ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL APPLIED SCIENCES

M.Sc. THESIS

MEHMET BİLGİLİ

THE WIND ENERGY POTENTIAL IN SOME LOCATIONS OF TURKEY

DEPARTMENT OF MECHANICAL ENGINEERING

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ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ

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YÜKSEK LİSANS TEZİ

MAKİNA MÜHENDİSLİĞİ ANABİLİM DALI

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ABSTRACT

M.Sc. THESIS

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Supervisor : Prof. Dr. Beşir ŞAHİN
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The aim of this study is to establish the meteorological basis for the assessment of wind energy resources in East Mediterranean Region of Turkey and provide suitable data for evaluating the potential wind power. For this purpose, hourly wind data which were observed between the years 1992 and 2001 at Antakya, İskenderun and Dörtyol Meteorological Stations were used. Calculations were made using appropriate computer programs which were prepared for study and a numerical model which is known as WASP (Wind Atlas Analysis and Application Program). The dominant prevailing wind directions, the mean values, the daily, monthly and annual variations and the frequency distributions were determined. Results were classified according to the height above ground level. Finally, the Wind Atlas of these regions, in the form of contours of constant wind speed and wind potential, were produced.

Key Words: Wind energy, Frequency distribution, Wind Atlas, WASP

ÖZ

YÜKSEK LİSANS TEZİ

TÜRKİYE'NİN BAZI BÖLGELERİNDE RÜZGAR ENERJİSİ POTANSİYELİ

MEHMET BİLGİLİ

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Bu çalışmanın amacı, Türkiye'nin Doğu Akdeniz Bölgesi'ndeki rüzgar enerji kaynaklarının değerlendirilmesi için meteorolojik temelleri tespit etmek ve rüzgar gücü potansiyelinin değerlendirilmesi için uygun bilgileri sağlamaktır. Bu amaç için Antakya, İskenderun ve Dörtyol Meteoroloji İstasyonu'nda 1992 ve 2001 yılları arasında gözlenen saatlik rüzgar bilgileri kullanılmıştır. Hesaplamalar, bu çalışma için hazırlanılan uygun bilgisayar programları ve WASP (Rüzgar Atlas Analiz ve Uygulama Programı) olarak bilinen nümerik bir model kullanılarak yapılmıştır. Hakim rüzgar yönleri, ortalama değerler, günlük, aylık ve yıllık değişimler ve frekans dağılımı belirlenmiştir. Sonuçlar yer yüzeyinden yüksekliklere göre sınıflandırılmıştır. Sonunda, bu bölgelerin Rüzgar Atlası, rüzgar hız ve potansiyel değerleri üretilmiştir.

Anahtar Kelimeler: Rüzgar enerjisi, Frekans dağılımı, Rüzgar Atlası, WASP

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NOMENCLATURE

WASP	:Wind Atlas Analysis and Application Program
DMİ	: Devlet Meteoroloji İşleri Genel Müdürlüğü
EİE	: Elektrik İşleri Etüd İdaresi
TEAŞ	: Türkiye Elektrik Kurumu
SRDF	: Standard regional dependence function
GWh	: Gigawatt hour
GW	: Gigawaat
MW	: Megawatt
E(v)	: Mean power density (W/m^2)
ρ	: Mean density (kg/m^3)
v	: Wind speed (m/s)
<v>	: Mean wind speed (m/s)
n	: Elevation factor
p(v)	: Probability function
P(v)	: Cumulative probability function
t	: Time
T	: Period
f	: Frequency
σ	: Standard daviation
$P_w(v)$	: Weibull distribution
$P_R(v)$	: Rayleigh distribution
c, A	: Scale parameter (m/s)
k	: Shape parameter
P_a	: Wind energy (w)
$<P_a/A>$	: Mean wind energy potential (W/m^2)
A	: Area (m^2)
Γ	: Gamma function
v_{mec}	: Wind speed of maximum energy carrier (m/s)
v_{mp}	: Most probable wind speed (m/s)

*	: Position of the site
α_1	: Angle from north to first corner (°)
α_2	: Angle from north to second corner (°)
R_1	: Radial distance to first corner (m)
R_2	: Radial distance to second corner (m)
h	: Height (m)
d	: Depth (m)
P	: Porosity (fraction 0-1)
z_0	: Roughness length (m)
A_H	: Average horizontal area (m^2)
S	: Cross-section facing (m^2)
ΔS	: Relative speed-up (m/s)
u_2	: Wind speed at the top of the hill (m/s)
u_1	: Wind speed over the terrain upstream of the hill (m/s)
L	: Characteristic length of the hill (m)

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1. INTRODUCTION

Wind energy can be used for many processes, such as powering windmills, pumping water, generating waves in ocean and sailing boats. Wind energy is environmentally clean but unfortunately not persistent for long durations.

Due to limited fossil fuel resources and increased cost of conventional power, renewable alternative sources have received increasing attention from the world. Today, new and renewable energy sources such as wind, geothermal, biomass and wave energy have gained importance. One of the best alternative sources of power is wind energy. The wind is perhaps most suitable and cost effective for such applications as electric power production (İncecik and Erdoğmuş, 1995). There is a substantial increase in energy demand in Turkey because of its growth of industrial development. Turkey's present energy sources are insufficient and the need of energy is growing rapidly. The major electrical energy producer in Turkey is the Turkish Electricity Authority (TEAŞ, Türkiye Elektrik Kurumu). In 1970, the total installed generation capacity of Turkey was 2.235 MW and production was 86.247 GWh, in 1995, the total installed capacity reached to 20.952 MW and the total production was 86.247 GWh, in 2000, the total installed capacity reached to 27.391 MW and the total production was 124.200 GWh. According to the projection of TEAŞ, the installed capacity will reach 60.034 MW by the year 2010, the total production will be 313.913 GWh (Güngör and Bozkurt, 1999). As it can be seen from the stated numerical values, Turkey must duplicate its production of electricity in 10 years time.

Besides the high population growth rate, rapid development and industrialization, Turkey's electrical energy demand increases rapidly. For this reason, Turkey must try to expand electrical energy production sources otherwise, in the forthcoming years Turkey may need to have energy production based on imported sources beside the domestic sources.

Turkey is not a rich country in terms of energy resources. Although considerable potential is present in forms of lignite and hydraulic energy but petroleum and uranium reserves are negligible compared to the world reserves. This suggests that Turkey will remain a net energy-importing country and faces the challenge of industrialization in a competitive word spending its scarce hard currency resources on imported energy. Primary energy resources consumed in Turkey include hard coal, lignite, asphaltite, oil, natural gas, hydro, geothermal, wood, animal and plant waste and solar energy. Secondary resources such as coke and briquettes are also produced in Turkey (Güngör and Bozkurt, 1999). According to the record of 1994, total coal reserves were 1.126 x 10^6 tons, lignite reserves at Elbistan were 3.357 x 10^6 tons, together with a total of 4.718 x 10^6 tons elsewhere. Geothermal energy potential was 2.450 MW, hydraulic energy potential was 34.736 MW. There are very little quantities of asphaltite, bituminous shale, crude oil or uranium. Total amount of primary energy sources in Turkey is given in Table 1.1 (Demirbaş, 2001). The installed capacity and electricity generation by the main energy resources are given in Table 1.2. Wind energy is one of the most promising and potential sources of energy, even though its availability varies from place to place.

Table 1.1. Amount of primary energy sources in Turkey

Sources	Apparent	Probably	Possible	Total
Hard coal (million tons)	428	449	249	1126
Lignite (million tons)				
Elbistan	3357	-		3357
Other	3987	626	110	4718
Asphaltite (million tons)	45	29	8	82
Bituminous schist (million tons)	555	1086	269	1641
Hydropower (MW)	34736	-	-	34736
Crude oil (million tons)	36	-	-	36
Natural gas (million tons)	8	-	-	8
Nuclear (tons)				
Uranium	9129	-	-	9129
Thorium	380000			380000
Geothermal (MW)				
Electrical	200	-	-	200
Thermal	1000	-	-	2250

Table 1.2. Main energy resources used for electricity generation in Turkey during 2001

Energy source	Installed capacity		Electricity generation	
	(MW)	(%)	(GW)	(%)
Coal	335	1,3	4046	3,3
Lignite	6510,7	25,3	34371,5	28
Crude oil	2299,6	8,9	10366,2	8,4
Natural gas	4850,7	18.8	49549,2	40
Geothermal	17,5	0,068	89,6	0,07
Hydropower	11672,9	45,4	24009,9	19,6
Wind	18,9	0,073	64,2	0,05
Total	25705,3	100	122496,6	100

Wind is air in motion whose driving force is the uneven heating and cooling of the earth's surface. The horizontal component of the air movement, parallel to the earth's surface, is a measure of the wind in both direction and magnitude. Wind transfers energy which might be dangerous due to its conversion to the pressures exerted on structures, i.e. wind loadings or it is a potential threat to ocean liners as a result of wind generated waves or variations under the influence of eddies or gusts. In practice, the relationship between the wind and the pressure or temperature fields given by isobaric and isothermal maps enable estimates to be made of wind in the absence of anemometers (Şen, 1997).

Since the surface of the earth is neither flat nor homogeneous, the amount of heat energy that is absorbed varies spatially as well as temporally. Consequently, this creates temperature, pressure and density (specific mass) differences that, in turn, create forces that enable air to move from one place to another. It is evident that, depending on the surface features (morphology) of the earth, some areas would be preferable to others for extracting kinetic energy from the wind in the boundary layer of the atmosphere. Recently, with the increasing significance on environmental problems, clean energy generation becomes dominant in every aspect of energy usage. Wind energy is very clean but not persistent for long durations. Even so, at times of potential wind energy generation, other sources and especially fossil fuel combustion must be substituted with wind energy (Şen, 1997).

Wind energy has a huge potential to contribute to our future energy needs, but in order for this potential to be fully realized, the technology must be both economically competitive and environmentally acceptable. Table 1.3 compares the cost of wind energy on a modestly windy site (7.5 m/s) with new coal, nuclear and gas power stations (Mays, 1996).

Table 1.3. The cost of electricity generation (ECU Cents/KWh)

Sources	Capital	Fuel	O & M	Total	External	Full cost
Wind(7.5 m/s site)	5.2	0	1.6	6.8	0.05	6.85
Coal	2.0	2.8	0.7	5.5	2.5	8.0
Nuclear	5.1	1.9	1.3	8.3	2.5	10.8
Gas	0.25	2.8	0.6	3.65	0.95	4.6

The costs are broken down into capital cost (including interest charges), fuel cost and operation and maintenance cost. A total of direct costs are then given in ECU Cents per kWhr. From this it can be seen that whilst wind energy and at 6.8 ECU cents/KWhr is cheaper than nuclear, it is more expensive than the direct cost of both coal and gas. A further column in table gives a mean value for the "external" cost of generation which is not generally charged to the electricity consumer, but which someone inevitably has to pick up in due course. If these are added and a "full cost" is calculated, it can be seen that wind energy, with its low external cost, is already cheaper than both coal and nuclear generation (Mays, 1996).

Turkey is one of the suitable countries to use wind energy. The registration depending to the wind energy existing in the first potential determining studies to determine manageable energy of developed wind energy systems on usable places in our country, have been determined. At these first determinations it was remarkable that the regions Marmara, Aegean and South-East Anatolia concerning wind energy potential were promising. In addition to the general value, studies concerning energy production of wind to determine the potential are being established and managed in appropriate areas in various regions with wind potential. Table 1.4 shows the wind potential according to the regions (Limon, 2002). In our country wind data collected by state meteorological organization together with the general purposed records. Preparation of nation - wide planning depending on new and renewable energy resources and assessment of possibilities of utilization is possible with identifying potential of new and renewable energy resources. For this purpose EİE (Elektrik İşleri Etüd İdaresi) started a study. In this study, EİE evaluated natural wind energy potential over the country using DMİ's (Devlet Meteoroloji İşleri Genel Müdürlüğü) monthly wind speed and directions. The wind data measurements of EİE showed that some locations of Turkey have high wind energy potential. Monthly wind speeds from wind data acquisition station of EİE are given in Table 1.5.

Table 1.4. Wind potential

Regions	Yearly average of wind speed (m/s)	Yearly average of wind power density (W/m^2)
South-East Anatolia	2.69	29.33
Mediterranean	2.50	21.36
Aegean	2.65	23.47
Middle Anatolia	2.46	20.14
Eastern Anatolia	2.12	13.19
Marmara	3.29	51.91
Black Sea	2.38	21.31

Table 1.5. Monthly wind speeds from wind data acquisition station of EİE (m/s)

Station	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
Nurdağı	3.8	4.7	4.5	6.0	-	11.4	13.7	13.7	10.7	4.8	3.3	3.2
Belen	5.4	4.6	4.7	5.1	6.2	8.7	11.0	11.0	8.3	5.3	5.0	4.5
Akhisar	5.8	6.5	7.9	5.3	5.7	6.5	10.0	8.4	4.8	6.7	4.8	6.7
Didim	5.4	5.2	5.7	4.7	3.7	4.3	5.3	4.5	4.0	4.1	4.8	5.5
Kocadağ	9.5	9.4	10.0	7.1	7.4	7.2	10.3	8.3	6.4	8.3	8.3	10.6
Datça	5.4	5.8	5.6	5.5	5.2	5.9	7.8	8.3	6.2	5.9	5.0	4.9
Bandırma	5.5	5.6	6.9	-	-	-	6.9	5.4	4.1	6.4	3.8	5.7
Karabiga	7.6	6.9	7.2	5.3	5.3	5.1	6.7	7.2	6.4	7.1	6.7	6.9
Gökçeada	8.4	7.9	7.8	5.4	6.2	5.3	7.4	6.5	5.8	7.3	6.8	8.3
Söke	4.2	4.4	4.5	3.4	3.8	6.4	6.7	6.5	3.0	3.6	3.2	3.5
Sinop	5.7	4.8	4.6	5.5	4.4	4.9	5.3	3.8	4.6	4.4	4.5	4.4
Yalıkavak	6.0	7.7	6.8	7.8	5.7	5.8	6.9	6.6	5.5	5.2	5.3	7.0
Antakya	1.6	1.7	2.2	2.5	3.1	4.3	5.0	4.4	3.0	1.8	1.4	1.4
İskenderun	2.5	2.5	2.5	2.5	2.4	2.8	3.3	3.1	2.2	1.7	1.9	2.6
Dörtyol	0.7	0.9	1.0	0.9	0.9	0.9	0.9.	0.9	0.8	0.7	0.7	0.7

Table 1.6. Potential wind generation areas

Operating wind farms		
Project	Characteristic (MW)	Place
Çeşme Alaçatı	7.2	İzmir/Çeşme/Alaçatı
Bozcaada	10.2	Çanakkale
Projected of wind farms		
Project	Characteristic (MW)	Place
Kocadağ	2x25.2=50.4	İzmir/Çeşme/Kocadağ
Çanakkale	30	Çanakkale
Mazıdağı	39	İzmir/Çeşme/Alaçatı
Datça	28.8	Muğla/Datça

Datça	12.5	Muğla/Datça
Yalıkavak	7.92	Muğla/Datça
İntepe	30	Çanakkale/İntepe
İntepe	13.2	Çanakkale/İntepe
Akhisar	12	Manisa/Akhisar
Akhisar	30	Manisa/Akhisar
Bandırma	15	Balıkesir/Bandırma
Beyoba	7.92	Manisa/Akhisar
Çeşme	12	İzmir/Çeşme
Karaburun	22.5	İzmir/Karaburun
Gökçeada	1.62	Çanakkale/Gökçeada
Kocadağ	43.5	İzmir/Çeşme/Kocadağ
Yaylaköy	15	İzmir/Karaburun
Lapseki	15	Çanakkale/Lapseki
Şenköy	12	Hatay/Şenköy
Hacıömerli	45	İzmir/Hacıömerli
Belen	20-30	Hatay/Belen
Kapıdağ	20-35	Balıkesir/Erdek
Karabiga	15-50	Çanakkale/Karabiga
Kumkale	12-6	Çanakkale/Kumkale
Mazıdağı-2	90	İzmir/Çeşme
Yellice Belen	70-100	Karaburun/Yellice

It is estimated that the usable wind energy potential in Turkey is around 10.000 MW, there is 19 MW wind power central now. As for the installed wind power capacity of the world is 21.000 MW. Presently, there are 3-wind powers central in Turkey (Ünlü, 2002). All information about wind power centrals and projects in Turkey was given in Table 1.6. (Tezcan, 2001).

During the last decade of the 20th century, grid-connected wind capacity worldwide has doubled approximately every three years. Wind energy was the fastest growing energy technology in the 1990s, in terms of percentage of yearly growth of installed capacity per technology source. The growth of wind energy, however, is not evenly distributed around the world (see Table 1.7 and Table 1.8). By the end of 1999, around 69% of the worldwide wind energy capacity was installed in Europe, a further 19% in North America and 10% in Asia and the Pacific (Ackerman and Söder, 2000).

Table 1.7. Operational wind power capacity in Europe (installed capacity MW)

Country	End-1995	End-1999
Germany	1136	4445
Denmark	619	1742
Spain	145	1530
Netherlands	236	410
UK	200	356
Sweden	67	220
Italy	25	211
Greece	28	87
Ireland	7	73
Portugal	13	60
Austria	3	42
Finland	7	38
France	7	23
Norway	4	13
Luxembourg	0	10
Belgium	0	9
Turkey	0	9
Czech Republic	7	7
Poland	1	7
Russia	5	5
Ukraine	1	5

Switzerland	0	3
Latvia	0	1
Romania	0	1
Total	2518	9307

Table 1.8. Operational wind power capacity worldwide (installed capacity MW)

Region	End-1995	End-1996	End-1997	End-1998	End-1999
Europe	2518	3216	4766	6469	9307
North America	1676	1681	1611	2010	2619
South and Central America	11	32	38	52	87
Asia and Pacific	626	897	1149	1257	1403
Middle-East and Africa	13	13	24	26	39
Total worldwide	4844	5839	7588	9814	13455

2. LITERATURE SURVEY

Since, marking has adapted to the conveniences and extensive uses of electrical power, several methods have been implemented to generate electric power by burning of fossil fuels, such as coal, petroleum products and natural gas to run steam turbines. Utilization of rivers and water falls produce hydro–power. Nuclear energy is also used for production of the electric energy.

A historical background of wind energy systems was reviewed by Hanağasıoğlu (1999). He stated that Wind and wind energy have always played an important role in the historical and economical development of Asia including Anatolia.

İncecik and Erdoğmuş (1995) investigated the variability of the wind power on the western coast of Anatolia, considering the Weibull distribution. For their study, routinely measured hourly wind speeds from eight stations operated by the Turkish Meteorological Service were used. These locations have been chosen to cover the whole western Anatolia coast. They are Ayvalık, Bodrum, Bozcaada, Çanakkale, Dikili, Edremit, Gökçeada and İzmir. The wind data covers the period 1979-1983. According to the results of this analysis, the northern parts of the region (e.g. Çanakkale, Gökçeada and Bozcaada islands) have the maximum scale parameters in winter. The Çanakkale, Gökçeada, Bozcaada, Ayvalık and Bodrum locations present the largest variance among the stations and higher energy potential than others. Monthly wind power ranges from 13.1 to 562.4 W/m^2 at 10 m for all locations. It can be seen that the maximum monthly men wind speed appears at Bozcaada as 6.36 m/s. There is also a steady trend of strong winds over the year at this island location. From the results of this study can be found that Bozcaada is best suited for the application of wind energy among all the stations.

Pashardes and Christofides (1995) performed the statistical analysis of wind speed and direction in Cyprus using the WASP model; in their analysis hourly mean values for wind speed and direction for each separate hour of the day were used. Wind speed direction data covering mainly the period from 1981 to 1992, were evaluated from 20 observation points. As a result of this analysis, the wind atlas of the island was produced in the form of contours of constant wind speed. According to this, Cyprus is not characterized by high wind potential, several areas are identified as having annual mean wind speeds greater than 5 m/s at 10 m height. These locations are situated in the southern coastal zone of the island and in some exposed locations in the mountains. These areas seem to be very promising for wind turbines installation.

Dündar and İnan (1996) investigated wind energy application possibilities for a specific island (Bozcaada) in Turkey. In their study, wind data which are measured hourly at Bozcaada State Meteorological Station at 10 m above ground level between the years 1975 and 1984 were used. Twenty-seven obstacles around the measurement point were determined. The effects of these obstacles are corrected by the WASP. The topographical impacts on wind stream were ignored. As a result of this analysis, in the winter months, wind speeds are greater than those in summer months. In addition, day time speeds are greater than night time speeds. Approximately 68 % of total wind speed data was found to be greater than 4.5 m/s as calculated from the observed meteorological wind data. This value is suitable for most Wind Energy Conversion Systems (WECS) that are used for electricity production. The average of observed wind speeds at 10 m was calculated to be 6.2 m/s. After the corrections were made to eliminate the obstacles effects, 10 m mean wind speed is found to be 6.4 m/s from WASP.

