An Experimental Investigation of the Parameters to Classify Wind Sites

by

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ABSTRACT

Wind data measured on Izmir Institute of Technology campus area have been used to evaluate the wind power potential on this location. Measured data set and its evaluation showed that Izmir Institute of Technology campus area has a considerable wind potential. Mean wind speeds have been found 7.03 m/s at 10 m height and 8.14 m/s at 30 m height. The prevailing wind direction has also been found as north direction. WAsP and WindPRO softwares have been used to evaluate the wind statistics and energy calculations. Wind turbines with 600 kW and 1500 kW nominal power have been fitted as the most efficient ones. Suitable sites were selected according to created average wind speed map and wind energy maps of campus area. Fourty seven 600 kW turbines with a total capacity of 28.2 MW and twenty six 1500 kW turbines with a total capacity of 39 MW were located on the selected sites separately. The annual energy productions of the 600 kW and 1500 kW wind turbines have been calculated as respectively 100.3 GWh/year and 122.4 GWh/year.

ÖZ

Bu çalisma kapsaminda yörenin rüzgar gücü potansiyelinin bulunmasi amaciyla Izmir Yüksek Teknoloji Enstitüsü kampüs alaninda rüzgar ölçümleri yapildi. Ölçülen rüzgar degerleri ve bu verilerin irdelenmesi ile Izmir Yüksek Teknoloji Enstitüsünün kampüs arazisinde önemli ölçüde büyük rüzgar enerjisi potansiyelinin varligi saptandi. Ölçüm alinan bölgede, ortalama rüzgar hizlari 10 m yükseklik için 7.03 m/s, 30 m yükseklik için 8.14 m/s, ana rüzgar yönün de kuzey olarak hesaplandi. Rüzgar istatistikleri ve enerji hesaplarinda WindPRO ve WAsP paket programlari kullanildi. Bölge için en verimli türbin tiplerinin 600 kW ve 1500 kW nominal güçteki türbinler oldugu tespit edildi. Olusturulan ortalama rüzgar hizi ve rüzgar enerjisi haritalarindan uygun bölgeler seçildi. Incelenen bölgenin enerji üretimi açisindan uygun bulunan alanlarina, toplam kurulu gücü 28.2 MW olan 47 adet 600 kW'lik ve toplam kurulu gücü 39 MW olan 26 adet 1500 kW'lik rüzgar türbinin yerlestirildigi varsayilarak, sirasiyla 100.3 GWh/yil ve 122.4 GWh/yil enerji üretilebilecegi saptandi.

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CHAPTER I

INTRODUCTION

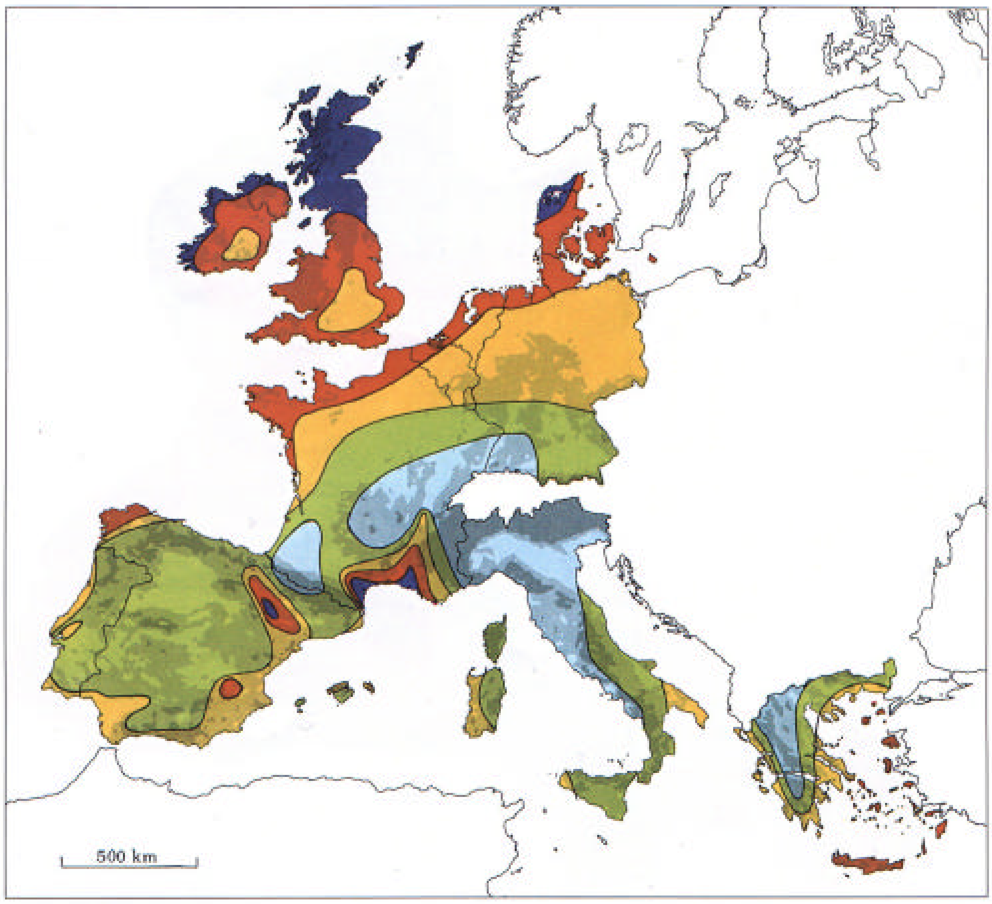
Wind results from expansion and convection of air as solar radiation is absorbed on earth. On a global scale these thermal effects combine with dynamic effects from the earth's rotation to produce prevailing wind patterns. The kinetic energy stored in the winds is about $0.7x10^{21}$ J. About 1% of absorbed solar radiation, 1200 TW is dissipated in this way [1].

Due to limited fossil fuel resources and their environmental impacts in the forms of air pollution, acid rain and greenhouse effects new and renewable energy resources have received increasing attention from all over the world. Renewable energy resources have gained importance due to increased cost of conventional energy resources as well. Among the renewable resources such as wind, solar, geothermal, biomass and wave energy, wind seems to be the most suitable and cost effective power source for electricity production.

In the year 2000, installed wind energy capacity set a new record with the addition of 4495 MW of new generating capacity. The cumulative installed capacity of 18449 MW at the end of 2000 supplied approximately 37 TWh (37 billion kWh) per year. 19 MW of the total installed capacity is in Turkey [2].

Detailed knowledge of the characteristics of the natural wind is necessary for the design and planning of wind energy systems. Geographical areas are rated in terms of available wind power density. This is done by using wind speed measurements. But this is a very difficult task because of the transitions in direction and speed of wind at most sites. Many studies have been completed to estimate the wind potential in different parts of the world. Some of those studies have been performed for southern Sweden by Hillring and Krieg [3]; Malaysia by Sopian, Othman and Wirsat [4]; East Mediterranean by Haralambopoulos [5]; Australia by Morgan [6]; Saudi Arabia by Alawaji, Eugenio and Elani [7]; and by Sahin and Aksakal [8]; Scotland by Saluja and Douglas [9]; Uruguay by Cataldo and Numes [10]; China by Han Mays [11].

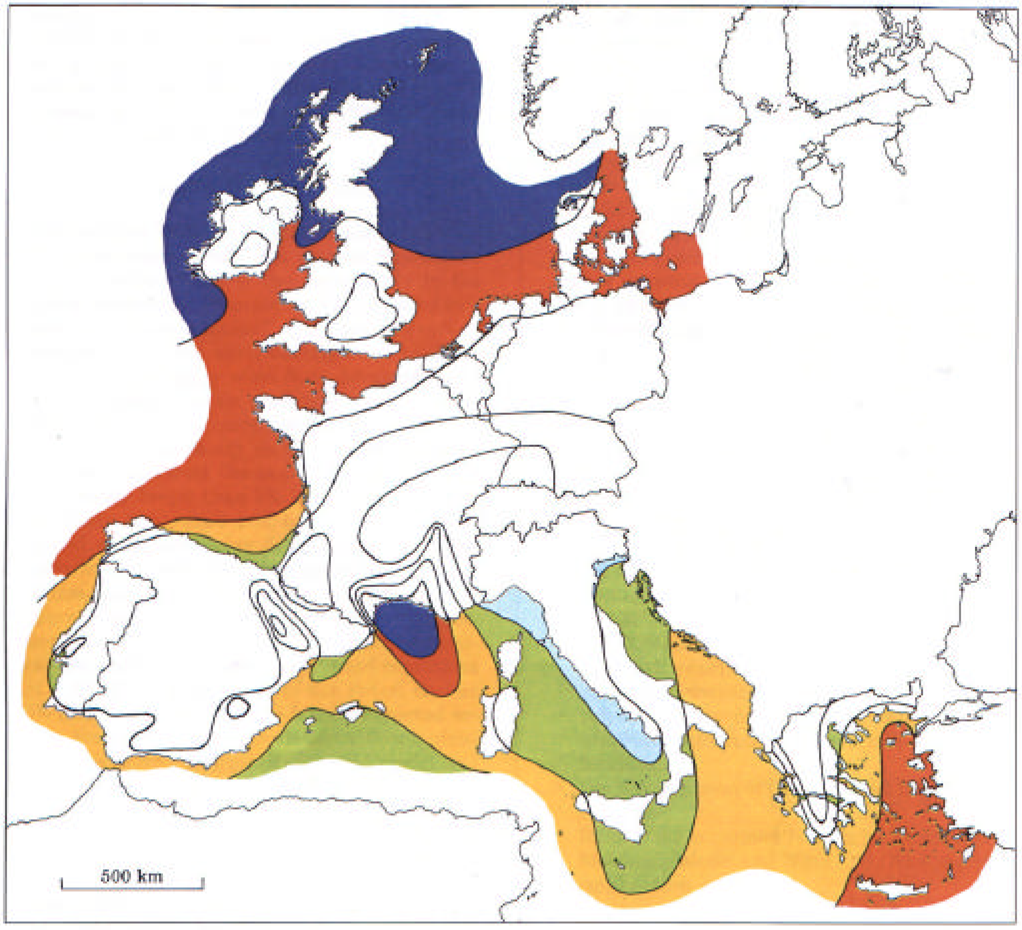
The estimation of the wind resource ranges from the overall estimation of the mean energy content of the wind over a large area which is called regional assessment to the prediction of the average yearly energy production of a specific wind turbine at a specific location which is called siting. A regional assessment is, often, called wind atlas.



Wind resources[1] at 50 metres above ground level for five different topographic conditions										
	Sheltered terrain[2]		Open plain[3]		At a sea coast[4]		Open sea[5]		Hills and ridges[6]	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
	> 6.0	> 250	> 7.5	> 500	> 8.5	> 700	> 9.0	> 800	> 11.5	> 1800
	5.0-6.0	150-250	6.5-7.5	300-500	7.0-8.5	400-700	8.0-9.0	600-800	10.0-11.5	1200-1800
	4.5-5.0	100-150	5.5-6.5	200-300	6.0-7.0	250-400	7.0-8.0	400-600	8.5-10.0	700-1200
	3.5-4.5	50-100	4.5-5.5	100-200	5.0-6.0	150-250	5.5-7.0	200-400	7.0- 8.5	400- 700
	< 3.5	< 50	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 7.0	< 400

1. The resources refer to the power present in the wind. A wind turbine can utilize between 20 and 30% of the available resource. The resources are calculated for an air density of 1.23 kg m^{-3}, corresponding to standard sea level pressure and a temperature of 15°C. Air density decreases with height but up to 1000 m a.s.l. the resulting reduction of the power densities is less than 10%.
2. Urban districts, forest and farm land with many windbreaks (roughness class 3).
3. Open landscapes with few windbreaks (roughness class 1). In general, the most favourable inland sites on level land are found here.
4. The classes pertain to a straight coastline, a uniform wind rose and a land surface with few windbreaks (roughness class 1). Resources will be higher, and closer to open sea values, if winds from the sea occur more frequently, i.e. the wind rose is not uniform and/or the land protrudes into the sea. Conversely, resources will generally be smaller, and closer to land values, if winds from land occur more frequently.
5. More than 10 km offshore (roughness class 0).
6. The classes correspond to 50% overspeeding and were calculated for a site on the summit of a single axisymmetric hill with a height of 400 metres and a base diameter of 4 km. The overspeeding depends on the height, length and specific setting of the hill.

Figure 1.1 Distribution of wind resources in Europe. By means of the legend the available wind energy at a height of 50 meters can be estimated for five topographical conditions [12].



Wind resources over open sea (more than 10 km offshore) for five standard heights										
	10 m		25 m		50 m		100 m		200 m	
	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}	$m\,s^{-1}$	Wm^{-2}
	> 8.0	> 600	> 8.5	> 700	> 9.0	> 800	> 10.0	> 1100	> 11.0	> 1500
	7.0-8.0	350-600	7.5-8.5	450-700	8.0-9.0	600-800	8.5-10.0	650-1100	9.5-11.0	900-1500
	6.0-7.0	250-300	6.5-7.5	300-450	7.0-8.0	400-600	7.5- 8.5	450- 650	8.0- 9.5	600- 900
	4.5-6.0	100-250	5.0-6.5	150-300	5.5-7.0	200-400	6.0- 7.5	250- 450	6.5- 8.0	300- 600
	< 4.5	< 100	< 5.0	< 150	< 5.5	< 200	< 6.0	< 250	< 6.5	< 300

Figure 1.2 Distribution of wind resources in Europe over open sea [12].

European Wind Atlas shows a very high wind capacity over the Aegean Sea and its sea coast regions [12]. Therefore, the western region of Turkey, which has a long coast to Aegean Sea, appears to have potential wind sources and wind energy generation. Several studies have been performed to estimate the wind potential in western Turkey. The assessments of wind power are studied by Tolun, Mentes, Aslan and Yükselen for Gökçeada [13]; Incecik and Erdogmus [14], and Sen and Sahin [15] for western Turkey; Türksoy [16], and Dündar and Inan [17] for Bozcaada. Because of the absence of a reliable and accurate Wind Atlas of Turkey, we need more studies on this field in order to recover the handicap in wind energy planning of Turkey.

The power output of a wind turbine is proportional to the third power of the wind speed due to aerodynamic reasons. Therefore, a precise prediction of the wind speed on a site is essential. Measurements taken from rooftops, airports where the surrounding area is open and unobstructed of meteorological stations under the influence of local obstacles such as buildings may not be reliable.

In this study, the wind energy potential of Izmir Institute of Technology campus area is investigated. The study presented here, also, is an attempt to bridge the gap in order to create Turkish Wind Atlas.

CHAPTER II

WIND AND WIND ENERGY

2.1 Wind

Wind energy is rightfully an indirect form of solar energy since chiefly the uneven heating of the earth's crust induces wind by the sun. It has been estimated that about 2 percent of all solar radiation falling on the face of the earth is converted to kinetic energy in the atmosphere and that 30 percent of this kinetic energy occurs in the lowest 1000 m of elevation. It is thus said that the total kinetic energy of the wind in this lowest kilometer, if harnessed, can satisfy considerable energy demand of the world.

Winds can be broadly classified as planetary and local. Planetary winds are caused by greater solar heating of the earth's surface near the equator than near the northern or southern poles. This causes warm tropical air to rise and flow through the upper atmosphere toward the poles and cold air from the poles to flow back to the equator nearer to the earth's surface. The direction of motion of planetary winds with respect to the earth is affected by the rotation of the earth. The western motion toward the equator and the eastern motion toward the poles result in large counterclockwise circulation of air around low-pressure areas in the northern hemisphere and clockwise circulation in the southern hemisphere[18].

Local winds are caused by two mechanisms. The first is differential heating of land and water. Solar insolation during the day is readily converted to sensible energy of the land surface and partly consumed in evaporating some of that water. The landmass becomes hotter than the water, which causes the air above land to heat up and become warmer than the air above water. The warmer lighter air above the land rises, and the cooler heavier air above the water moves in to replace it. This is the mechanism of shore breezes. A night, the direction of the breezes is reversed because the landmass cools more rapidly than the water. Hills and mountainsides cause the second mechanism of local winds. The air above the slopes heats up during the day and cools down at night, more rapidly than the air above the low lands. This causes heated air during the day to rise along the slopes and relatively cool heavy air to flow down at night.

Winds are very much influenced by the ground surface at altitudes up to 100 meters. The wind will be slowed down by the earth's surface roughness and obstacles. Wind speeds are affected by the friction against the surface of the earth. In general, the more pronounced the roughness of the earth's surface; the more the wind will be slowed down. Forests and large cities obviously slow the wind down considerably, while concrete runways in airports will only slow the wind down a little. Water surfaces are even smoother than concrete runways, and will have even less influence on the wind, while long grass and shrubs and bushes will slow the wind down considerably.

The roughness of the earth surface diminishes the velocity of the wind. With growing heights above ground level, the roughness has less effect and the velocity of the wind increases. Wind speed varies considerably with height above ground. This is called wind shear.

Figure 2.1 shows the form of wind speed variation with height (z) in the near-to-ground boundary layer up to about 100 m. At z=0 the air speed is always zero. Within the height of local obstruction wind speed increases erratically, and violent directional fluctuations can occur in high winds. Above this erratic region, the height/wind speed profile is given by expressions of the form

$$z - d = z_0 e^{\left(\frac{u_z}{V}\right)} \tag{2.1}$$

Hence

$$u_z = V Ln \frac{z-d}{z_0} \tag{2.2}$$

Here (d) is the zero plane displacement with magnitude a little less than the height of local obstructions, z_0 is the roughness length and (V) is a characteristic speed. On Figure 2.1 the function is extrapolated to negative values of (u) to show the form of the expression.

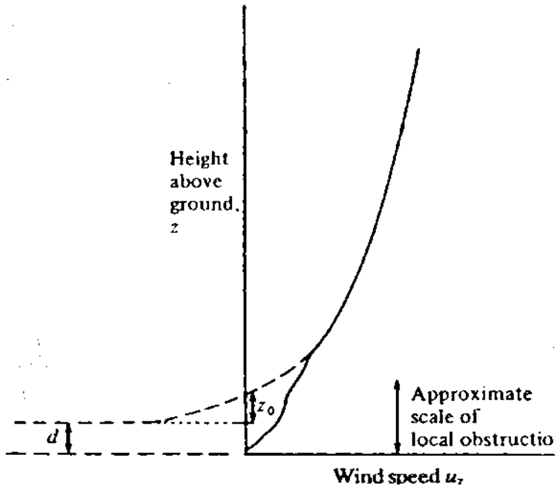


Figure 2.1 Wind speed variation with height [1].

