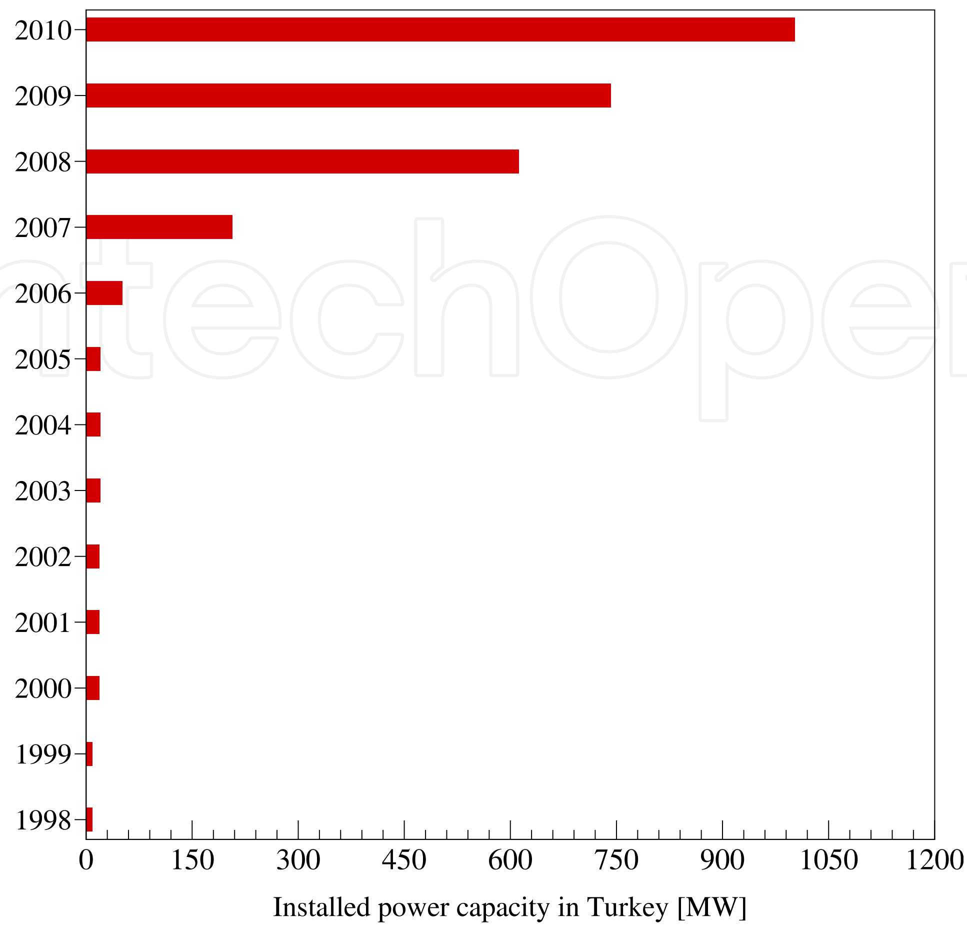


Fig. 1. Cumulative variation of wind power installed in Turkey

wind power in Turkey is shown in Fig. 1(Electricity Market Regulatory Authority, 2010). It is expected that the installed wind power capacity in Turkey will reach about 3500 MW up to end of 2010 year.

Wind energy prices are based on local conditions and require to analyze for each country. The characteristics and the distribution of wind speeds of a site have to be investigated in detail for effective using this energy. When a wind energy conversion system will install in a site, many factors such as the wind speed, wind power, the generator type have to be taken into account and a feasibility study must be done. A lot of studies related to the wind characteristics and wind power potential have been made in many countries worldwide by researchers such as Rehman (2004), Ahmet Shata and Hanitsch (2006), Acker et. al (2007), Bagiorgas et al. (2007), Bouzidi et al. (2009), Nouni et al. (2007), Chang and Tu (2007), Ngalaa et al. (2007), Zhou et al. (2010) etc.

In Turkey, a lot of studies of the estimation of wind characteristics have been achieved by researchers. Bilgili et al. (2004) and Sahin et al. (2005) investigated the wind power potential for selected seven different sites (Antakya, Samandag, Karatas, Adana, Yumurtalýk, Dortyol and Iskenderun) in the Southern Anatolia. Their results show that the contours of constant wind speed and power potential could lead the private power developers to decide the locations of appropriate wind farms. Bilgili and Sahin (2009), and Sahin and Bilgili (2009) studied wind energy density in the southern and southwestern region of Turkey. The dominant wind directions, probability distributions, Weibull parameters, mean wind speeds, and power potentials were determined according to the wind directions, years, seasons, months, and hours of day, separately. It is obtained that these regions have a reasonable wind power potential and they are suitable for planting wind energy turbines. In addition, according to authors Belen-Hatay is the most promising and convenient site for production of electricity from wind power. Bilgili et al. (2010) and Bilgili and Sahin (2010) investigated statistically wind energy density of Akhisar, Bababurnu, Belen, Datca, Foca, Gelendost, Gelibolu, Gokceada and Soke districts which are located in the southern, southwestern and western region of Turkey. The Weibull and Rayleigh probability density functions, and the Wind Atlas Analysis and Application Program (WAsP) packet program were used to analyze the measured data collected by the General Directorate of Electrical Power Resources Survey Administration. They concluded that the Weibull probability density function and WAsP program provide better power density estimations than Rayleigh probability density function for all stations enjoying a reasonable wind power potential. They found that Gokceada and Gelibolu were the most promising and convenient sites to product the electricity from the wind energy. Furthermore, Bilgili and Sahin (2010) presented the electric power plants in Turkey and, their capacities and resources used in the electricity generation in order to update the electric energy statistics. The status of thermal, hydro, wind, and geothermal power plants in Turkey was classified according to the electricity utilities.

Kurban and Hocaoglu (2010) studied the possible wind energy potential in Eskisehir, Turkey using the data collected in the observation station established at Iki Eylul Campus of Anadolu University. And they (2010) investigated the wind statistics and energy calculations for Eskisehir region using the Wind Atlas Analysis and Application Program (WAsP) software. They selected suitable sites to locate wind turbines optimally according to the created wind power and wind speed maps. Eighteen different wind turbines with nominal powers between 200 and 2,000 kW are considered to product energy. Karsli and Gecit (2003) determined the wind power potential of the Nurdagi/Gaziantep district located in the south of Turkey using Weibull parameters of the wind speed distribution. Their results show that the district has a mean wind speed of 7.3 m/s at 10m height and mean power density of 222 W/m2. Akpinar and Akpinar (2004) evaluated the wind energy potential of Maden-Elazig in eastern Turkey and obtained that the mean speed varies between 5 and 6 m/s and yearly mean power density is 244.65 W/m2. Kose (2004) and Kose et al. (2004) determined the possible wind energy potential at the Dumlupinar University-Kutahya main campus using their own observation station. Celik (2003) analyzed the wind energy potential of Iskenderun based on the Weibull and the Rayleigh models using 1-year measured hourly time-series wind speed data.

It can be generated more power from wind energy by selection of wind farm site with suitable wind electric generator and establishment of more number of wind stations. The selection and installing of suitable wind electric generator to produce electrical energy economically in the windy areas requires a number of activities that include the investigation of the source, feasibility assessment etc. Ozerdem et al. (2006) carried out both technical and economical feasibility study for a wind farm in Izmir-Turkey using three diverse scenarios for economical evaluation. It was shown that the generating cost per kWh and internal rate of return value for all three scenarios were promising. Celik (2007) analyzed economically suitable power generation using wind turbines which have nominal power range form 0.6 to 500 kW. This study showed that Iskenderun was amongst the possible wind energy generation regions, and the lowest cost of electricity at \$0.15 per kWh was obtained in the wind turbine with 500 kW.

Gökçek et al. (2007a, 2007b) studied wind energy potential and energy cost analysis of Kirklareli in the Marmara Region, Turkey. The results of their study indicated that Kirklareli enjoyed well enough wind energy potential and the wind turbine with 2300 kW rated power realized the highest annual energy production and the electrical energy cost per kWh was estimated as about 0.06 \$ for turbine specific cost as 700 \$/kW. Genç and Gökçek (2009), and Gökçek and Genç (2009) investigated the evaluation of wind potential, and electricity generation and cost of wind energy conversion systems in Central Anatolia Turkey. They has concluded that Pinarbasi among considered sites has a remarkable potential of wind energy for utilization and can be evaluated as marginal area for cost-effective electrical energy generation as the costs of wind energy conversion systems are lowered. Furthermore, according to the result of the calculations, it was shown that the wind energy conversion system of capacity 150 kW produce the energy output about 121 MWh per year in the Pinarbasi for hub height 30 m and also energy cost varies in the range of 0.29-30.0 \$/kWh for all wind energy conversion systems considered.

2. Wind Characteristic

2.1 Wind Energy Meteorology

The atmosphere of the earth absorbs solar radiation during the day. Then it delivers heat to space at a lower temperature at night time. In this process, the regions where the air pressure is temporarily higher or lower than average occur. This difference in air pressure causes air mass to flow from the region of higher pressure to that of lower pressure. This flow of air masses is called as *wind*.