The wind energy potential of Gökçeada in the Northern Aegean Sea was reviewed by Tolun et al.(1995). In their study, wind data collected over a period of three years at four different locations were used to estimate the regional mean wind speed distribution of Gökçeada. By using the WASP program, obstacle, orographic and roughness effects on the wind were eliminated. It was demonstrated that a high winds speeds and power exist in Gökçeada, as well as in the northwestern part of Turkey. Annual wind speed and potential in the Çınaraltı Station are 5.9 m/s and 342 W/m^2 respectively. They stated that the wind energy potential of this island is similar in pattern to that in Denmark and Great Britain.

Jamil, Parsa and Majidi (1995) investigated wind power statistics and evaluation of wind energy density. They aimed to find out the wind energy density and other wind characteristics with the help of the Weibull probability distribution function. They emphasized that the Weibull and Rayleigh probability functions are useful tools for wind energy density estimation but are not quite appropriate for properly fitting the actual wind data of low mean speed, short-time records. In this study, Weibull probability function and parameters were explained with an example.

Karslı and Geçit (2001) performed a study of the determination of wind power potential of Nurdağı/Gaziantep district stated in the south of Turkey. Wind data used in this study was taken by Turkish Electrical Power Resources Development Administration at Nurdağı. It was demonstrated that the district has a mean wind speed of 7.3 m/s at 10 m height and observed highest value of wind speed is 23.3 m/s. Furthermore mean power of the site is found as 222 W/m^2. They stated that the site encourages investment and represents a promising area for the production of the electricity.

Durak and Şen (2000) investigated the wind power potential in Turkey and Akhisar case study. According to the results of this analysis, the average wind speed is 5.8 m/s in the Akhisar area. The average wind power density emerged as 308 W/m^2. most often the winds are northerly or northeasterly, in addition to south and southeasterly. They calculated that the annual wind energy output in this region varies between 31.416 MWh and 41.560 MWh.

The regional wind energy potential of Turkey was reviewed by Öztopal, Şahin, Akgün and Şen (1998). In this study, wind speed and energy maps of Turkey have been presented and the potential areas identified with the emphasis on their significance. According to this analysis, in general, potential wind areas in Turkey lie in the northwestern and northern parts and at locations along the Aegean sea cost. However, the most single locations are in the Gökçeada Island and Bandırma area. Other potential areas are along the middle Black sea region and eastern Mediterranean areas. These are all along the sea coasts, but among the inland areas. Diyarbakır in southeastern Anatolia provides a potential area.

Şen and Şahin (1998) proposed a standard regional dependence function based on the concept of semivariogram. This function present quantitatively the regional dependence of the wind phenomenon recorded at irregularly scattered sites over an area. Standard regional dependence function (SRDF) provides a unique opportunity for the establishment of a regional prediction of wind velocity and energy by using weighted averages. Weightings are obtained through the SRDF provides that the distance between two sites is known. Statistical behavior of wind energy at a single site was derived by Şen (1996) considering simultaneous variations in the pressure, temperature and wind speed measurements.

Şen (2000) investigated the stochastic wind energy formulation. In the results of his analysis, the application of the stochastic wind energy formulation is performed for meteorological factor records at Çanakkale city in the northeastern part of Turkey.

The European wind energy resources were investigated by Petersen, Troen and Mortensen (1988). In their study, two hundred meteorological stations in the European Community countries were selected for calculating regional wind climatologies. Distribution of the wind resources in Europe and variation of mean energy density as a function of height and roughness class have been presented.

Shabbaneh and Hasan (1997) performed wind energy potential in Palestine. In their study, Weibull parameters of the wind speed distribution function were computed for 49 weather stations in Palestine. Wind potentials in kWh/m^{2}yr were calculated at the stations, then contours of wind potential were drawn. They stated that electricity from the wind can be generated in some locations at a cost of 0,07 $/kWh.

Bellarmine and Uequhart (1996) investigated wind energy for the 1990s and beyond. They stated that wind energy has helped mankind for centuries. Today, wind energy is being considered as a viable alternative energy source, with the objective of reducing the harmful effects of conventional electric power generation. The contribution of wind energy to utilities has increased considerably during the past decade. Wind energy has made significant progress along the learning curve toward technological maturity.

Iniyan, Suganthi and Jagadeesan (1998) performed critical analysis of wind farms for sustainable generation. In their study, the performance of wind turbine generators have been analysed and the average technical availability and capacity factor are found to be 92%, 54% and 19% respectively.

Exploitation of wind as an energy source to meet the world's electricity demand was demonstrated by Sesto and Casale (1998). They performed an introduction to the basic aspects of the exploitation of wind energy for electricity generation, as regards both the characteristics of the source and the features and state-of-the-art of today's wind energy conversion systems. They also performed an overview of worldwide applications of wind energy and of the various factors currently driving the wind turbine market.

3. MATERIALS AND METHOD

The mean power in the wind can be estimated by using the mean power density as:

$$E(v) = 0{,}5 \rho v^3 . p_w(v) \tag{1}$$

where ρ is the mean density of air (=1.225 kg /m^3). v^3 is the mean value of the third power the wind speed and $p_w(v)$ is the estimated Weibull distribution. The Weibull distribution is accepted to give a good fit to wind data and wind energy applications.

The objective of this study is to perform a preliminary investigation of the wind energy potential in the south-east region of Mediterranean for generation of electric power. For this purpose, routinely measured hourly wind speeds from certain stations operated by the Turkish Meteorological Service was used.

3.1. Wind Data

For this study, routinely measured hourly wind speeds and directions from 3 stations operated by the Turkish Meteorological Service will be used. These locations have been chosen to cover the south-east region of Mediterranean. The wind data covers the period 1992-2001. The measurements were obtained at heights other than the standard 10 m. Several mathematical representations of the variation of wind speed with height have been proposed. One of them is the power law equation:

$$\frac{V_2}{V_1} = \left(\frac{Z_2}{Z_1}\right)^n \tag{2}$$

Where V_2 and V_1 are the wind speeds at heights Z_2 and Z_1, respectively. These values were adjusted to 10 m using the power law variation. Here n dimensionless exponent depends on atmospheric stability and roughness.

Table 3.1.1. Elevation factor for different conditions

Condition	Elevation factor
Water areas (lakes, open sea), sand surfaces	0.10 – 0.13
Farmland with very few buildings, trees etc.	0.13 – 0.20
Many trees, farmland with closed appearance	0.20 – 0.27
Suburbs, shelter belts	0.27 – 0.40

3.2 Method of Analysis

Here, we are going to use a mathematical model for probability function that exist in the open literature considering all the statistical data of wind for the proposed region. Probability function, say p(v) has to satisfy the following equation:

$$\int_0^\infty p(v)dv = 1 \tag{3}$$

Where v is the wind speed in m/s. It follows:

$$P(v > v^*) = 1 - \int_0^{v^*} p(v)dv = \int_{v^*}^\infty p(v)dv \tag{4}$$

Where $P(v)$ is the cumulative probability function. By the multiplication of cumulative probability with 8760 (one year has 24x365=8760 hours) we get the total hours of wind with speeds greater than v^* . In the same manner we can calculate the cumulative probability $P(v_1 < v < v_2)$ by;

$$P(v_1 < v < v_2) = \int_{v_1}^{v_2} p(v)dv \tag{5}$$

provided that the probability function $p(v)$ is known for the region. In the literature two functions called Weibull and Rayleigh are widely used for this purpose. (Jamil, Parsa and Majidi, 1995)

The wind speed behavior of a region is a function of altitude, season and hour of measurements. Generally, one year of records and weather watching is sufficient to predict the long-term seasonal mean wind speed to within an accuracy of 10% with a confidence level of 90%. Let v be the wind speed in m/s for a given site at a known altitude. Since v is a continuous function of time t, its mean for a period T can be derived from the equation 6,

$$\langle v\rangle = \frac{1}{T}\int_0^T v(t)dt \tag{6}$$

And for n different speed records the mean speed is easily given by

$$\langle v\rangle = \sum_{i=1}^{N} f_i v_i / \sum_{i=1}^{N} f_v \tag{7}$$

Where f_i is the frequency of each observed speed class. For the case where the probability function of the region is known, the mean speed has to be determined as;

$$\langle v\rangle = \int_0^\infty v p(v)dv \tag{8}$$

First, we must produce frequency table and diagram of wind speed to show the distribution pattern. An example is given in the Table 3.2.1 to provide a summary of the present analysis.

Table 3.2.1. The wind speed measurement data

No i	Wind speed range v (m/s)	Mean wind speed v_i (m/s)	Frequency f_i (hours)	Frequency $p_{(v)}$ (%)	Probability $P(v)$
1	0-2	1.0	1400	1400/8664=16.15	0.1615882
2	2-4	3.0	1803	1803/8664=20.81	0.3696907
3	4-6	5.0	1567	1567/8664=18.08	0.5505540
4	6-8	7.0	1468	1468/8664=16.94	0.7199907
5	8-10	9.0	1154	1154/8664=13.31	0.8531855
6	10-12	11.0	881	881/8664=10.16	0.9548706
7	12-14	13.0	296	296/8664=3.41	0.9890350
8	14-16	15.0	70	70/8664=0.8	0.9971144
9	16-18	17.0	16	16/8664=0.18	0.9989612
10	18-20	19.0	9	9/8664=0.1	0.9999999
		Total	8664	100	

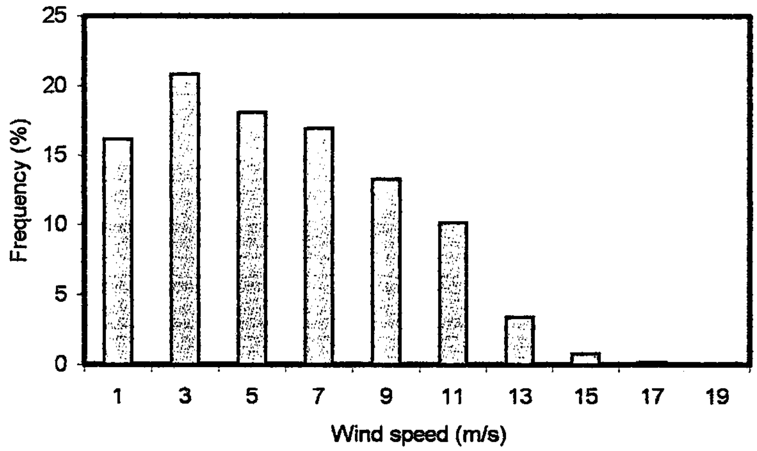

Figure 3.2.1. Frequency diagram

We have arranged the wind data from a meteorological station in Table 3.2.1. These are the data of 361 days of wind observation, 24 times a day, with the measurements in statistical form. Figure 3.2.1 shows the histogram of the wind frequency distribution of the given wind data.

The mean wind speeds shown in Table 3.2.1 are calculated by equation (7) which is $\langle v \rangle = 5.81$ m/s and its standard deviations determined by equation (9) which is σ=3.56 m/s.

$$\sigma = \left[\frac{1}{n-1} \sum_{i=1}^{N} f_i (v_i - \langle v \rangle) \right]^{1/2} \tag{9}$$

In the 5th column of Table 3.2.1 we have given the percentage probability for each wind range according to the relation;

$$p(v_i) = \frac{f_i}{\sum_{i=1}^{N} f_i} = \frac{f_i}{n} (i = 1,2,....N) \tag{10}$$

The cumulative probability in the 6th column of Table 3.2.1 is determined by;

$$P(v_j) = \sum_{i=1}^{j} p(v_i) \tag{11}$$

Where $j \leq i$ and $p(v_i)$ is the probability of each velocity v_i for $i = 1,2,.....,N$. The probability of having all wind speeds will be unity, i.e.;

$$P(v_N) = \sum_{i=1}^{N} p(v_i) = 1 \tag{12}$$

3.3. Weibull Distribution

It is known that there are several efforts to construct an adequate statistical model for describing the wind speed frequency distribution, which may be used for predicting the energy output. The Weibull distribution has been accepted to give a good fit to wind data and wind energy applications. The Weibull distribution is a two-parameter distribution. This distribution is expressed as;

$$p_w(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{13}$$

Where, v is wind speed (m/s), c is scale factor (units of speed) (m/s) and k is shape factor (dimensionless).

This kind of distribution allows the evaluation of several important wind distribution properties in terms of scale and shape parameters (İncecik and Erdoğmuş, 1995). Using k=2 and $c = 2\langle v \rangle / \sqrt{\pi} = 1.12838\langle v \rangle$ in equation 13, The Rayleigh distribution will become;

$$p_R(v) = \frac{\pi v}{2\langle v \rangle^2} \exp\left[-\frac{\pi}{4}\left(\frac{v}{\langle v \rangle}\right)^2\right] \tag{14}$$

Both equations (13) and (14) are useful relations to describe the actual wind speed distribution. We explain here a method for evaluation of the c and k values with the help of collected wind data

3.3.1. The Cumulative Probability Method for c and k Evaluation

We apply this method for data given above. From equation (3) we have

$$\int_0^\infty p(v)dv = \int_0^v p(v)dv + \int_v^\infty p(v)dv = 1 \tag{15}$$

or

$$\int_0^\infty p(v)dv = 1 - P(v) \tag{16}$$

After integration of $p(v)$ from v to infinity we get;

$$\exp\left[-\left(\frac{v}{c}\right)^k\right] = 1 - P(v) \tag{17}$$

This is the cumulative probability function of a Weibull distribution. To write this in a linear form we take the logarithm of equation (17) twice, i.e.;

$$-\left(\frac{v}{c}\right)^k = \ln[1 - P(v)] \tag{18}$$

$$k\ln(v) - k\ln(c) = \ln[-\ln[1 - P(v)]] \tag{19}$$

Now let us say;

$$x = \ln(v) \quad \text{and} \quad y = \ln[-\ln[1 - P(v)]] \tag{20}$$

In this way equation (18) will have a linear form $y = Ax + B$, if $A = k$ and $B = -k\ln(c)$ where $c = \exp(-B/A)$. Therefore, the Weibull parameters are related to the parameters A and B of the line. A is the slope of the line and B is its intersection point ordinate with the y axis. The values of x_i and y_i are collected for the data given in Table 3.3.1.1.

The analytical calculation of A and B is possible with the help of the least squares method.

$$A = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad \text{and} \quad B = \bar{y} - A\bar{x} \tag{21}$$

$$\bar{x}=\frac{1}{n}\sum_{i=1}^{N} f_i x_i \quad \text{and} \quad \bar{y}=\frac{1}{n}\sum_{i=1}^{N} f_i y_i \tag{22}$$

For the given data in Table 3.3.1.1 these are worked out and their values are $\bar{x}=1{,}50371$ and $\bar{y}$=-0,16692. With the help of equations (21) we can then find $k = A = 1.518232$ and

$$c=\exp\left(\frac{-B}{A}\right)=\exp\left(\frac{-\bar{y}+A\bar{x}}{A}\right)=5.021109 \ \ m/s \tag{23}$$

These (k,c) are the values of the Weibull parameters (Jamil, Parsa and Majidi, 1995).

Table 3.3.1.1. The values of x_i and y_i

i	$x_i=\ln(v_i)$	$y_i=\ln[-\ln(1-P(v_i))]$	f_i
1	0.000000	-1.7358752	1400
2	1.098612	-0.7731767	1803
3	1.609438	-0.2234692	1567
4	1.945910	0.2413234	1468
5	2.197225	0.6515883	1154
6	2.397895	1.1308285	881
7	2.564949	1.5069727	296
8	2.708050	1.7661047	70
9	2.833213	1.9271120	16
10	2.944439	2.8115408	9

3.4. Evaluation of Mean Wind Energy Density

One of the important wind characteristics is its mean energy density. The instantaneous wind energy is related with the third power of its speed according to the relation

$$P_a=\frac{1}{2}\rho A v^3 \tag{24}$$

Where $\rho = 1.225\ kg/m^3$ is the air density. Which depends on the altitude (air pressure) and temperature. Here, density is constant for measurements of wind speeds at 10 m height and having normal ambient temperature. A is the area. To find the mean wind energy density one has to calculate $\langle P_a / A \rangle$ i.e.;

$$\left\langle \frac{P_a}{A} \right\rangle = \frac{1}{2}\rho \langle v^3 \rangle = \frac{1}{2}\rho \int_0^{\infty} v^3 p(v) dv \qquad (25)$$

After integration for the Weibull probability model it follows that

$$\left\langle \frac{P_a}{A} \right\rangle = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) \qquad (26)$$

Where c and k are the Weibull parameters and Γ is the usual gamma function. Other wind characteristic are also summarized in Table 3.4.1 using the Weibull model of the wind probability function (Jamil, Parsa and Majidi, 1995).

Table 3.4.1. Wind power evaluation

Wind energy density (W/m^2)	$\left\langle \frac{P_a}{A} \right\rangle = \frac{1}{2}\rho c^3 \Gamma\left(1 + \frac{3}{k}\right) = 151.56$ (27)
Wind speed of maximum energy carrier (m/s)	$v_{mec} = c\left(1 + \frac{2}{k}\right)^{1/k} = 8.73$ (28)
Most probable wind speed (m/s)	$v_{mp} = c\left(1 - \frac{1}{k}\right)^{1/k} = 2.47$ (29)
Mean wind speed (m/s)	$\langle v \rangle = c\Gamma\left(1 + \frac{1}{k}\right) = 4.52$ (30)
Standard deviation of wind speeds (m/s)	$\sigma = c\left[\Gamma\left(1 + \frac{2}{k}\right) - \Gamma^2\left(1 + \frac{1}{k}\right)\right]^{1/2} = 3.04$ (31)

3.5. Determination of Wind Energy Potential Using WASP

WASP is a PC-program for the vertical and horizontal extrapolation of wind climate statistics. It contains several models to describe the wind flow over different terrains and close to sheltering obstacles. The meteorological measurements are effected by the local characteristics of the measurement site, it is necessary to clean the data for these local effects before they are used at a new site. These effects are shelter from nearby obstacles, such as houses, hangars, shelter belts etc; the effect of roughness, and the effect of the orography (height variations of the terrain). To quantify these effects you need (Mortensen, Lendberg, Troen and Petersen, 1993);

i) Description of the dimensions and location of near-by obstacles,

ii) Description of the roughness of the surrounding area, and

iii) Digitized height contour map of the site.

3.5.1. Hourly Wind Speed and Direction

The meteorological input to WASP may be raw processed data. Raw data are usually measurements of wind speed and direction, either in the form of a time series or compiled into a climatological table. These data will reflect the specific conditions under which they were obtained. Strictly speaking, they represent only the exact point of measurement. In order to extrapolate such data, one must take into account the effect of nearby obstacles, the surface roughness conditions, and the effect of the terrain height variations around the meteorological stations. Only after "cleaning", the data in this way can be used for estimating the wind climate at other places around the meteorological station. Observations of wind speed and direction in the form of a time series may be entered to WASP.

3.5.2. Shelter Behind Obstacles

Shelter is defined as the relative decrease in wind speed caused by an obstacle in the terrain. The reduction of wind speed due to shelter from an infinitely long two-dimensional obstacle of zero porosity is shown in Figure 3.5.2.1 (Dündar, 1997). The shelter decreases with diminishing length and increasing porosity of the obstacle.

Obstacles are considered by WASP as 'boxes' with a rectangular cross-section and footprint. Each obstacle must be specified by its position relative to the site, its dimensions and must be assigned a porosity. Figure 3.5.2.2 defines the quantities that specify a single obstacle and that must be input to WASP (Dündar, 1997).

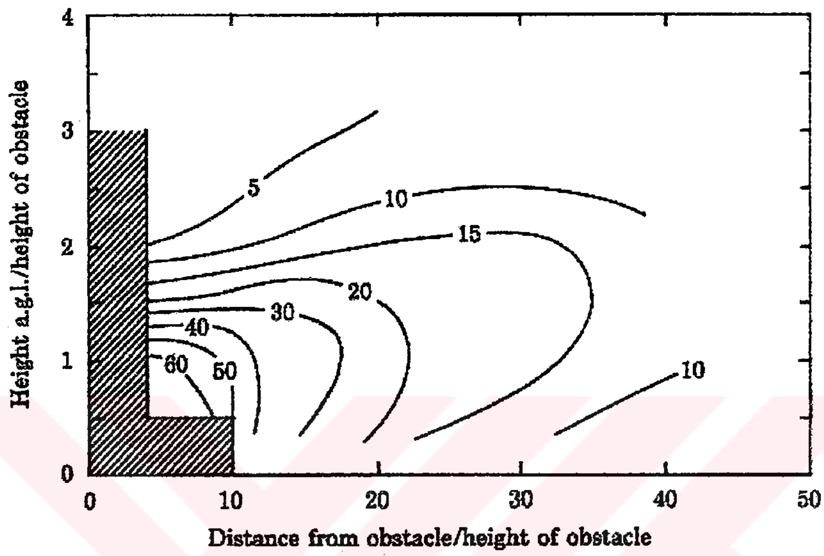

Figure 3.5.2.1. Reduction of wind speed in percent due to shelter by a two-dimensional obstacle

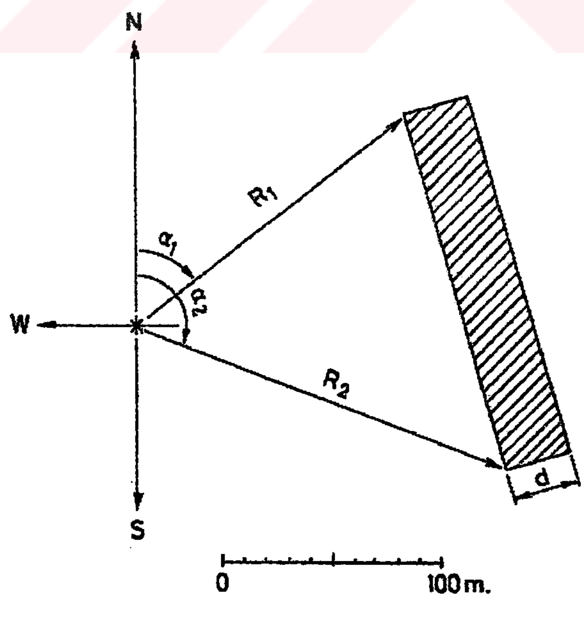

Figure 3.5.2.2. Providing shelter information.