Sometimes still a power law is used for the description of the wind profile like:

$$V_2 = V_1 \left(\frac{h_2}{h_1} \right)^a \qquad (2.3)$$

with:

V_2= Wind speed at height h_2

V_1= Wind speed at height h_1

Value α is dependent on the roughness elements of the ground and is different from z_0. It is often stated that $\alpha = \frac{1}{7} = 0.14$ for open sites. There is increasing evidence that α varies with season and time through the day.

In areas with a very uneven terrain surface, and behind obstacles such as buildings there is similarly created a lot of turbulence, with very irregular wind flows, often in whirls or vortexes in the neighborhood (Figure 2.2).

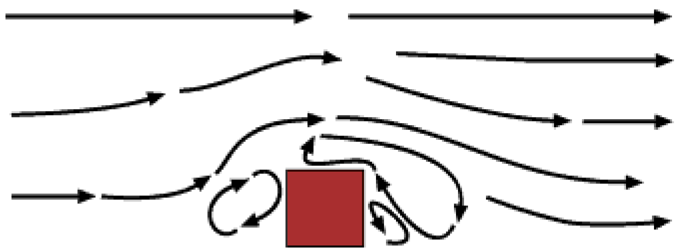


Figure 2.2 Turbulence behind obstacles [19].

A common way of siting wind turbines is to place them on hills or ridges overlooking the surrounding landscape. In particular, it is always an advantage to have as wide a view as possible in the prevailing wind direction in the area.

On hills, one may also experience that wind speeds are higher than in the surrounding area. Once again, this is due to the fact that the wind becomes compressed on the windy side of the hill, and once the air reaches the ridge it can expand again as its soars down into the low-pressure area on the lee side of the hill.

2.2 Wind Speed and Power Relations

Wind turbines use the kinetic energy of the wind flow. Their rotors reduce the wind velocity from the undisturbed wind speed far in front of the rotor to a reduced air stream velocity behind the rotor. The difference in wind velocity is a measure for the extracted kinetic energy which turns the rotor connected electrical generator.

The total power of a wind stream is equal to the rate of the incoming kinetic energy of that stream, or

$$P_{tot} = \dot{m}\frac{V_i^2}{2} \qquad (2.4)$$

where

P_{tot}= total power, W

$\dot{m}$ = mass-flow rate, kg/s

V_i = incoming velocity m/s

The mass-flow rate is given by the continuity equation

$$\dot{m} = rAV_i \tag{2.5}$$

where

r = incoming wind density, kg/m^3

A= cross- sectional area of stream, m^2

thus

$$P_{tot} = \frac{1}{2} rAV_i^3 \tag{2.6}$$

Thus the total power of a wind stream is directly proportional to its density, area, and the cube of its velocity (Figure 2.3).

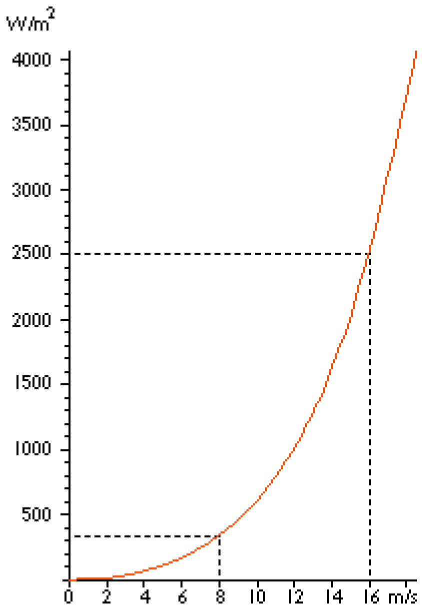


Figure 2.3 Wind power is proportional to cube of wind speed.

Air density r is a function of height and meteorological condition. Wind speed increases with height, is affected by local topography, and varies greatly with time. We consider r constant with time and over the area of the air column. A typical value for r is 1.2 kg/m^3 at sea level, and useful power can be harnessed in moderate winds when

V~10 m/s. In this condition P=600 W/m^2. In gale force conditions V~25 m/s, so P~10000 W/m^2

It will shortly be apparent that the total power discussed above cannot all be converted to mechanical power. Consider a horizontal-axis, propeller type wind turbine which is the most common type today. Assume that the incoming wind pressure and velocity, far upstream of the turbine, are P_e and V_e, respectively. V_e is less than V_i because kinetic energy is extracted by the turbine (as shown in Figure 2.4).

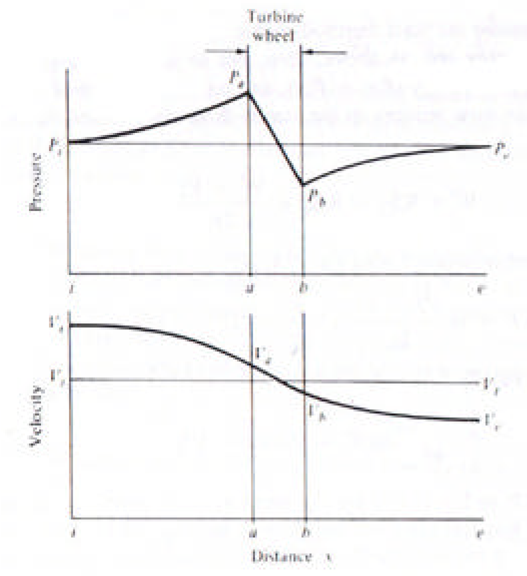


Figure 2.4 Wind pressure and wind velocity change in the turbine[18].

Considering the incoming air between (i) and (a) as a thermodynamic system, and assuming that the air density remains constant, that the change in potential energy is zero, and no heat or work are added or removed between (i) and (a), the general energy equation reduces to the kinetic and flow energy terms only,

Thus

$$P_i v + \frac{V_i^2}{2} = P_a v + \frac{V_a^2}{2} \tag{2.7}$$

or

$$P_i + \frac{rV_i^2}{2} = P_a + \frac{rV_a^2}{2} \tag{2.8}$$

where v and r are the specific volume and its reciprocal, the density, respectively, both considered constant. Last equation is the familiar Bernoulli equation.

Similarly, for the exit region b-e

$$P_e + \frac{rV_{ei}^{\ 2}}{2} = P_b + \frac{rV_b^{\ 2}}{2} \qquad (2.9)$$

The wind velocity across the turbine decreases from (a) to (b) since kinetic energy is converted to mechanical work there. The incoming velocity V_I does not decrease abruptly but gradually as it approaches the turbine to V_a and as it leaves it to V_e. Thus that is, the wind pressure rises as it approaches, then as it leaves the wheel.

Combining both equations gives

$$P_a - P_b = \left(P_i + r\left(\frac{V_i^{\ 2} - V_a^{\ 2}}{2} \right) \right) - \left(P_e + r\left(\frac{V_e^{\ 2} - V_b^{\ 2}}{2} \right) \right) \qquad (2.10)$$

It is reasonable to assume that, far from the turbine at (e), the wind pressure returns to ambient, or

$$P_e = P_i \qquad (2.11)$$

and that the velocity within the turbine, V_t, does not change because the blade width a-b is thin compared with the total distance considered, so that

$$V_t » V_a » V_b \qquad (2.12)$$

Combining Equations gives

$$P_a - P_b = r\left(\frac{V_i^2 - V_e^2}{2}\right) \tag{2.13}$$

The axial force F_x, in the direction of the wind stream, on a turbine wheel with projected area, perpendicular to the stream A, is given by

$$F_X = (P_a - P_b)A = r\left(\frac{V_i^2 - V_e^2}{2}\right) \tag{2.14}$$

This force is also equal to the change in momentum of the wind $\Delta(\dot{m}V)$ where $\dot{m}$ is the mass-flow rate given by

$$\dot{m} = rAV_t \tag{2.15}$$

thus

$$F_X = \frac{1}{g_c} rAV_t(V_i - V_e) \tag{2.16}$$

Equating Eqs. 2.14 and 2.16 gives

$$V_t = \frac{1}{2}(V_i + V_e) \tag{2.17}$$

We shall now consider the total thermodynamic system bounded by inlet and exit. The changes in potential energy are, as above, zero, but so are the changers in internal energy ($T_i = T_e$) and flow energy ($P_i v = P_e v$), and no heat is added or rejected. The general energy equation now reduces to the steady-flow work (W) and kinetic energy terms

$$W = KE_i - KE_e = \left(\frac{V_i^2 - V_e^2}{2}\right) \tag{2.18}$$

The power (P) is the rate of work.

$$P = \dot{m}\left(\frac{V_i^2 - V_e^2}{2}\right) = \frac{1}{2} A V_t \left(V_i^2 - V_e^2\right) \qquad (2.19)$$

$$P = \frac{1}{4} r A \left(V_i + V_e\right)\left(V_i^2 - V_e^2\right) \qquad (2.20)$$

When $V_t = V_i$ and $V_e = 0$; that is, the wind comes to a complete rest after leaving the turbine. This obviously, is an impossible situation because the wind cannot accumulate at turbine exit. It can be seen from last equation, where V_e results in reduced power. There this is an optimum exit velocity $V_{e\ opt}$ that results in maximum power P_{max}, which is obtained by differentiating P with respect to V_e for given V_i and equating the derivative to zero $\frac{\partial P}{\partial V_e} = 0$, which gives

$$3V_e^2 + 2V_i V_e - V_i^2 = 0 \qquad (2.21)$$

This is solved for a positive V_e to give optimum value $V_{e\ opt}$

$$V_{e\ opt} = \frac{1}{3} V_i \qquad (2.22)$$

then P_{max}

$$P_{max} = \frac{8}{27}\, r\, A\, V_i^3 \qquad (2.23)$$

The ideal, or maximum, theoretical efficiency η_{max} (also called the power coefficient) of a wind turbine is the ratio of the maximum power obtained from the wind (Figure 5).

$$h_{max} = \frac{P_{max}}{P_{tot}} = \frac{16}{27} = \mathbf{0.5926} \qquad (2.24)$$

In other words, a wind turbine is capable of converting no more that 60 percent of the total power of a wind to useful power. Analysis could have proceeded in terms of the ratio b= $\frac{V_e}{V_i}$, sometimes also called an interference factor and C_P is the fraction of power extracted, where P_0 is the power in the unperturbed wind. The power coefficient:

$$P_{tot} = C_P P \qquad (2.25)$$

$$C_p = \frac{P}{P_{tot}} \qquad (2.26)$$

$$C_{pmax} = \frac{16}{27} = \mathbf{0.59} \qquad (2.27)$$

The criterion for maximum power extraction ($C_{pmax} = \frac{16}{27}$) is called the **Betz Criterion**, and may be applied to all turbines set in an extended fluid stream. Thus it applies to power extraction from tidal and river currents (Figure2.5).

In practical operation, a good commercial wind turbine may have a maximum power coefficient of about 0.4. This may be described as having an efficiency relative to the Betz criterion of 0.4/0.59=68%.

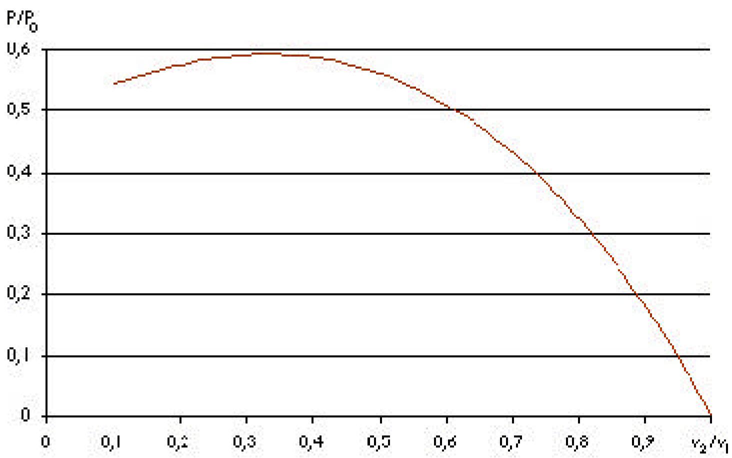


Figure 2.5 The graph shows "Betz Criterion".

The power coefficient tells you how efficiently a turbine converts the energy in the wind to electricity. Very simply, we just divide the **electrical power output** by the **wind energy input** to measure how technically efficient a wind turbine is.

2.3 Turbine Types

Wind power for mechanical purposes, milling and water pumping, has been established for many hundreds of years. Modern designs for electricity production date from about 1930 to about 1955. At this time development subsided owing to the availability of cheap oil, but interest reawakened and increased rapidly from about 1973. A few of the older machines are still able to operate, but most machines have been built since about 1980 and incorporate modern engineering design and materials. Of particular importance has been the use of microelectronic monitoring and control.

A device for direct mechanical work is often called a 'windmill' or just a 'wind turbine'. If electricity is produce the combination of turbine and generator may be called a 'wind generator' or an 'aerogenerator'. Because of the confusion of these terms, the acronym WECS is increasingly used (wind energy conversion system).

The extraction of power from the wind with modern turbines and energy conversion systems is an established industry. Machines are manufactured with a capacity from a few kilowatt to several megawatt in Europe, the United States and, increasingly, in other parts of the world.

2.3.1 Horizontal Axis Machines

We consider here the propeller type. The dominant driving force is lift. Blades on the rotor may be in front (upwind) or behind (downwind) of the tower. Upwind turbines need a tail some other mechanism to maintain orientation, such as side-facing fan tail rotors. Downwind turbines may be quite seriously affected by the tower, which produces wind shadow and turbulence in the blade path. Perturbations of this kind cause cyclic stresses on the structure, noise and output fluctuations. Wind may be expected to veer frequently in a horizontal plane, and rotor must turn (yaw) to follow the wind without oscillation. Upwind and downwind machines of capacity greater than about 50 kW are usually turned by electric motors in a controlled mode.

Two and three-bladed rotors are common for electricity generation [1]. The three-bladed rotors operate smoothly and may be cross-linked for greater rigidity.

Gearing and generators are usually at the top of the tower in a nacelle. It is possible to run a shaft down the tower for power generation at ground level but the complications are usually thought to outweigh the advantages. Multi-blade rotors, having high starting torque in light winds, are used for water pumping and other low frequency mechanical power.

Although the average efficiency for these turbines is somewhat above 20 per cent, the efficiency varies very much with the wind speed. The mechanical efficiency of the turbine is largest (in this case 44 per cent) at a wind speed around some 9 m/s. This is a deliberate choice by the engineers who designed the turbine. At low wind speeds efficiency is not so important, because there is not much energy to harvest. At high wind speeds the turbine must waste any excess energy above what the generator was designed for. Efficiency therefore matters most in the region of wind speeds where most of the energy is to be found.

Usually, wind turbines are designed to start running at wind speeds somewhere around 3 to 5 meters per second. This is called the **cut in wind speed**. The wind turbine will be programmed to stop at high wind speeds above, say 25 meters per second, in order to avoid damaging the turbine or its surroundings. The stop wind speed is called the **cut out wind speed**.

The power curve of a wind turbine is a graph that indicates how large the electrical power output will be for the turbine at different wind speeds. Power curves are based on measurements in areas with low turbulence intensity, and with the wind coming directly towards the front of the turbine. Local turbulence and complex terrain (e.g. turbines placed on a rugged slope) may mean that wind gusts hit the rotor from varying directions. It may therefore be difficult to reproduce the power curve exactly in any given location.

Consequently, there may be errors up to plus or minus 10 percent even in certified power curves.

Figure 2.6 Horizontal axis wind turbines installed in Alacati/Turkey.

2.3.2 Vertical Axis Machines

By turning with a vertical axis, a machine can accept wind from any direction without adjustment. The other main benefit is that gearing and generations can be directly coupled to the axis at ground level. The principal disadvantages are: (1) Many vertical axis machines have suffered from fatigue failures arising from the many natural resonance in the structure, and (2) the rotational torque from the wind varies periodically within each cycle, and thus unwanted power periodioties appear at the output. As a result the great majority of working machines are horizontal axis, not vertical. Nevertheless research and development on several types of vertical axis machine continue, for both small and large commercial systems [1].

(1) Cup anemometer: This device rotates by drag force. The shape of this cup produces a nearly linear relationship between rotational frequency and wind speed.

(2) Savonius rotor (turbo machine): There's complicated motion of the wind through and around the two curved sheet airfoils. The driving force principally drags. The construction is simple and inexpensive. The lift solidity produces high starting torque, so Savonius rotors are used for water pumping.

(3) Darrieus rotor: This rotor has two or three thin curved blades with air section. The driving forces are lift, with maximum torque occurring when blade is moving across the wind at a speed much greater than the wind speed. Uses are for electricity generation. The rotor is not usually self-start. Therefore movement may be initiated with the electrical generator as a motor (Figure 2.9).

(4) Musgrove rotor: The blades of this form of rotor are vertical for nonpower generation, but tip or turn about a horizontal point for control shutdown. There are several variations, which are all design to have the advantage of failsafe shut down in strong winds.

(5) Evans rotor: The vertical blades twist about a vertical axis for control and failsafe shut down.

Figure 2.7 Darious rotor installed in USA.

2.4 Wind Energy Estimation

Having the cubic relation with the power, the wind speed is the most critical data needed to appraise the power potential of a candidate site. The wind is never steady at any site. It is influenced by the weather system, the local land terrain, and the height above the ground surface. The wind speed varies by the minute, hour, day, season and year. Therefore, the annual mean speed needs to be averaged over 10 or more years. Such a long term average raises the confidence in assessing the energy- capture potential of a site. However, long term measurements are expensive, and most projects cannot wait that long. In such situations, the short term, say one year, data is compared with a nearby site having a long term data to predict the long term annual wind speed at the site under consideration. This is known as the "measure, correlate and predict (mcp)" technique [20].

Since wind is driven by the sun and the seasons, the wind pattern generally repeats over the period of one year. The wind site is usually described by the speed data averaged over the calendar months. The wind-speed variations over the period can be described by a probability distribution function.

2.4.1 Weibull Probability Distribution

The variation in wind speed are best described by the Weibull probability distribution function 'h' with two parameters, the shape parameter (k), and the scale parameter (c). The probability of wind speed being (v) during any time interval is given by the following:

$$h(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)} e^{-\left(\frac{v}{c}\right)^{k}} \quad \text{for } 0 < v < \infty. \tag{2.28}$$

In the probability distribution chart, h is plotted against v over a chosen time period, where:

$$h = \frac{fraction\_of\_time\_wind\_speed\_is\_between\_v\_and\_(v-\Delta v)}{\Delta v} \tag{2.29}$$

By definition of the probability function, probability that the wind speed will be between zero and infinity during that period is unity, i.e:

$$\int_0^\infty h \cdot dv = 1 \tag{2.30}$$

if we choose the time period of one year, then express the probability function in terms of the number of hours in the year, such that:

$$h = \frac{number\_of\_hours\_the\_wind\_is\_between\_v\_and\_(v-\Delta v)}{\Delta v} \tag{2.31}$$

The unit of 'h' is hours per year per meter / second, and the integral (Eqn. 2.30) becomes 8760 (the total number of hours in the year) instead of unity.