Wind has two characteristics: wind speed and wind direction. Wind speed is the velocity of the air mass which travels horizontally through the atmosphere. Wind speed is often measured with an anemometer in kilometers per hour (kmph), miles per hour (mph), knots, or meters per second (mps) (Pidwirny, 2006). An anemometer (Fig. 2) consists of three open cups attached to a rotating spindle. Wind direction is called as the direction from where a wind comes from. Direction is measured by an instrument called a wind vane which is shown in Fig. 2. The wind vane instrument has a bullet shaped nose attached to a finned tail by a metal bar. The anemometer and wind vane are positioned in the atmospheric at a standard distance of 10 meters above the ground.

Information on the direction of wind can be presented in the wind roses. The wind rose is a chart which indicates the distribution of wind in different direction. Fig. 3 describes the sixteen principal directions of wind. Meteorology reports the wind direction using one of these sixteen directions. And aeronautical meteorology uses the degree concept based on the 360 degrees found in a circle for the wind direction, while climatological and synoptical meteorology uses the sixteen principal directions.

Wind always blows from high pressure region to low pressure region. High/low pressure region is a region whose pressure is higher/lower than its surroundings. The velocity of wind is based on pressure gradient force. If the pressure gradient force is greater, the faster wind will blow. If the isobars which are a line drawn through points of equal pressure on a weather map (Fig. 4) are closely spaced, a meteorologist can forecast wind speed to be high due to the fact that the pressure gradient force is great. In areas where the isobars are spaced widely apart, the pressure gradient is low and light winds normally exist. For example, when the low pressure region in the north of Black Sea in the surface weather chart taken from Turkish State

Fig. 2. Anemometer used to measure wind speed and direction (Pidwirny, 2006)

Meteorological Service (Turkish State Meteorological Service, 2010) is considered, the winds in the A region are faster than the winds in the B region. Because A region inside yellow circle has the four isobars while B region inside brown circle enjoying same diameter with yellow circle has the two isobars.

There are three another forces acting on wind: coriolis force which the rotation of the Earth creates, centrifugal force which is directed towards the center of rotation and friction force which the Earth's surface creates. The coriolis force and centrifugal force only influence wind direction, while frictional force have a negative effect on wind speed and are limited to the lower one kilometer above the Earth's surface (Pidwirny, 2006).

2.2 Wind Speed Distribution in Turkey

Turkish Wind Atlas shown for open plains in Figure 5 was prepared using Wind Atlas Analysis and Application Program by Turkish State Meteorological Services and Electrical Power Resources Survey and Development Administration in 2002 (Dündar et al., 2002). In this study, the observations have been done for 96 meteorological stations distributed homogeneously over Turkey, and 45 of these observation stations were used for the preparation of the Wind Atlas. In this Wind Atlas, the legend for closed plains was given in Table 1. As shown in Figure 5 and Table 1, there are many suitable sites especially in coastal areas and central region (Pinarbasi) of Turkey to product electricity from wind energy.

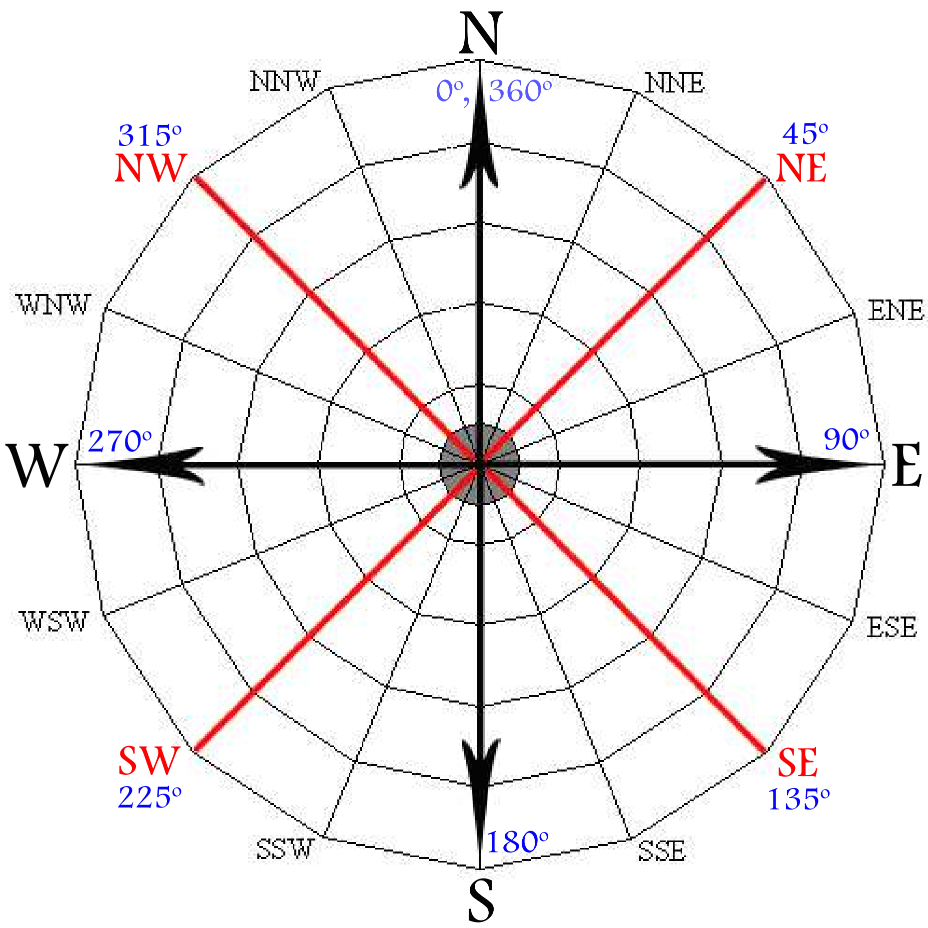


Fig. 3. Wind rose

2.3 Wind Speed Variation With Height

It is necessary that the wind data extrapolate for the turbine hub heights since the wind data are measured at 10 m height above ground. In order to calculate of wind speeds at any height, log law can be used. Log law boundary layer profile (Archer and Jacobson, 2003) incorporates a roughness factor based on the local surface roughness scale z_s (m),

$$v = v_0 \left(\frac{\ln(z/z_s)}{\ln(z_0/z_s)} \right) \tag{1}$$

where v is the wind speed to be determine for the desired height (z), v_0 is the wind speed at recorded at standard anemometer height (z_0). Surface roughness is based on land use category such as urban, cropland, grassland, forest, water, barren, tundra, etc. The land use category can be selected from the Engineering Sciences Data Unit (Engineering Sciences Data Unit, 2010).

2.4 Weibull and Rayleigh Wind Speed Statistics

In order to describe the wind speed frequency distribution, there are several probability density functions. The probability density functions point out the frequency distribution of wind speed, and which the interspace of the most frequent wind speed is, and how long a wind turbine is out and on of action. The Weibull and the Rayleigh functions are the two most

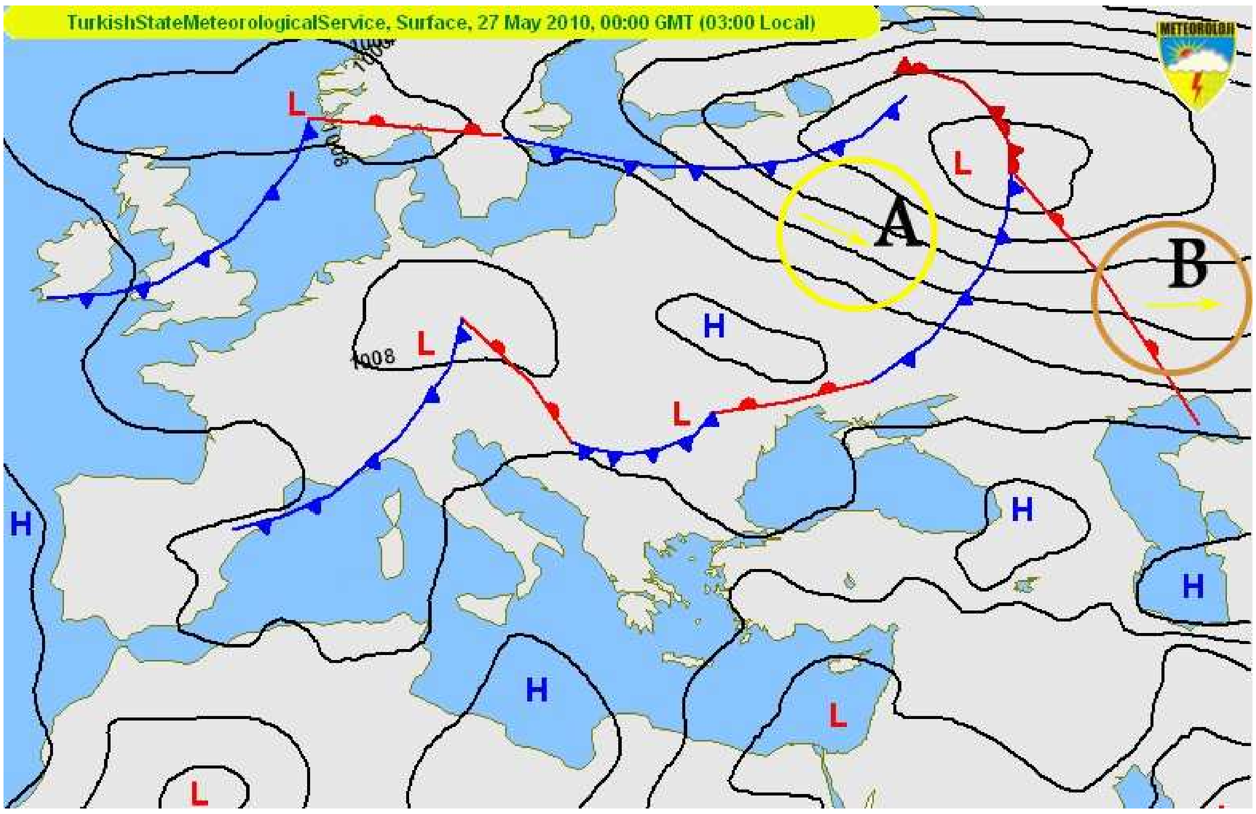


Fig. 4. The surface weather chart (Turkish State Meteorological Service, 2010)