Angles are measured from 0° (north) to 360° clockwise. Obstacles are thus specified relative to a specific site and are not linked directly to the topographic map.

As a general rule, the porosity can be set equal to zero for buildings and ~ 0.5 for trees. A row of similar buildings with a separation between them of one-third the length of a building will have a porosity of about 0.33. For windbreaks the characteristics listed in the table below may be applied. The porosity of trees changes with foliation, i.e. the time of year and like the roughness length, the porosity should be considered a climatological parameter (Moretensen, Landberg, Troen and Petersen, 1993).

Table 3.5.2.1. Porosity of windbreaks

Windbreak appearance	Porosity (*P*)
Solid (wall)	0
Very dense	< 0.35
Dense	0.35 - 0.50
Open	> 0.50

The porosity is the ratio, expressed in Table 3.5.2.1 as a fraction, of the area of the windbreaks 'pores', to its total area.

3.5.3. The Roughness of a Terrain

Areas of different roughness are apparent on most topographical maps. Examples are: water areas (the sea, fjords, lakes), sand surfaces, bare soil, moor, open farmland, farmland with many shelter belts, forests, villages, and cities. The landscape can be classified into areas of similar roughness on the basis of the information contained in the map, as well as any other information available, e.g. aerial photographs. This classification may be thought of as dividing the landscape into a number of terrain types or roughness classes – often in more detail than the classes mentioned above. When the classification has been done, a roughness length z_0 can be assigned to each class; one possible relation between roughness class and roughness length was given above (Mortensen, Landberg, Troen and Petersen, 1993).

3.5.3.1. The Roughness Length

The roughness of a terrain is commonly parameterized by a length scale called the roughness length z_0. Formally, z_0 is the height where the mean wind speed becomes zero, if the wind profile has a logarithmic variation with height. This usually occurs during moderate and strong wind conditions. A simple empirical relation between the roughness elements and the roughness length has been given by Mortensen, Landberg, Troen and Petersen (1993). A roughness element is characterized by its height h and the cross-section facing the wind S. Further, for a number of roughness elements distributed evenly over an area, the density can be described by the average horizontal area, A_H, available to each element. Then

$$z_0 = 0.5\frac{h.S}{A_H} \tag{32}$$

This relation gives a reasonable estimation of z_0 when A_H is much larger than S. It tends to overestimate z_0 when A_H is of the order of S; this is because, when the roughness elements are close to each other, the flow is 'lifted' over them. Then only a fraction of S and h contributes to the roughness. Furthermore, the lifting of the flow requires measuring the height above the ground from somewhere between the top of the roughness elements and half the height of the elements. This height is referred to as a displacement length. The displacement length must often be taken into account on sites with forests, cities, and tall vegetation. Finally, the equation assumes that the porosity is approximately zero, i.e. the roughness elements are solid. For porous roughness elements z_0 from the equation above must be reduced by a fraction equal to the porosity.

The roughness of a particular surface area is determined by the size and distribution of the roughness elements that it contains; for land surfaces these are typically vegetation, built-up areas and the soil surface. In the European Wind Atlas the different terrains have been divided into four types, each characterized by its roughness elements. Each terrain type is referred to as a roughness class. A description and illustration of these four roughness classes is given in the figures below which furthermore give the relation between roughness length and roughness class, the former being the commonly used length scale to characterize the roughness of a terrain (Mortensen, Landberg, Troen and Petersen, 1993).

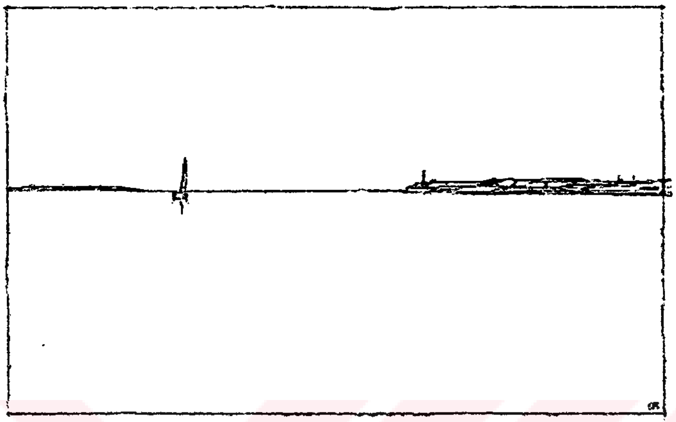

Figure 3.5.3.1.1. Example of terrain corresponding to roughness class 0

An example of terrain is shown in Figure 3.5.3.1.1 represents the roughness class 0 such as water areas. This class comprises the sea, fjords, and lakes. For these types of the roughness length is taken as $z_0 = 0.0002$ m.

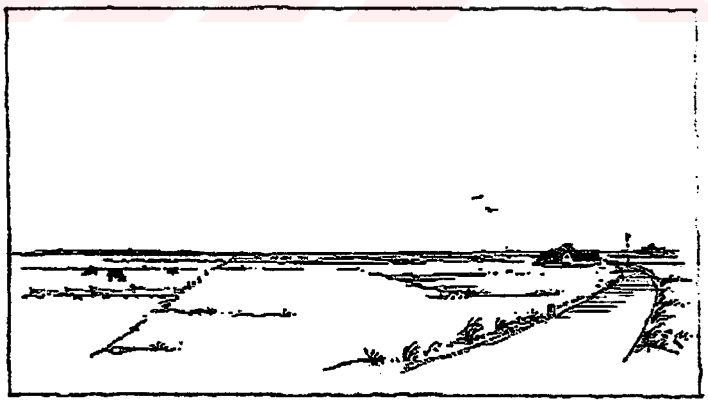

Figure 3.5.3.1.2. Example of terrain corresponding to roughness class 1

An example of terrain as seen in Figure 3.5.3.1.2 which corresponds to the roughness class 1, for example, open areas with few windbreaks. The terrain appears to be very open and is flat or gently undulating. Single farms and stands of trees and bushes can be found in these types of terrain. The roughness length is $z_0 = 0.03$ m.

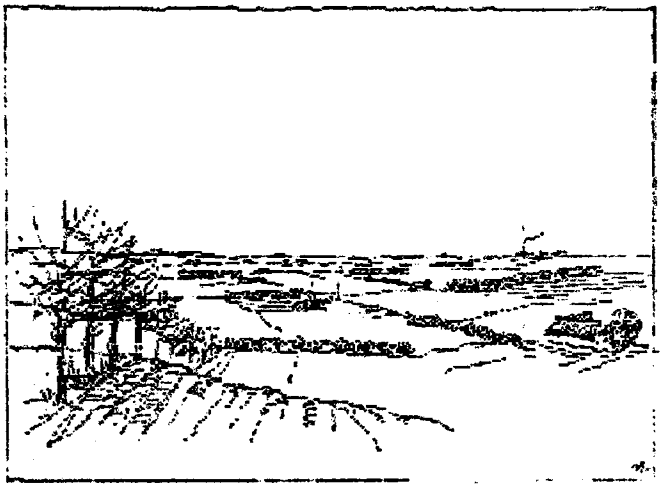

Figure 3.5.3.1.3. Example of terrain corresponding to roughness class 2

The classification of roughness includes the terrain as seen in Figure 3.5.3.1.3 as called to roughness class 2 contains farm land with wind-breaks, the mean separation of which exceeds 1000 m, and some scattered built-up areas. This type of terrain is characterized by large open areas between the many windbreaks, giving the landscape an open appearance. The terrain may be flat or undulating. There are many trees and buildings. Here, the roughness length is z_0 = 0.10 m.

Figure 3.5.3.1.4. Example of terrain corresponding to roughness class 3

Figure 3.5.3.1.4 presents the roughness class 3 which includes the urban districts, forests, and farm land with many windbreaks. The farm land is characterized by the many closely spaced windbreaks, the average separation being a few hundred meters. Forest and urban areas also belong to this class. The class 3 should be taken as $z_0 = 0.40$ m.

Table 3.5.3.1.1 indicates the relation between roughness length, terrain surface characteristics and roughness class given in the European Wind Atlas (Mortensen, Landberg, Troen and Petersen, 1993). So, these parameters are required to be used for the elimination roughness effect on the measured wind speed data.

Table 3.5.3.1.1. Roughness length, surface characteristics and roughness class

z_0 [m]	Terrain surface characteristics	Roughness Class
1.00	city	**3** (0.40 m)
0.80	forest	
0.50	suburbs	
0.40		
0.30	shelter belts	**2** (0.10 m)
0.20	many trees and/or bushes	
0.10	farmland with closed appearance	
0.05	farmland with open appearance	**1** (0.03 m)
0.03	farmland with very few buildings/trees	
0.02	airport areas with buildings and trees	**0** (0.0002 m)
0.01	airport runway areas	
0.008	mown grass	
0.005	bare soil (smooth)	
0.001	snow surfaces (smooth)	
0.0003	sand surfaces (smooth)	
0.0002		
0.0001	water areas (lakes, fjords, open sea)	

3.5.4. Orography

Orographic elements such as hills, valleys, cliffs, escarpments and ridges exert an additional influence on the wind. Near the summit or crest of these features the wind accelerates on the other hand, near the foot and in valleys the wind decelerates.

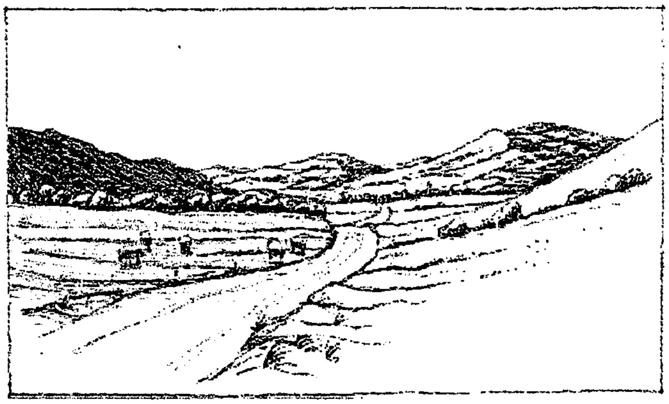

Figure 3.5.4.1. Orographic elements

The effects of height variations in the terrain on the wind profile can most clearly be demonstrated by the results from the international field experiments at the Askervein hill on the Isle of South Uist in the Hebrides. Figure 3.5.4.2 shows a perspective plot of the Askervein hill (Mortensen, Landberg, Troen and Petersen, 1993). The line along which measurements of wind speed and direction were recorded is indicated by the meteorological towers.

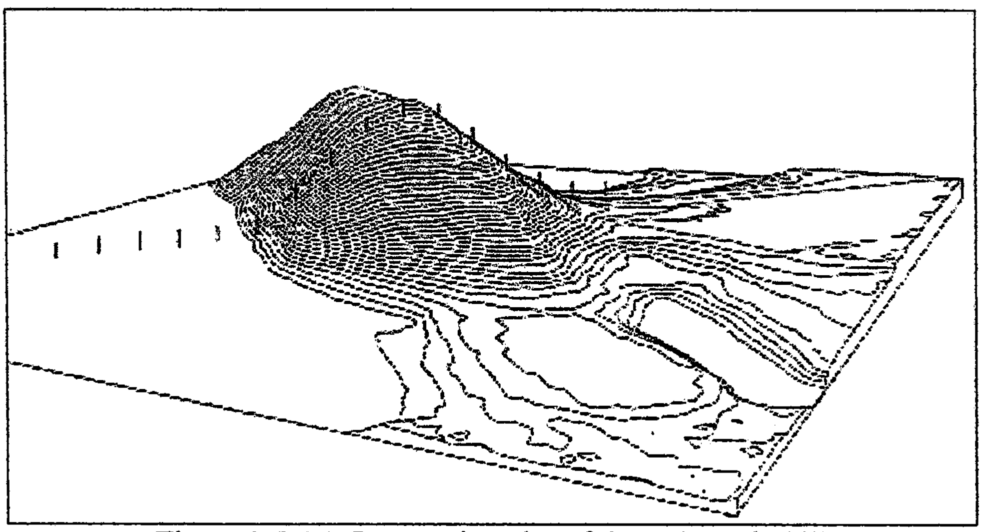

Figure 3.5.4.2. Perspective plot of the Askervein hill

3.5.4.1. Horizontal Speed-Up Profile

The experimental data are shown in Figure 3.5.4.1.1 with the relative speed-up at 10 m above ground level. plotted against the distance from the crest. The relative speed-up is defined as:

$$\Delta S = \frac{u_2 - u_1}{u_1} \tag{33}$$

Where u_2 and u_1 are the wind speeds at the same height above ground level at the top of the hill and over the terrain upstream of the hill, respectively.

The data in Figure 3.5.4.1.1 are obtained for a wind direction almost perpendicular to the orientation of the ridge. Results of three numerical models are also shown in the figure: the BZ-model used in WASP and two other models. Some noteworthy characteristics from Figure 3.5.4.1.1 are:

- The speed-up at the crest is 80 percent as compared with the undisturbed upstream mean wind speed
- The negative speed-up (speed-down) in the front and lee of the hill is 20 to 40 per cent as compared with the undisturbed upstream mean wind speed

Measurements are indicated by dots and results from the orographic model by squares. Results from two other numerical models are shown by a full and dashed line, respectively (Mortensen, Landberg, Troen and Petersen, 1993).

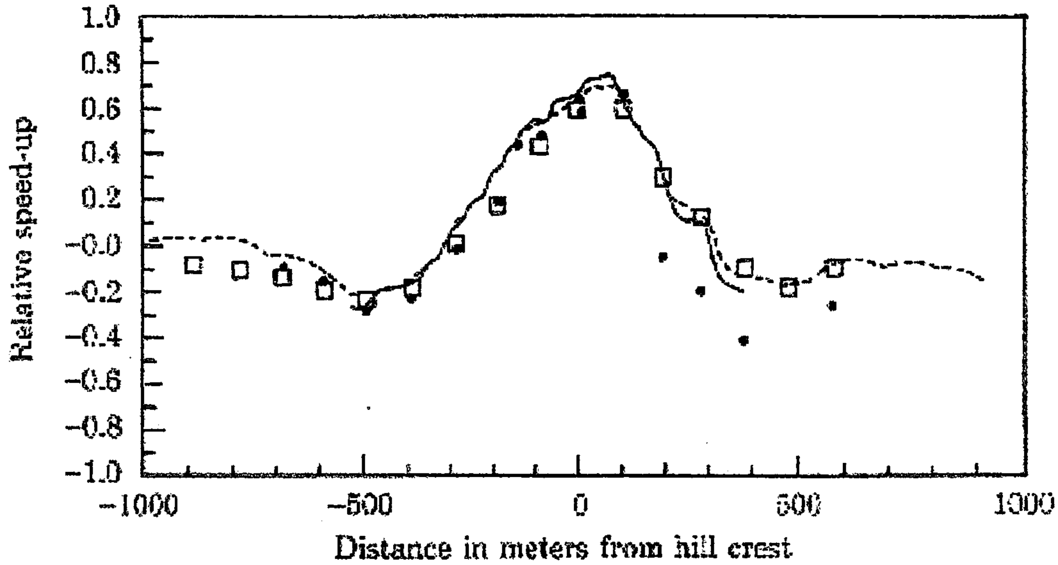

Figure 3.5.4.1.1. Relative speed-up ratios for flow over the Askervein hill at 10 m above ground level.

3.5.4.2. Vertical Speed-Up Profile

The wind speed profile over an idealized hill, with upstream and wind speed profiles at the top of the hill are shown in Figure 3.5.4.2.1. Two length scales characterizing the flow are indicated. Here, L is a characteristic length of the hill, here – following traditional nomenclature – the half width at the middle of the hill; l is the height of maximum relative speed-up.

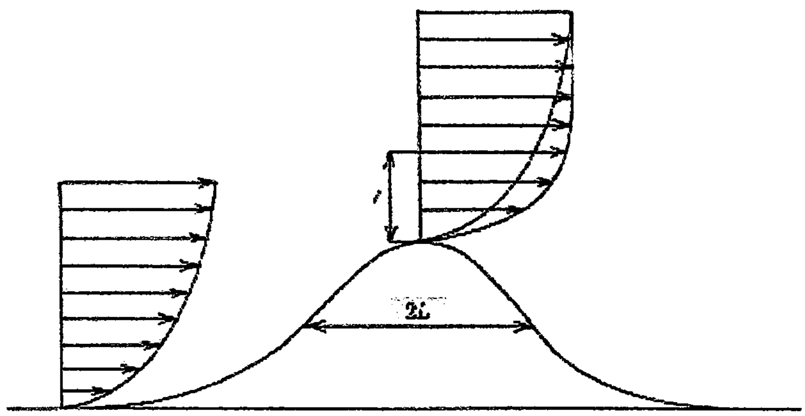

Figure 3.5.4.2.1. The flow over an idealized hill, with upstream and hill-top wind profiles

It is evident that hill exerts a profound influence on the flow, and this has to be taken into account as carefully as possible. But one should be aware of that all the height changes in the terrain influence the flow, for example, a 5% height increase can have a 5% impact on the mean wind speed – possibly at hub height resulting in a 15% increase of the available power (Mortensen, Landberg, Troen and Petersen, 1993).

WASP packet uses the numeric models that are defined in section 3.5. During the analysis of data that measured at the meteorological station effects of obstacles, change of surface roughness and variations of terrain height which have an impact on the wind speed were taken into account. These corrected results through computations are real wind speed and potential data. However, for the predictions of wind speed and its potential at different locations one has to use corrected wind speeds of meteorological stations. If there weren't obstacles around the meteorological station the values of measured wind speed would certainly be high.

4. RESULTS AND DISCUSSION

Turkey is under the influence of various air masses due to the its geographic position that promote the potential wind energy generation possibilities. Durak and Şen (2002) reviewed that the northerly winds over the Balkan peninsula and Black Sea provide strong winds during the winter period. Although, most of the Black Sea coast is composed of Sudden hills, escarpments and cliffs in the hinterland that reduces the wind generation potential areas. But along the Black Sea coast, there are the most suitable areas for wind power generation.

In the western part of Turkey geomorphological structures have long valleys that run perpendicular to the Aegean Sea coast which give the possibility of strong wind movement. There are many suitable locations along the coastal line on the Anatolian main land and islands in the Aegean Sea.

Although, the Mediterranean coast which is presently studied has a perpendicular valleys, the Taurous mountains are located away from the see coast in many locations. These locations are exposed to southerly winds which are not as strong as the northerlies wind which occurs over the Black Sea. But, the eastern Mediterranean region at the vicinity of İskenderun and Antakya regions receives wind which is suitable for wind power generations. (Durak and Şen, 2002)

In the present work it is only focused on the wind energy potential on land. But, the analysis of flow characteristics in the near-shore and off-shore were ignored in the present studies.

Analysing the effectiveness of the wind energy potential over a wide region, the topographic and climatic conditions must be taken into account. Variation of surface properties such as land-sea-lake-river interfaces and variable roughness parameters, the local wind profile as well as wind potential will be affected significantly (Durak and Şen, 2002). Here, the terrain and obstacles are referred to as the roughness of terrain. Hills, cliffs, ridges and escarpments which exert an additional influence on the wind speed are called orographic elements.

Four basic data are considered necessary for WASP packet program that is used in determination of wind potential. These are hourly wind sped and direction, sheltering obstacles, surface roughness changes and orograph data (terrain height). These factors in present work were taken into account preciously.