Figure 2.10 is the plot of (h) versus (v) for three different values of (k). The curve on the left with k=1 has a heavy bias to the left, where most days are windless (v=0). The curve on the right with k=3 looks more like a normal bell shape distribution, where some days have high wind and equal number of days have low wind. The curve in the middle with k=2 is a typical wind distribution found at most sites. In this distribution, more days have lower than the mean speed, while few days have high wind. The value of (k) determines the shape of the curve, hence is called the 'shape parameter'.

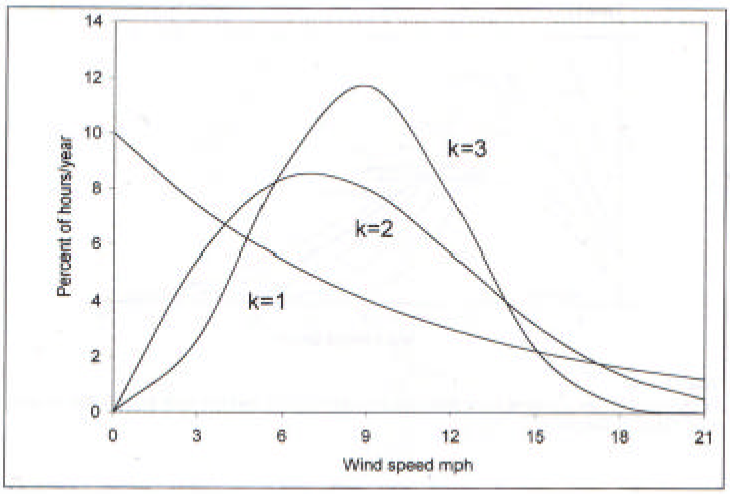


Figure 2.8 Weibull probability distribution function with scale parameter c=10 and shape parameter k=1,2 and 3 [21].

The Weibull distribution with k = 1 is called the exponential distribution which is generally used in the reliability studies. For k>3, it approaches the normal distribution, often called the Gaussian or the bell-shape distribution.

Figure 2.11 shows the distribution curves corresponding to k = 2 with different values of c ranging from 8 to 16 mph (1mph = 0.446 m/s). For greater values of (c), the curves shift right to the higher wind speeds at is, the higher the (c), the more number days have high winds. Since this shifts the distribution of hours at a higher speed scale, the (c) is called the scale parameter.

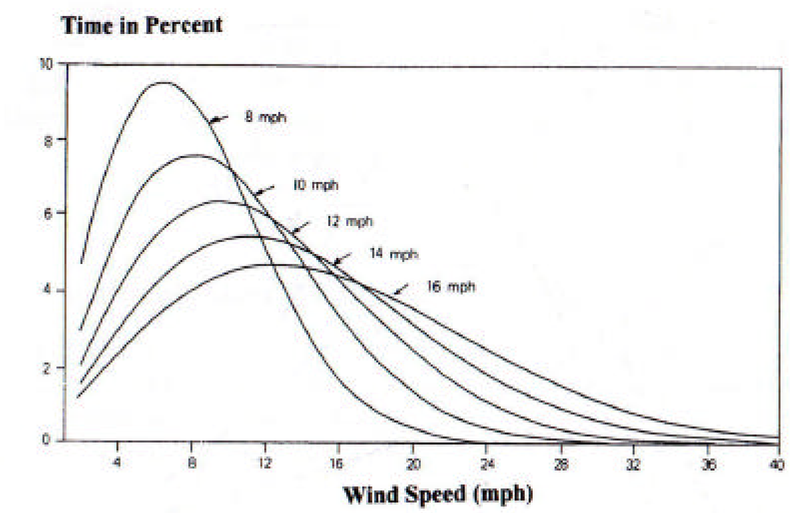


Figure 2.9 Weibull probability distribution with shape parameter k=2 and the scale parameters ranging from 8 to 16 miles per hour(mph) [21].

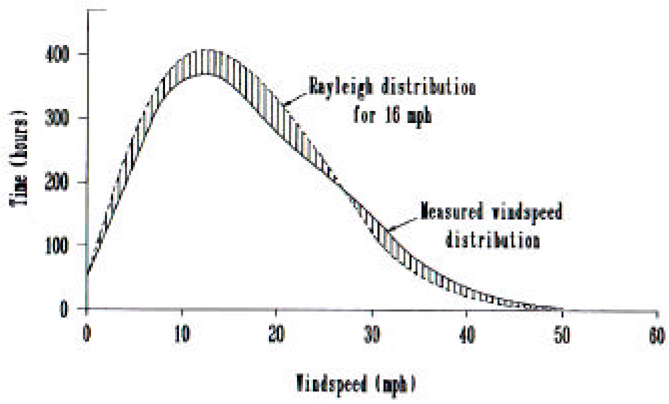


Figure 2.10 Rayleigh distribution of hours/year compared with measured wind-speed distribution [21].

At most sites the wind speed has the Weibull distribution with k = 2, which is specifically known as the Rayleigh distribution. The actual measurement data taken at most sites compare well with the Rayleigh distribution, as seen in Figure 2.11. The Rayleigh distribution is then a simple and accurate enough representation of the wind speed with just one parameter, the scale parameter (c).

Summarizing the characteristics of the Weibull probability distribution function:

k = 1 makes it the exponential distribution, $h = e^{-lv}$ where $l = \frac{1}{c}$;

k = 2 makes it the Rayleigh distribution, $h = 2l^2 \times V \cdot e^{-(lv)^2}$ and

k > 3 makes it approach a normal bell-shape distribution. (2.32)

Since most wind sites would have the scale parameter ranging from 20 to 30 kilometers per hour (about 5 to 10 m/s), and the shape parameter ranging from 1.5 to 2.5 (rarely 3.0), our discussion in the following sections will center around those ranges of (c) and (k).

Figure 2.12 display the number of hours on the vertical axis versus the wind speed on the horizontal axis with distributions of different scale parameters c = 10, 15, and 20 mph and shape parameters k = 1.5, 2, and 3. The values of h in all three sets of curves are the number of hours in a year in the speed interval v+Δv divided by Δv.

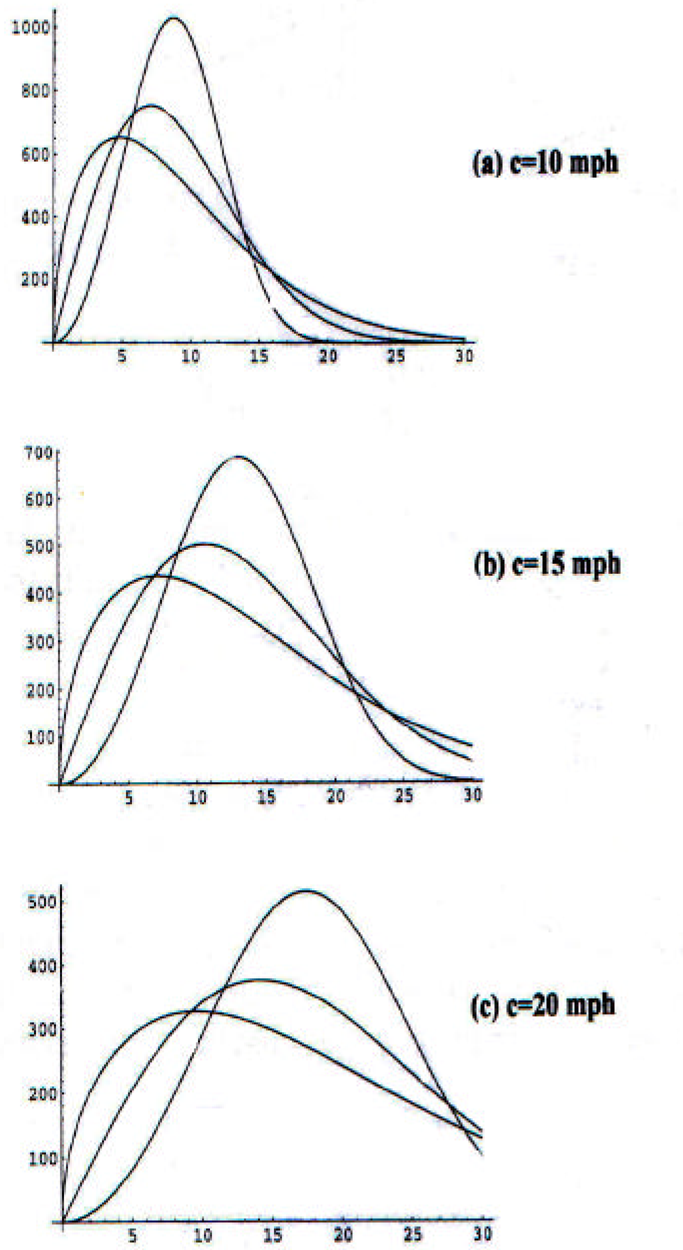


Figure 2.11 Weibull distributions of hours/year with three different shape parameters k=1.5, 2 and 3 [21].

2.4.2 Mode and Mean Speeds

We now define the following terms applicable to the wind speed:

Mode speed is defined as the speed corresponding to the hump in the distribution function. This is the speed the wind blows most of the time.

Mean speed over the period is defined as the total area under the h-v curve integrated from v = 0 to ∞, divided by the total number of hours in the period (8760 if the period is one year). The annual mean speed is therefore the weighted average speed and is as follows:

$$V_{mean} = \frac{1}{8760}\int_0^{\infty} h \cdot v \cdot dv \; . \qquad (2.33)$$

For (c) and (k) values in the range found at most sites, the integral expression can be approximated to the Gamma function:

$$V_{mean} = c\,\Gamma\left(1+\frac{1}{k}\right) \qquad (2.34)$$

For the Rayleigh distribution with k = 2, the Gamma function can be further approximated to the following:

$$V_{mean} = 0.90 \cdot c. \qquad (2.35)$$

This is a very simple relation between the scale parameter (c) and V_{mean}, which can be used with reasonable accuracy. For example, most sites are reported in terms of their mean wind speeds. The (c) parameter in the corresponding Rayleigh distribution is then c = V_{mean} /0.9. The k parameter is of course 2.0 for the Rayleigh parameters. Thus, we have the Rayleigh distribution of the site using the generally reported mean speed as follows:

$$h(v) = \frac{2v}{c^2} e^{-\left(\frac{v}{c}\right)^2} = \frac{2v}{\left(V_{mean}\right)^2} e^{-\left(\frac{v}{V_{mean}}\right)^2} \qquad (2.36)$$

2.4.3 Estimation of Energy Production

The annual energy production of a wind turbine is the most important economic factor. Uncertainties in determination of the annual wind speed and power curve contribute to the total uncertainty in predicted annual energy yield and lead to higher financial risk. In the following it is shown how to calculate the annual energy production (AEP).

The annual energy production can be estimated by the following methods:

- Wind speed histogram and power curve
- Theoretical wind speed distribution and power curve.

If the wind speed histogram is known from measurements, a good estimation of AEP can be calculated by using the measured histogram and the power curve. For each wind speed bin the number of hours in the bin are multiplied with the corresponding power generated by the turbine to get the energy production in that bin. These values are summed to get the annual energy production.

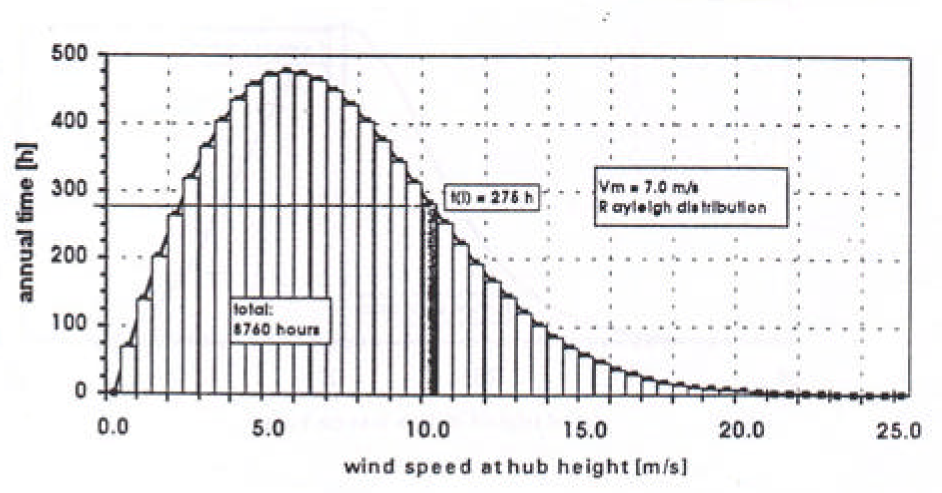


Figure 2.12 Example of measured wind speed histogram (v[i]=10.25 m/s; t[i]=275 h)[20].

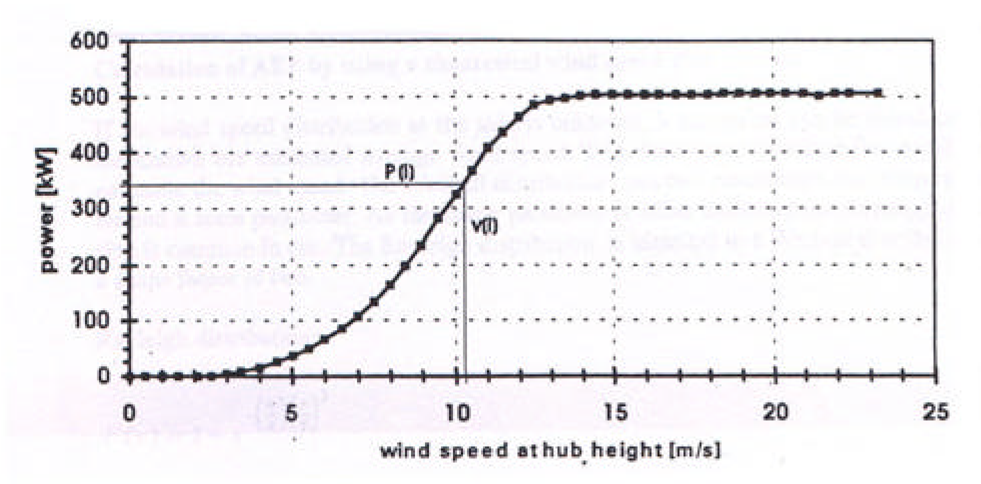


Figure 2.13 Example of measured power curve at standard air density (1.225 kg/m3)[20].

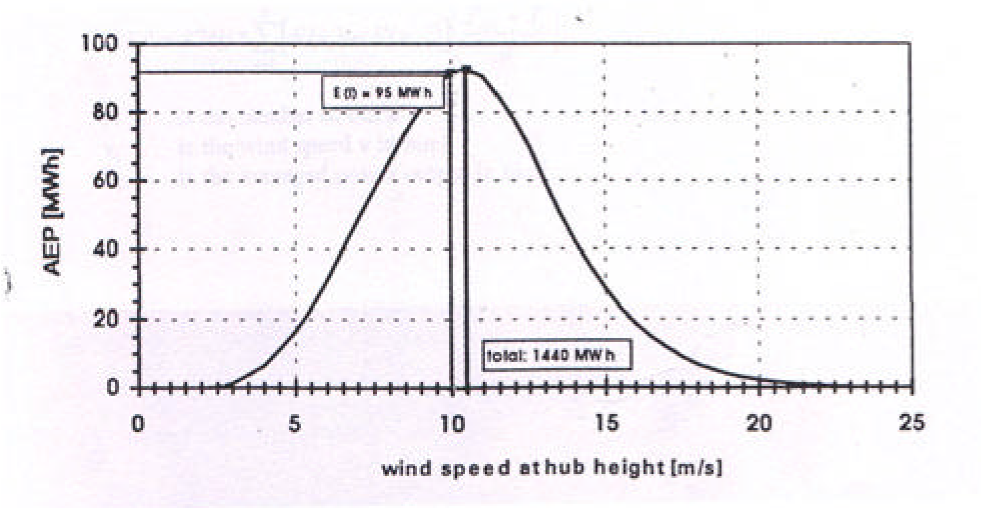


Figure 2.14 Example of estimated energy in bin (i)[20].

The total energy production in one year (AEP) is: E = Σ p[i]*h[i]

If the wind speed distribution at the site is known, a histogram can be calculated from the known are estimated average wind speed. Two theoretical distributions are in use to calculate the wind speed. The Weibull distribution uses two parameters, shape parameter and scale parameter. As the shape parameter is often unknown the Rayleigh distribution is common in use.

Rayleigh distribution:

$$F(v) = 1 - e^{-\left(\frac{p}{4}\right)\left(\frac{v}{\bar{v}}\right)^2} \tag{2.37}$$

where

F(v) is the Rayleigh cumulative distribution for wind speed

v is the annual average wind speed at hub height

$\bar{v}$ is the annual average wind speed at hub height

The annual energy production is then

$$AEP = 8760 \cdot \sum_{i=1}^{N} \left[F(v_i) - F(v_{i-1})\right]\left(\frac{P_{i-1} + P_i}{2}\right) \tag{2.38}$$

where

N is the number of bin's

v_i is the wind speed (v) in bin (i)

P_i is the averaged power output in bin (i)

Same calculation principles are used in Wind Energy Estimations by WindPRO and WAsP software in Chapter 7.

CHAPTER III

MEASUREMENT PARAMETERS

Wind speed measurements are the most critical measurements for wind resource assessment, performance determination and prediction of the annual energy yield. In economic terms uncertainties translate directly into financial risk. There is no other branch where the importance of uncertainties in wind speed measurement is as great as in wind energy.

Best practice wind speed measurements over a period of at least one year reduce the financial risk of a wind farm significantly as the uncertainties of proper wind speed measurements are much lower than flow model predictions. A representative position within the wind farm area has to be chosen. For large wind farms in complex terrain two or three representative met mast positions should be chosen. At least one measurement should be performed at hub height of the planned turbines because extrapolation from a lower height to hub height causes additional uncertainties [22].

3.1 Basic Parameters

The core of the monitoring program is the collection of wind speed, wind direction, and air temperature data. A description of each parameter, its purpose, and appropriate monitoring height(s) is presented below and summarized in Table 3.1. These nominal parameters are recommended to obtain the basic information needed to evaluate resource-related wind energy feasibility issues.

Table 3.1 Basic Measurement Parameters [23].

Measurement Parameters	Monitoring Heights
Wind Speed (m/s)	10 m, 30 m, 40 m
Wind Direction (degrees)	10 m, 30 m, 40 m
Temperature (°C)	3 m

3.1.1 Wind Speed

Wind speed data are the most important indicator of a site's wind shear characteristics, conducting turbine performance simulations at several turbine hub heights, and for back up. Heights typical of recent wind measurement programs are 40 m, 30 m, and 10 m.