Color	Wind speed (m/s)	Wind power (W/m^2)
Dark blue	>6.0	>250
Red	5.0-6.0	150-250
Yellow	4.5-5.0	100-150
Green	3.5-4.5	50-100
Cyan	<3.5	<50

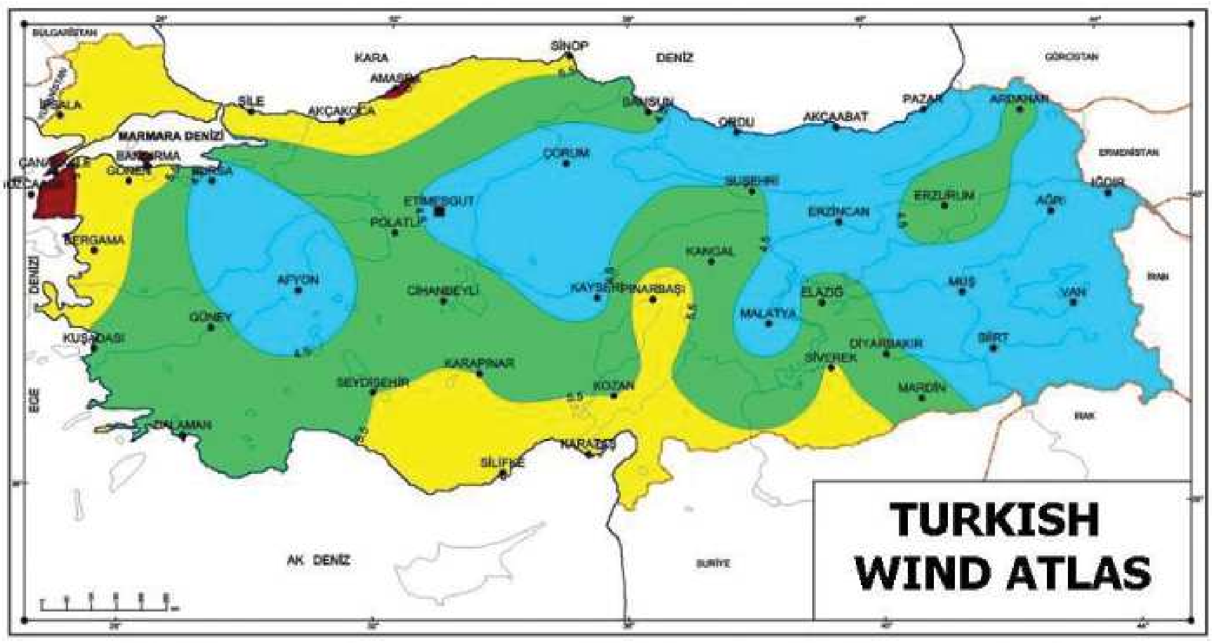
Table 1. The wind speed distributions for closed plains on Turkish Wind Atlas (Dündar et al., 2002)

known. The Weibull is a special case of generalized gamma distribution, while the Rayleigh distribution is a subset of the Weibull (Johnson, 2006). The Weibull is a two parameter distribution while the Rayleigh has only one parameter and this makes the Weibull somewhat more versatile and the Rayleigh somewhat simpler to use (Johnson, 2006). The Weibull distribution function is expressed as

$$f_w(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{2}$$

where v is the wind speed, c Weibull scale parameter in m/s, and k dimensionless Weibull shape parameter. These parameters can be determined by the mean wind speed-standard deviation method (Justus et al., 1977) using Eqs. 3 and 4.

$$k = \left(\frac{\sigma}{\overline{v}}\right)^{-1.086} \quad (1 \leq \text{k} \leq 10) \tag{3}$$



Wind resources at 50 m above ground level for open plains (roughness class 1)

v (m/s)	> 7.5	6.5 – 7.5	5.5 – 6.5	4.5 – 5.5	< 4.5
P (W/m²)	> 500	300 - 500	200 - 300	100 - 200	< 100

Fig. 5. Turkish Wind Atlas (Dündar et al., 2002)

$$c = \frac{\overline{v}}{\Gamma\left(1 + \frac{1}{k}\right)} \tag{4}$$

where $\overline{v}$ is the mean wind speed and σ is the standard deviation. $\overline{v}$ is calculated using Eq. 5 and σ using Eq. 6 (Zhou et al., 2006).

$$\overline{v} = \frac{1}{n}\left(\sum_{i=1}^{n} v_i\right) \tag{5}$$

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}\left(v_i - \overline{v}\right)^2\right]^{0.5} \tag{6}$$

where n is the number of hours in the period of the time considered such as month, season or year.
The dimensionless shape parameter, k of Weibull distribution is assumed as 2 in Rayleigh distribution functions. The probability density function of the Rayleigh distribution is expressed as

$$f_R(v) = \frac{\pi v}{2\overline{v}^2} \exp\left[-\left(\frac{\pi}{4}\right)\left(\frac{v}{\overline{v}}\right)^2\right] \tag{7}$$

The wind power density of any windy site per unit area based on any probability density function to estimate the wind power can be expressed as

$$P_m = \frac{1}{2}\rho \int_0^\infty v^3 f(v) dv \tag{8}$$

where ρ is the standard air density, 1.225 kg/m^3. When the Weibull function is chosen as distribution function $f(v)$, the average wind power density is calculated as

$$P_{mw} = \frac{1}{2}\rho \bar{v}^3 \frac{\Gamma(1+3/k)}{[\Gamma(1+1/k)]^3} \tag{9}$$

3. Electrical Power of Wind Energy Conversion System

Annual wind energy output, Ewt for any windy site can be calculated using the time-series wind speed data of that site and the power curve of a wind turbine. In order to predict the wind energy output to be obtained from the wind turbine, an algebraic equation of degree n according to the power curve of the wind turbine between cut-in and rated speed or cut-in speed and cut-out speed can be expressed as Eq. 10.

$$P_i(v) = \begin{cases} 0, & v < v_{ci} \\ \left(a_n v^n + a_{n-1} v^{n-1} + ... + a_1 v + a_0\right), & v_{ci} \le v < v_R \\ P_R, & v_R \le v < v_{co} \quad or \\ \left(a_n v^n + a_{n-1} v^{n-1} + ... + a_1 v + a_0\right), & v_{ci} \le v < v_{co} \\ 0, & v \ge v_{co} \end{cases} \tag{10}$$

where a_n,a_{n-1}, a_1 and a_0 are regression constants, v_{ci} is the cut-in speed, v_R is the rated speed, v_{co} is the cut-out speed and P_R is the rated power and also $P_i(v)$ is the power generating in the related wind speed.
The total energy generated by the operational turbine over a period is calculated by adding up the energy output of all possible wind speeds. In this study, the energy output from a wind turbine was obtained with Eq. 11 using the hourly mean wind speeds.

$$E_{wt} = \sum_{i=1}^{n} P_i(v) t \tag{11}$$

where n is the number of hours in the period of the considered time such as year, season or month, t is one hour time duration.
Capacity factor, C_f is an indicator of both the turbine type and the wind speed in a site considered. The capacity factor is important for assessing the performance of a wind turbine in a site considered (Sathyajith, 2006). Annual value of the capacity factor can be calculated as

$$C_f = \frac{E_{wt}}{E_{rated}} \tag{12}$$

4. Energy Cost Analysis of Wind Energy

The fuel of wind energy may be free, but the equipment necessary to use the wind energy can be expensive, so economic analysis of the wind energy is quite important. The wind turbine has to enjoy low operating cost. There are several factors affecting the unit energy cost of

electricity produced in the wind turbines. These factors may vary from a country to another country.
The total capital investment and operating cost for wind electric generators have to been known to determine the unit cost of electricity. In general, the cost per unit energy is found by dividing the amount of energy produced to the total expenditures made along the certain time interval. All costs of acquiring, owning, and disposing of a system must be considered to make safely economic decisions. However, the value of money during the useful lifetime of wind energy conversion system considered should be taken into account in the cost analysis.
The levelized cost of electricity method is one of the most important indicators for evaluating fiscal performance of power supply systems such as wind energy conversion system (Gökçek and Genç, 2009). The levelized cost of electricity method can be used to calculate the unit cost throughout the useful life of a system. The levelized cost of the wind energy conversion system is the ratio of the total annualized cost of the wind energy conversion system to the annual electricity produced by this system (Gökçek and Genç, 2009). The generation cost of the electrical energy of 1 kWh using a wind turbine system using the levelized cost of electricity method can be defined as