4.1. Basic Data

Wind data used in present study were taken from DMİ data base. In study of 3 regions which cover measured and corrected analytical studies, hourly wind data between the years 1997-2001 were used. Wind data were measured hourly at 10 m above the ground level in many stations. Observed values were adapted to 10 m above the ground level for meteorological stations measured at different height above the ground level. The height measurements at stations that are investigated as detailed in this study, is 10 m for Antakya, Dörtyol and 17 m for İskenderun. Hourly wind data that were prepared by WASP computational program are given respectively for Antakya, İskenderun and Dörtyol regions in Tables 4.1.1, 2 and 3. The first columns (sector) of these tables show wind directions with 30° intervals. The frequency in these directions of wind was given as a percentage (%) in the second columns. In the other columns (from 1 up to 17), the range of frequency for each column of wind was given as period of time. For example, in the column which begins with "2", the period of time for the frequency values show that the wind speed happens in between 2.1 m/s and 3.0 m/s. Here, "A" and "k" parameters in last two columns are Weibull distribution coefficients that are the basic hypothesis of WASP model. The coefficients in the bottom lines are the normalized frequencies of wind speeds according to the wind intervals (per thousand). In the left side at the bottom of the table, in five years time 43.824 measurements of wind speeds were made at Antakya meteorological station. During five years, zero values of wind speed is measured only for 9 times. On the right hand side in bottom of the table the mean wind speed (m/s) and the energy potential (W/m^2) are shown.

Table 4.1.1. Hourly wind data in Antakya Meteorological Station

Sect degree	Freq %	<1	2	3	4	5	6	7	8	9	11	13	15	17	>17	A (m/s)	k
0:	2.0	548	363	70	17	2	0	0	0	0	0	0	0	0	0	1.2	1.51
30:	27.6	189	498	251	54	7	2	0	0	0	0	0	0	0	0	1.9	2.11
60:	7.3	236	501	234	27	1	0	0	0	0	0	0	0	0	0	1.8	2.32
90:	0.5	770	204	22	4	0	0	0	0	0	0	0	0	0	0	0.8	1.40
120:	0.4	712	250	25	13	0	0	0	0	0	0	0	0	0	0	0.9	1.34
150:	0.2	627	275	49	20	20	10	0	0	0	0	0	0	0	0	1.0	1.02
180:	0.7	467	373	95	41	14	10	0	0	0	0	0	0	0	0	1.4	1.35
210:	55.1	58	113	142	203	230	179	68	8	0	0	0	0	0	0	4.4	3.02
240:	3.4	417	361	80	54	59	21	9	0	0	0	0	0	0	0	1.6	1.14
270:	0.8	713	202	64	18	3	0	0	0	0	0	0	0	0	0	0.9	1.12
300:	0.6	870	88	31	12	0	0	0	0	0	0	0	0	0	0	0.7	1.20
330:	1.3	625	286	48	25	12	4	0	0	0	0	0	0	0	0	1.0	1.10
Total		157	267	171	132	131	100	38	5	0	0	0	0	0	0	3.1	1.70

Number of calms (included): 9 Mean wind speed : 2.8 m/s

Number of observations : 43824 Mean energy density: 29 W/m²

Table 4.1.2. Hourly wind data in İskenderun Meteorological Station

Sect degree	Freq %	<1	2	3	4	5	6	7	8	9	11	13	15	17	>17	A (m/s)	k
0:	4.2	125	287	271	131	80	41	16	13	13	13	7	3	0	0	2.8	1.20
30:	9.5	126	289	251	127	71	44	23	20	18	18	8	4	1	0	2.8	1.10
60:	4.0	195	330	201	120	49	26	27	13	11	15	8	2	2	0	2.5	1.05
90:	2.7	246	386	200	73	44	18	14	3	9	3	2	0	2	0	2.0	1.08
120:	8.5	290	404	120	68	45	34	20	7	5	5	1	1	0	0	1.7	0.95
150:	9.1	274	476	103	52	33	23	19	11	5	4	1	0	0	0	1.6	0.94
180:	9.9	237	420	114	82	56	47	23	14	3	3	0	0	0	0	1.9	1.03
210:	13.2	303	458	85	52	36	27	20	11	5	2	0	0	0	0	1.6	0.95
240:	9.1	150	261	151	132	118	90	54	26	11	7	0	0	0	0	3.4	1.55
270:	7.2	109	176	167	143	125	109	86	54	24	8	0	0	0	0	4.2	1.82
300:	16.4	84	213	215	168	125	88	55	30	14	8	1	0	0	0	3.7	1.69
330:	6.3	103	297	264	145	81	56	27	13	3	7	2	0	1	0	2.9	1.38
Total		186	333	168	109	76	54	34	20	10	7	2	1	0	0	2.7	1.21

Number of calms (included): 89 Mean wind speed : 2.6 m/s

Number of observations : 43680 Mean energy density: 37 W/m²

Table 4.1.3. Hourly wind data in Dörtyol Meteorological Station

Sect Degree	Freq %	<1	2	3	4	5	6	7	8	9	11	13	15	17	>17	A (m/s)	k
0:	5.7	623	197	84	49	29	14	4	0	0	0	0	0	0	0	1.1	0.94
30:	5.8	720	194	58	18	6	2	0	0	0	0	0	0	0	0	0.9	1.03
60:	0.9	958	39	3	0	0	0	0	0	0	0	0	0	0	0	0.6	2.22
90:	1.4	899	81	17	3	0	0	0	0	0	0	0	0	0	0	0.7	1.44
120:	36.6	721	271	7	1	0	0	0	0	0	0	0	0	0	0	0.9	1.50
150:	4.0	787	163	28	7	7	2	2	1	1	2	1	0	0	0	0.8	0.81
180:	4.8	728	196	61	13	1	0	0	0	0	0	0	0	0	0	0.9	1.16
210:	9.5	503	423	58	12	3	1	0	0	0	0	0	0	0	0	1.3	1.69
240:	12.8	358	592	48	2	1	0	0	0	0	0	0	0	0	0	1.4	2.70
270:	8.7	417	513	67	4	0	0	0	0	0	0	0	0	0	0	1.4	2.28
300:	4.6	523	420	54	2	0	0	0	0	0	0	0	0	0	0	1.2	1.86
330:	5.0	582	353	57	8	1	0	0	0	0	0	0	0	0	0	1.1	1.52
Total		613	337	38	7	3	1	0	0	0	0	0	0	0	0	1.1	1.34

Number of calms (included): 760 Mean wind speed : 0.9 m/s

Number of observations : 43800 Mean energy density: 2 W/m²

4.2. Shelter Behind Obstacle Data

The shelter behind obstacles around the measurement point that cause impacts on measured wind speed and direction were researched and determined in its place. The interpretation of predicted results were given for Antakya, İskenderun, and Dörtyol in Tables 4.2.1, 2 and 3 respectively.

Table 4.2.1. Obstacle characteristics around the Meteorological Station of Antakya

Obstacle No	α_1 (°)	R_1 (m)	α_2 (°)	R_2 (m)	h (m)	d (m)	Porosity P
1	20	28	32	32	6	7	0.00
2	20	60	32	52	20	23	0.00
3	11	65	353	54	20	23	0.00
4	60	97	67	94	20	20	0.00
5	78	52	96	52	20	20	0.00
6	109	71	119	78	20	20	0.00
7	82	85	92	85	20	20	0.00
8	132	83	144	85	20	20	0.00
9	144	46	164	55	10	15	0.00
10	177	84	185	75	20	20	0.00
11	164	100	169	90	15	20	0.00
12	205	81	213	80	6	10	0.00
13	215	75	224	76	6	10	0.00
14	253	67	259	61	22	20	0.00
15	259	51	269	42	6	10	0.00
16	269	62	278	58	6	10	0.00
17	290	31	321	32	22	20	0.00
18	215	19	245	21	6	2	0.50
19	54	132	60	128	20	20	0.00
20	68	130	74	128	20	20	0.00
21	341	85	355	90	20	23	0.00
22	27	95	35	88	20	23	0.00
23	240	109	245	102	6	12	0.00
24	229	106	236	108	6	6	0.00

Table 4.2.2. Obstacle characteristics around the Meteorological Station of İskenderun

Obstacle No	α_1 (°)	R_1 (m)	α_2 (°)	R_2 (m)	h (m)	d (m)	Porosity P
1	254	44	270	38	4	10	0.00
2	263	65	267	68	6	18	0.00
3	237	80	257	85	6	23	0.00
4	116	17	143	14	4	19	0.00
5	87	83	92	86	15	30	0.50
6	53	138	67	119	6	35	0.33
7	120	78	125	71	7	5	0.00
8	109	100	117	85	7	11	0.00
9	173	59	176	59	20	3	0.00
10	161	86	165	89	7	28	0.00
11	150	120	156	124	7	31	0.00
12	147	162	151	165	7	30	0.00
13	231	108	237	108	4	36	0.00
14	157	207	209	72	20	27	0.00
15	165	220	214	105	20	27	0.00
16	173	239	218	140	20	27	0.00
17	156	223	161	231	20	172	0.00
18	163	235	169	248	20	172	0.00
19	170	251	176	269	20	172	0.00

Table 4.2.3. Obstacle characteristics around the Meteorological Station of Dörtyol

Obstacle No	α_1 (°)	R_1 (m)	α_2 (°)	R_2 (m)	h (m)	d (m)	Porosity P
1	194	23	327	43	10	3	0.50
2	190	164	280	89	15	2	0.50
3	250	90	265	94	3	7	0.33
4	194	190	275	110	5	85	0.50
5	317	11	45	22	4	38	0.50
6	20	66	28	57	9	10	0.00
7	31	54	41	48	9	10	0.00
8	51	124	67	118	15	20	0.00
9	54	190	75	184	15	20	0.33
10	112	88	120	73	20	10	0.00
11	109	106	115	117	15	14	0.00
12	119	125	124	139	15	14	0.00
13	127	149	130	162	15	14	0.00
14	132	170	135	187	15	14	0.00
15	115	53	125	45	6	10	0.00
16	6	52	105	27	10	3	0.50
17	98	22	180	11	5	10	0.50
18	154	194	163	194	10	32	0.00
19	130	63	137	57	6	9	0.00
20	151	49	162	48	6	14	0.00
21	146	141	151	137	6	11	0.00
22	0	97	355	95	6	14	0.00
23	5	102	14	111	6	10	0.00
24	333	83	337	82	6	7	0.00

4.3. Roughness and Topographic Data

The topographical data were obtained by using maps with 1/100.000 and 1/250.000 scale on appropriate computer program. The information about the stations and the elevations above sea level were given in Table 4.3.1.

Table 4.3.1. Meteorological station positions

Station	Latitude	Longitude	Altitude (m)	Height of anemometer (m)
Antakya	36°.12’	36°.10’	100	10
İskenderun	36°.35’	36°.10’	4	17
Dörtyol	36°.51’	36°.13’	28	10

The maps that indicate selected regions are shown in Figures 4.3.1, 2 and 3. The elevations on map are shown as a meter (m). Interval length between two contour lines is 100 m. The roughness data of the regions were obtained by using city plans together with maps which are mentioned above. These data are given in Tables 4.3.2, 3 and 4. The values of z and x in these tables present the roughness lengths (m) and variation intervals of roughness (m) starting from the wind speed measuring points.

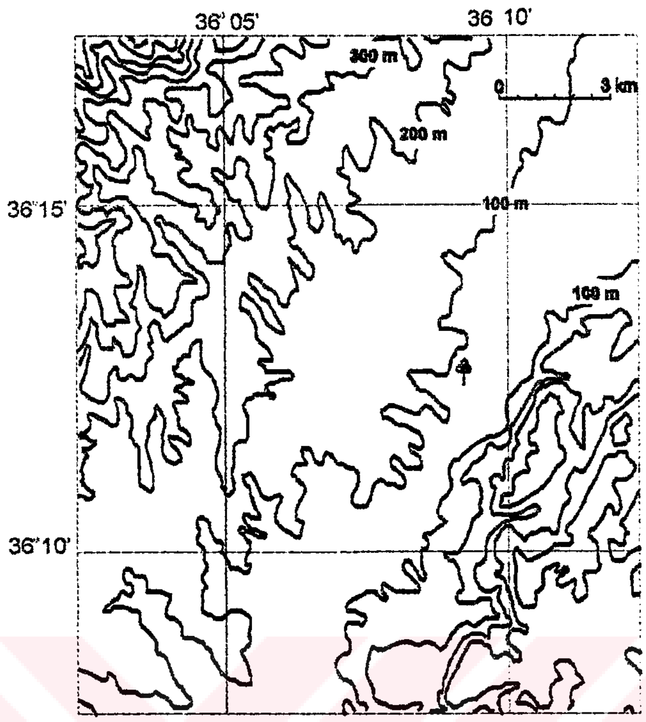

Figure 4.3.1. Topographical map of Antakya

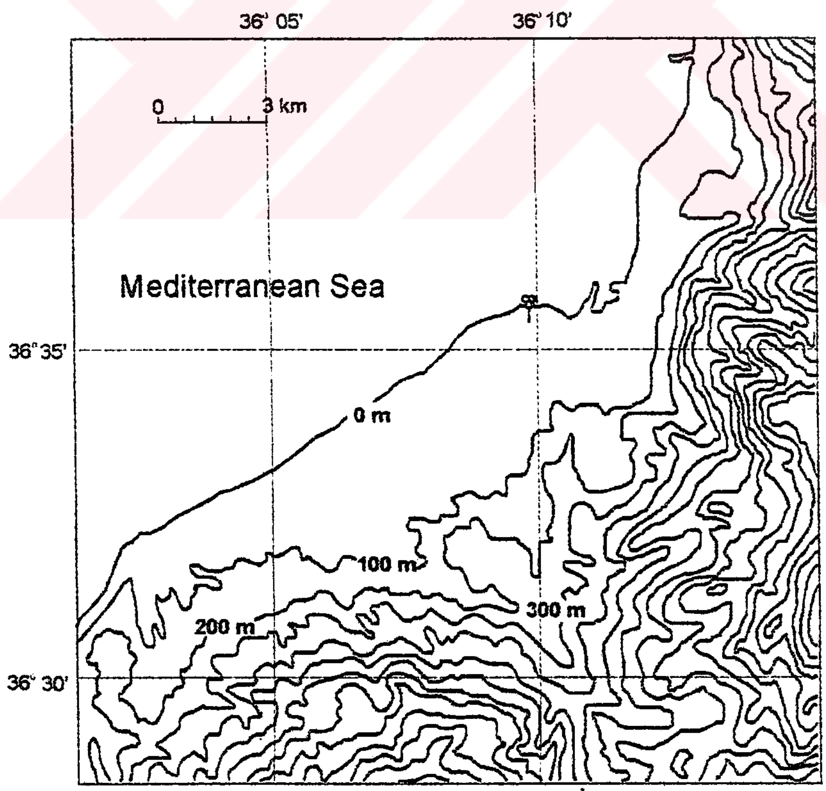

Figure 4.3.2. Topographical map of İskenderun

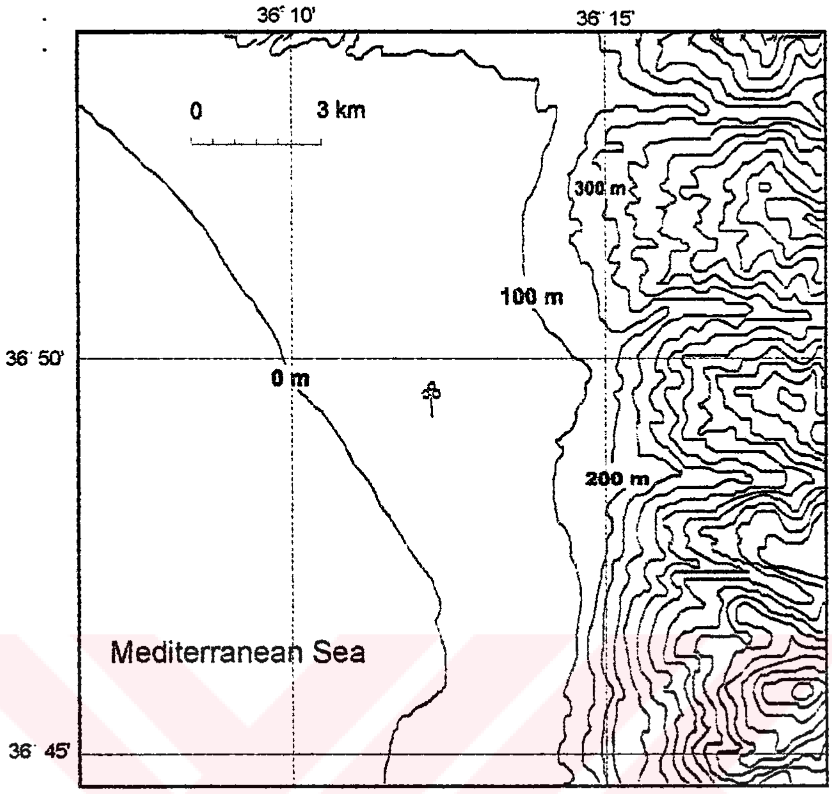

Figure 4.3.3. Topographical map of Dörtyol

Table 4.3.2. Roughness characteristics around the Meteorological Station of Antakya

Sector (degree)	z_{01} (m)	x_1 (m)	z_{02} (m)	x_2 (m)	z_{03} (m)	x_3 (m)	z_{04} (m)	x_4 (m)	z_{05} (m)	x_5 (m)	z_{06} (m)
0	0.4	1000	0.1	3500	0.03						
30	0.4	1200	0.1	3000	0.03						
60	0.4	1500	0.1	4500	0.03						
90	0.4	800	0.1	3000	0.03						
120	0.4	1100	0.1	2500	0.03						
150	0.4	1500	0.1	2500	0.005						
180	0.03	75	0.1	1500	0.03						
210	0.03	80	0.1								
240	0.03	110	0.1	9000	0.005						
270	0.03	45	0.1	900	0.03						
300	0.3	1000	0.03								
330	0.3	800	0.03								

Table 4.3.3. Roughness characteristics around the Meteorological Station of İskenderun

Sector (degree)	z_{01} (m)	x_1 (m)	z_{02} (m)	x_2 (m)	z_{03} (m)	x_3 (m)	z_{04} (m)	x_4 (m)	z_{05} (m)	x_5 (m)	z_{06} (m)
0	0.005	40	0								
30	0.005	50	0								
60	0.5	700	0								
90	0.5	3200	0.2	4600	0.3						
120	0.5	2800	0.2	4500	0.3						
150	0.5	2500	0.03	2850	0.05	3500	0.1				
180	0.5	1500	0.3	3000	0.05						
210	0.5	1000	0.3	7000	0.03						
240	0.5	2000	0								
270	0.5	300	0								
300	0.05	50	0								
330	0.05	40	0								

Table 4.3.4. Roughness characteristics around the Meteorological Station of Dörtyol

Sector (degree)	z_{01} (m)	x_1 (m)	z_{02} (m)	x_2 (m)	z_{03} (m)	x_3 (m)	z_{04} (m)	x_4 (m)	z_{05} (m)	x_5 (m)	z_{06} (m)
0	0.3	7000	0.05								
30	0.3	9000	0.05								
60	0.3	4700	0.05								
90	0.3	5000	0.05								
120	0.3	4900	0.05								
150	0.1										
180	0.1										
210	0.1	2100	0								
240	0.1	1900	0								
270	0.1	2300	0								
300	0.1	4000	0								

4.4. Wind Energy Distributions in Antakya Region

The direction of the wind is of decisive significance for the evaluation of the possibilities of utilizing wind power. The direction statistics play an important role in the optimal positioning of a wind park in a given area. Figure 4.4.1 shows Antakya wind rose obtained from the analysis of data using WASP. The dominant prevailing wind direction for Antakya Meteorological Station is 210°. In this region, southern winds are effective. After southern winds, northern winds are effective. The effect of wind that is observed at the lowest degree is in the direction of 150°.

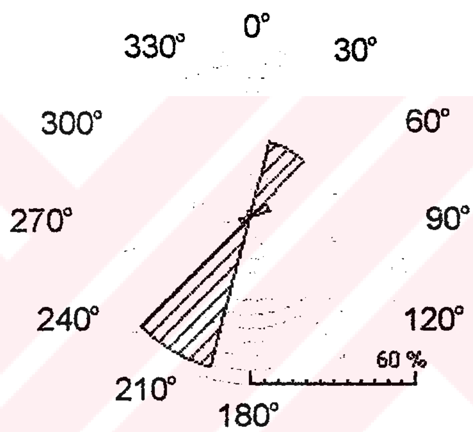

Figure 4.4.1. Antakya wind rose

The frequency distribution of the wind speeds help towards answering questions of how long is a wind power plant out of action in the case of lack of wind, which is the rage of the most frequent wind speeds, and how often does the wind power plant achieve its rated output. Figure 4.4.2 shows the frequency distribution of the mean hourly wind speeds for Antakya meteorological station. This figure indicates that the hourly wind speed is higher than 3 m/s in 40.5% of occasions.