-40 m: This height represents the approximate hub height of most utility-scale wind turbines. Actual hub heights are usually in the 30 m to 50 m range.

-30 m: This level approximates the minimum height reached by the blade tip portion of a rotating turbine rotor and will help define the wind regime encountered by a typical turbine rotor over its swept area.

-10 m: This is the universally standard meteorological measurement height. However, in locations where the interference of local vegetation (e.g., forest) at this height is unavoidable, an alternative low-level height of 10 m above the forest canopy may be used.

These significant measurement heights are becoming commonly observed. Additional or alternative heights can also be selected.

3.1.2 Wind Direction

To define the prevailing wind direction(s), wind vanes should be installed at all significant monitoring levels. Wind direction frequency information is important for identifying preferred terrain shapes and orientations and for optimizing the layout of wind turbines within a wind farm.

3.1.3 Temperature

Air temperature is an important descriptor of a wind farm's operating environment and is normally measured either near ground level, or near hub height. In most locations the average near ground level air temperature will be within 1°C of the average at hub height. It is also used to calculate air density, a variable required to estimate the wind power density and a wind turbine's power output.

3.2 Optional Parameters

You may expand your monitoring effort to include additional measurement parameters. Possible optional parameters are presented in detail below and summarized in Table 3.2.

Table 3.2 Optional measurement parameters.

Measurement Parameters	Monitoring Heights
Solar Radiation (W/m^2)	3-4 m
Vertical Wind Speed (m/s)	38 m
Delta Temperature (°C)	38 m
	3 m
Barometric Pressure (kPa)	2-3 m

3.2.1 Solar Radiation

You may want to take advantage of your wind program to measure the solar resource for later solar energy evaluating studies. Solar radiation, when used in conjunction with wind speed and time of day, can also be an indicator of atmospheric stability and is used in numerical wind flow modeling. The recommended measurement height is 3 to 4 m above ground.

3.2.2 Vertical Wind Speed

This parameter provides more detail about a site's turbulence and can be a good predictor of wind turbine loads. Historically this parameter has been a research measurement, but as wind energy development spreads into new regions of the country, regional information on vertical wind velocity may become important. To measure the vertical wind component (w) as an indicator of wind turbulence, a "w" anemometer should be located near the upper basic wind speed monitoring level.

3.2.3 Change in Temperature with Height

This measurement, also referred to as delta temperature (ΔT), provides information about turbulence and historically has been used to indicate atmospheric stability. A matched set of temperature sensors should be located near the lower and upper measurement levels without interfering with the wind measurements.

3.2.4 Barometric Pressure

Barometric pressure is used with air temperature to determine air density. It is difficult to measure accurately in windy environments because of the dynamic pressures induced when wind flows across an instrument enclosure. An indoor or office environment is a preferred setting for a pressure sensor. Therefore, most resource assessment programs do not measure barometric pressure and instead use data taken by a regional weather station that are then adjusted for elevation.

3.3 Recorded Parameters and Sampling Intervals

The measured parameters presented in this section represent internal processing functions of the data logger. All parameters should be sampled once every one or two seconds and recorded as averages, standard deviations, and maximum and minimum values. Data recording should be serial in nature and designated by a corresponding time and date stamp Each is presented below and summarized in Table 3.3.

Table 3.3 Basic and optional parameters.

Measured Parameters	Recorded Values
Wind Speed (m/s)	Average Standard Deviation Maximum/Minimum
Wind Direction (degrees)	Average Standard Deviation Maximum Gust Direction
Temperature (°C)	Average Maximum/Minimum
Solar Radiation (W/m^2)	Average Maximum/Minimum
Vertical Wind Speed (m/s)	Average Standard Deviation
Barometric Pressure (hPa)	Average Maximum/Minimum
Delta Temperature(°C)	Average Maximum/Minimum

3.3.1 Average Value

The average value should be calculated for all parameters on a ten-minute basis, which is now the international standard period for wind measurement. Except for wind direction, the average is defined as the mean of all samples. For wind direction, the average should be a unit vector (resultant) value. Average data are used in reporting wind speed variability, as well as wind speed and direction frequency distributions.

3.3.2 Standard Deviation Value

The standard deviation should be determined for both wind speed and wind direction and is defined as the true population standard deviation s for all one or two second samples within each averaging interval. The standard deviations of wind speed and wind direction are indicators of the turbulence level and atmospheric stability. Standard deviation is also useful in detecting suspect or erroneous data when validating average values.

3.3.3 Maximum and Minimum Value

Maximum and minimum values should be determined for wind speed and temperature at least daily. The maximum (minimum) value is defined as greatest (lowest) one or two second reading observed within the preferred period. The coincident direction corresponding to the maximum (minimum) wind speed should also be recorded.

CHAPTER IV

MONITORING STATION INSTRUMENTATION

4.1 Basic Sensors

Meteorological sensors are designed to monitor specific environmental parameters. This section describes instruments for measuring wind speed, wind direction, and air temperature. Table 4.1 lists the nominal specifications for these sensors.

Table 4.1 Nominal specifications of the sensors [23].

Specification	Anemometer (Wind Speed)	Wind Vane (Wind Direction)	Temperature Probe
Measurement Range	0 to 50 m/s	0° to 360° (≤8° deadband)	-40° to 60°C
Starting Threshold	≤1.0 m/s	≤1.0 m/s	N/A
Distance Constant	≤4.0 m	N/A	N/A
Operating Temperature Range	-40° to 60°C	-40° to 60°C	40° to 60°C
Operating Humidity Range	0% to 100%	0% to 100%	0% to 100%
System Error	≤ 3%	≤5°	≤1°C
Recording Resolution	≤0.1 m/s	≤1°	≤0.1°C

4.1.1 Wind Speed

Cup or propeller anemometers are the sensor types most commonly used for the measurement of near-horizontal wind speed.

4.1.1.1 Cup Anemometer:

This instrument consists of a cup assembly (three or four cups) centrally connected to a vertical shaft for rotation. At least one cup always faces the oncoming wind. The aerodynamic shape of the cups converts wind pressure force to rotational torque. The cup rotation is nearly linearly proportional to the wind speed over a specified range. A transducer in the anemometer converts this rotational movement into an electrical signal, which is sent through a wire to a data logger.

The data logger then uses known multiplier (or slope) and offset (or intercept) constants to calculate the actual wind speed.

4.1.1.2 Propeller Anemometer:

This instrument consists of a propeller (or prop) mounted on a horizontal shaft that is oriented into the wind through the use of a tail vane. The propeller anemometer also generates an electrical signal proportional to wind speed.

Although the two sensor types differ somewhat in their responsiveness to wind speed fluctuations, there is no clear advantage of one type over the other. In practice, the cup type is most commonly used for resource assessment.

In this study, two Ammonit brand three cups “Classic” model anemometer are being used. They are mounted on IYTE mast at 10 m and at 30 m. Their technical data are as following: Measurement range 0.3 ... 50 m/s, Accuracy ± 2 % of measurement value or ± 0.3 m/s, Resolution 0.05 m/s, Distance constant 5 m, Max. wind load 60 m/s, Ambient temperature -35 °C ... + 80 °C, Power supply 4 - 18 V DC - approx. 0.35 mA, Heating 24 V AC/DC max. 20 W, Weight without cable 1 kg [24].

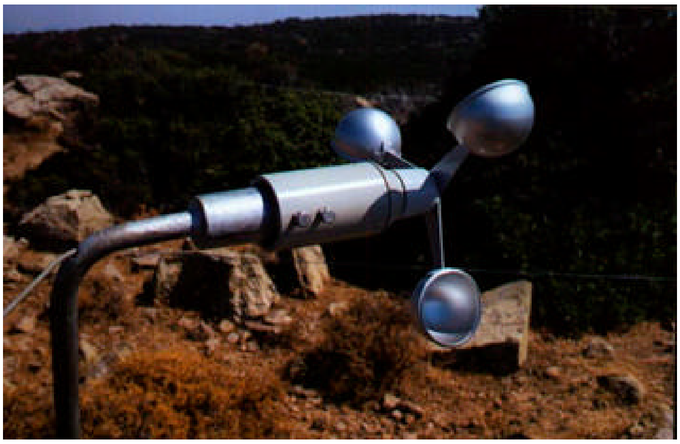


Figure 4.1 Anemometer at site.

4.1.2 Wind Direction

A wind vane is used to measure wind direction. The most familiar type uses a fin connected to a vertical shaft. The vane constantly seeks a position of force equilibrium by aligning itself into the wind. Most wind vanes use a potentiometer type transducer that outputs an electrical signal is transmitted via wire to a data logger and relates the vane’s position to a known reference point (usually true north). Therefore, the alignment (or orientation) of the wind vane to a specified reference point is important.

The data logger provides a known voltage across the entire potentiometer element and measures the voltage where the wiper arm contacts a conductive element. The ratio between these two voltages determines the position of the wind vane. This signal is interpreted by the data logger system, which uses the ratio (a known multiplier) and the offset (a known correction for any misalignment to the standard reference point) to calculate the actual wind direction. Electrically the linear potentiometer element does not cover a full 360°. This “open” area is the deadband of the wind vane. When the wiper arm is in this area, the output signal is random. Some manufacturers compensate for the deadband in their data logger software to prevent random signals. Therefore, the deadband area should not be aligned into or near the prevailing wind direction.

When choosing a wind vane, the same selection criteria as for the anemometer are applicable. Particular attention to the size of the open deadband area of the potentiometer should be paid; this should not exceed 8°. The resolution of the wind vane is also important. Some divide a complete 360° rotation into 16°, 22.5° segments. This resolution is too coarse for optimizing the layout of a wind turbine array.

In this study, Ammonit brand “Classic” type wind vane is chosen because of its simple design and low maintenance requirements. With the help of a potentiometer the physical property is converted into an analogue resistor output signal. At zero the transducer has to pass the „north transition“ between the margins of zero and 2 kohm. Its technical data are as following: Measurement range 0 ... 360° without north gap, Accuracy ± 2°, Resolution 1°, Damping coefficient > 0.3, Max. wind load 60 m/s, Ambient temperature -35 °C ... + 80 °C, Power supply max. 50 V, max. 100 mA, Heating 24 V AC/DC max. 20 W, Weight without cable 1.5 kg [24].

Figure 4.2 Wind vane at the site.

4.1.3 Air Temperature

A typical ambient air temperature sensor is composed of three parts: the transducer, an interface device, and a radiation shield. The transducer contains a material element (usually nickel of platinum) with a relationship between its resistance and temperature. Thermistors, resistance thermal detectors (RTDs), and semiconductors are common element types recommended for use. The resistance value is measured by the data logger (or an interface device), which uses a known equation to calculate the actual air temperature. The transducer is housed within a radiation shield to protect it from direct solar radiation.

In this study, Ammonit “temp-humidityprobe” series xPC model is selected because of its compact size and stick version sensor with fixed connected cable. The temperature measurement is made by Pt100-resistor (1/3 DIN). The signal is available directly (4-wire-connection) or as an analogue output as well. The relative humidity is measured by a capacitive sensing element and the value will be placed at the output as analogue signal. For protection against rain and direct radiation a weather and radiation shield is mounted. Humidity has no influence on the energy analysis, but the readings can help to asses the danger of freezing at the location.

Technical data of temperature probe is as following:

Temperature range -30 .. +70 °C, Accuracy ± 0.2 K, Additional error ± 0.004 %/K (<10 °C, >40 °C), Resolution 0.1 °C, Response time 5 min. Measurement principle Pt100 - 1/3 DIN, Output signal 4-wire-connection or 0..1 V, Ambient temperature -40 °C ... + 80 °C Operation supply 9 - 30 V DC - approx. 1 mA Protection (sensor/electronic) IP 30 / IP 65 Weight Sensor without cable 0.350 kg, shield 1 kg [23].

Technical data of humidity probe is as following:

Humidity range 0 .. 100 % r.H., Accuracy ±2 % r.H., Additional error ± < 0.1 %/K (<10 °C, >40 °C) Resolution 1 % r.H. Response time 5 min., Measurement principle capacitive, Output signal 0..1 V, Operation supply 9 - 30 V DC - approx. 1 mA Protection (sensor/electronic) IP 30 / IP 65 [23].

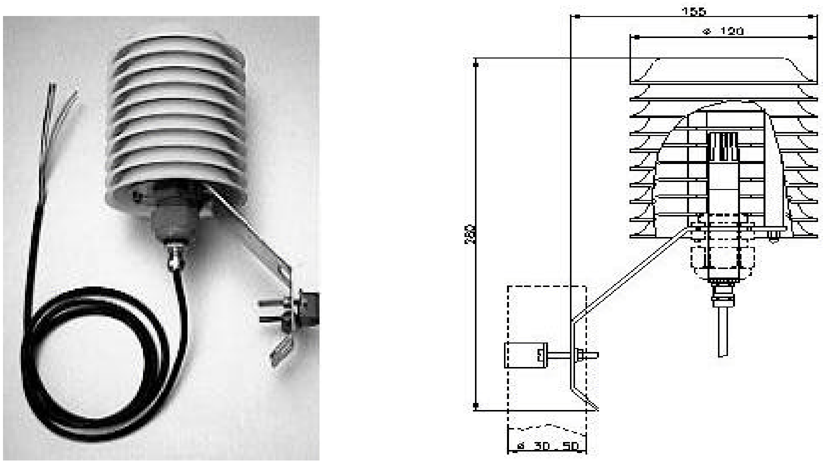


Figure 4.3 Ammonit thermo/hygro probe [24].

4.2 Optional Sensors

In addition to the required measurements, it is possible to include optional sensors for solar radiation, vertical wind speed, ΔT, and barometric pressure. Table 4.2 lists the nominal specifications for these sensors.

Table 4.2 Specifications for optional sensors [23].

Specifications	Pyranometer (Solar Radiation)	W Anemometer (Vertical Wind Speed)	DT Sensors (Delta Temperature)	Barometer (Atmospheric Pressure)
Measurement Range	0 to 1500 W/m^2	0 to 50 m/s	-40 to 60 °C	94 to 106 kPa (sea level equivalent)
Starting Threshold	N/A	≤1.0 m/s	N/A	N/A
Distance Constant	N/A	≤4.0 m	N/A	N/A
Operating temperature Range	-40 to 60 °C	-40 to 60 °C	-40 to 60 °C	-40 to 60°C
Operating Humidity Range	0 to 100%	0 to 100%	0 to 100%	0 to 100%
System accuracy	≤ 5 %	≤ 3%	≤ 0.1 °C	≤ 1 kPa
Recording resolution	≤1 W/m^2	≤ 0.1 m/s	≤ 0.01°	≤ 0.2 kPa

4.2.1 Global Solar Radiation

A pyranometer is used to measure global, or total, solar radiation, which combines direct sunlight and diffuse sky radiation. One common type uses a photodiode that generates a small voltage (millivolts) across a fixed resistance proportional to the amount of solar radiation (insolation). Another common type uses a thermopile, a group of thermal sensors that react to radiant energy and produce a voltage proportional to temperature.

An output current is measured from both types by the data logger, which uses a known multiplier and offset to calculate the global solar radiation. The current output is usually very small (microamps or less). Normally, the measuring instrument will have a "dropping" resistor and an amplifier that conditions the signal to obtain adequate output range

4.2.2 "W" Anemometer

The propeller anemometer is especially suited for measuring the vertical wind component. It consists of a propeller mounted on a fixed vertical arm. The sensor requires a transducer that can electrically relate both the rotational direction (indicative of upward or downward motion) and the speed of the propeller. This signal is usually a polarized DC voltage that is interpreted by the data logging system. The polarity indicates rotational direction; the magnitude indicates rotational speed. The data logger then uses a known multiplier and offset to calculate the actual vertical wind speed.

4.2.3 Delta Temperature Sensors

The parameter ΔT is used to determine atmospheric stability and is defined as the temperature difference between a matched pair of temperature sensing subsystems located at different heights. The sensor types previously cited are applicable and are usually tested over a specified range and matched by the manufacturer. Identical subsystems are required because of the inherent errors in the method and equipment used. According to EPA Quality Assurance Handbook (1989), the maximum allowable ΔT error is 0.003°C/m. Using the monitoring configuration of 10 m and 40 m levels, the allowable error would be approximately 0.1°C, which is quite small. To minimize errors caused by environmental factors such as direct sunlight, both monitoring heights should use identical equipment (e.g., radiation shield, mounting hardware, etc.) so they similarly respond to the ambient conditions. When the difference between the two values is taken, both errors are about the same and cancel each other out in the equation. To reduce radiation errors during all conditions, a radiation shield that uses either forced (mechanical) or natural (passive) aspiration is required.

4.2.4 Barometric Pressure Sensors

A barometer measures atmospheric (barometric) pressure. Several barometric pressure sensors are commercially in use. Most models use a piezo electric transducer that provides a standard output to a data logger. This may require an external power source to operate properly.

In this sudy, Ammonit PTB 100 A model air pressure transducer is used. This analogue barometer is available for different pressure ranges. It is based on a capacitive principle of operation. It needs 12Volt DC power supply and additional protection. Therefore it is installed in steel cabinets with an external voltage supply. Its technical data are as following: Range 800 … 1600 hPa, Resolution 1hPa, Long-term stability ±0.1 hPa/year, Reproducibility ±0.03hPa, Response time is 1s [25].

4.3 Data Loggers

Data loggers come in a variety of types and have evolved from simple strip chart recorders to integrated electronic on-board cards for personal computers. Many manufacturers offer complete data logging systems that include peripheral storage and data transfer devices.

Data loggers can be grouped by their method of data transfer, either in-field or remote. Those that feature remote phone modem or cellular phone data transfer capabilities allow you to obtain and inspect stored data without making frequent site visits.

The data logger should be electronic and compatible with the sensor types, number of sensors, measurement parameters, and desired sampling and recording intervals. It should be mounted in non-corrosive, water-tight, lockable electrical enclosure to protect itself and peripheral equipment from the environment and vandalism. It should also:

- Be capable of storing data values in a serial format with corresponding time and date stamps

- Contribute negligible errors to the signals received from the sensors

- Have an internal data storage capacity of at least 40 days

-Operate in the same environmental extremes as those listed in Table 5.1

-Offer retrievable data storage media

Operate on battery power.

Every electronic data logger has some type of operating software that includes a small internal data buffer to temporarily store incremental (e.g., once per second) data internal algorithms use this buffer to calculate and record the desired data parameters. The data values are stored in one of two memory formats. Some data loggers have a fixed internal program that cannot be altered; others are user-interactive and can be programmed for a specific task. This program, and the data buffer are usually stored in volatile memory. Their drawback is that they need a continuous power source to retain data. Data loggers that incorporate the use of internal backup batteries or use non-volatile memory are available. They are preferred because data cannot be lost due to low battery voltage.