$$C_{el} = \frac{C_{wt}F_{wt} + C_{in}F_{in} + C_{ci}F_{ci} + C_{bb}F_{bb} + C_{misc}F_{misc} + C_{(om)esc}}{E_{wt}} \quad [\$/kWh] \tag{13}$$

where C_{el} and $C_{(om)esc}$ are the cost of energy output and the cost of annual operation and maintenance escalated, respectively. And F_{wt}, F_{in}, F_{ci}, F_{bb} and F_{misc} are the annual charge rate on capital for wind turbine, inverter, civil work and installation, battery bank and other miscellaneous equipments, respectively. The annual charge rate on capital and can be expressed by the following equation;

$$F = \frac{r}{[1 - (1+r)^{-n}]} \tag{14}$$

where n and r are the useful system lifetime (year) and the discount rate, respectively.
The total investment cost of a wind energy conversion system is given as;

$$C_{wecs} = C_{wt} + C_{bb} + C_{ci} + C_{in} + C_{misc} \quad [\$] \tag{15}$$

where C_{wt}, C_{bb}, C_{ci}, C_{in} and C_{misc} are the cost of the wind turbine, the cost of battery bank, the cost of civil work and installation, the cost of the inverter and the cost of miscellaneous equipments (connecting cables, control panel and other components). Furthermore, while the a wind energy conversion system is being bought from a company, the total investment cost of the system, C_{wecs}, can be also known as;

$$C_{wecs} = I_{wecs}P_r \quad [\$] \tag{16}$$

where I_{wecs} and P_r are the specific cost and rated power of the wind energy conversion system.
A distribution of relative costs different components of a typical 5 kW wind energy conversion system is the wind machine 74%, miscellaneous components 10%, battery bank 9%, civil work and installation 4%, inverter 3% (Nouni et al. 2007). In this study, the evaluation of cost was considered as this cost break-up for all wind energy conversion systems. The total investment cost of any wind energy conversion system in terms of rated power was taken as mean of value read from Table 2 (Sathyajith 2006). And the costs of the wind turbine, battery bank, civil work and installation cost, inverter and miscellaneous equipments were calculated by using Eqs. 15 and 16 and used in Eq. 13.

Wind Turbine Size (kW)	Specific Cost, I_{wecs}, (\$/kW)
10-20	2200-2900
20-200	1500-2300
200 >	1000-1600

Table 2. Cost of wind turbines based on the rated power

The cost of operation and maintenance escalated, $C_{(om)esc}$, can be calculated as;

$$C_{(om)esc} = \frac{C_{om}}{r - e_{om}} \left[1 - (1 + e_{om})^n (1 + r)^{-n} \right] \quad [\$/year] \tag{17}$$

where C_{om} is the cost of operation and maintenance for the first year and e_{om} is ratio of escalation of the operation and maintenance. Of course, the cost of operation and maintenance of new wind energy conversion system is low. However, this cost will certainly increase as the time goes on. In addition, this cost is affected from the conditions of wind site, the quality of components and turbine design (Morthorst, 2004). The operation and maintenance cost, C_{om} is generally considered as 15% of the annual cost of wind energy conversion system (Nouni et al., 2007).

5. A Case Study: Energy Cost Analysis of Wind Energy in Central Turkey

In this section, the energy cost analysis of wind energy of Pinarbasi, Develi, Nigde, Kirsehir and Sinop in Central Turkey was studied. In this study, energy costs of large-scale wind energy conversion systems at these observation stations considered were determined using the levelized cost of electricity method. In order to energy cost analysis, the estimation of wind characteristics and potential of Kayseri, Pinarbasi, Develi, Sariz, Tomarza, Kirikkale, Nigde, Nevsehir, Kirsehir, Yozgat, Bogazliyan, Corum and Sinop in Central Turkey were presented in previous studies (Genç and Gökçek, 2009; Gökçek and Genç, 2009; Genç, 2010). For these observation stations, wind data recorded using the cup anemometer for the years between 2000 and 2006 was taken from the Turkish State Meteorological Service. In the Turkish State Meteorological Service, the wind direction and wind speed are recorded by means of mechanical strip chart recorder on paper. The cup anemometer is placed over the observation building to be at a height of 10 m above the ground in all observation stations. The buildings around these observation stations are not too big to affect the wind speed and direction. Most of the meteorological observation stations of the Turkish State Meteorological Service in Turkey are located in almost-clear terrain and outside the city center and the big buildings. But Sinop observation station of the Turkish State Meteorological Service are near city center. The geographical specifications and wind characteristics of these observation stations at 10 m height from the ground are given (Genç and Gökçek, 2009; Gökçek and Genç, 2009; Genç, 2010) in Table 3.

As is shown in this table, at 10 m height the maximum annual mean wind speed, $\overline{v}$, is 3.67 m/s in Pinarbasi, the maximum Weibull shape parameter, k, is 1.88 in Develi, the maximum Weibull scale parameter, c, is 4.09 m/s in Pinarbasi, and the standard deviation, σ, is 2.56 m/s in Pinarbasi. In Pinarbasi, both the mean wind speed and standard deviation is maximum. In other words, Pinarbasi has larger both wind speed and variance of wind speed.

Station	Latitude(N)	Longitude(E)	Altitude (m)	$\overline{v}$ (m/s)	k	c (m/s)	σ
Pinarbasi	$38^{o}\ 43'$	$36^{o}\ 24'$	1500	3.67	1.49	4.09	2.56
Sinop	$42^{o}\ 01'$	$35^{o}\ 10'$	32	3.02	1.21	3.22	2.54
Kirsehir	$39^{o}\ 09'$	$34^{o}\ 10'$	1007	2.49	1.36	3.19	1.88
Nigde	$37^{o}\ 58'$	$34^{o}\ 41'$	1211	2.48	1.64	2.76	1.58
Develi	$38^{o}\ 23'$	$35^{o}\ 30'$	1180	2.60	1.88	2.97	1.48
Kirikkale	$39^{o}\ 51'$	$33^{o}\ 31'$	747	2.16	1.43	2.38	1.56
Tomarza	$38^{o}\ 27'$	$35^{o}\ 48'$	1347	2.24	1.20	2.42	1.92
Nevsehir	$38^{o}\ 35'$	$34^{o}\ 40'$	1260	2.00	1.56	2.23	1.33
Bogazliyan	$39^{o}\ 12'$	$35^{o}\ 15'$	1066	2.07	1.10	2.15	1.90
Yozgat	$39^{o}\ 49'$	$34^{o}\ 48'$	1298	1.93	1.67	2.16	1.20
Corum	$40^{o}\ 33'$	$34^{o}\ 57'$	776	1.71	1.11	1.78	1.55
Sariz	$38^{o}\ 29'$	$36^{o}\ 30'$	1500	1.69	1.26	1.87	1.40
Kayseri	$38^{o}\ 44'$	$35^{o}\ 29'$	1093	1.60	1.16	1.72	1.43
Sivas	$39^{o}\ 45'$	$37^{o}\ 01'$	1285	1.30	1.35	1.42	0.99

Table 3. Geographical specifications and wind characteristics of the observation stations at 10 m height on the ground

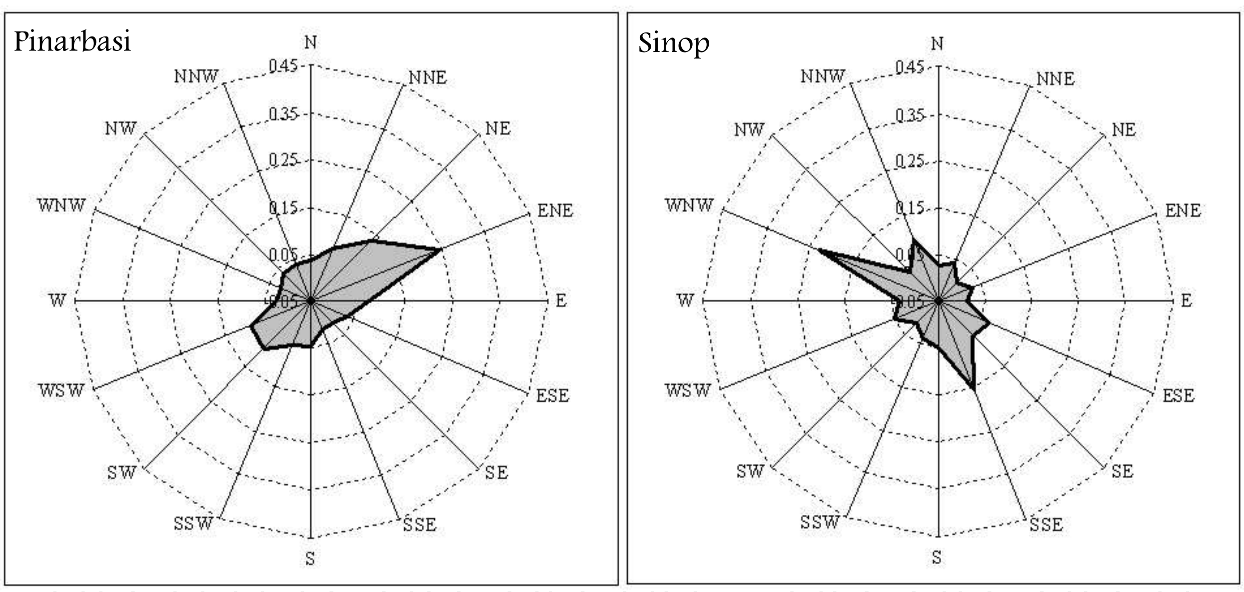


Fig. 6. The distribution of mean wind directions in Pinarbasi and Sinop

In order to calculate of wind speeds at any hub height, log law was used in this study. For log law, the local surface roughness scale z_s was selected as in Table 4 for all observation station from the Engineering Sciences Data Unit (Engineering Sciences Data Unit, 2010). The wind speeds of these observation stations at 50 m hub height using log law were obtained by considering the land use category of the observation stations. It is shown that these obtained mean annual wind speeds are correspond to the values on Turkish Wind Atlas for closed plains (Table 1). Pinarbasi and Sinop are in yellow region where the mean annual wind speed is between 4.5 m/s and 5.0 m/s on Turkish Wind Atlas for closed plains (Table 1) and it is obtained that Pinarbasi has the wind speed of 5.08 m/s and Sinop has the mean annual wind speed of 4.64 m/s at 50 m hub height in this study. These obtained wind speeds are correspond