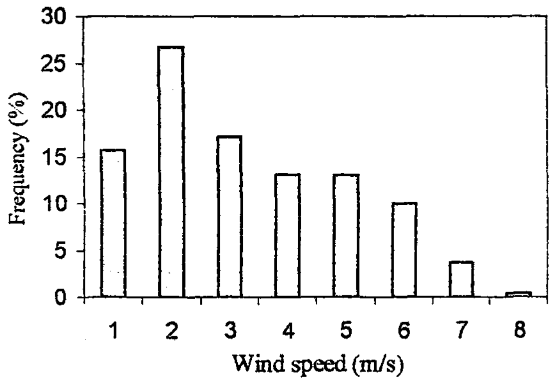

Figure 4.4.2. Frequency distribution of wind speeds at Antakya meteorological station

The daily time-evolution of wind speed is quite important for the integration of wind power into the overall energy supply. Figure 4.4.3 shows the daily time variation of the mean hourly wind speed between 1992 and 2001 for Antakya station. As a result the lowest wind speeds of the day appear generally in the morning time, at 07:00 a.m.. However, the highest wind speeds appear in the afternoon between 11:00 a.m. and 06:00 p.m..

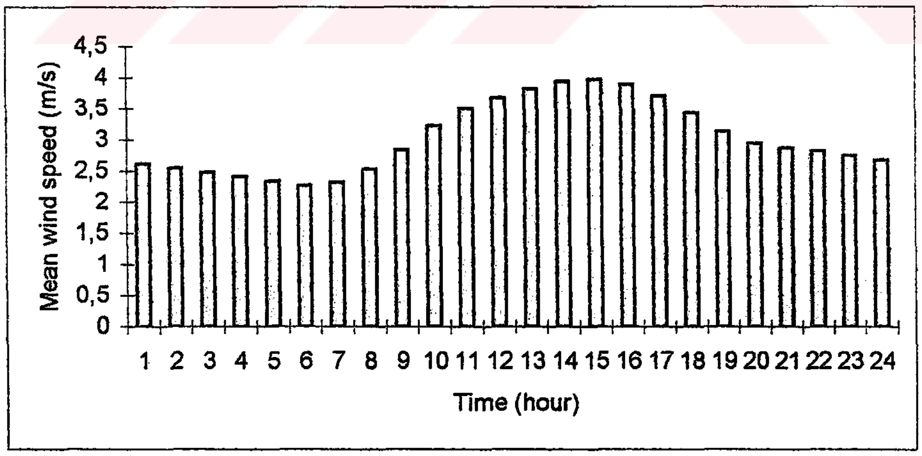

Figure 4.4.3. The daily time variation of the mean hourly wind speeds at Antakya meteorological station

The monthly variation of the mean wind speeds is shown in Figure 4.4.4. Accordingly, the wind speeds in Antakya region present a high rate of difference during a year. The highest monthly mean wind speed occurs in the months of July and August and the lowest in the months of November and December.

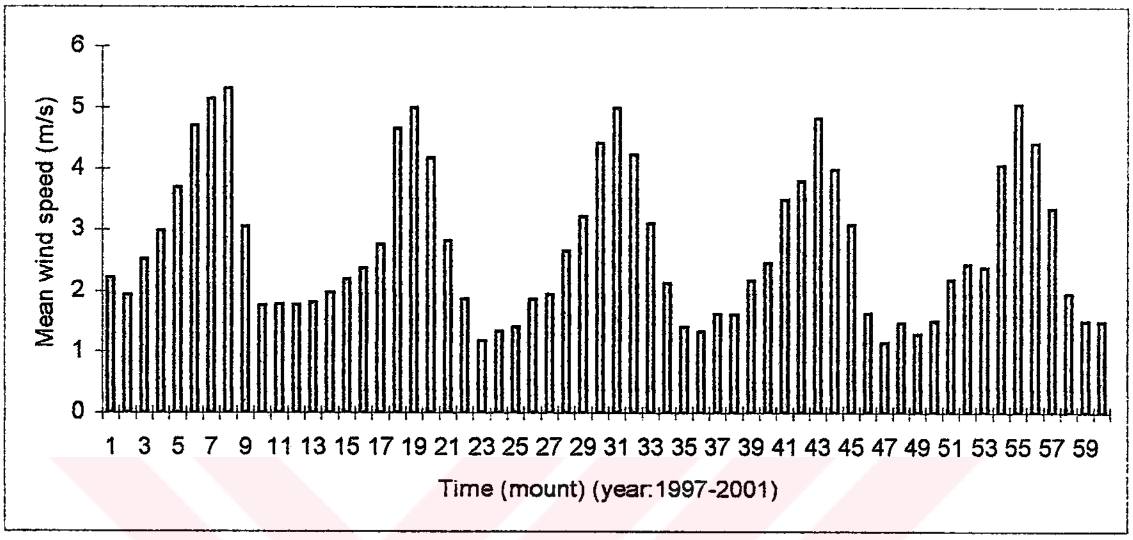

Figure 4.4.4. The monthly variation of mean wind speeds at Antakya meteorological station

The yearly wind provides basic information about the wind strength and consequently about the supply of wind power. The yearly mean wind speeds measured in Antakya meteorological station and predicted wind energy potentials are given in Table 4.4.1. As a result, the wind speeds present a substantial difference during ten years. In 1992 the mean wind speed is 3.3 m/s and the mean wind energy potential 42 is W/m^2. But, in 2001 the mean wind speed is 2.6 m/s and the mean wind energy potential is 26 W/m^2. The reason of this decrease in the wind speed is terrain surface around the meteorological station changes substantially during the period of 10 years. These results suggests that meteorological stations have to be moved from their presents places to a places where the height of roughness and other parameter which effect the speed wind at the meteorological stations.

Table 4.4.1. Yearly mean wind speed and energy potential at Antakya meteorological station (h=10m)

Years	Mean wind speed (m/s)	Mean energy potential (W/m^2)
1992	3.30	42
1993	3.40	46
1994	3.30	47
1995	3.20	44
1996	3.30	43
1997	3.10	38
1998	2.70	28
1999	2.70	29
2000	2.60	26
2001	2.60	26

In the analysis made for the wind speed measuring point, all of shelter behind obstacles, roughness and topographical data which effect the wind speed and direction were not eliminated. The wind speeds were reconsidered again by taking the effect of these parameters into account. With WASP packet program, wind speeds and potentials including corrected wind speeds and potentials were obtained for standard heights by having the effect of these parameters into account and using hourly wind data. The results of measured and corrected analysis were shown in Table 4.4.2, Figures 4.4.5 and 6. The results presented in these table and figures indicate that obstacles have an impact on the wind speed and alter the wind direction particularly for lower level of height.

Table 4.4.2. Results of measured and corrected values of wind speeds and potential at Antakya meteorological station

Height	Measured values				Corrected values			
(m)	A (m/s)	k	v (m/s)	P(w/m^2)	A (m/s)	k	v (m/s)	P(w/m^2)
10	3.1	1.58	2.8	35	6.2	1.79	5.5	220
25	5.9	1.97	5.2	167	7.8	1.86	6.9	417
50	9.2	1.93	8.1	656	9.3	1.92	8.2	679
100	10.9	2.06	9.7	1026	10.9	2.06	9.7	1026

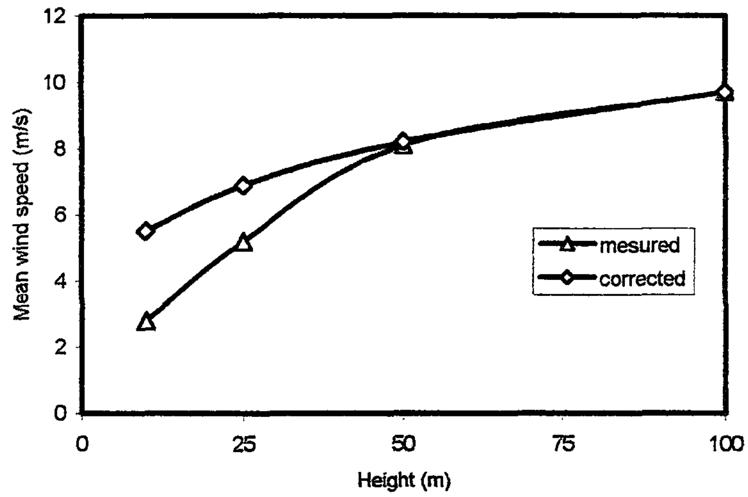

Figure 4.4.5. Variation of the measured and corrected wind speeds at Antakya meteorological station

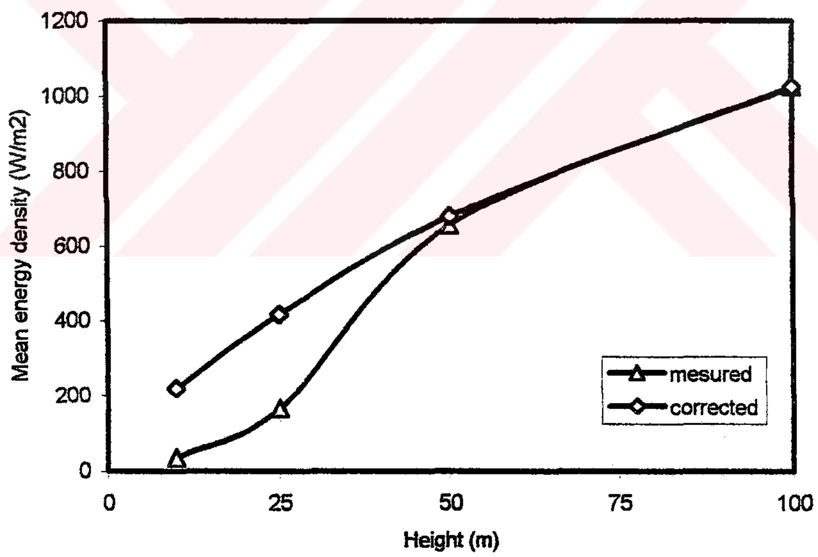

Figure 4.4.6. Variation of wind energy potentials computed from the measured and corrected wind speeds at Antakya meteorological station

A retardation of the wind speed due to the obstacles around Antakya Meteorological Station were presented with the wind direction for standard heights in Table 4.4.3. As it is seen, when the measurement height is 10 m above the ground level the highest rate of decrease in wind speed occurs in the direction of 0° (north) with 75.4% of occasions. On the other hand, the lowest rate of decrease happens in the direction of 210° with 21.9% of occasions.

Table 4.4.3. Variation of wind speed with height due to the effect of obstacles around the Meteorological Station of Antakya

Direction (^{0})	Wind speed variation (%)			
	10 m	25 m	50 m	100 m
0	75.4	50.0	1.3	0.0
30	71.4	39.1	1.1	0.0
60	63.7	43.3	3.7	0.0
90	63.9	42.5	1.3	0.0
120	43.9	91.6	1.3	0.0
150	72.7	20.4	0.8	0.0
180	70.2	38.0	1.6	0.0
210	21.9	4.2	0.2	0.0
240	32.5	11.7	0.3	0.0
270	46.6	26.9	0.9	0.0
300	63.0	38.3	0.1	0.0
330	38.6	25.7	0.7	0.0

The wind speeds and potentials with roughness class are given in Table 4.4.4. Besides, using the resource file formed by WASP, the maps of wind speed and potential were drawn for the heights of 10, 25, and 50 m respectively. These maps are shown in Figures 4.4.7, 8, 9, 10, 11 and 12. The wind speed and potential can be seen on these maps directly at every points. It is apparent from figures that wind energy resources vary greatly over Antakya. The maps show that several locations can quite reasonably be considered favorable for the production of wind energy. It is known that there is no wind turbine placed in the region of Antakya for the electricity production. An efficient wind turbine are available at present time. It is hoped that more effective and efficient wind turbine will soon be developed around the world. The present results suggest that it can be profitable to establish a wind farm.

Table 4.4.4. Variations of wind speed and potential with roughness at Antakya meteorological station

Height	Unit	R-class 0 (0.000)	R-class 1 (0.030 m)	R-class 2 (0.100 m)	R-class 3 (0.400 m)
Height 1	ms-1	9.5	6.7	5.8	4.5
(z = 10 m)	Wm-2	1039	407	266	126
Height 2	ms-1	10.3	7.9	7.0	5.8
(z = 25 m)	Wm-2	1328	638	462	269
Height 3	ms-1	11.0	9.0	8.1	6.9
(z = 50 m)	Wm-2	1584	873	669	433
Height 4	ms-1	11.8	10.3	9.4	8.1
(z= 100 m)	Wm-2	1935	1219	955	658
Height 5	ms-1	12.8	12.1	11.0	9.6
(z =200 m)	Wm-2	2446	1899	1479	1022

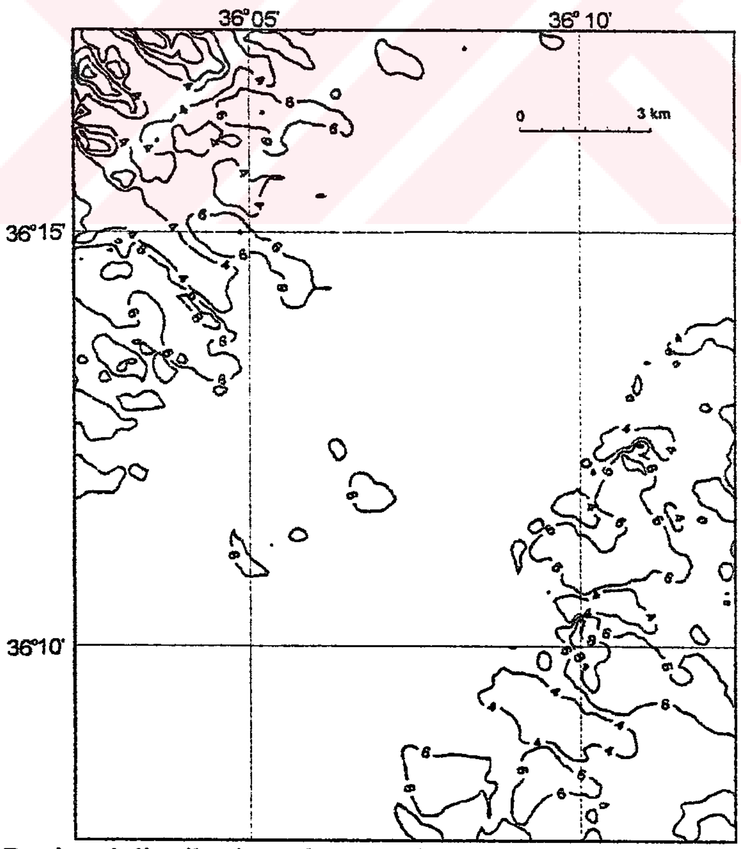

Figure 4.4.7. Regional distribution of mean wind speed in Antakya region at h=10 m above the ground level

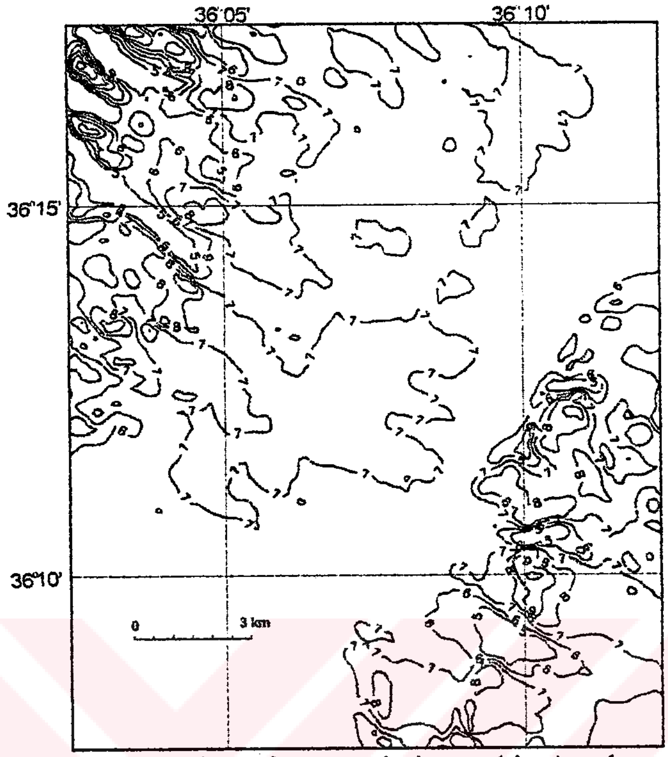

Figure 4.4.8. Regional distribution of mean wind speed in Antakya region at h=25 m above the ground level

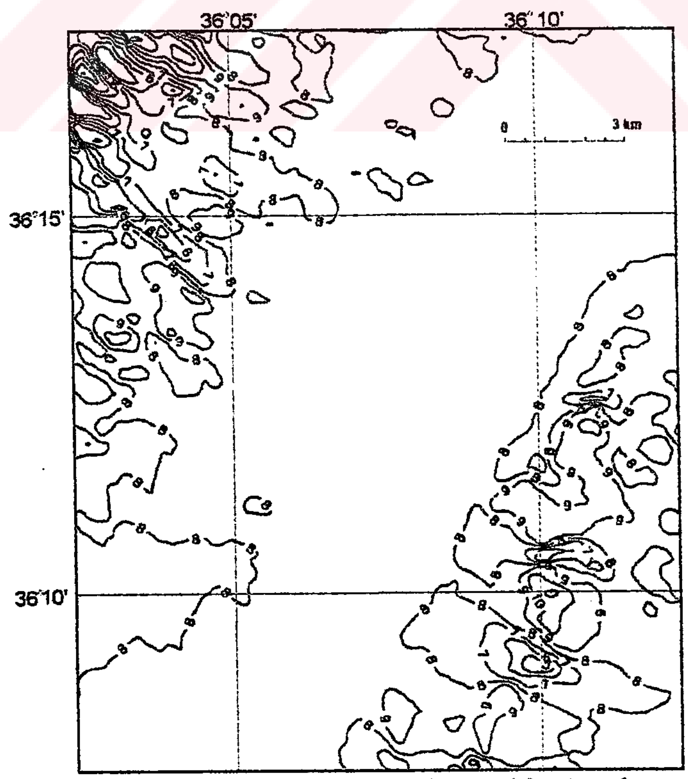

Figure 4.4.9. Regional distribution of mean wind speed in Antakya region at h=50 m above the ground level

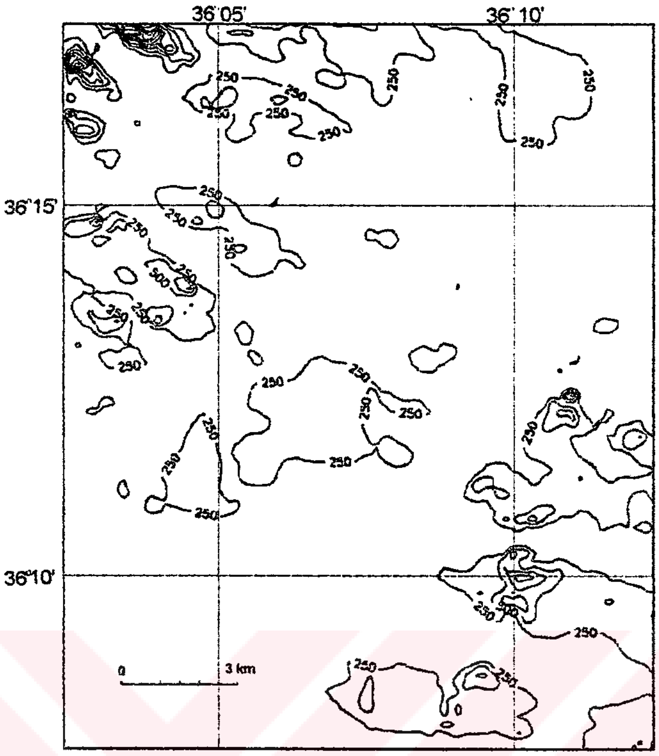

Figure 4.4.10. Regional distribution of mean wind energy potential in Antakya region at h=10 m above the ground level

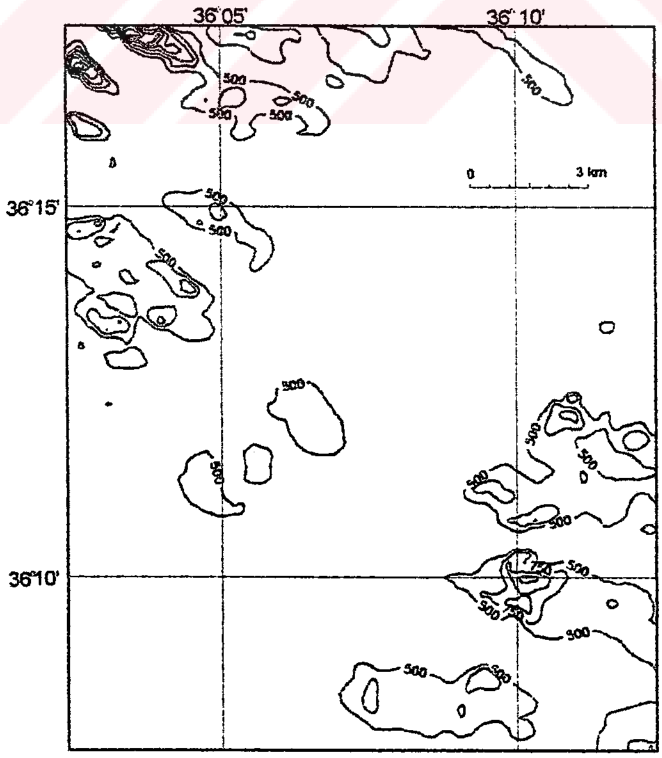

Figure 4.4.11. Regional distribution of mean wind energy potential in Antakya region at h=25 m above the ground level

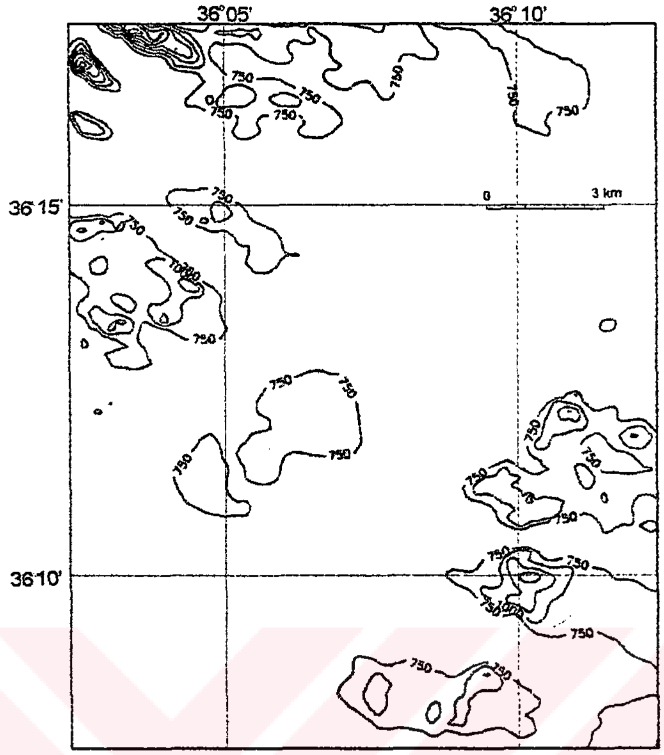

Figure 4.4.12. Regional distribution of mean wind energy potential in Antakya region at h=50 m above the ground level

4.5. Wind Energy Distributions in İskenderun Region

The dominant prevailing wind direction for İskenderun Meteorological Station is 300° as seen in Figure 4.5.1. In this region, western winds are effective. After western winds, southern winds are effective. The effect of wind that is observed at the lowest degree is in the direction of 90°.