Data processing and storage methods depend on data logger chosen. A basic understanding of how the logger processes data is important with respect to data protection issues. There are two commonly used formats for recording and storing data, ring memory and fill and stop [26].

- Ring Memory: In this format, data archiving is continuous. However, once the available memory is filled to capacity, the newest data record is written over the oldest. The data set must be retrieved before the memory capacity of the storage device is reached.

- Fill and Stop Memory: In this configuration, once the memory is filled to capacity, no additional data are archived. This effectively stops the data logging process until more memory becomes available. The device must be replaced or downloaded and erased before the data logger can archive new data.

Most manufacturers offer several options for data storage devices. The most common are presented in Table 4.3 below.

Table 4.3 Data storage devices [23].

Storage Device	Description	Memory/Storage Configuration	Download Method/Needs
Solid State Module	Integrated electronic device that directly interfaces with the data logger.	Ring or Fill and Stop Volatile	Read and erased onsite or replaced. Reading device and software required.
Data Card	Programmable read write device that plugs into a special data logger socket.	Fill and Stop Volatile/Non-volatile	Read and erased on-site or replaced. Reading device and software required.
EEPROM Data Chip	An integrated circuit chip incorporating an electrically erasable and programmable read-only memory device	Fill and Stop Non-volatile	EEPROM reading device and software required.
Magnetic Media	Familiar floppy disk or magnetic tape (i.e., cassette).	Fill and Stop Volatile/Non-volatile	Software required to read data from the media.
Portable Computer	Laptop or notebook type computer	Magnetic Media Type	Special cabling, interface device, and/or software may be required.

WICOM-CM wind computer from Ammonit is mounted on IYTE mast. It is capable to calculate three wind speeds and one wind direction and is equipped with additional inputs for a barometer, a thermometer, and a hygrometer. This additional data is recorded just, as the other measurement values, as mean, maximum and minimum values and as standard deviation in measurement series. Air temperature and air pressure are needed to calculate air density. Temperature and humidity give information about the weather conditions, e.g. if your site is in danger of frost.

Programming and data retrieval of Ammonit data loggers is done with serial RS232 interface (PC software is included). The RS232 interface also allows operation of remote data transfer for easy data control and retrieval. The current operating condition of the measurement equipment can be controlled through the display.

Figure 4.4 Ammonit Wicom CM data logger [27].

4.4 Data Transfer Equipment

Data are typically retrieved and transferred to a computer either manually or remotely.

4.4.1 Manual Data Transfer

This method requires site visits to transfer data. Typically this involves two steps: (1) remove and replace the current storage device (e.g., data card) or transfer data directly to a laptop computer; and (2) upload the data to a central computer in an office. The advantage of the manual method is that it promotes a visual on-site inspection of the equipment. Disadvantages include additional data handling steps (thus increasing potential data loss) and frequent site visits.

Figure 4.5 Manual data transfer from IYTE mast.

4.4.2 Remote Data Transfer

Remote transfer requires a telecommunication system to link the in-field data logger to the central computer. The communications system may incorporate direct wire cabling, modems, phone lines, cellular phone equipment, or RF telemetry equipment, or some combination thereof. An advantage of this method is that you can retrieve and inspect data more frequently than you can conduct site visits. This allows you to promptly identify and resolve site problems. Disadvantages include the cost and time required to purchase and install the equipment. This may prove worthwhile in the long term if data monitoring problems can be spotted early and quickly remedied.

Figure 4.6 GSM modem system [26].

IYTE mast was also equipped with Siemens M29 GSM-system, which makes it possible to make a remote contact with the station by computer or mobile phone. The

GSM-system includes: the modem, an antenna and an activation unit, so that the modem can be switched on and off at programmed times. The arrangement of the cables is seen in the Figure 4.6.

“CALLaLOG” which is a Windows application program is being used for remote and manual data transfer and configuration of wind computer. All parameter settings also can be transferred to logger. In online operation it is possible to observe the current measurement values.

For site analysis and wind energy yield prognosis the statistics of all Ammonit systems can be imported directly to the Windows software “ALWIN”. With this software graphs and evaluations can be drafted easily.

WicomCM data logger has a connection for an external DC supply which is being used for battery which is charged by a solar power module.

4.5 Power Supplies

All electronic data logger systems require a main power source that is sized to meet the total power requirements of the system. A backup power supply should be included to minimize chances of data loss caused by power failure. The backup system should be designed with the objective of saving the stored data. This can be accomplished by shutting down peripheral devices (modems, cellular telephones, and other data transfer equipment) at a designated low voltage level, or isolating a particular power source that is dedicated to protecting the data.

Most systems offer a variety of battery options including long-life lithium batteries or lead acid cells with various charging options (AC or solar powered). Examples of power supplies are presented below.

4.5.1 AC Power

AC power (through a power transformer) should be used as the direct source of system power only if a battery backup is available. In this case, AC power should be used to trickle charge a storage battery that provides power to the data logger. Be sure to install a surge/spike suppression device to protect the system from electrical transients. In addition, ensure that both systems are properly tied to a common earth ground.

4.5.2 Lead Acid Battery

A deep discharge, gel type lead acid storage battery is the preferred power source. It withstands repeated discharge and recharge cycles without significantly affecting the energy storage capacity of the battery. It also offers a margin of safety over a wet acid battery, Because the acid is contained in a gel and cannot be easily spilled.

4.5.3 Solar Power

The solar recharge option is a convenient way to recharge a lead acid battery when AC power is unavailable. The solar panel must supply enough wattage to recharge the battery and maintain system power during extended periods of low solar conditions (i.e., winter months). As a precaution, the battery should be sized to provide at least a week of reserve capacity to power the entire system without recharging. Be sure that the solar panel is reverse bias protected with a diode to prevent power drain from the battery at night. In addition, the solar panel must include a voltage regulator to supply a voltage compatible with the battery and to prevent overcharging.

4.6 Towers and Sensor Support Hardware

4.6.1 Towers

There are two basic tower types for sensor mounting: tubular and lattice. For both, tilt-up, telescoping, and fixed versions are available. In addition, these versions may be either guyed or self-supporting. For most sites, tubular, tilt-up guyed types are recommended for their ease of installation (the tower can be assembled and sensors mounted and serviced at ground level), minimal ground preparation, and relative low cost. Towers should:

- Have an erected height sufficient to attain the highest measurement level
- Be able to withstand wind and ice loading extremes expected for the location
- Be structurally stable to minimize wind-induced vibration
- Have guy wires secured with the proper anchor type, which must match the site's soil conditions
- Be equipped with lightning protection measures including lightning rod, cable, and grounding rod

- Be secured against vandalism and unauthorized tower climbing

- Have all ground-level components clearly marked to avoid collision hazards

- Be protected against corrosion from environmental effects, including those found in marine environments [23].

4.6.2 Sensor Support Hardware

The sensor support hardware includes the masts (vertical extensions) and mounting booms (horizontal extensions). Both must position the sensor away from the support tower to minimize any influence on the measured parameter caused by the tower and the mounting hardware itself. Sensor support hardware should:

- Be able to withstand wind loading extremes expected for the location

- Be structurally stable to minimize wind-induced vibration

- Be properly oriented into prevailing wind and secured to the tower

- Be protected against corrosion from environmental effects, including those found in marine environments

- Not block the sensor housing drainage hole. Water accumulation and expansion during freezing conditions will likely damage the internal sensor components. Tubular (hollow) sensor masts should be used instead of solid stock material [23].

4.7 Grounding and Lightning Protection

Grounding equipment is especially important when using electronic data loggers and sensors. Electrical surge type events, such as electrostatic discharge, lightning induced spikes or surges, or a difference in ground potential, will likely occur over an extended monitoring period. For each event, The continuous data stream is at risk from individual sensor failures or a data logger meltdown. Tower and data logger manufacturers may provide complete grounding kits designed to protect their systems. It should be kept in mind that different monitoring areas may have different requirements. Sites prone to lightning activity likely require a higher level of protection. Protection against a direct strike cannot be guaranteed.

Figure 4.7 Erection of the IYTE mast.

4.8 IYTE Mast

IYTE mast is 30 m tall tubular tower, which was erected in July 2000. It has two Ammonit "Classic" series anemometers which are 10 m and at 30 m and a Ammonit "Classic" series wind vane at 30 m. Temperature, humidity and atmospheric pressure data are obtained from Ammonit "xPC" series temp&humidity probe and Ammonit pressure gauge, which are all mounted on the mast. Ammonit "WicomCM" type wind computer is connected with all sensors on the mast to collect data in time series. Wind computer's power is supplied from external battery charged by solar panel or from its two batteries inside in emergency cases. Mast is also equipped with Siemens M29 GSM modem system, which is used by wind computer to achieve remote connections for changing configurations and data transferring. Detailed technical data about all equipment are given in previous sections.

Figure 4.8 A view from IYTE mast

First data were measured at the end of July 2000. Data collected from July to end of year 2000 are collected in 1-hour interval. From the beginning of the year 2001 wind computer is reconfigured to collect data in 10-min interval. This reconfiguration is done to gain more precise results. Data transferring and configuration changes are possible by using "CALLaLOG" computer program. Data collected by wind computer are transferred to PC in campus at the beginning of every month. "ALWIN" program gives us chance to make first evaluations of collected data.

Figure 4.9 Erected IYTE mast.

CHAPTER V
SITE SELECTION

5.1 Site Selection Criteria

Looking at nature itself is usually an excellent guide to finding a suitable wind turbine site. If there are trees and shrubs in the area, you may get a good clue about the prevailing wind direction. If you move along a rugged coastline, you may also notice that centuries of erosion have worked in one particular direction [19].

Figure 5.1 Natural clue about prevailing wind direction [19].

Meteorology data, ideally in terms of a wind rose calculated over 30 years is probably best guide, but these data are rarely collected directly at selected site. Meteorologists already collect wind data for weather forecasts and aviation, and that information is often used to assess the general wind conditions for wind energy in an area. Precision measurement of wind speeds, and thus wind energy is not nearly as important for weather forecasting as it is for wind energy planning. Wind speeds are heavily influenced by the surface roughness of the surrounding area, of nearby obstacles (such as trees, lighthouses or other buildings), and by the contours of the local terrain. Without making calculations, which compensate for the local conditions under which the meteorology measurements were made, it is difficult to estimate wind conditions at selected site. In most cases using meteorology data directly will underestimate the true wind energy potential in an area. If there are already wind turbines in the area, their production results are an excellent guide to local wind conditions. But these information only give general idea selections of the site selection, it is not possible to make any estimation about wind energy production nor location and number of the wind turbines.

Grid connection is another issue that should be taken in the consideration. Obviously, large wind turbines have to be connected to the electrical grid. For smaller projects, it is therefore essential to be reasonably close to a 10-30 kilovolt power line if the costs of extending the electrical grid are not to be prohibitively high. The generators in large, modern wind turbines generally produce electricity at 690 volts. A transformer located next to the turbine, or inside the turbine tower, converts the electricity to high voltage (usually 10-30 kilovolts). The electrical grid near the wind turbine(s) should be able to receive the electricity coming from the turbine. If there are already many turbines connected to the grid, the grid may need reinforcement, i.e. a larger cable perhaps connected closer to a higher voltage transformer station. Both the feasibility of building foundations of the turbines, and road construction to reach the site with heavy trucks must be taken into account with any wind turbine project.

As the wind speed can vary significantly on short distances, e.g. some hundred meters, procedures for evaluating the location of future wind turbine sites generally consider all regional parameters which are likely to influence the wind conditions. Such parameters are

- Obstacles in the near surrounding,
- The environmental topography in the far region, which is characterized by the vegetation, land utilization and buildings (ground roughness description),
- The orography like hills may cause acceleration or deceleration effects on the air flow.

It is preferred to have as wide and open a view as possible in the prevailing wind direction, and we would like to have as few obstacles and as low a roughness as possible in that same direction. If you can find a rounded hill to place the turbines, you may even get a speed up effect in the bargain.

This information on the regional conditions is gained from topographical maps as well as from site visits to record the obstacles in the near surrounding. Also satellite data of the environment has been proven to be a valuable input.

In the wind energy business due to ensure the investors and government, feasibility of the project should be as precise as possible. Project managers do not stick with the data from the meteorology stations, wind measurement masts are erected in the site area to collect wind energy parameters which is essential for the wind energy estimations. Local conditions like topography orography and obstacles are also taken in consideration on selecting location of the mast. Mast should be located in the site area where characteristic wind parameters of the location can be measured as a representative of the whole site. After the frequency distribution of wind speeds is calculated by taking into account all regional aspects, the expected wind energy production can be established according to the wind turbine's power performance

5.2 Siting and Installation

5.2.1 Exposure

Location of the instrument is critical for wind measurement. In a sheltered location or on even a small building or hill of low relief, the measured wind may easily differ by - 50 percent to +100 percent in speed and 90° or more in direction from the wind representative of a wider area. To identify suitable locations for anemometers in difficult sites, it is advisable to make a detailed wind survey under various conditions of wind speed, wind direction and atmospheric stability, or to obtain the advice of a meteorologist or aerodynamicist. A discussion of the effects on the wind and the wind profile of atmospheric stability, surface roughness, terrain fetch and similar factors is very necessary [28].

In many applications wind measurements are made in order to estimate dispersion over a horizontal scale of about 100 m to 10 km. On this scale the representative wind is the wind measured at a height of 10 m over a flat open area substantially free of obstructions, where the anemometer is distant from any obstruction by at least 10 times the height of the obstruction, see Figure 5.2. Special projects may dictate measurement at greater heights.

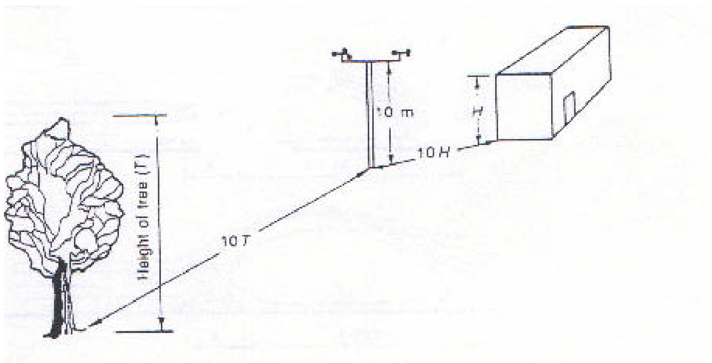


Figure 5.2 Example of siting wind instruments: A 10 m tower, located at least 10 times the height of obstruction away from those obstructions [28].

5.2.1.1 Vertical variation of the wind

Consideration of wind variation with height may influence the choice of height for an anemometer or indicate the need for more than one anemometer set at various heights.

In an atmosphere, which is unstable, or neutral, or stable to a small degree, the average wind speed in undisturbed flow increases with height in an approximately logarithmic manner. Example, the ratio of wind speeds at two levels, above at least twice the height of surface roughness elements, is proportional to the logarithm of the ratio of their heights.

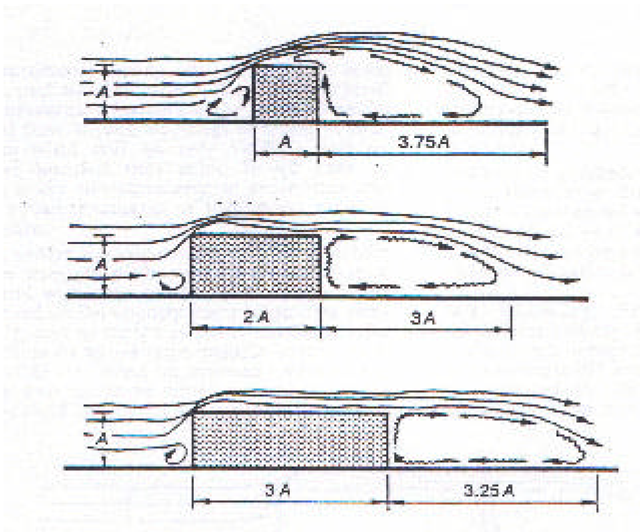


Figure 5.3 Flow over different roof pitches [28].

When the flow is disturbed, as when it has recently passed over a change in the roughness of the ground surface, the wind speed still increases with height, but in a more complex manner.

In a strongly stable atmosphere there may be strong variation of both wind speed and wind direction with height, therefore wind observations made at one height cannot be used without further information as an indication of the wind at another height.

5.2.1.2 Obstructions

The effect of obstructions does not lend itself to simple description. Figures 5.3, 5.4 and 5.5 illustrate wind flow over isolated buildings. They show that exposure downwind of a building, solid fence or wall will be unrepresentative, unless the anemometer is on a mast high enough to clear the area of increased wind speed (streamlines crowded) or decreased flow in the lee eddy or wake where the flow is turbulent. Diagrams in Figures 5.3, 5.4 and 5.5 may be taken also to represent smaller obstructions than buildings, but should not be regarded as precise. Porous structures such as rows of trees or mesh fences have similar but lesser effects. Diagrams in Figures 5.3, 5.4 and 5.5 are approximately to scale and may be used to estimate the distance above or away from an isolated obstruction at which a representative measurement may be made.

5.2.1.3 Multiple Obstructions

In a built up area, or in an area with many trees, the atmospheric motion responsible for dispersion on scales of 100 m to 10 km is represented by the wind in the undisturbed flow clear of the obstructions. Structures with gaps or rows (spaces between buildings, or streets) cause funneling of the airflow with local crowding of streamlines and changes of direction. However, suitable locations may be found in open level spaces where the 10 -times-the-height rule is satisfied. Failing this, the anemometer may be placed among the obstructions, typically 5 m to 10 m above their general level but, if on a building, well above the disturbed flow indicated in Figures 5.3, 5.4 and 5.5. It should be located away from obstructions, which are higher than the anemometer, at distances not less than 10 times the difference of the heights of the anemometer, and the obstructions.