Station	Land use category	z_s	Wind speed at 50 m (m/s)
Pinarbasi	Savannah	0.15	5.08
Sinop	Forest	0.5	4.64
Kirsehir	Mixed shrubland/grassland	0.3	3.63
Nigde	Mixed shrubland/grassland	0.3	3.62
Develi	Savannah	0.15	3.60
Kirikkale	Mixed shrubland/grassland	0.3	3.15
Tomarza	Savannah	0.15	3.10
Nevsehir	Mixed shrubland/grassland	0.3	2.92
Bogazliyan	Savannah	0.15	2.86
Yozgat	Mixed shrubland/grassland	0.3	2.82
Corum	Mixed shrubland/grassland	0.3	2.49
Sariz	Savannah	0.15	2.34
Kayseri	Mixed shrubland/grassland	0.3	2.33
Sivas	Urban	1.0	2.21

Table 4. Local surface roughness scales and wind speeds of the observation stations at 50 m height on the ground

to the values on Turkish Wind Atlas for closed plains (Table 1) except for Sivas and Sariz. The wind speeds of Sivas and Sariz are seen as less than the values on Turkish Wind Atlas, because Sivas observation station is in city center and Sariz observation station is on a plain between mountains. Finally, Pinarbasi and Sinop, can be characterized as marginal site (fairly good) in point of wind energy potential.

The direction of wind is an important factor for establishing the wind energy conversion system. If it is received the major share of the wind from a certain direction, it should be avoided any obstructions to the wind flow from this side. The distribution of the mean wind directions in Pinarbasi (Genç and Gökçek, 2009) and Sinop (Genç, 2010) which are marginal site is seen in Fig. 6. As is seen from this figure, the prevailing wind directions of Pinarbasi and Sinop are the east northeast (ENE, 67.5^o) and the west northwest (WNW, 270^o), respectively.

In this study, the wind speeds for all observation stations have been analyzed using the Weibull and Rayleigh probability density functions used to determine the wind potential of a site in a period of time. Figs. 7, 8 and 9 exhibits the actual, Weibull and Rayleigh distributions derived from observed the hourly wind data for the year 2003 regarding all observation stations considered. According to the probability density functions, the interspace which has the most frequent wind speed, and how long a wind turbine is out and on of action can be assessed. When it is looked at the Figs. 7, 8 and 9, it is seen that the distribution of wind speed of Pinarbasi, Sinop and Kirsehir is more widen than others. It means that their interspace which has the most frequent wind speed is more bigger than others and the wind energy capacity of these stations is more bigger. For example, the interspace of most frequent is between 0-10 m/s for Pinarbasi, while it is between 0-5 m/s for Kayseri. The Weibull distributions of Sinop, Kirsehir, Tomarza, Nevsehir, Bogazliyan, Corum, Sariz, and Sivas observation stations are in good agreement with actual data, whereas the Rayleigh distribution function is more accurate than the Weibull distribution function in the Pinarbasi, Nigde, Kirikkale, Yozgat and Kayseri wind observation stations. Furthermore, Fig. 10 shows the annual wind power density distributions in all observation stations for the year 2003. As showns in this figure, Pinarbasi has the maximum wind power (125 W/m^2) as actual, and the distributions of Weibull wind

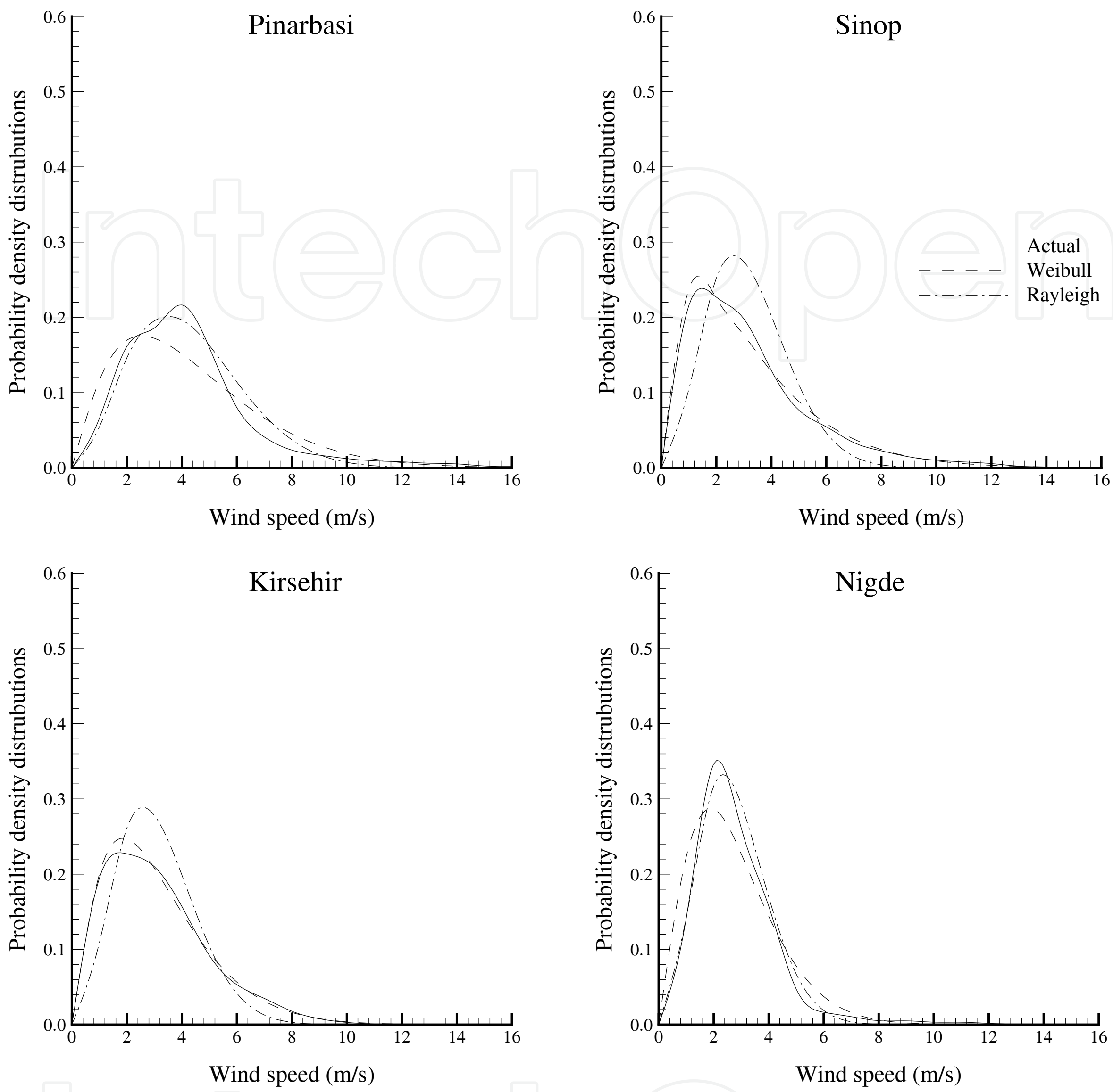


Fig. 7. Probability density distributions in Pinarbasi, Sinop, Kirsehir and Nigde for the year 2003

power of Yozgat, Bogazliyan, Sivas, Corum, Tomarza, Sariz, Nevsehir, Kirikkale and Kirsehir observation stations for year 2003 are in good agreement with actual data.