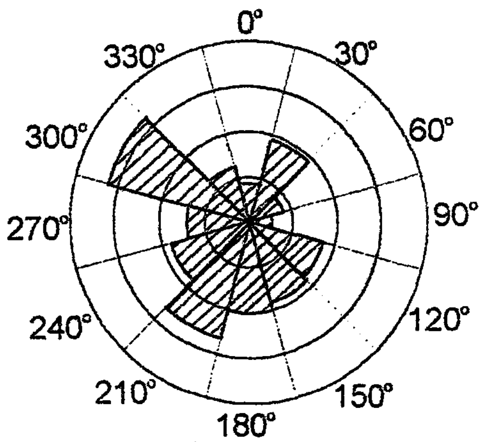

Figure 4.5.1.İskenderun wind rose

Figure 4.5.2 shows the frequency distribution of hourly mean wind speeds for İskenderun meteorological station. This figure reveales that the hourly wind speed is higher than 3 m/s in 31.3% of occasions.

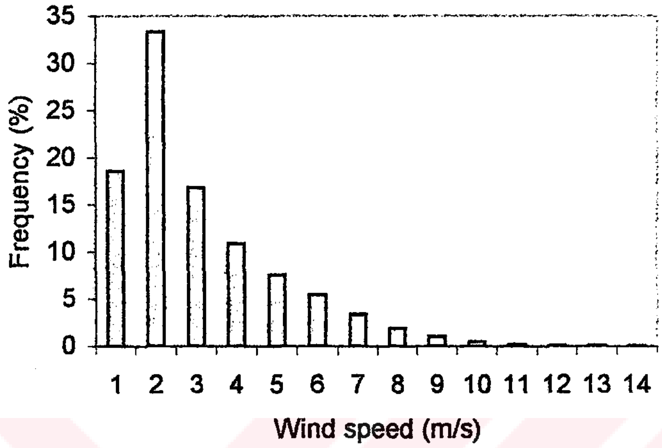

Figure 4.5.2. Frequency distribution of wind speeds at İskenderun meteorological station

Figure 4.5.3 shows the time variation of the hourly mean wind speed on daily bases for 10 years between 1992 and 2001. As a result the lowest wind speeds appear generally in the morning around 07:00 a.m.. However, the highest wind speeds appear in the afternoon between 12:00 a.m. and 07:00 p.m.. This monthly averaged wind speed varies mainly from 2 m/s to a maximum 3.7 m/s as seen in this figure.

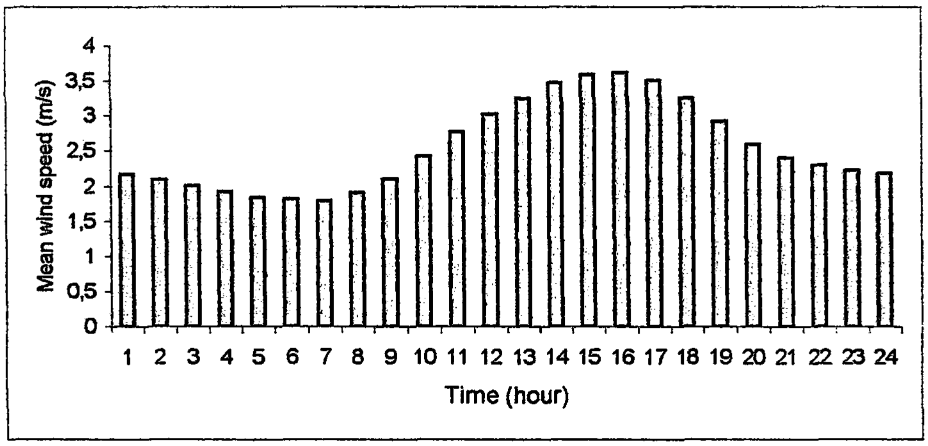

Figure 4.5.3. The daily time variation of the mean hourly wind speeds at İskenderun meteorological station

The variation of monthly mean wind speeds is shown in Figure 4.5.4. The highest monthly mean wind speed occurs in July and August and the lowest value occurs in October and November.

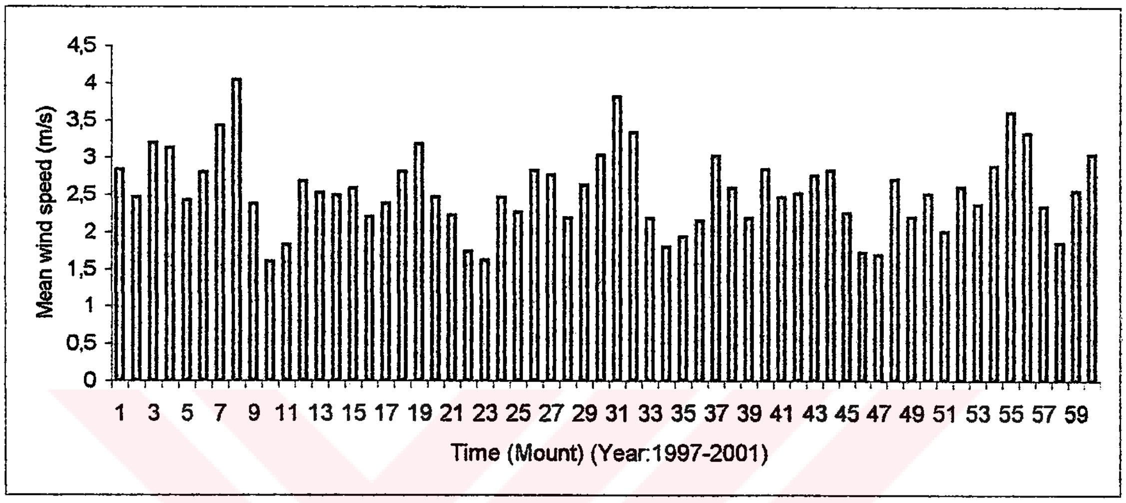

Figure 4.5.4. The variation of monthly mean wind speeds at İskenderun meteorological station

The yearly mean wind speeds measured at İskenderun meteorological station and wind energy potentials are given in Table 4.5.1. The differences of wind speeds for 10 years between 1992 and 2001 are not significant. In 1992 the mean wind speed is 2.6 m/s and the mean wind energy potential 44 W/m^2. On the other hand in 2001 the mean wind speed is 2.6 m/s and the mean wind energy potential 36 W/m^2.

Table 4.5.1. Yearly mean wind speed and energy potential at İskenderun meteorological station (h=17m)

Years	Mean wind speed (m/s)	Mean energy potential (W/m^2)
1992	2.60	44
1993	2.50	36
1994	2.60	40
1995	2.40	33
1996	2.40	29
1997	2.70	46
1998	2.40	31
1999	2.60	37
2000	2.50	34
2001	2.60	36

The results of measured and corrected value of parameters were shown in Table 4.5.2 and Figures 4.5.5 and 6. Presented results indicate that between measured and corrected wind speed values there is a high rate of differences. A maximum difference occurs at 10 meter above the ground level. This discrepancy gradually decreases while the height of measuring level increases. However, above 50 meter from the ground level the values of wind speed and wind potential increase linearly with height. Curves which present measured and corrected wind speeds collide with one another. This case also happens for the predictions wind potentials.

Table 4.5.2. Results of measured and corrected values of wind speeds and potential at İskenderun meteorological station

Height (m)	Measured values				Corrected values			
	A (m/s)	k	v (m/s)	P (w/m^2)	A (m/s)	k	v (m/s)	P (w/m^2)
10	1.9	1.01	1.9	25	2.9	0.83	3.2	198
25	3.4	0.99	3.4	149	3.6	0.81	4.0	436
50	4.2	0.80	4.7	713	4.2	0.79	4.7	753
100	4.8	0.78	5.5	1242	4.8	0.78	5.5	1242

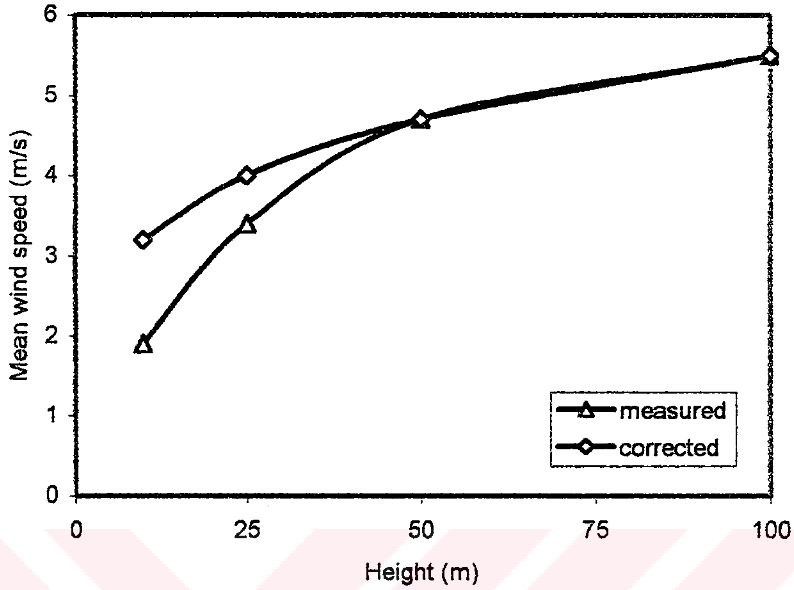

Figure 4.5.5. Variation of the measured and corrected wind speeds at İskenderun meteorological station

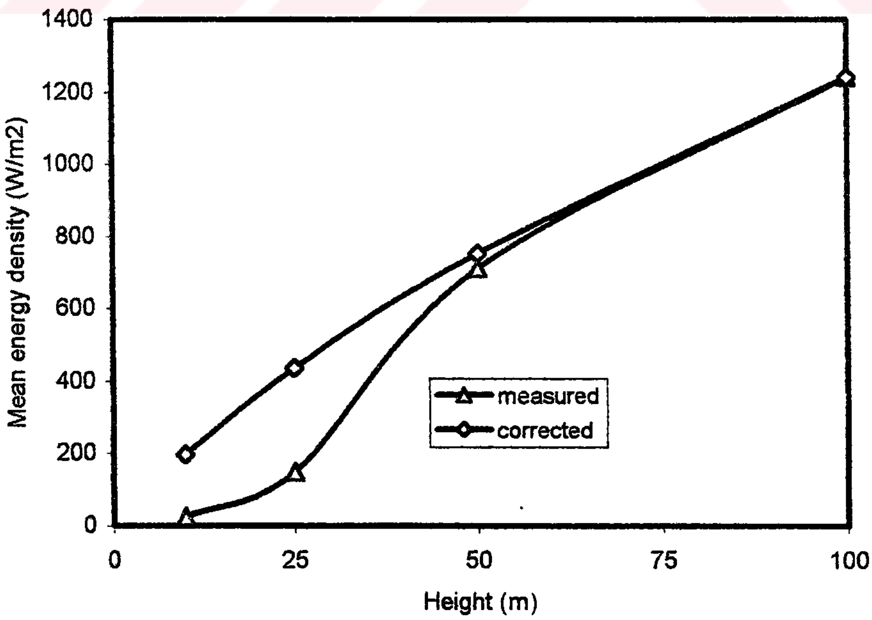

Figure 4.5.6. Variation of wind energy potentials computed from the measured and corrected wind speeds at İskenderun meteorological station

Obstacles impacts on the wind speed around İskenderun Meteorological Station were given according to the wind directions for standard heights in Table 4.5.3. Measurements at 17 m above the ground level show that the highest decrease in wind speed occurs in the direction of 180° (south) with 81,3% of occasions. But the lowest decrease occurs in the directions of 0°, 30°, 300° and 330° with 0% of occasions.

Table 4.5.3. Variation of wind speed with height due to the effect of obstacles around the Meteorological Station of İskenderun

Direction	Wind speed variation (%)				
(^{0})	10 m	17 m	25 m	50 m	100 m
0	0.0	0.0	0.0	0.0	0.0
30	0.2	0.0	0.0	0.0	0.0
60	7.0	2.0	0.3	0.0	0.0
90	14.3	6.6	1.6	0.0	0.0
120	15.5	2.8	0.2	0.0	0.0
150	45.1	35.7	23.7	2.9	0.0
180	95.0	81.3	41.9	1.9	0.0
210	87.0	60.1	24.9	0.4	0.0
240	13.0	2.4	0.5	0.0	0.0
270	8.5	0.8	0.0	0.0	0.0
300	0.0	0.0	0.0	0.0	0.0
330	0.0	0.0	0.0	0.0	0.0

The wind speeds and potentials according to roughness classes are given in Table 4.5.4. Besides, using the resource file formed by WASP, the maps of wind speed and potential were established for 10, 25, and 50 m height above the ground level. These maps are shown in Figures 4.5.7, 8, 9, 10, 11 and 12. Numerical values of the wind speed and potential on each point can be seen from these maps directly. It is apparent from figures that wind energy resources vary greatly over İskenderun region. The maps show that several locations can quite reasonably be considered favorable for the production of wind energy. Figure 4.5.9 indicates that the wind speed at 50 m above the ground level is 5 m/s in most of part of İskenderun region.

Table 4.5.4. Variations of wind speed and potential with roughness at İskenderun meteorological station

Height	Unit	R-class 0 (0.000)	R-class 1 (0.030 m)	R-class 2 (0.100 m)	R-class 3 (0.400 m)
Height 1	ms-1	5.5	3.9	3.5	2.8
(z = 10 m)	Wm-2	1386	696	471	225
Height 2	ms-1	6.0	4.6	4.2	3.6
(z = 25 m)	Wm-2	1759	1062	810	482
Height 3	ms-1	6.4	5.2	4.8	4.3
(z = 50 m)	Wm-2	2092	1432	1124	756
Height 4	ms-1	6.9	5.9	5.5	5.0
(z= 100 m)	Wm-2	2468	1844	1546	1128
Height 5	ms-1	7.4	6.9	6.4	5.9
(z =200 m)	Wm-2	2934	2442	2110	1622

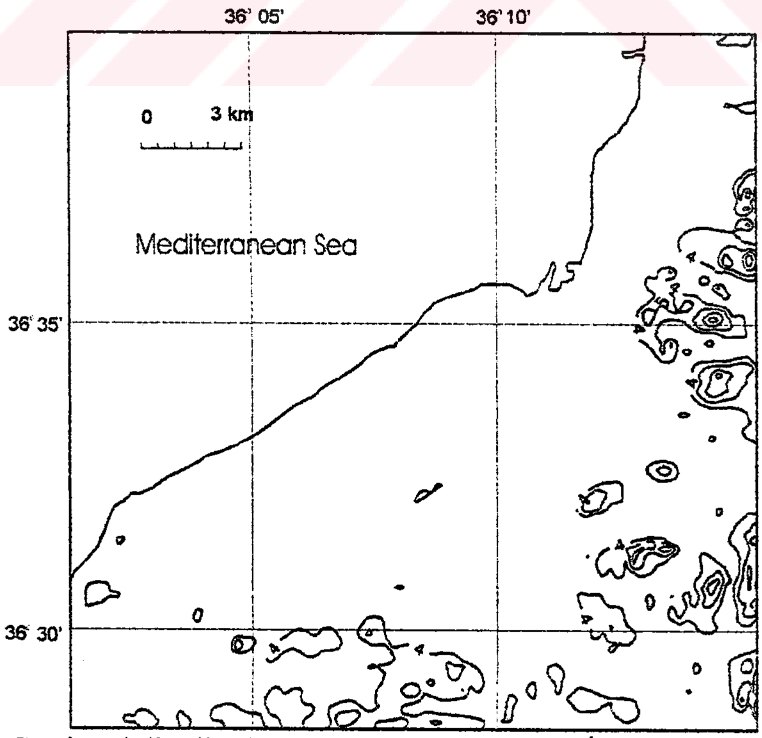

Figure 4.5.7. Regional distribution of mean wind speed in İskenderun region at h=10 m above the ground level

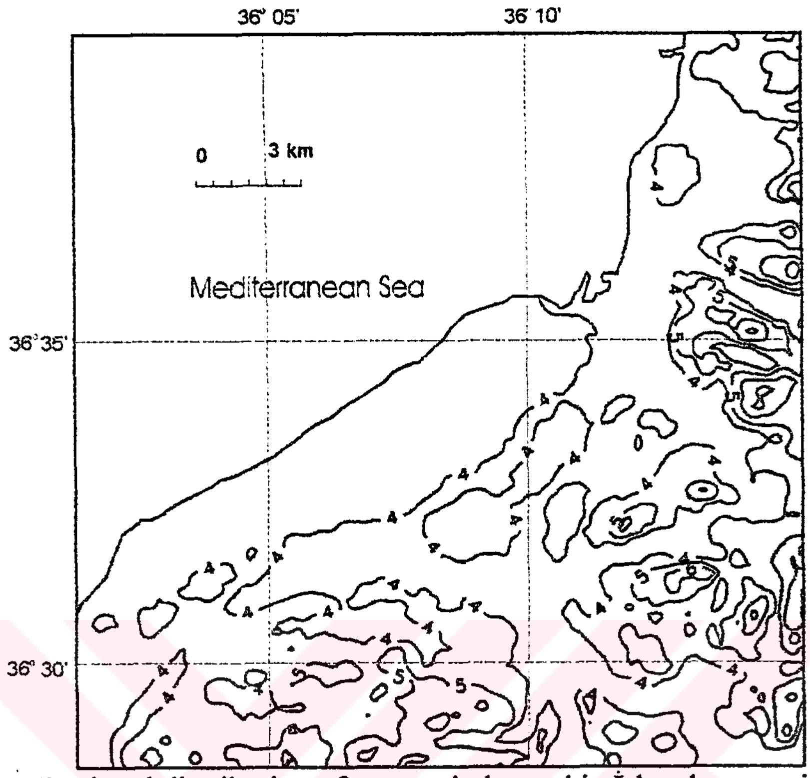

Figure 4.5.8. Regional distribution of mean wind speed in İskenderun region at h=25 m above the ground level