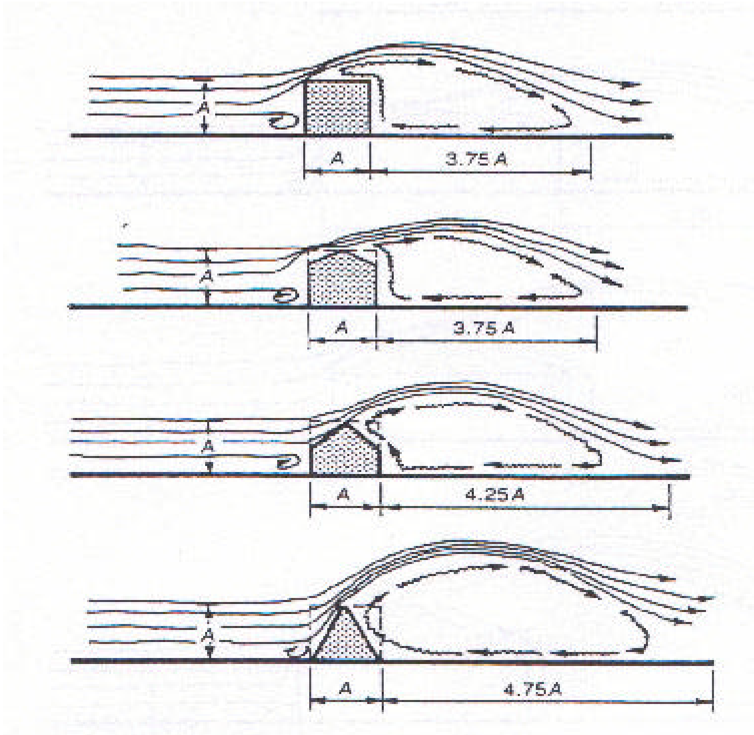


Figure 5.4 Flow over different roof pitches(length equal to height) [28].

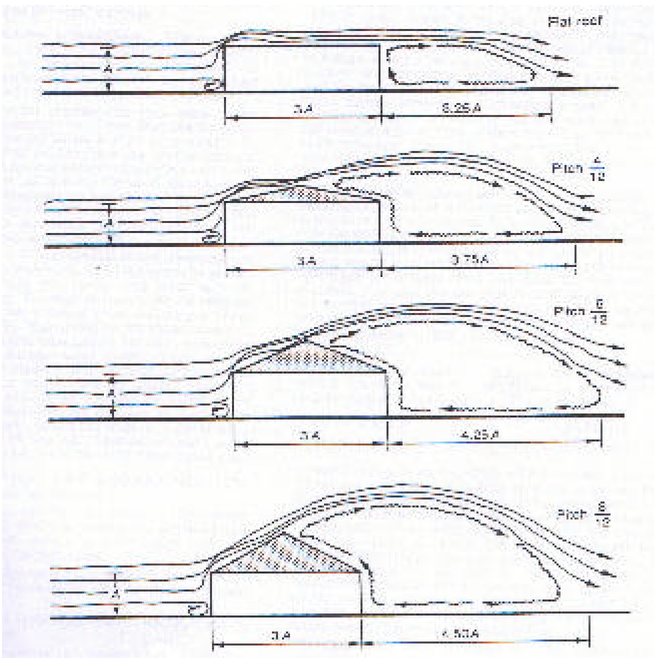


Figure 5.5 Flow over different roof pitches (length equal to three times the height)[28].

5.2.1.4 Measurements Among Obstructions:

In some special cases, such as estimation of dispersion on small scales, measurements of wind may be required within the disturbed flow among buildings or trees. In such locations the wind will be very variable and no representative location may exist. It will then be necessary to make measurements at more than one location to obtain estimates of ventilation rates or other quantities.

5.2.1.6 Hills, Valleys and Uneven Terrain:

Wind in hilly terrain varies strongly in the vertical and horizontal directions, and with time of day. The effect of hills may be observed on flat country many kilometers away from the hills, and at such a site it is unsafe to infer the wind at 50 m or above from measurements made at 10 m in stable air. Wind on exposed ridges of any size may be two or three times as strong as the representative wind because of the streamline crowding effect, not essentially different from Figures 5.3, 5.4 and 5.5. Valleys usually have lighter winds but may experience very strong flows in a markedly different direction from the representative wind if a funnel effect is present.

No general guidance to anemometer exposure can be given for hilly or dissected terrain. Choice of a site must be determined with regard to a precise statement of objectives, as to what feature of the flow is to be described, and on what scale. Measurements at more than one location may be needed.

5.3 Mounting

Wind measuring equipment should be mounted solidly. Horizontal and vertical alignment should each be checked with a good quality spirit level at two points 90° apart. Wind direction sensors should be oriented so that wind directions are measured clockwise from true north.

If wind vanes or anemometers are mounted on a tower or mast, they should be located in such a way that the tower does not significantly alter airflow at the point where sensors are located. The preferred procedure is to mount the wind vane and anemometer on top of the tower. If they are to be mounted partway up on a large tower, they should be mounted away from that tower on a bracket or boom by at least twice the maximum width of the tower at that level.

Anemometers mounted on towers of truss construction may be installed at less than two tower side lengths from the tower.

Anemometers and wind vanes should be mounted on the side of the tower best exposed to the wind that is most significant for the purpose the data are to serve. If there is no significant direction, they should be mounted on the side from which the wind blows most frequently.

Leads connecting the sensors and display or recording instruments should be shielded from extraneous signals and protected from physical damage.

5.4 Selection of the Site in the Campus Area

IYTE Campus area which is located in Urla, Izmir, occupies 3500 ha area (Figures 5.6 and 5.7). It includes several hills covered with typically Mediterranean bush. Topography of the region is hilly, rocky and steep with 15% -25% incline. Soil depth is very low and not suitable for vegetation. No agricultural or animal raising activities are being practiced in the area.

Before installation of the mast, appropriate site location was searched in the campus area according to criteria, which were mentioned above. Site with coordinates 465684 E, 4243843 N (in UTM coordinate system) at 400 m height is found to be the most suitable location in the area. It is between Sineklidag, Çitlik Dagi, Canavarlidag and Nurdag Mountains. Place is very rocky and hilly with 380 m average height. There were no obstacles detected around the measurement area. Surface roughness is low due to low plant heights which is important in wind shear. Site is directly open to the sea at north direction. The south and north west directions are covered with higher mountains. The chosen site for mast erection is considered that it can give typical wind data of the region for wind energy calculations.

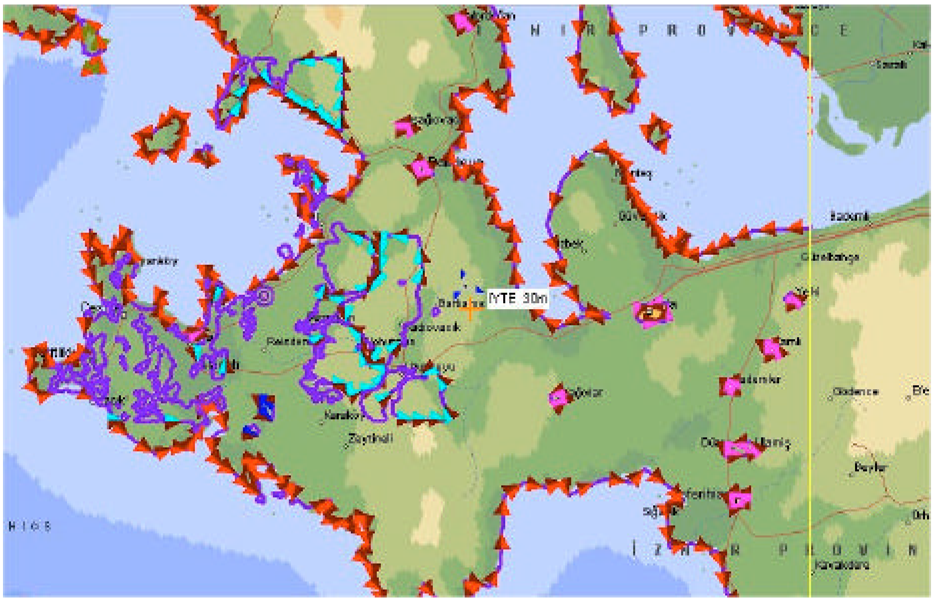


Figure 5.6 Location of the IYTE mast on Izmir map.

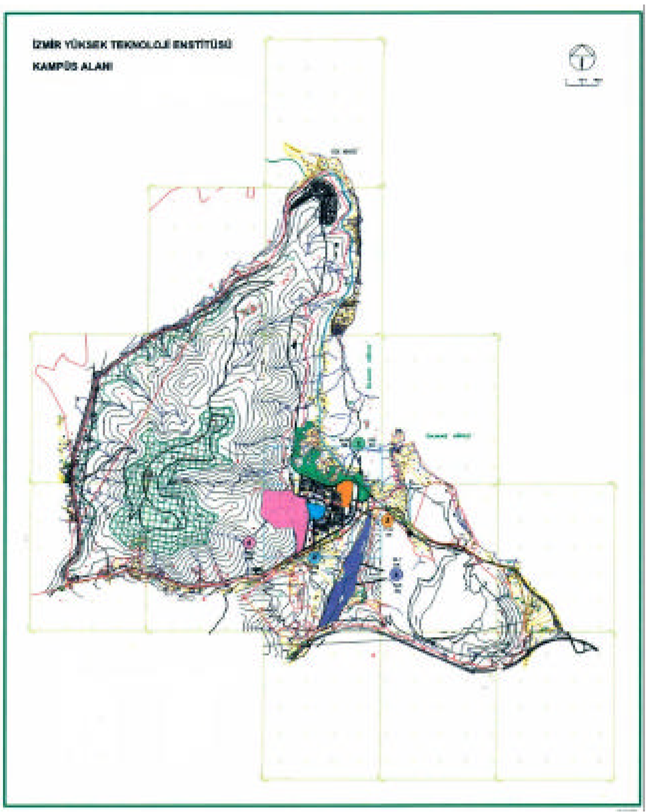


Figure 5.7 The campus map.

5.5 Wind Power Classes

The energy contained in wind, expressed in terms of wind power classes, range from class 1 (the least energy) to class 7 (the greatest). Wind power classes are based on the average "wind power density" expressed in watts per square meter (W/m^2). This factor incorporates the combined effects of the time variation of wind speed and the dependency of wind power on both air density and the cube of the wind speed. Each wind class is established on a range of average wind speeds at specified heights above the ground. In the same wind power class, the energy contained in the winds at 30 meters above the ground is 60% greater than the power density at 10 m [29].

Table 5.1 Table of wind power classes [29]

WIND POWER CLASS		WIND CHARACTERISTICS 50 METERS ABOVE GROUND		COMMERCIAL VIABILITY
		POWER (W/m^2)	SPEED (m/s)	
1	1-	0 - 100	0 – 4.4	VERY POOR
	1+	100 - 200	4.4 – 5.6	
2	2-	200 - 250	5.6 – 6.0	POOR
	2+	250 - 300	6.0 – 6.4	
3	3-	300 - 350	6.4 – 6.7	MARGINAL
	3+	350 - 400	6.7 – 7.0	
4	4-	400 - 450	7.0 – 7.3	GOOD
	4+	450 - 500	7.3 – 7.5	
5	5-	500 - 550	7.5 - 7.7	VERY GOOD
	5+	550 - 600	7.7 – 8.0	
6	6-	600 - 700	8.0 – 8.4	EXCELLENT
	6+	700 - 800	8.4 – 8.8	

CHAPTER VI

COLLECTING AND EVALUATING WIND DATA

In this thesis, several computer programs are used to transfer, collect and evaluate the wind data. CALLaLOG 98 program is used for transferring data to our computer from mast via GSM modem. Program called ALWIN is used for first evaluation of the data to have general idea about the wind speeds and wind distribution of that month. WindPRO which has played key role in the study, used for evaluation of all collected data to make wind energy analysis considering orography and topography of the site. It also allows us to make micrositing of the wind turbines to estimate energy productions according to measured data. This feature helps us to select the best fit turbine and to find optimum turbine locations in the site area. WAsP is very powerful software which is used for wind calculations. WAsP calculation methods are accepted as standard methods all over the world. WindPRO calls and uses WAsP program to make the wind energy calculations.

In the following we would like to give brief information about these programs.

6.1 CALLaLOG Software

CALLaLOG is a Windows running program for a quick and easy configuration of Ammonit data loggers. It is possible to set logger number, activate channels and functions, set time, insert pass word etc. and data transfer from data logger to PC [26].

There are two ways to connect PC to data logger: manual and remote. The mast in IYTE campus site is equipped with GSM modem which allows us to connect with our data logger manually as well as remote from anywhere. This connection is arranged by CALLaLOG. The actual measurement values can be observed online at any time.

6.2 ALWIN Software

ALWIN is a software system for wind energy applications. ALWIN combines the wind potential of a location with the technical data of a wind power station and calculates a prognosis of the possible profit. The program allows the manual input of Rayleigh and Weibull Parameters as well as the measuring heights, calculates the roughness length and the wind speeds at any given heights and shows all data and results clearly in graphs and tables. It is very convenient to use it very well to make simple analysis with statistical basic data and to check the influence of temperature, site and hub-heights just as well as the effects of incorrect measurements [30].

6.3 WindPRO Software

WindPRO is a Windows 95/98/ME or NT/2000 based software suite for projecting single WTGs and Wind Farms. WindPRO consists of several modules of which each has its purpose. The user is thus free to combine the modules exactly according to his needs and budget. In our institute we have BASIS and ENERGY modules [31].

The WindPRO Philosophy is Object Orientated Projecting. A WTG project consists of a number of objects among which the WTGs are a key element. The program distinguishes between existing and new WTGs and this makes it possible to calculate, e.g., the output from the new WTGs only including the influence from existing WTGs.

Other objects are Wind Monitoring Towers, Local Obstacles, Noise Sensitive Areas, Transformers, etc. Some of the objects determine the wind energy, other determines the environmental aspects and yet others determine the feasibility of the project. Common for all objects is that you need to know the coordinates of each object to perform calculations. One very strong facility of WindPRO is that the software automatically picks up the coordinates from a map on the PC Screen. You simply scan your maps into the PC or use maps from a CD-ROM or other digital sources. When the maps have been converted to the PC and calibrated with known coordinates, the process begins. You simply select the relevant objects from the toolbox and place them on the map.

Finally, you are asked for additional data to complete the input. ETG objects are linked to the unique WindPRO WTG database, which lists most of the WTGs available on the market. This enables quick comparison of alternative project proposals.

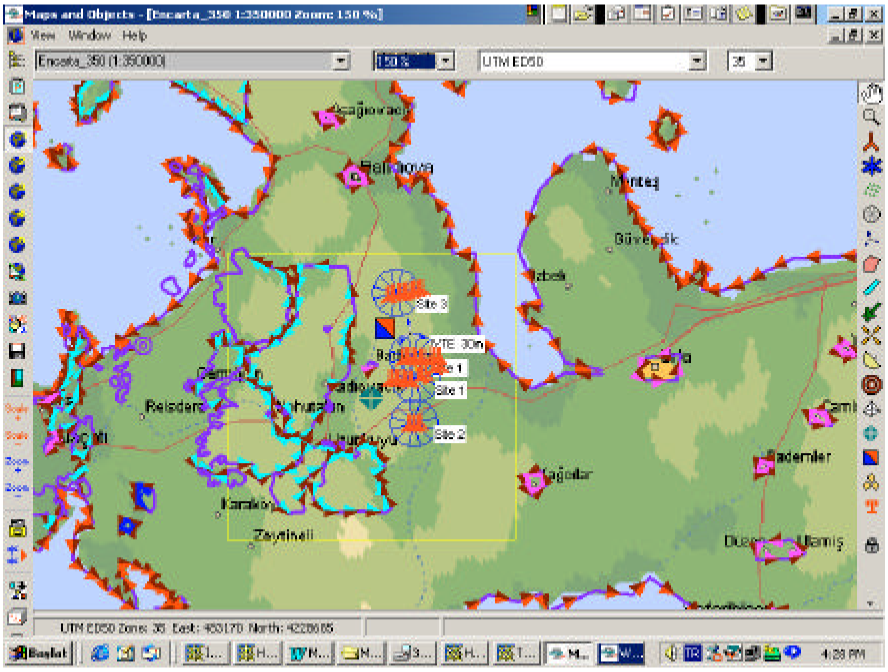


Figure 6.1 WindPRO program map window.

6.3.1 BASIS Module of WindPRO

The BASIS module in WindPRO is necessary for the use of any of the other calculation modules. It contains the 4 following elements: Project Management / Globe (Project Explorer) WTG Catalogue Map Management System Projecting / Input data.

The first element, Project Management, is a tool for the effective administration of your projects. Projects are presented either in a list or on a map. The Map management System is the tool for linking scanned maps or maps from CD to WindPRO, to make them available for the projecting work and the inputting of data, which is done directly on these digital background maps.

Finally, the WTG Catalogue contains the necessary data on wind turbines necessary data on wind turbines necessary for projecting. With the BASIS module, the user can also perform a BASIS printout, which gives an overview of all objects in the project and a map with their geographic positions. To perform calculations it is necessary to use one of the other available calculation modules.

6.3.2 ENERGY Module of WindPRO

6.3.2.1 ATLAS, Energy:

Calculates the energy production of a single WTG based on a given terrain description (roughness, hills and obstacles), wind statistics and power curves.

The calculation model was originally developed by RISOE, but it has been modified by EMD. The calculation of the influence of hills and obstacles is based on relatively simple terrain conditions as compared to the more advanced calculation used in the WAsP model (RISOE). Apart from that, the ATLAS model is similar to the WAsP model as described in the European Wind Atlas.

Necessary Input Data (Objects):

Wind Turbine (Hub height and power curve):

Normally, the power curves can be found in the WTG catalogue, but user defined WTGs or power curves can be added. Several different WTG types and hub heights can be included in the same calculation.

Site Data Object (Wind Statistics and terrain description):

One or more sets of wind statistics describing in general, the long term wind conditions. The software contains Wind Statistics for several countries and regions. Based on Measured data (METEO module) and the WAsP interface module, new wind statistics can be generated.

Terrain Description

The terrain is described through:

A Roughness Classification covering the nearest 20 km from the site in 8-12 directional sectors depending on the actual Wind Statistics used. Roughness classes or changes can be entered graphically on screen. Hills given as length and height in each sector.

Local Obstacles within approx. 1 km from the Wind Turbine with heights of ¼ of the hub height or more are entered in the site data object. Distance to obstacle, total width and width in sector can be entered graphically.

The WindPRO module ATLAS for energy production calculations is a simple model, which can be used for relatively simple terrain conditions. In more complex terrain the use of the WAsP model via the WindPRO WAsP interface module is necessary. As a guideline, simple terrain can be characterized as an area with only minor and gently rolling hills with differences of height of less than 50 m and only a few, large obstacles in each sector (only one obstacle can be entered for each sector). ATLAS requires that you have the wind statistics describing the general long-term wind conditions for the region in a structured form, e.g. generated by STATGEN 9 (via WAsP). The roughness classification is the most important part in the ATLAS calculation and can be entered either in tabular form or graphically directly on a map on your PC screen.

6.3.2.2 METEO, Energy:

There will be 2 different ways to calculate the energy production of a WTG with METEO:

Weibull: Measured data are Weibull fitted and the data are integrated with the WTG power curve.