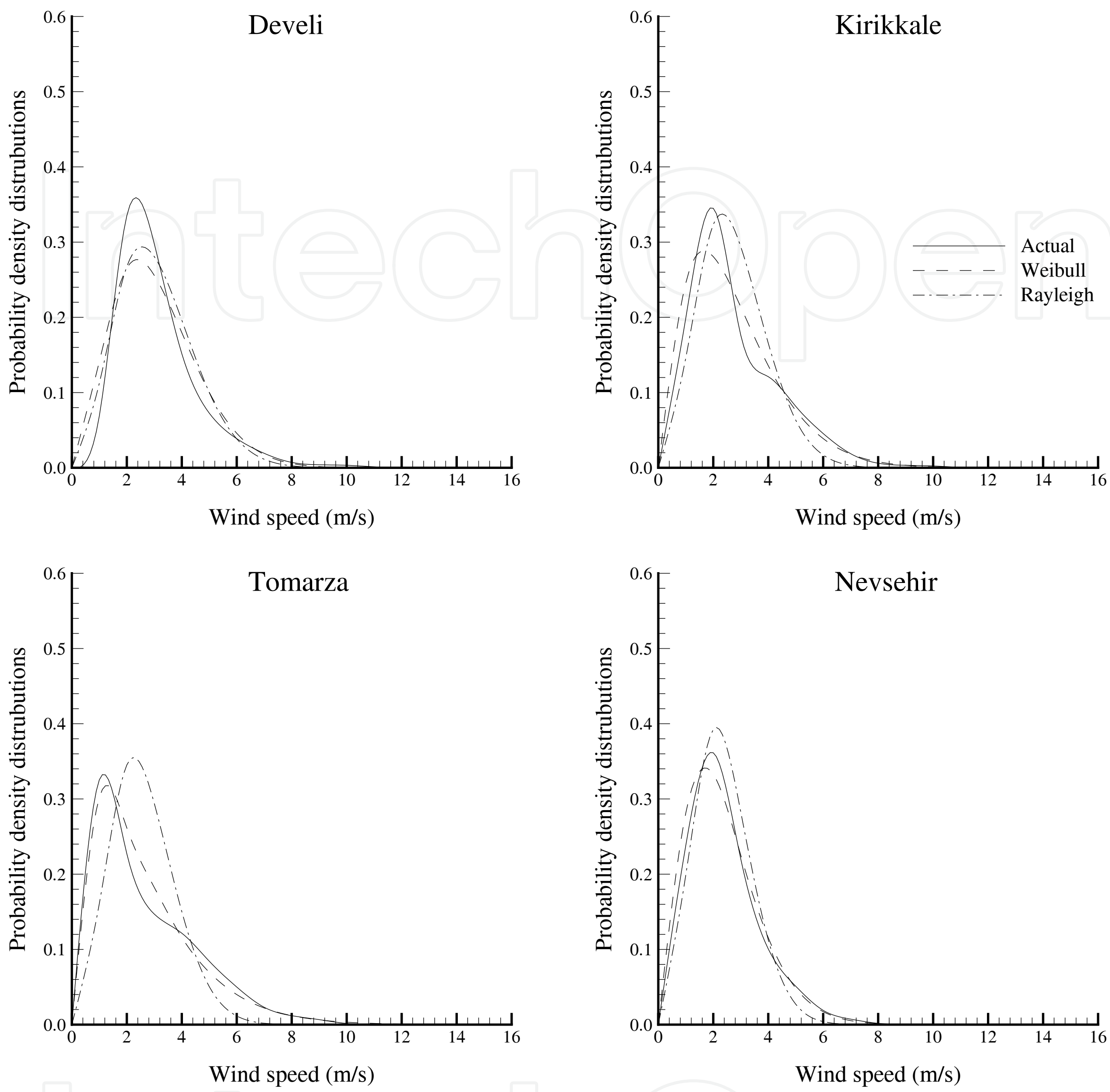


Fig. 8. Probability density distributions in Develi, Kirikkale, Tomarza and Nevsehir for the year 2003

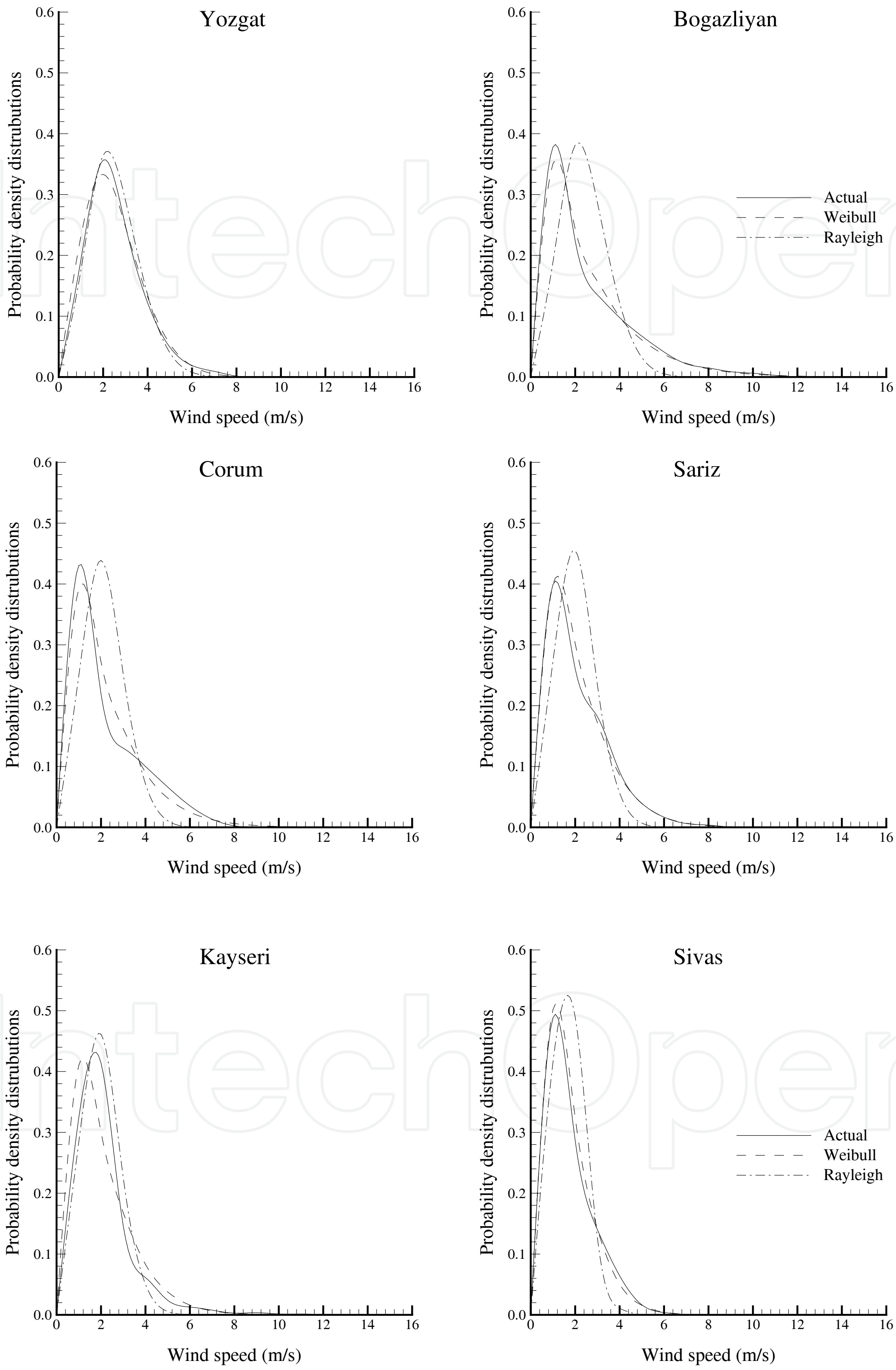


Fig. 9. Probability density distributions in Bogazliyan, Yozgat, Corum, Sariz, Kayseri and Sivas for the year 2003

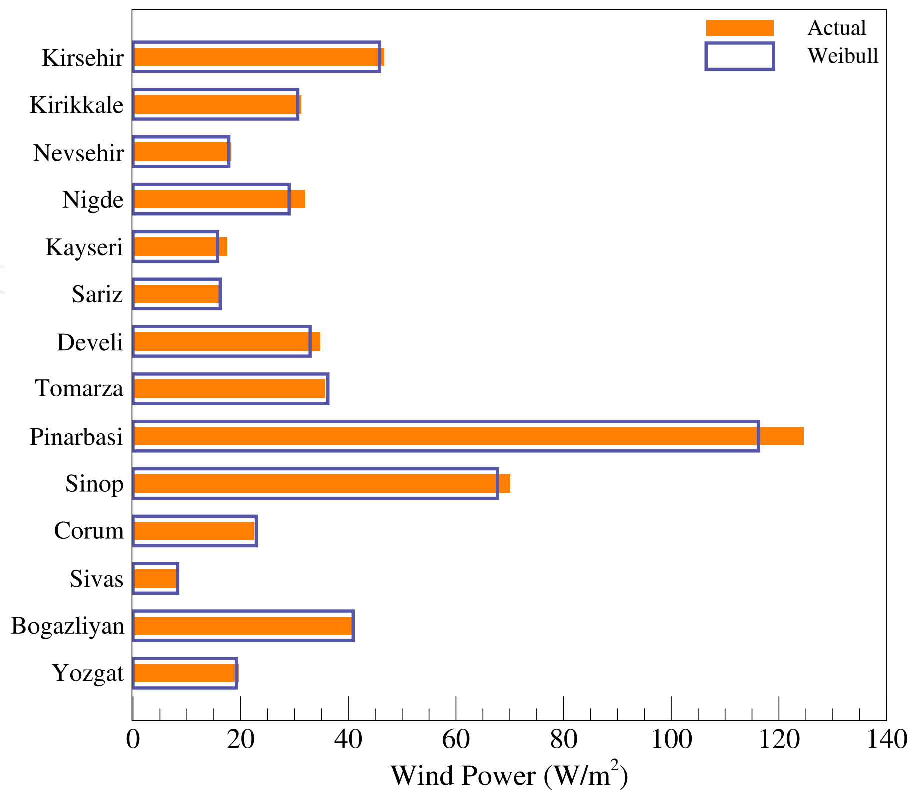


Fig. 10. Annual wind power density distributions in all observation stations for the year 2003