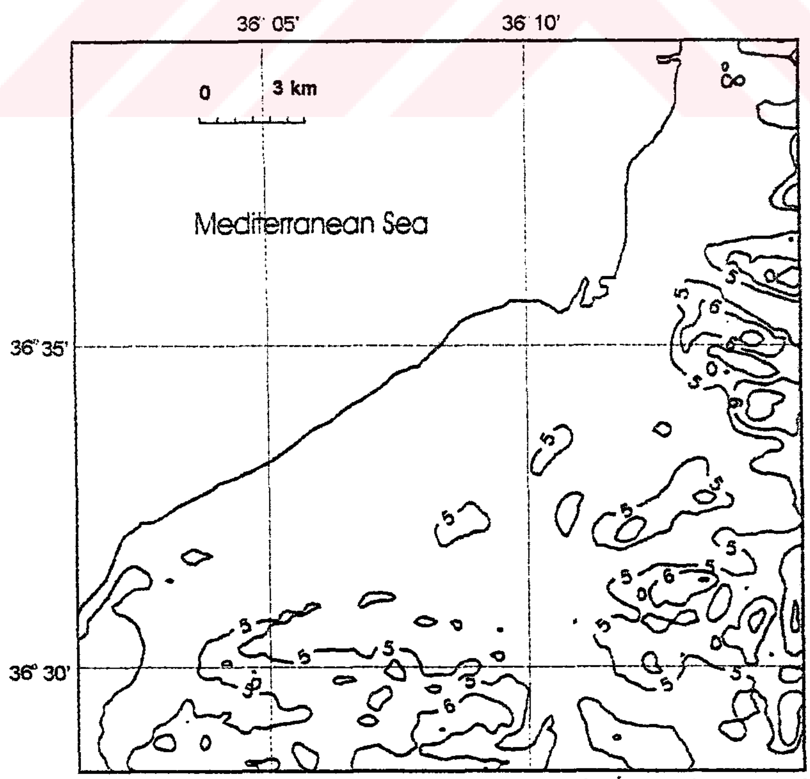

Figure 4.5.9. Regional distribution of mean wind speed in İskenderun region at h=50 m above the ground level

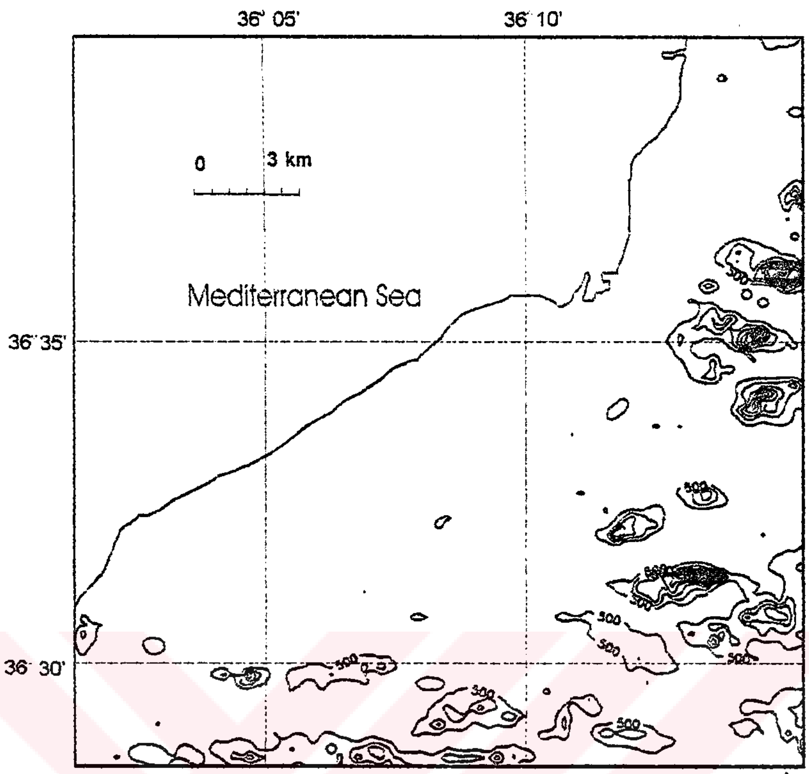

Figure 4.5.10. Regional distribution of mean wind energy potential in İskenderun region at h=10 m above the ground level

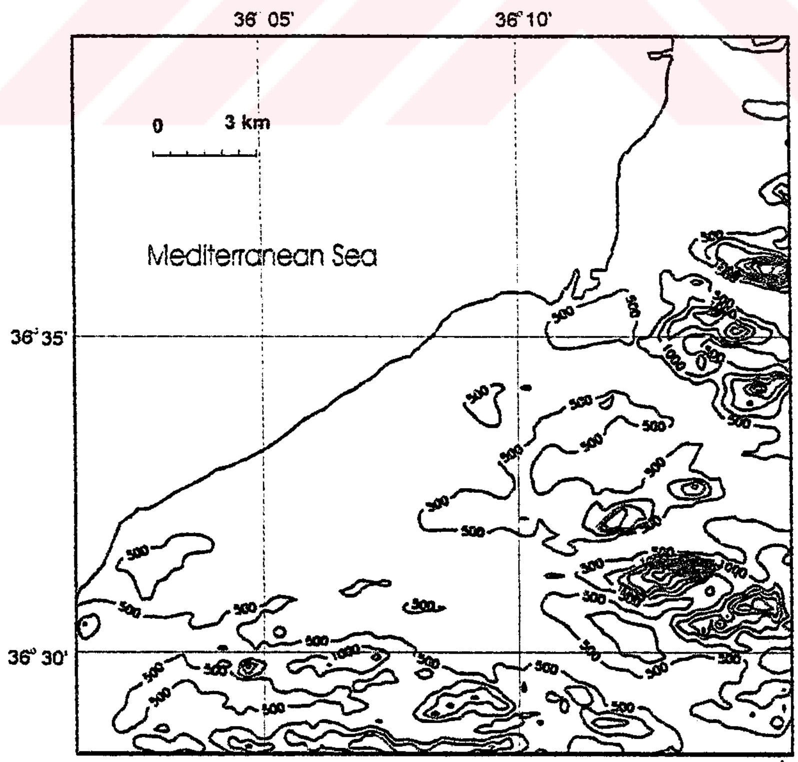

Figure 4.5.11. Regional distribution of mean wind energy potential in İskenderun region at h=25 m above the ground level

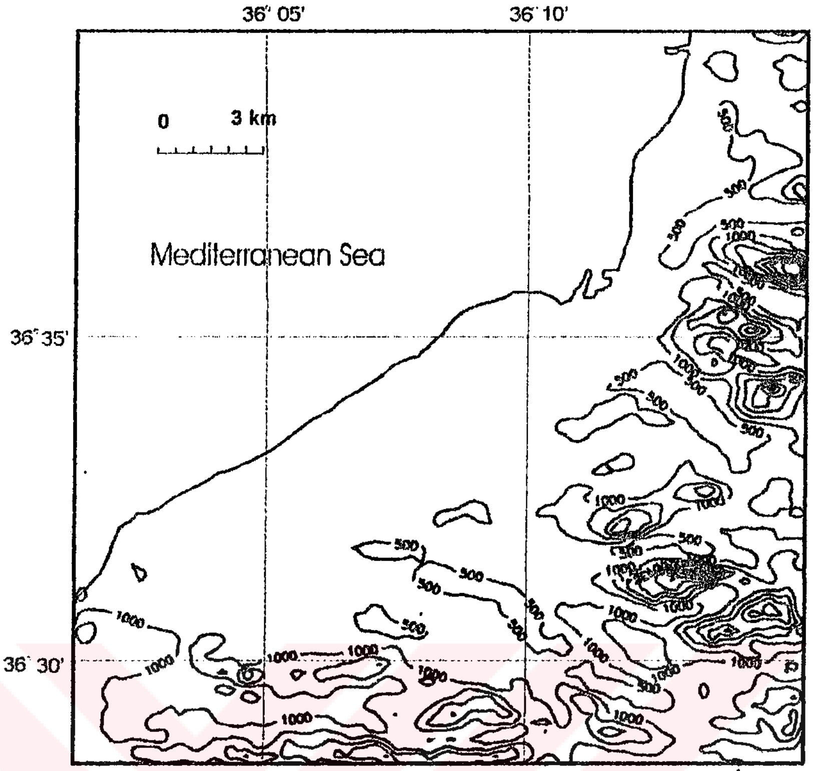

Figure 4.5.12. Regional distribution of mean wind energy potential in İskenderun region at h=50 m above the ground level

4.6. Wind Energy Distributions in Dörtyol Region

The dominant prevailing wind direction of Dörtyol Meteorological Station is 120° as seen in Figure 4.6.1. In this region, eastern winds are effective. The effect of wind that is observed at the lowest level is in the direction of 60°.

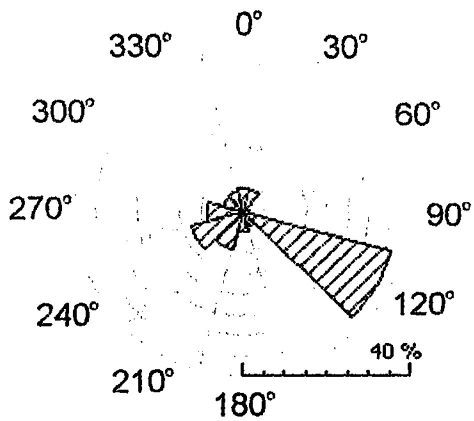

Figure 4.6.1. Dörtyol wind rose

Figure 4.6.2 shows the frequency distribution of the hourly mean wind speeds of Dörtyol meteorological station. This figure indicates that the hourly wind speed is higher than 3 m/s in 1.3 % of occasions.

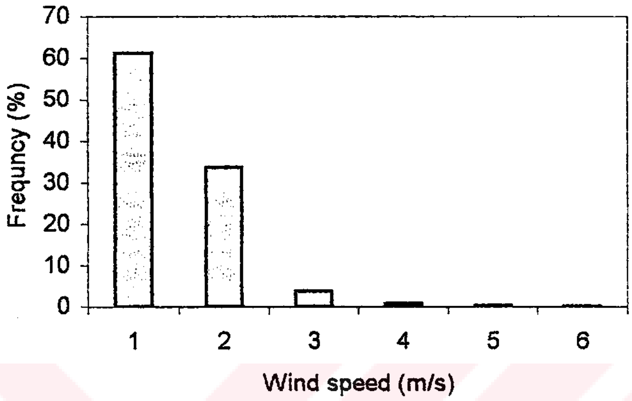

Figure 4.6.2. Frequency distribution of wind speeds at Dörtyol meteorological station

Figure 4.6.3 shows the time variation of the hourly mean wind speed on daily bases for 10 years between 1992 and 2001 for Dörtyol meteorological station. The daily lowest wind speeds appear generally in the morning at 07:00 a.m.. However, the highest wind speeds appear in the afternoon between 10:00 a.m. and 06:00 p.m..

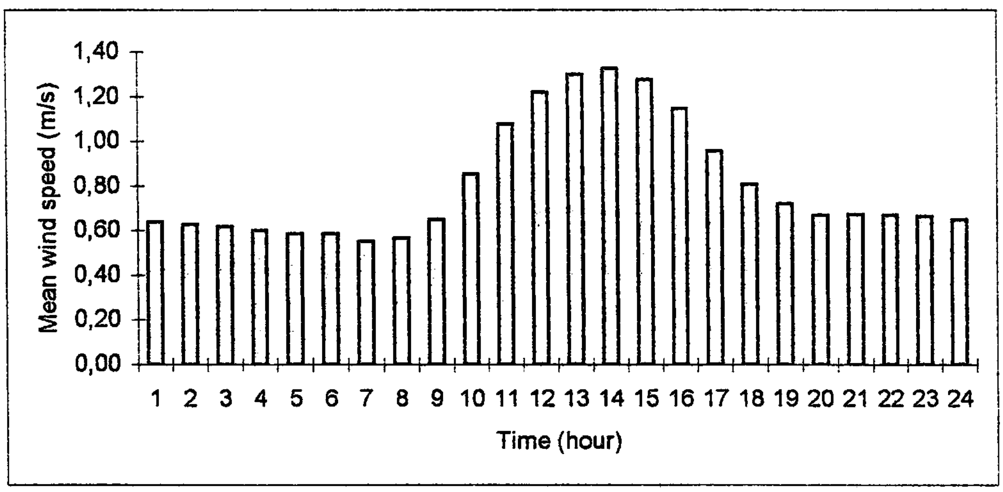

Figure 4.6.3. The daily time variation of the hourly mean wind speeds at Dörtyol meteorological station

Stations examined (Antakya, İskenderun and Dörtyol) reveals that variations of hourly wind speed in day time more or less occurs at the same period of time.

The monthly variation of the mean wind speeds is shown in Figure 4.6.4. As seen in this figure the wind speeds in Dörtyol region vary during the period of twelve months.

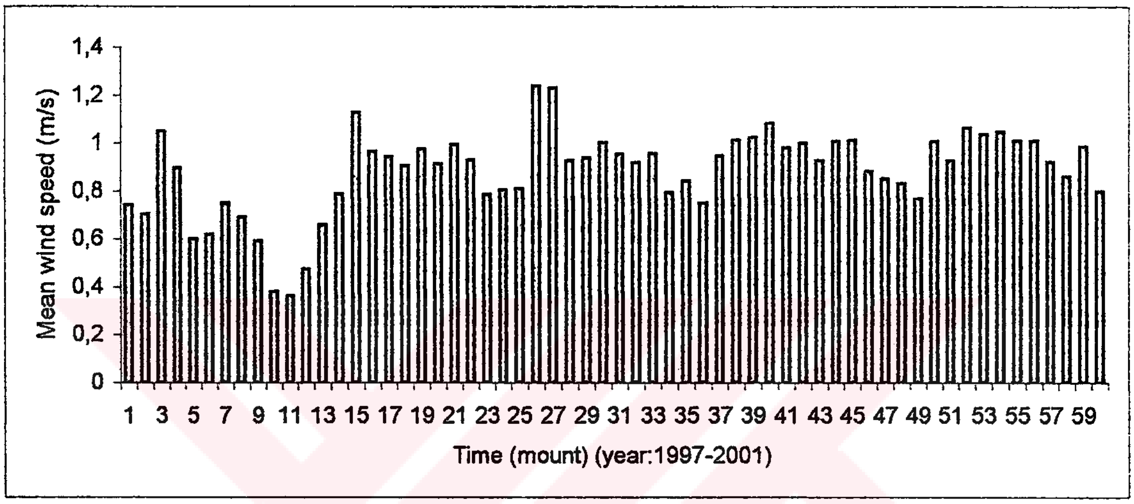

Figure 4.6.4. The monthly variation of mean wind speeds at Dörtyol meteorological station

The yearly mean wind speeds measured between 1992 and 2001 at Dörtyol meteorological station and wind energy potentials are given in Table 4.6.1. The wind speeds over ten year do not vary much, comparing to the results measured at Antakya and İskenderun meteorological stations. For example, in 1992 the mean wind speed is 0.8 m/s and the mean wind energy potential 2 W/m^2. But, in 2001 the mean wind speed is 1.0 m/s and the mean wind energy potential 1 W/m^2 at Dörtyol meteorological station.

Table 4.6.1. Yearly mean wind speed and energy potential at Dörtyol meteorological station

Years	Mean wind speed (m/s)	Mean energy potential (W/m^2)
1992	0.8	2
1993	0.8	1
1994	0.7	1
1995	0.7	1
1996	0.6	1
1997	0.7	1
1998	0.9	2
1999	0.9	2
2000	1.0	2
2001	1.0	1

Measured of corrected values of wind speeds, related parameters, and related wind potential were shown in Table 4.6.2, Figures 4.6.5 and 6. Obstacles around Dörtyol Meteorological Station cause an impact on wind speed and influence direction. The present roughness reduces the wind speed that are measured at the station. So, it is obvious that these data has to be corrected.

Table 4.6.2. Results of measured and corrected values of wind speeds and potential at Dörtyol meteorological station

Height (m)	Point analysis				Corrected analysis			
	A (m/s)	k	v (m/s)	P (w/m^2)	A (m/s)	k	v (m/s)	P (w/m^2)
10	1.1	1.17	1.0	3	3.1	1.35	2.8	45
25	3.2	1.41	2.9	43	3.9	1.39	3.6	86
50	4.7	1.46	4.2	133	4.7	1.45	4.3	137
100	5.7	1.52	5.1	217	5.7	1.52	5.1	217

Corrected values of wind speeds and wind energy potentials presented in Figures 4.6.5 and 6 indicate that the level of wind speeds increases substantially comparing to the measured values of the wind speeds. This situation reveals that obstacles around Dörtyol meteorological station is extremely high to reduced the speed of wind substantially. At 10 meter height above the ground level corrected speed of winds three time more than the level of measured wind speed.

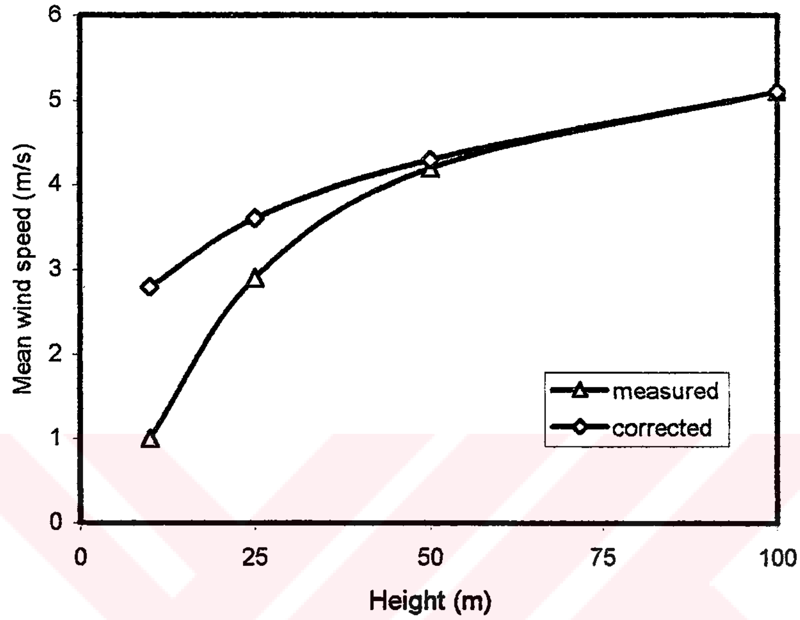

Figure 4.6.5. Variation of the measured and corrected wind speeds at Dörtyol meteorological station

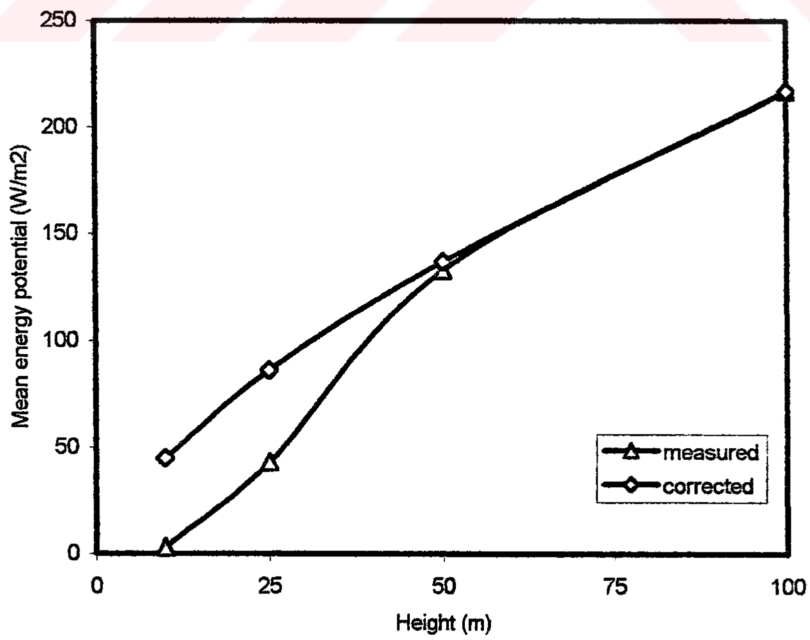

Figure 4.6.6. Variation of wind energy potentials computed from measured and corrected wind speeds at Dörtyol meteorological station

Variations of wind speed which are effected by obstacles situated around the meteorological station with height and direction are shown in Table 4.6.3. When the measurement height is 10 m, the highest decrease in wind speed is in the direction of 120° with 79.2% of occasions. On the other hand the lowest decrease in wind speed occurs in the direction of 180° with 12.8% of occasions.

Table 4.6.3. Variation of wind speed with height due to the effect of obstacles around the Meteorological Station of Dörtyol

Direction	Wind speed variation (%)			
(°)	10 m	25 m	50 m	100 m
0	24.6	1.8	0.0	0.0
30	65.0	3.6	0.0	0.0
60	73.6	22.0	1.7	0.0
90	47.2	5.8	0.4	0.0
120	79.2	35.9	1.9	0.0
150	30.6	6.2	0.4	0.0
180	12.8	3.1	0.2	0.0
210	65.5	14.1	0.5	0.0
240	70.5	13.6	0.2	0.0
270	65.2	11.6	0.2	0.0
300	41.3	6.9	0.0	0.0
330	22.2	0.7	0.0	0.0

The wind speeds and potentials according to the roughness classes are given in Table 4.6.4. Besides, using the resource file formed by WASP, the maps of wind speed and potential were constructed for 10 m, 25 m and 50 m above the ground level respectively. These maps are shown in Figures 4.6.7, 8, 9, 10, 11 and 12. The values of wind speed and potential on each point can be seen from these maps directly. It is apparent from figures that wind energy resources vary greatly over Dörtyol. These maps show that several locations can quite reasonably be considered favorable for the production of wind energy. Examining the map presented in Figure

4.6.8 for 25 m height above the ground level shows that in most places the speed of wind is 4 m/s and over.