Measure: The measured wind data are directly integrated with the power curve.

In both cases there will be features for height correction of the measured data from measuring height to hub height. This method is based on simple Hellmann exponential profile, where the wind gradient exponent can be entered sector wise or automatically calculated from additional measuring heights.

Necessary Input Data (Objects)

Wind Turbine (Power curve): Normally, the Power Curve can be found in the WTG Catalogue.

Meteorological Data:

Joint distribution of wind speed and direction can be given as one of the three following:

Time Series (wind speed, wind direction, turbulence intensity, date and time)

Histogram table (wind speed distribution and turbulence intensity for each directional sector)

Weibull Data for each directional sector.

The METEO module is both an advanced import and analysis module for measured wind data and a way to calculate energy yield of a WTG based on measured wind data.

6.3.2.3 WAsP Interface (+STATGEN), Energy:

Its function is calculation of the energy production of a wind turbine/wind farm in complex or normal terrain. The module uses the WAsP software from RISOE as calculation “engine” for calculating the wind speed distribution based on a wind statistics and terrain description, which means that WAsP version 4, 5 or 7 is required and linked to WindPRO. In our project we had WAsP 7.0 installed and linked to WindPRO.

The energy production calculation is simple integration of wind frequency distribution and power curve for the WTG. The wind distribution is calculated by the wind atlas method, here calculated with the WAsP software.

Necessary Input Data (Objects)

Wind Turbine (Hub height and power curve):

Site Data Object (Wind Statistics and terrain description):

The Wind Data are given as one or more sets of Wind Statistics. The program can average several Wind Statistics with the option of using the reciprocal distance as weighting factor or manual input or weighting factors.

Terrain Description:

Local Obstacles objects:

Information about the height and porosity of the obstacles completed the Obstacle description.

In contrast to the ATLAS module, which is limited to simple terrain conditions, the WAsP interface allows using digitized height contour lines and a free definition of obstacles.

6.3.2.4 RESOURCE, Energy:

Its function is to calculate and present wind resources on the basis of: One or more wind statistics for the region, digitized roughness and height contour line maps and local obstacles. Also previously calculated .rsf files from WAsP can be presented with this module.

The program calls the WAsP program from RISOE. When no local obstacles are used, the WAsP resource file option is called. When Local Obstacles are used in the calculation a ‘normal’ WAsP calculation is called for each calculation point.

The wind data are given as one or more sets of wind statistics. The program can average more wind statistics with the option of using the reciprocal distance as a weighting factor.

The terrain is described through:

A roughness line map which covers app. 20 km around the calculation area.

A height contour line map, which covers app. 5 km around the calculation area (depends on the complexity of the terrain).

Local Obstacles

Heights to be calculated: Several heights above terrain level can be calculated.

The WindPRO module RESOURCE calculates the predefined area with the specified resolution by reading and limiting map files for each 1 x 1 km. Then it calls WAsP and writes the result to a .rsf file. A .RSF file contains the Weibull A and k parameters for each wind direction and height.

When the calculation is finished, different parameters for presentation can be selected.

6.3.2.5 PARK, Energy:

The wind distribution by each WTG position is calculated. The wind distribution is then adjusted using the PARK model. This requires information of Ct curve of the WTGs and a Wake Decay Constant. Finally the adjusted wind distribution is integrated with the power curve of the WTGs for the energy yield calculation.

Wind Turbine (Position and type): There are many advanced features for designing a wind farm layout. To mention some: creation of rows with equal distance, cloning of these for fast parallel rows, use of distance circles around each WTG. PARK layout coordinates can also be imported simply from ASCII files or Spreadsheets simply by using the 'copy/paste' function.

Wind Data: The Wind Data are given as output from one of the 4 modules mentioned previously. More sets of wind data can be used in a PARK calculation, e.g. measurements for different places in a wind farm area. The PARK calculation automatically takes the nearest set of wind data. Especially by using the WasP interface, individual wind data can be calculated for each WTG position by just one Site Data Object, which is linked to digitized height contour and roughness lines. Local obstacles are treated individually relative to each WTG position.

PARK is very flexible tool for calculating wind farm production. WTGs can be entered as both existing and new WTGs and treated separately in the printout, while all is included in the calculation. Even the loss of existing WTGs caused by the new WTGs is calculated automatically in one process if required. There are no limits in using different WTG types or hub heights in same calculation.

6.4 WAsP Software

WAsP is a PC-program for the vertical and horizontal extrapolation of wind data. It contains several models to describe the wind flow over different terrain and close to sheltering obstacles. WAsP consists of five main calculation blocks:

Analysis of raw data. This option enables an analysis of any time-series of wind measurements to provide a statistical summary of the observed, site-specific wind climate. This block is implemented in a separate tool, the OWC Wizard.

Generation of wind atlas data. Analyzed wind data can be converted into wind atlas data sets. In a wind atlas data set the wind observations have been 'cleaned' with respect to site-specific conditions. The wind atlas data sets are site-independent and the wind distributions have been reduced to standard conditions.

Wind climate estimation. Using a wind atlas data set calculated by WAsP or one obtained from another source – e.g. the European Wind Atlas – the program can estimate the wind climate at any specific point by performing the inverse calculation as is used to generate a wind atlas. By introducing descriptions of the terrain around the predicted site, the models can predict the actual, expected wind climate at this site.

Estimation of wind power potential. The total energy content of the mean wind is also calculated by WAsP. Furthermore, an estimate of the actual, annual mean energy production of a wind turbine can be obtained by providing WAsP with the power curve of the wind turbine in question.

Calculation of wind farm production. Given the thrust coefficient curve of the wind turbine and the wind farm layout, WAsP can finally estimate the wake losses for each turbine in the farm and thereby the net annual energy production of each wind turbine and of the entire farm, i.e. the gross production minus the wake losses.

The program thus contains analysis and application parts, which may be summarized in the following way:

Analysis

time-series of wind speed and direction —> wind statistics

wind statistics + site description —> wind atlas data sets

Application

wind atlas data + site description —> estimated wind climate

estimated wind climate + power curve —> estimated power production

Wind farm production

est. power productions + wind turbine and farm characteristics —> gross and net annual energy production of each turbine and of wind farm

The question of primary interest in wind power applications is: "What power production can be expected from a given wind turbine at a given site?" To answer this, it is necessary to know the power curve of the wind turbine as well as the probability density function of the wind speed at hub height. The product of these two functions gives the power density curve, the integral of which is the mean power production (European Wind Atlas, 1989). This integral is evaluated by WAsP in terms of the Weibull distribution parameters and approximating the power curve with a piecewise linear function.

The probability density function or distribution function gives the frequency of occurrence of a given wind speed. Estimating the relevant probability density function or Weibull distribution is the very purpose of the wind atlas methodology.

Hence, to calculate the power production of a wind turbine, you need the predicted wind climate for the site and the following turbine characteristics:

- The wind turbine hub height [m]
- The power curve [m/s and kW].

Given the change of wind speed with height above ground level, the hub height of the wind turbine in question must be known accurately. This height is usually set automatically by inserting a power curve member to WAsP, but it can also bet set or changed in the turbine site control dialog.

In general, the hub height is simply the nominal hub height given by the wind turbine manufacturer. This is the height provided in the wind turbine data files.

The power curve for any given wind turbine depends on air density, which changes with temperature and air pressure (elevation). The power curve is usually referred to a standard air density of 1.225 kg/m^3, corresponding to conditions of standard sea level pressure and an air temperature of 15ºC. This is also the fixed air density value used in this version of WAsP when calculating the power density.

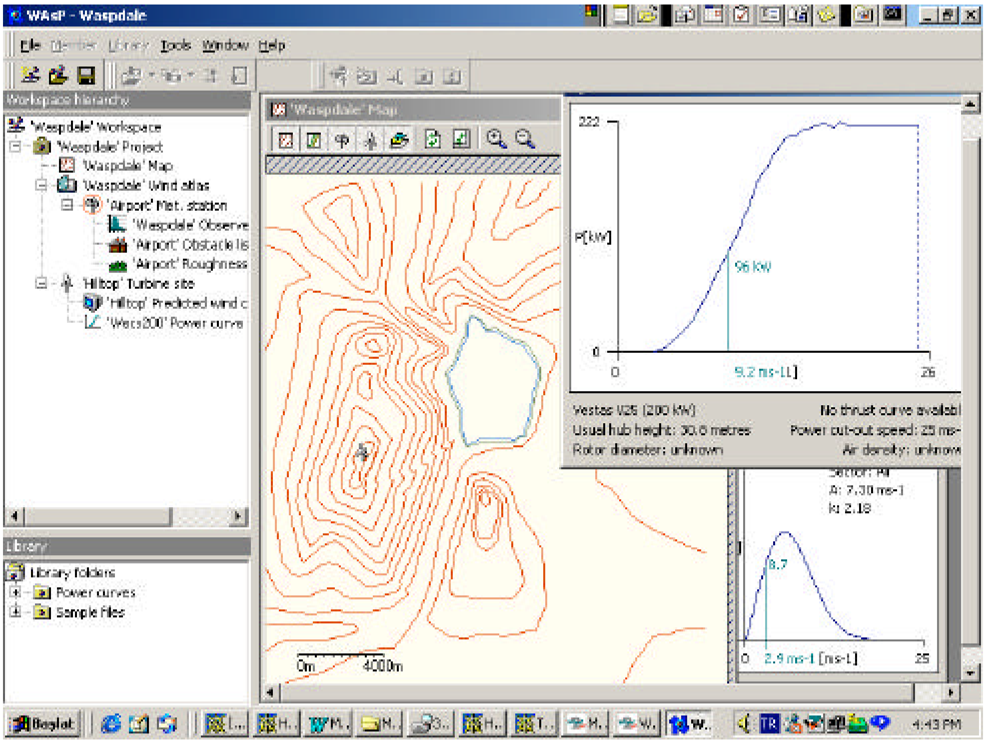


Figure 6.2 View of the WAsP program.

The procedures and equations used by WAsP for calculating the mean power production of a wind turbine are given here:

Once the power curve P(u) is measured for a wind turbine, the mean power production can be estimated provided the probability density function of the wind speed at hub height is determined either by measurements or a siting procedure:

$$P = \int_0^\infty \Pr(u)P(u)du \qquad (6.1)$$

If the probability density function Pr(u) has been determined through the siting procedure, it is given as a Weibull function in which case the expression of the mean power production becomes:

$$P = \int_0^\infty \left(\frac{k}{A}\right)\left(\frac{u}{A}\right)^{k-1} \exp\left(-\left(\frac{u}{A}\right)^k\right) P(u)du \qquad (6.2)$$

As a general rule, this integral cannot be computed analytically and numerical methods must be used.

Actual power curves are rather smooth and can be well approximated by a piece-wise linear function with a few nodes. Using this approximation, the power can be written as:

$$P(u) = \frac{P_{i+1} - P_i}{u_{i+1} - u_i}(u - u_i) + P_i \quad (6.3)$$

which allows for an analytical solution of Eq. (6.2).

$$P = \sum_i \frac{P_{i+1} - P_i}{a_{i+1} - a_i}(G_k(a_{i+1}) - G_k(a_i)) \quad (6.4)$$

where $\alpha_i = u_i/A$. The function $G_k(\alpha)$ is 1/k times the incomplete gamma function of the two arguments 1/k and α^k.

In some situations a discontinuity can be found in the power curve. In case of a jump in power from P_i to P_{i+1} at $u_i = u_{i+1}$, the contribution to the sum from this interval becomes:

$$\left(P_{i+1} - P_i\right)\exp(-a_i^k) \quad (6.5)$$

By using Eqs. (4) and (5) the mean power can be theoretically calculated for any power curve simply by dividing it into a sufficient number of linear sections. In practice, the method will only be useful if the power curve can be approximated by a small number of linear sections.

From the wind data, how much power will be generated by the turbine at a given wind speed can be calculated. If the plan was to erect the turbine at exactly the same place where the meteorological data had been collected, then it would be a really simple task to work out how much power to expect.

However, the proposed turbine site is often completely different from the meteorological station at the airport: the properties of the meteorological station itself will affect the wind data recorded there. In addition, the properties of the turbine site will have an effect on the way that the wind behaves near the turbine. It is also unlikely that the turbine would be erected at the same height as the anemometer.

What you need is a way to take the wind climate recorded at the meteorological station, and use it to predict the wind climate at the turbine site. That's what WAsP does.

Using WAsP, you can analyze the recorded data, correcting for the recording site effects to produce a site-independent characterization of the local wind climate. This site-independent characterization of the local wind climate is called a *wind atlas or regional wind climate.* You can also use WAsP to apply site effects to wind atlas data to produce a site-specific interpretation of the local wind climate.

Providing a prediction in any case will therefore be a two-stage process. First, the data from the meteorological station need to be analyzed to produce a wind atlas, and then the resulting wind atlas needs to be applied to the proposed turbine site to estimate the wind power.

CHAPTER VII

RESULTS AND DISCUSSION

7.1 Data

Data collected from the IYTE mast have been used to evaluate the wind potential of IYTE Campus Area. Data, which had been collected between July 21^{st} of 2000 and November 30^{th} of 2001, have been used in this evaluation. In the year 2000 data were collected in 1 hour intervals with a rate of 24 observations per day. Data were collected with a rate of 144 observations per day in year 2001 using ten minutes interval. In this period 50403 observations were collected. Missing data which should not excess 10% according to standards [23], represent 3.7% of the total observation data and 3.2% of the measurement period. Missing data were not taken into account. Collected data include date and time stamp, wind direction and standard deviation of wind speed, max, min, average and deviation values of wind speeds of anemometer at 10 m and anemometer at 30 m, humidity, temperature and barometric pressure.

Digital height contour map which covers approximately 5 km around the IYTE mast area and roughness line map which covers about 20 km around measurement area were created and loaded into WindPRO software. Map of Izmir from Encarta Digital Atlas and Campus area maps are used in the WindPRO software. There were no obstacles detected around measurement point in 12 sectors.

WindPRO and WAsP programs have been used to evaluate the wind statistics which are sectorial Weibull (A) and (k) parameters for 12 sectors and for different heights (10 m and 30 m). The same softwares using collected data created wind energy and wind speed maps of the campus area. The most convenient locations for utilizing wind power were determined. The most suitable turbine has been selected and the power productions of the turbines that are assumed to be installed at convenient locations were evaluated.

7.2 Analysis of Atmospheric Parameters

Temperature, humidity and atmospheric pressure are measured for twelve months. Temperature and atmospheric pressure are measured to find average air density which is used in energy calculations. Humidity values are not used in the calculations. Although, humidity is measured to have a data about atmospheric conditions and if there is freezing conditions in the area. Table 7.1 shows monthly average of measured temperature, humidity and barometric pressure values.

Temperature average of the year is 16.3°C. Maximum monthly average temperature was measured in July 2000 with 26.2°C and minimum average temperature was measured in December 2000 with 8.2°C.

Barometric pressure average of the 12 months is 967 hPa. Maximum average of 995 hPa was measured in January 2001 and minimum average of 955 hPa was measured in July 2000.

Yearly average of relative humidity is 65%. Maximum and minimum monthly averages are 42% and 82% which were measured respectively in July 2000 and December 2000.

Air density of the area is determined by WindPro program using average values of barometric pressure and temperature. Air density is calculated as 1.165kg/m^3 for IYTE campus area.

Table 7.1 Monthly average values of humidity, temperature and atmospheric pressure.

Months	Hygro (%)	Thermo (°C)	Baro (hPa)
Jul-00	*42*	*26.3*	*955*
Aug-00	*49*	*23.2*	*957*
Sep-00	*56*	*20.5*	*958*
Oct-00	*75*	*14.2*	*961*
Nov-00	*73*	*13.8*	*962*
Dec-00	*82*	*8.2*	*967*
Jan-01	*74*	*10.6*	*995*
Feb-01	*75*	*10.9*	*994*
Mar-01	*71*	*12.5*	*958*
Apr-01	*75*	*17.2*	*974*
May-01	*68*	*15.9*	*961*
Jun-01	*46*	*21.9*	*960*
Average of the year	**65**	**16.3**	**967**

7.3 Wind Analysis of Monthly Mean Speeds

Wind speeds were measured by two anemometers which were located at 10 m and 30 m. The reason of measuring wind speeds at two different heights is to calculate wind shear value. In energy calculations where energy producion of different turbines with different hub heights are determined. Figure 7.1 and Figure 7.2 show monthly mean speed variations at 10 m and 30 m. According to graphs, maximum mean speeds occurred in December 2000 and August and November 2001. Months with minimum mean wind speed are November 2000 and May and September 2001. Total mean speed at 10 m is 7.03 m/s and 8.14 m/s at 30 m (see Figure 7.3 and 7.4). From these collected data, it can be said that monthly average speed of IYTE campus area is always higher than cut-in speeds of most horizontal axis wind turbines. Calculated total mean wind shear value is 0.13 (in Figure 7.5 and 7.6).

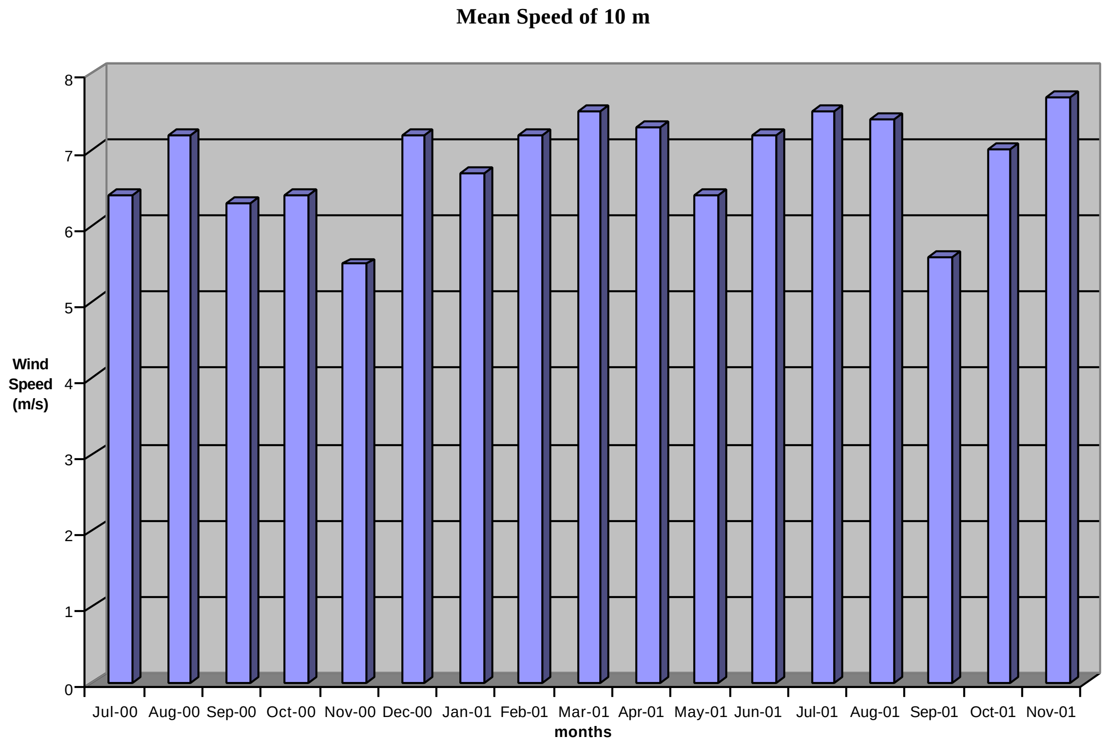


Figure 7.1 Variation of monthly mean wind speeds at 10 m.