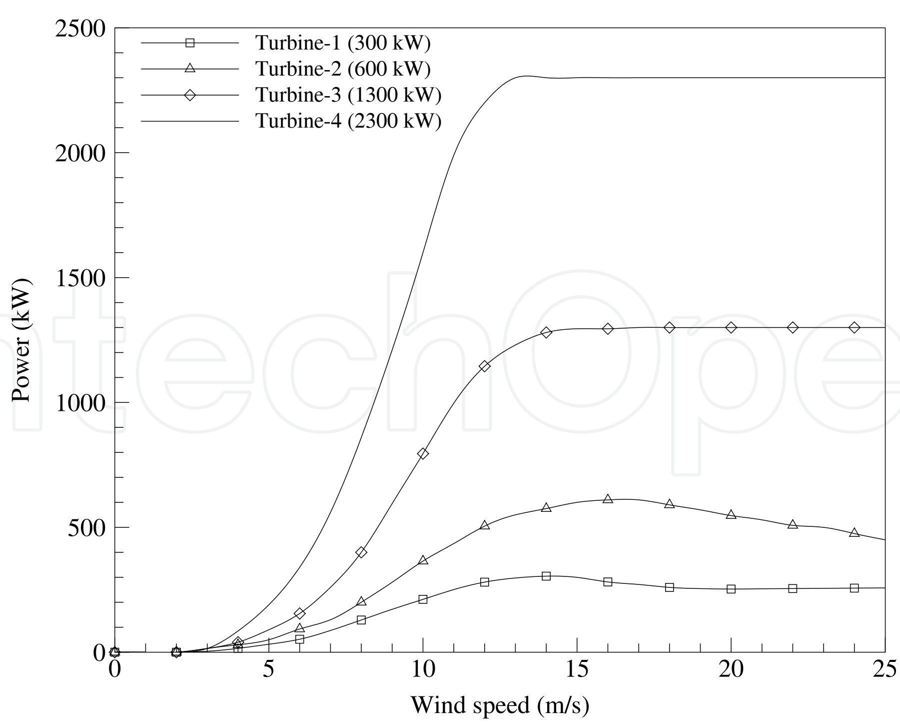


Fig. 11. Power curves of wind turbines selected

The wind powered electrical energy is affected from the design characteristics of the turbine and the wind potential. Instead of designing a wind turbine for the site if a wind energy conversion system which is suitable for the site is selected, the energy cost of this system will be less. Because the designing a wind turbine for the site requires extra funds, so it should be chosen from the existing wind turbines suitable for the wind characteristics of the site in the market. And, the feasibility study and economic analysis of the system should be done to select the wind turbines suitable for the wind characteristics of the site. In this study, the economic analysis of wind energy conversion systems was carried out using the large scale wind energy conversion systems with different rated power. The power curves of the large scale (200 kW) wind turbines (named as Turbine-1 (300 kW), Turbine-2 (600 kW), Turbine-3 (1300 kW) and Turbine-4 (2300 kW)) considered in this study are given in Fig. 11. The technical specifications of these wind turbines are listed in Table 5 (Freris 1990, Pullen 2007).

Characteristics	Turbine-1	Turbine-2	Turbine-3	Turbine-4
Rated power (kW)	300	600	1300	2300
Hub height (m)	30	40	60	80
Rotor diameter (m)	33	44	62	90
Swept area (m^2)	875	1520	2830	6362
Cut-in wind speed (V_{ci}) (m/s)	3	3	3	4
Rated wind speed (V_R) (m/s)	15	15	15	13
Cut-off wind speed (V_R) (m/s)	25	25	25	25

Table 5. Technical specifications of the wind energy conversion systems considered

Furthermore, in order to evaluate the costs of wind powered electrical energy ($/kWh) using these wind energy conversion systems considered for Pinarbasi, Sinop, Kirsehir, Nigde and Develi whose mean annual wind speeds are higher than 3.5 m/s, some assumptions were agreed as follows :

- The lifetime of wind energy conversion system, n was considered as 25 years.
- The discount rate, r was assumed as 12%.
- The operation and maintenance cost, C_{om} was considered as 15% of the annual cost of wind energy conversion system (Nouni et al., 2007)
- The useful life of the battery bank was taken as 7 (Nouni et al., 2007)
- The useful life of the inverter was considered as 10 years (Nouni et al., 2007)
- The escalation ratio of operation and maintenance, battery bank and inverter were assumed as 3.5% based on the annual average of twelve months of Producer Price Index of Turkish Statistical Institute (Turkish Statistical Institute, May 2010).
- Furthermore, it was assumed that the wind energy conversion system would produce same energy output in each year during its useful lifetime.
- The specific turbine cost was taken as 1000 $/kW for large wind energy conversion systems in this study.

According to these assumptions, the annual energy outputs, capacity factors, the costs of energy output computed to estimate the performance of the different wind energy conversion systems in Pinarbasi, Sinop, Kirsehir, Nigde and Develi observation stations are given in Table 6. When it is looked at the Table 5, it is seen that the maximum annual energy output,

(E_{wt}) is 4058,143 MWh/year for Pinarbasi and 3330,763 MWh/year for Sinop produced from Turbine-4 enjoying 2300 kW rated power at 100 m hub height whereas the minimum annual energy output is 117,737 MWh/year produced from Turbine-1 with 300 kW rated power in Nigde at 50 m hub height. It can be concluded that the annual power output of Turbine-4 in Pinarbasi can supply the annual electricity consumption of 434 households which are 14% of 3051 households in Pinarbasi city center (Pinarbasi District, 2010) when it is considered the data of Wind and Hydropower Technologies Program, which is approximately 9360 kWh per year (Wind and Hydropower Technologies Program, 2003).

WECS		Turbine-1 (300 kW)			Turbine-2 (600 kW)		
Hub height (m)		50	80	100	50	80	100
Pinarbasi	E_{wt}(kWh/year)	441515	560086	620075	678387	832002	906448
	C_f	0.17	0.21	0.24	0.13	0.16	0.17
	C_{elc} ($/kWh)	0.13	0.10	0.09	0.17	0.14	0.13
Sinop	E_{wt}(kWh/year)	330707	447390	507447	536381	710666	799973
	C_f	0.13	0.17	0.19	0.10	0.14	0.15
	C_{elc} ($/kWh)	0.17	0.13	0.11	0.22	0.16	0.14
Kirsehir	E_{wt}(kWh/year)	131787	176618	200303	235101	303945	339734
	C_f	0.05	0.07	0.08	0.04	0.06	0.06
	C_{elc} ($/kWh)	0.44	0.33	0.29	0.49	0.39	0.34
Nigde	E_{wt}(kWh/year)	117737	159872	182154	219260	286161	320636
	C_f	0.04	0.06	0.07	0.04	0.05	0.06
	C_{elc} ($/kWh)	0.49	0.36	0.32	0.53	0.40	0.36
Develi	E_{wt}(kWh/year)	146338	198443	226924	248777	311527	346087 3
	C_f	0.06	0.08	0.09	0.05	0.06	0.07
	C_{elc} ($/kWh)	0.39	0.29	0.25	0.46	0.37	0.33
WECS		Turbine-3 (1300 kW)			Turbine-4 (2300 kW)		
Hub height (m)		50	80	100	50	80	100
Pinarbasi	E_{wt}(kWh/year)	1347479	1733873	1931328	2775982	3628222	4058143
	C_f	0.12	0.15	0.17	0.14	0.18	0.20
	C_{elc} ($/kWh)	0.19	0.14	0.13	0.16	0.12	0.11
Sinop	E_{wt}(kWh/year)	997194	1387077	1595469	2046408	2886966	3330763
	C_f	0.09	0.12	0.14	0.10	0.14	0.17
	C_{elc} ($/kWh)	0.25	0.18	0.16	0.22	0.15	0.13
Kirsehir	E_{wt}(kWh/year)	391615	522453	593292	698218	992149	1153126
	C_f	0.03	0.05	0.05	0.03	0.05	0.06
	C_{elc} ($/kWh)	0.64	0.48	0.42	0.63	0.44	0.38
Nigde	E_{wt}(kWh/year)	358206	481710	547622	565673	839912	991640
	C_f	0.03	0.04	0.05	0.03	0.04	0.05
	C_{elc} ($/kWh)	0.69	0.52	0.46	0.78	0.52	0.44
Develi	E_{wt}(kWh/year)	424690	565792	641770	688535	1005863	1185565
	C_f	0.04	0.05	0.06	0.03	0.05	0.06
	C_{elc} ($/kWh)	0.59	0.44	0.39	0.64	0.44	0.37

Table 6. Annual energy outputs, the capacity factors and the costs of electrical energy produced using wind energy conversion systems considered for different hub heights