Table 4.6.4. Variations of wind speed and potential with roughness at Dörtyol meteorological station

Height	Unit	R-class 0 (0.000)	R-class 1 (0.030 m)	R-class 2 (0.100 m)	R-class 3 (0.400 m)
Height 1	ms-1	5.0	3.5	3.1	2.4
(z = 10 m)	Wm-2	239	104	68	33
Height 2	ms-1	5.5	4.2	3.8	3.2
(z = 25 m)	Wm-2	302	159	116	68
Height 3	ms-1	5.9	4.8	4.4	3.8
(z = 50 m)	Wm-2	357	210	163	107
Height 4	ms-1	6.3	5.6	5.1	4.5
(z= 100 m)	Wm-2	460	301	232	159
Height 5	ms-1	6.9	6.8	6.2	5.5
(z =200 m)	Wm-2	632	546	416	278

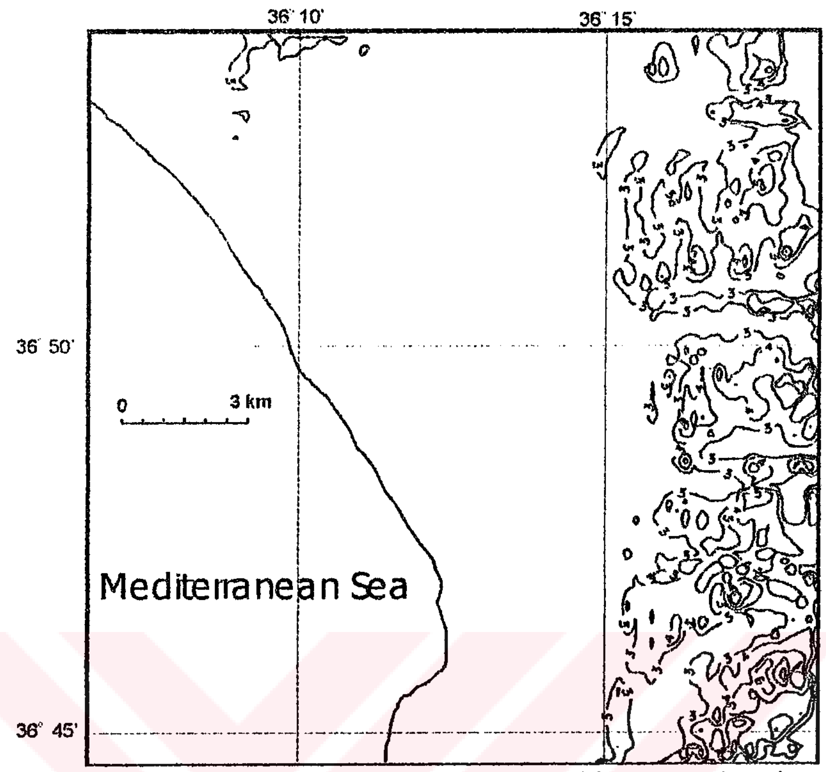

Figure 4.6.7. Regional distribution of mean wind speed in Dörtyol region at h=10 m above the ground level

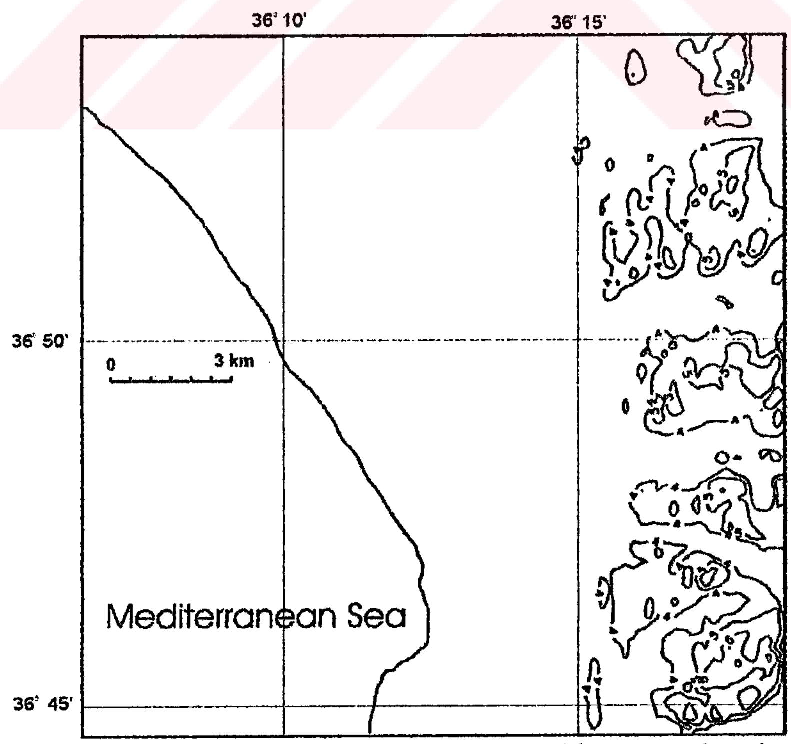

Figure 4.6.8. Regional distribution of mean wind speed in Dörtyol region at h=25 m above the ground level

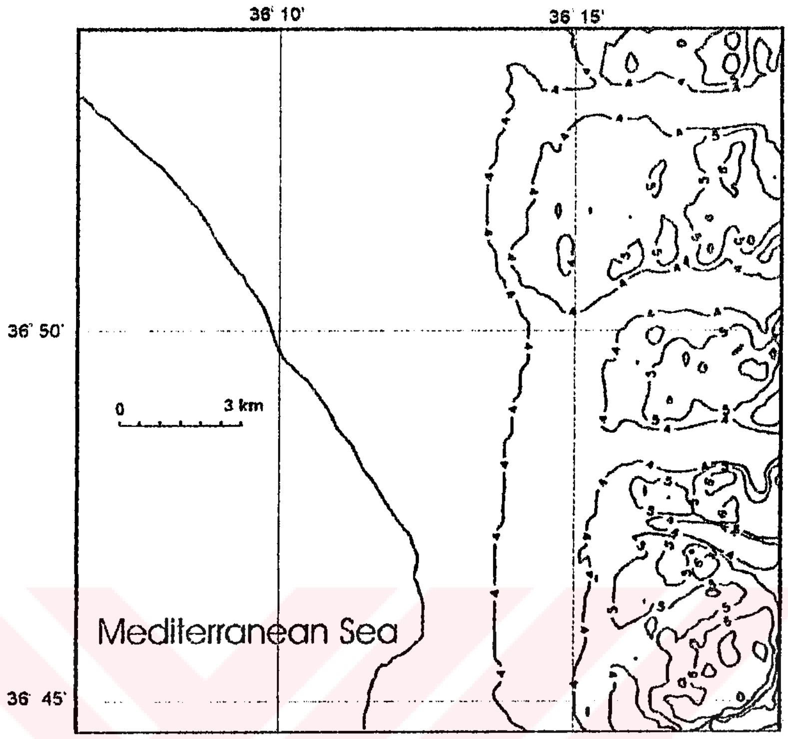

Figure 4.6.9. Regional distribution of mean wind speed in Dörtyol region at h=50 m above the ground level

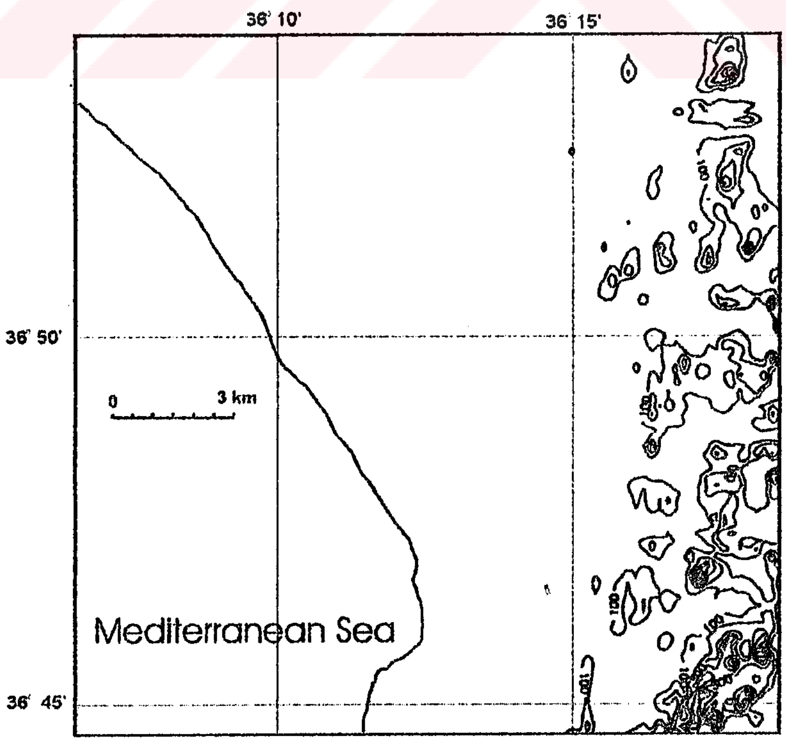

Figure 4.6.10. Regional distribution of mean wind energy potential in Dörtyol region at h=10 m above the ground level

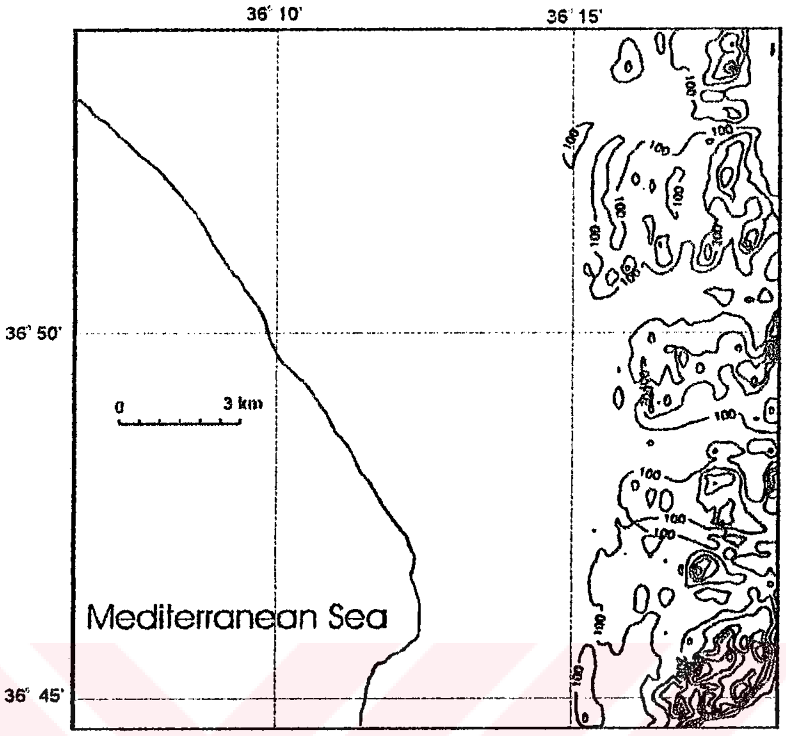

Figure 4.6.11. Regional distribution of mean wind energy potential in Dörtyol region at h=25 m above the ground level

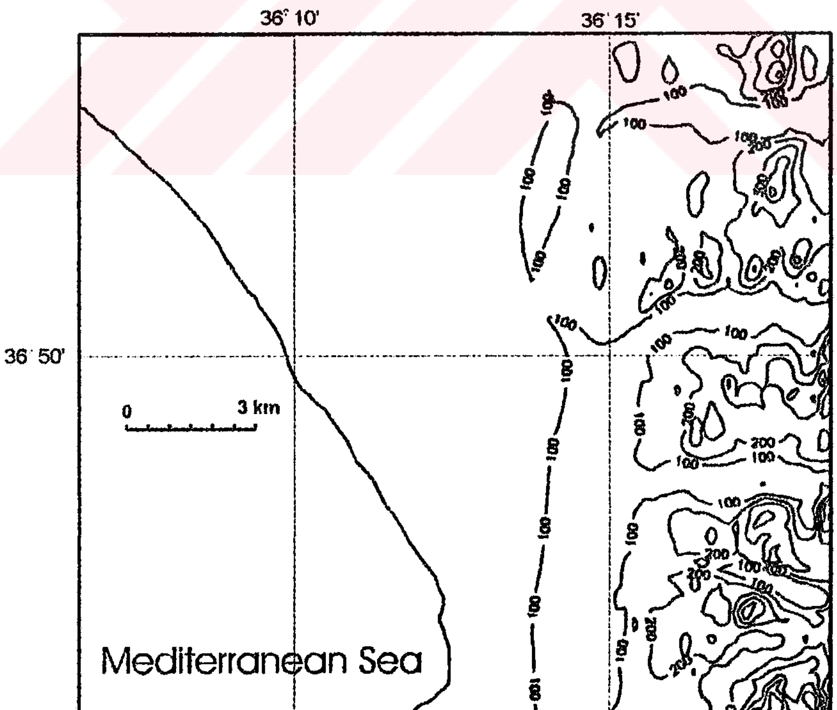

Figure 4.6.12. Regional distribution of mean wind energy potential in Dörtyol region at h=50 m above the ground level

4.7. Computations For Some Meteorological Stations of Turkey

The estimated scale and shape parameters and mean energy values at 21 stations are given in Table 4.7.1. The wind data covers the period 1999-2000. The shape parameters are within the range 1.04 and 1.96 for all stations. Scale parameters also vary between 0.8 and 6.8 m/s. It is found that Çanakkale, Güney, Bozcaada, Amasra, Bandırma and Sinop present higher energy potential than the others.

Table 4.7.1. Scale and shape parameters and mean energy in some stations of Turkey

Stations	Scale parameter (A) (m/s)	Shape parameter (k)	Mean wind speed (m/s)	Mean energy density (W/m^2)
Çanakkale	4.0	1.55	3.5	74
Kuşadası	2.0	1.36	1.9	11
Samsun	2.5	1.32	2.3	23
Sinop	2.8	1.04	2.5	66
Silifke	2.0	1.29	1.9	13
Şile	3.3	1.76	3.0	32
İpsala	3.2	1.63	2.8	33
Polatlı	2.3	1.37	2.1	18
Güney	4.7	1.96	4.0	82
Seydişehir	1.9	1.30	1.7	11
Karapınar	2.4	1.36	2.2	20
Karataş	3.1	1.92	2.7	23
Çorum	1.7	1.09	1.6	13
Bozcaada	6.8	1.85	5.9	276
Afyon	2.0	1.30	1.9	13
Bandırma	4.3	1.63	3.6	83
Bursa	1.8	1.20	1.6	12
Amasra	5.5	1.39	5.0	229
Dalaman	2.4	1.31	2.2	22

Bergama	0.8	1.73	2.6	22
Cihanbeyli	3.0	1.62	2.7	29
Antakya	3.1	1.71	2.7	27

5. CONCLUSIONS AND RECOMMENDATIONS

As seen from the result of present analysis, the rate of wind energy potential in Antakya, İskenderun and Dörtyol regions is high enough to produce electricity, particularly, southwestern winds are effective in Antakya region. But, Northwestern winds in İskenderun and southeastern winds in Dörtyol are effective. The wind speed over the years varies substantially especially at Anatakya Meteorological Station. The reason of this variation of wind speed is due to the obstacles around the station. For all regions that examined in present work, day time wind speeds are greater than night time wind speeds. The lowest wind speeds of the day appear generally in the morning at 07:00 a.m.. However, the highest wind speeds appear in the afternoon between 11:00 a.m. and 07:00 p.m.. The wind speeds in all regions vary substantially during the one period of year. The highest wind speeds are usually obtained in the summer months.

Weibull parameters, wind speeds and energy densities increase with height. In all meteorological stations, shelter behind obstacles, which cause an impact on wind speed and direction, influence observed data substantially and reduce wind speeds. The effect of these obstacles disappears above the 50 m height.

The result of this study encourages the utilization of the wind energy potential. This study has explicitly demonstrated the presence of high wind speeds and power in these regions. Antakya and İskenderun are characterized by high wind potential. In many areas of Anatakya region and in some areas of İskenderun region, there are mean wind speeds greater than 5 m/s at 10 m height. These areas seem to be very promising for wind turbines installations. As for in Dörtyol region, several areas are identified as having mean wind speeds greater than 5 m/s at 10 m height above the ground level. These locations are situated in the mountains. These areas seem to be very convenient for wind turbines installation. However, their suitability and availability for these applications depend on other aspects too, such as being in close proximity to electrical grid lines, land ownership, road network infrastructure, etc.

Critical values of mean wind speed which is given by European Wind Energy Association are given as;

- 6.5 m/s good
- 7.5 m/s well
- 8.5 m/s very well

So, it is seen that at 50 m height above the ground level, Antakya region ca be evaluated as well since the mean wind speeds are 7.5 m/s in many areas of Antakya region. The mean wind speeds especially in south and east regions of İskenderun and in east regions of Dörtyol are between 5 m/s and 7 m/s. These regions can also be evaluated as good for the production of wind energy.

A different classification which is taken into consideration wind energy density is given as;

- $P < 100$ W/m^2 weak
- 100 W/m^2 $< P <$ 300 W/m^2 good
- 300 W/m^2 $< P <$ 700 W/m^2 well
- $P > 700$ W/m^2 very well

So, According to this classifications, at 50 m above earth level, Antakya region can be evaluated as well because mean wind energy density is greater than 300 W/m^2 in all regions. In Antakya, İskenderun and Dörtyol, there are some regions where mean energy density is more than 700 W/m^2.

Areas where there are high rate of mean energy density are favourable for exploitation of wind energy conversion systems. If one considers, for example the wind turbine working with wind speeds between 3 and 5 m/s, it is possible to produce wind energy almost all regions that are considered in the present work for many hours and during 9 month in year.

It can be concluded that, present regions are suitable for the plantation wind energy turbines. It is not only convenient for wind turbine farm as a land scope but also it is very efficient in terms of wind speed. There are very large areas to construct wind energy farms.

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APPENDIX

Table 5.1. Gamma function (for $1 \le x \le 2$)
For the other values use the formula: $\Gamma(x+1) = x.\Gamma(x)$

x	Γ (x)	x	Γ (x)	x	Γ (x)	x	Γ (x)
1	1	1,25	0,9064	1,5	0,88623	1,75	0,91906
1,01	0,99433	1,26	0,9044	1,51	0,88659	1,76	0,92137
1,02	0,98884	1,27	0,9025	1,52	0,88704	1,77	0,92376
1,03	0,98355	1,28	0,90072	1,53	0,88757	1,78	0,92623
1,04	0,97844	1,29	0,89904	1,54	0,88818	1,79	0,92877
1,05	0,9735	1,3	0,89747	1,55	0,88887	1,8	0,93138
1,06	0,96874	1,31	0,896	1,56	0,88964	1,81	0,93408
1,07	0,96415	1,32	0,89464	1,57	0,89049	1,82	0,93685
1,08	0,95973	1,33	0,89338	1,58	0,89142	1,83	0,93969
1,09	0,95546	1,34	0,89222	1,59	0,89243	1,84	0,94261
1,1	0,95135	1,35	0,89115	1,6	0,89352	1,85	0,94561
1,11	0,9474	1,36	0,89018	1,61	0,89468	1,86	0,94869
1,12	0,94359	1,37	0,88931	1,62	0,89592	1,87	0,95184
1,13	0,93993	1,38	0,88854	1,63	0,89724	1,88	0,95507
1,14	0,93642	1,39	0,88785	1,64	0,89864	1,89	0,95838
1,15	0,93304	1,4	0,88726	1,65	0,90012	1,9	0,96177
1,16	0,9298	1,41	0,88676	1,66	0,90167	1,91	0,96523
1,17	0,9267	1,42	0,88636	1,67	0,9033	1,92	0,96877
1,18	0,92373	1,43	0,88604	1,68	0,905	1,93	0,9724
1,19	0,92089	1,44	0,88581	1,69	0,90678	1,94	0,9761
1,2	0,91817	1,45	0,88566	1,7	0,90864	1,95	0,97988
1,21	0,91558	1,46	0,8856	1,71	0,91057	1,96	0,98374
1,22	0,91311	1,47	0,88563	1,72	0,91258	1,97	0,98768
1,23	0,91075	1,48	0,88575	1,73	0,91467	1,98	0,99171
1,24	0,90852	1,49	0,88595	1,74	0,91683	1,99	0,99581
1,25	0,9064	1,5	0,88623	1,75	0,91906	2	1

CIRRICULUM VITAE

Mehmet Bilgili was born in December 14, 1971 in Adana, Turkey. In 1998, he graduated from High School, and enrolled at Çukurova University to study mechanical engineering. In 1992, he graduated from the Department of Mechanical Engineering. He began working as a mechanical engineer at Adana Police Directorate since 1992. He started his M.Sc. studies in 2001 at the Department of Mechanical Engineering of Çukurova University. He is married and has two children.