Capacity factor, C_f is not the same with the efficiency, and a higher capacity factor is not an indicator of higher efficiency or vice versa. Capacity factor is a factor in measuring the

productivity of a wind energy conversion system. The large-scale wind turbines typically run at less than full capacity and operate in capacity factor of 20% to 40%. As is seen from Table 6, the maximum capacity factor was obtained in Pinarbasi with Turbine-1 (300 kW) at 100 m hub height as 24%, meanwhile the minimum capacity factor is 3 % being obtained from Turbine-3 (1300 kW) and Turbine-4 (2300 kW) at 50 m hub height in Kirsehir, Nigde and Develi.
According to the cost analysis, it is seen that the minimum cost of energy output is 0.09 $/kWh in Pinarbasi and 0.11 $/kWh in Sinop with Turbine-1 (300 kW) at 100 m hub height, while the maximum energy cost is 0.78 $/kWh in Turbine-4 (2300 kW) at 50 m hub height in Nigde.
The minimum cost of energy output in Table 6 is 0.09 $/kWh in Pinarbasi and 0.11 $/kWh in Sinop with Turbine-1 (300 kW) enjoying the 100 m hub height, while the energy cost of Turbine-4 (2300 kW) at 50 m hub height in Nigde has been calculated as maximum cost (0.78 $/kWh). According to renewable energy law, Turkey Energy Market Regulatory Authority determined mean wholesale trade price of electric as 13,32 Ykr/kWh (about 0.09 $/kWh) in December 19th, 2009 (Turkey Energy Market Regulatory Authority, 2009). The buying price of electricity is 0.09 $/kWh + Tax = 0.11 $/kWh. According to Turkey Energy Market Regulatory Authority, selling price should not be less than 0.11 $/kWh. As is seen in Table 6, the minimum cost of energy output is 0.09 $/kWh in Turbine-1 at 100 m hub height in Pinarbasi. It is seen clearly that this price is lower than the minimum selling price of electricity determined by Turkey Energy Market Regulatory Authority. Moreover, the wind energy cost of Sinop is equal to the minimum selling price of electricity determined by Turkey Energy Market Regulatory Authority. And, these costs will be decreased as the costs of wind energy systems are lowered based on the development of wind energy technology. In this case, it seems that using of wind energy in Pinarbasi and Sinop is economical.
When the effect of hub height on the capacity factor, energy production, and unit energy cost are investigated for Turbine-1 (300 kW) in Pinarbasi at three different hub heights (50, 80, 100 m) by helping Fig. 12, it can be seen that the capacity factor and annual energy output increase and the unit energy cost decreases due to fact that the mean wind speed increases, as hub height increases.

6. Conclusion

Clean and renewable energies obtaining from sunlight, wind or water around the earth do not make a net contribution of carbon dioxide to the atmosphere. Therefore, these energy sources should be used to protect our world, because of global warming and the injurious effects of carbon emissions. And so, it should be estimated the windy and sunny fields in Turkey, the unit cost of energy output of various wind and solar energy conversion systems. Today, wind energy seems to be reasonable due to the fact that the wind energy generating costs are lower than solar energy costs. Moreover, the wind energy has been experienced remarkably rapid growth in the last two decades because its energy generating cost decrease. In this study, it was presented the wind energy potential and characteristics, and the unit energy cost for the various wind energy conversion systems using the levelized cost of electricity method in different sites located in the Central Anatolia region of Turkey.
It is shown that the mean annual wind speeds obtained in this study are correspond to the values on Turkish Wind Atlas for closed plains. Pinarbasi and Sinop are in yellow region where the mean annual wind speed is between 4.5 m/s and 5.0 m/s on Turkish Wind Atlas for closed plains and it was obtained that Pinarbasi had the wind speed of 5.08 m/s and Sinop had the mean annual wind speed of 4.64 m/s at 50 m hub height in this study. Consequently, according to the mean annual wind speeds obtained in this study, Pinarbasi and Sinop can be

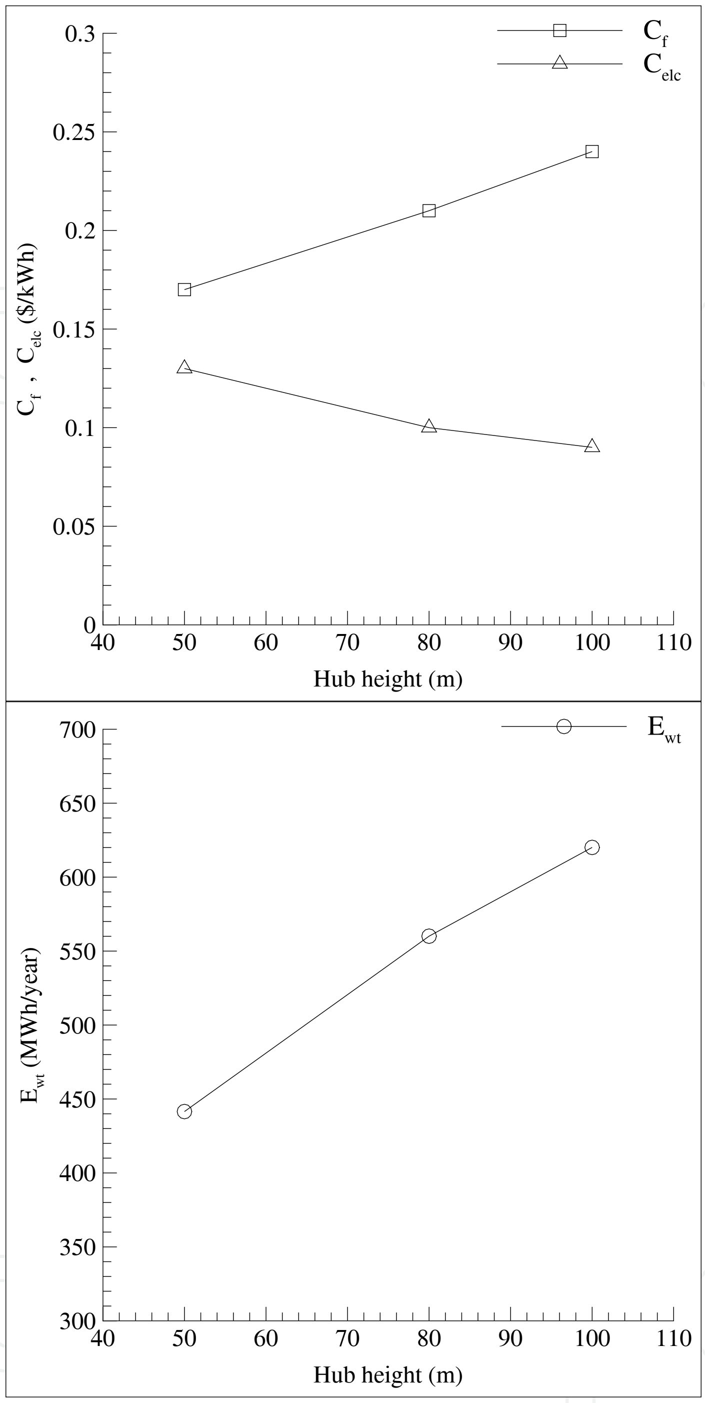


Fig. 12. Annual energy output, the capacity factor and the cost of electrical energy produced using wind energy conversion system with 300 kW rated power at different hub heights in Pinarbasi

characterized as marginal site (fairly good) in the Central Anatolia region of Turkey in point of wind energy potential.

Furthermore, it was found that the maximum annual energy output was 4058,143 MWh/year for Pinarbasi and 3330,763 MWh/year for Sinop produced from Turbine-4 enjoying 2300 kW rated power at 100 m hub height whereas the minimum annual energy output is 117,737

MWh/year produced from Turbine-1 with 300 kW rated power in Nigde at 50 m hub height. According to the cost analysis, it is seen that the minimum cost of energy output is 0.09 $/kWh in Pinarbasi and 0.11 $/kWh in Sinop with Turbine-1 (300 kW) at 100 m hub height, while the maximum energy cost is 0.78 $/kWh in Turbine-4 (2300 kW) at 50 m hub height in Nigde. These wind energy cost of Pinarbasi and Sinop are lower than and equal to the minimum selling price of electricity determined by Turkey Energy Market Regulatory Authority. And, it seems that using of wind energy in Pinarbasi and Sinop is economical.

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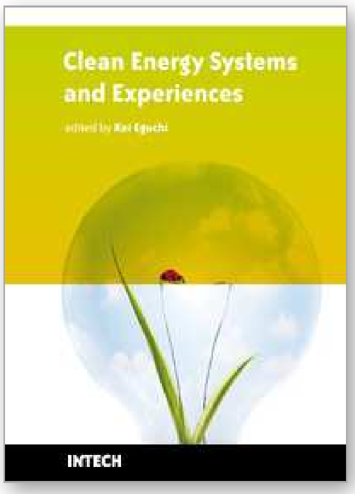

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This book reports the latest developments and trends in "clean energy systems and experiences". The contributors to each chapter are energy scientists and engineers with strong expertise in their respective fields. This book offers a forum for exchanging state of the art scientific information and knowledge. As a whole, the studies presented here reveal important new directions toward the realization of a sustainable society.