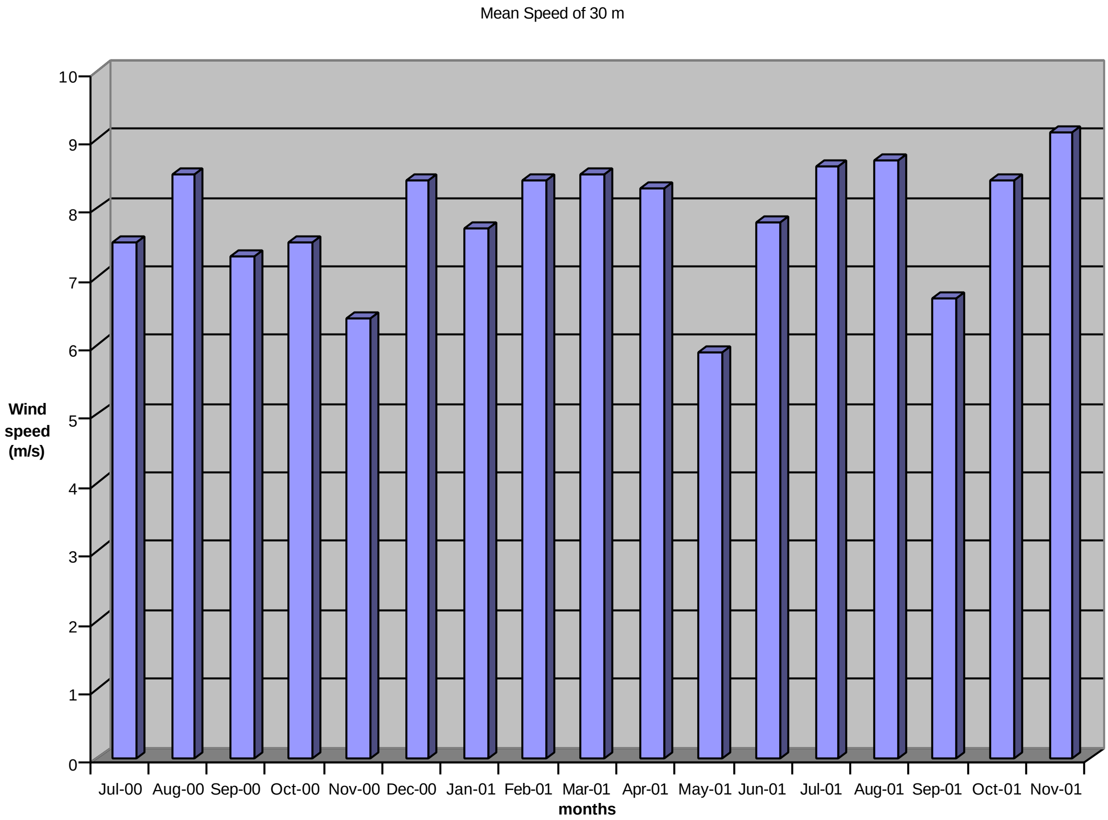
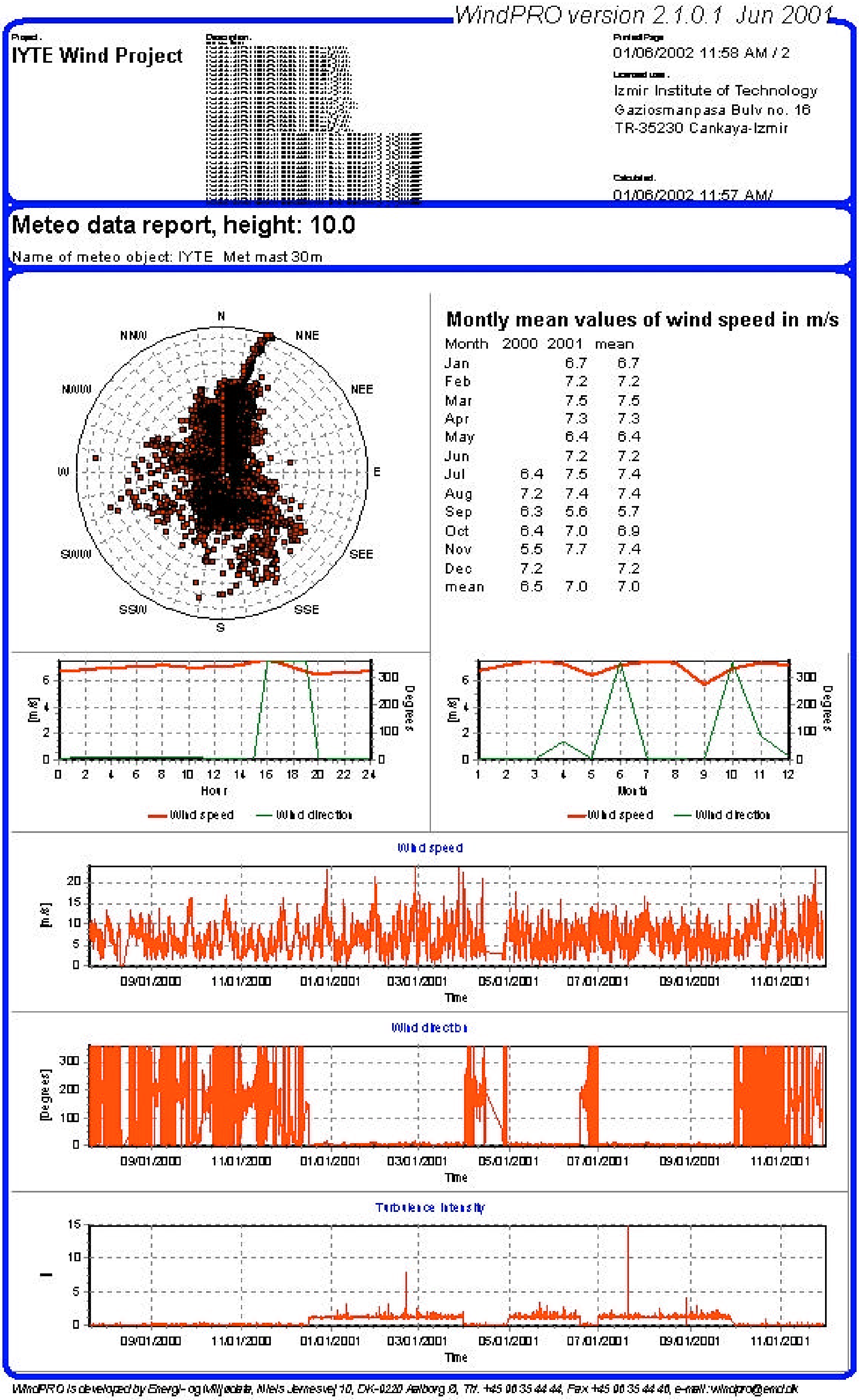


Figure 7.2 Variation of monthly mean wind speeds at 30 m.

7.4 Wind Direction Analysis

Figure 7.3 and 7.4 show wind roses for 10 m and 30 m. It is clearly seen that prevailing wind direction is north and north northeast on IYTE campus area. There are strong winds blowing from southern sectors but their frequencies are quite low. Weibull histograms are determined for twelve sectors at 10 m and 30 m heights separately (Figure 7.5 and 7.6). Histograms for each separate sector can be seen in Figure 7.7 and 7.8 for 10 m measurements and Figure 7.9 and 7.10 for 30 m measurements. These figures show that 78.6% at 10m height and 74.9% of the wind, blew from north. NNE sector is another main sector but its frequencies are only 4.7% for 10 m measurements and 5.3% for 30 m measurements. Other sectors' frequencies are not higher than 3.9%. The north seems the only wind direction to consider in wind projects which will be developed in IYTE campus area.


WindPRO version 2.1.0.1 Jun 2001

Project:
IYTE Wind Project

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TR-35230 Cankaya-Izmir

Calculated:
01/06/2002 11:57 AM/

Meteo data report, height: 10.0

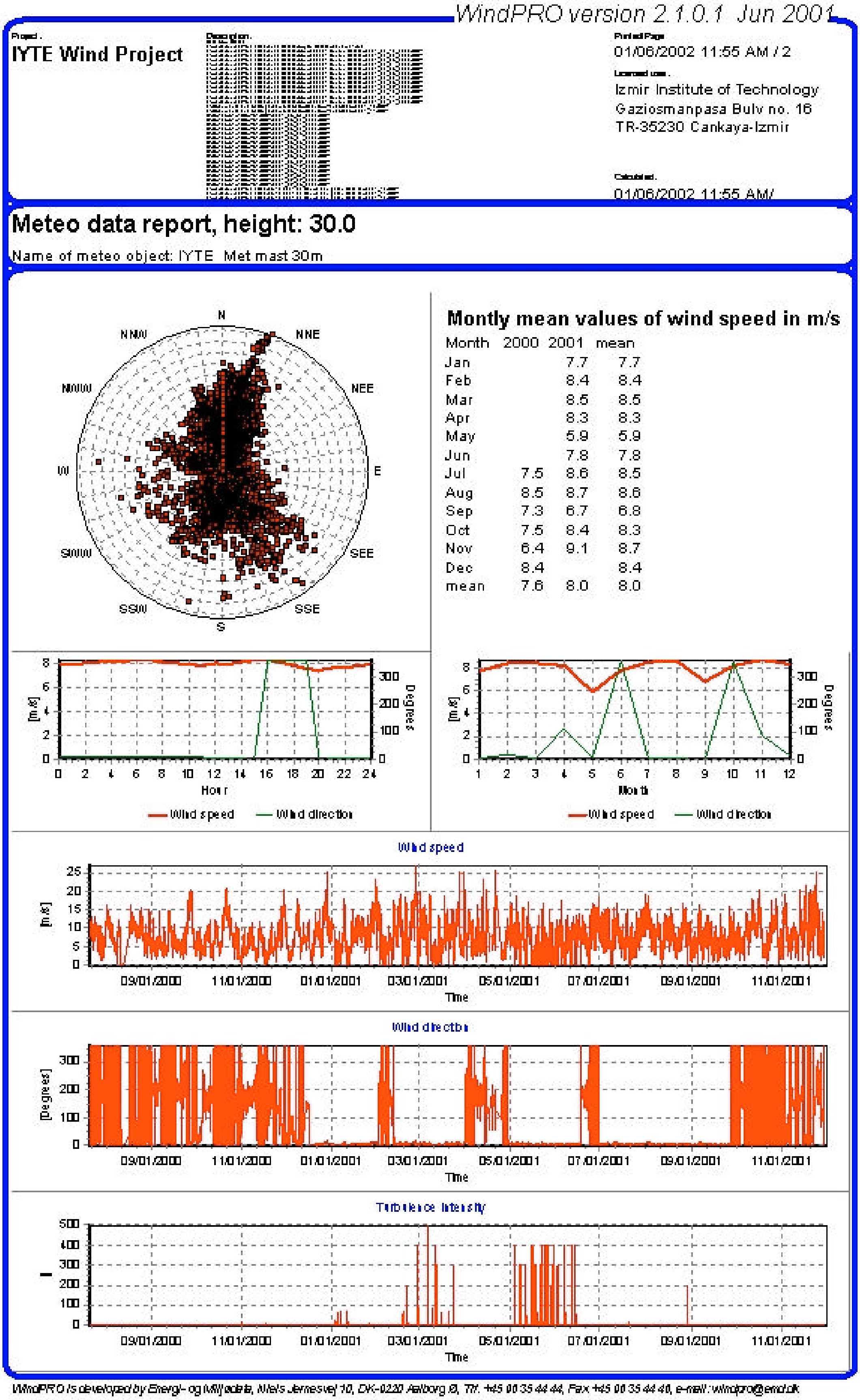
Name of meteo object: IYTE Met mast 30m

Montly mean values of wind speed in m/s

Month	2000	2001	mean
Jan		6.7	6.7
Feb		7.2	7.2
Mar		7.5	7.5
Apr		7.3	7.3
May		6.4	6.4
Jun		7.2	7.2
Jul	6.4	7.5	7.4
Aug	7.2	7.4	7.4
Sep	6.3	5.6	5.7
Oct	6.4	7.0	6.9
Nov	5.5	7.7	7.4
Dec	7.2		7.2
mean	6.5	7.0	7.0

WindPRO is developed by Energi- og Miljødata, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

Figure 7.3 Daily, monthly and total wind speed and wind direction variations, and total turbulence intensity variation of the measured data at 10 m height.


WindPRO version 2.1.0.1 Jun 2001

Project:
IYTE Wind Project

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Calculated:
01/06/2002 11:55 AM/

Meteo data report, height: 30.0

Name of meteo object: IYTE Met mast 30m

Montly mean values of wind speed in m/s

Month	2000	2001	mean
Jan		7.7	7.7
Feb		8.4	8.4
Mar		8.5	8.5
Apr		8.3	8.3
May		5.9	5.9
Jun		7.8	7.8
Jul	7.5	8.6	8.5
Aug	8.5	8.7	8.6
Sep	7.3	6.7	6.8
Oct	7.5	8.4	8.3
Nov	6.4	9.1	8.7
Dec	8.4		8.4
mean	7.6	8.0	8.0

WindPRO is developed by Energi- og Miljødata, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

Figure 7.4 Daily, monthly and total wind speed and wind direction variations, and total turbulence intensity variation of the measured data at 30 m height.

WindPRO version 2.1.0.1 Jun 2001

Project:
IYTE Wind Project

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Gaziosmanpasa Bulv no. 16
TR-35230 Cankaya-Izmir

Calculated:
01/06/2002 11:57 AM/

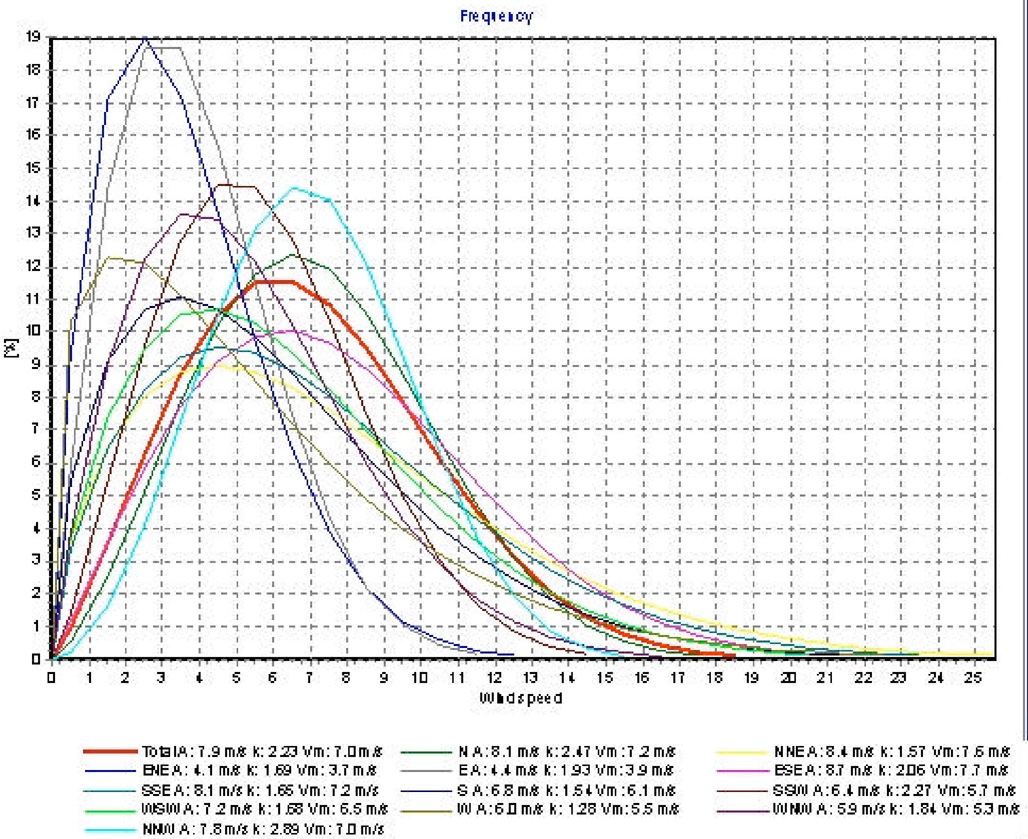
Meteo data report, height: 10.0

Name of meteo object: IYTE Met mast 30m

Weibull Data

k-parameter correction: 0.0080/m

Sector	A- parameter [m/s]	Mean wind speed [m/s]	k- parameter	Frequency	Frequency [%]	Wind shear
0-N	8.08	7.17	2.470	78.61	78.6	0.14
1-NNE	8.41	7.56	1.575	4.65	4.7	0.14
2-ENE	4.10	3.66	1.692	0.66	0.7	0.09
3-E	4.37	3.88	1.925	0.69	0.7	0.07
4-ESE	8.70	7.71	2.059	1.53	1.5	0.13
5-SSE	8.07	7.21	1.648	3.19	3.2	0.13
6-S	6.77	6.10	1.542	2.57	2.6	0.13
7-SSW	6.39	5.66	2.272	2.30	2.3	0.21
8-WSW	7.24	6.47	1.683	0.94	0.9	0.10
9-W	5.97	5.54	1.278	0.88	0.9	0.05
10-WNW	5.94	5.28	1.837	1.56	1.6	0.07
11-NNW	7.85	6.99	2.888	2.42	2.4	0.13
mean	7.94	7.03	2.228	100.00	100.0	0.14



WindPRO is developed by Energi- og Miljødata, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

Figure 7.5 Weibull parameters and Weibull distributions of the wind speed for 12 sectors according to measured data at 10 m height.

WindPRO version 2.1.0.1 Jun 2001

Project:
IYTE Wind Project

Description:

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Licensed user:
Izmir Institute of Technology
Gaziosmanpasa Bulv no. 16
TR-35230 Cankaya-Izmir

Calculated:
01/06/2002 11:51 AM/

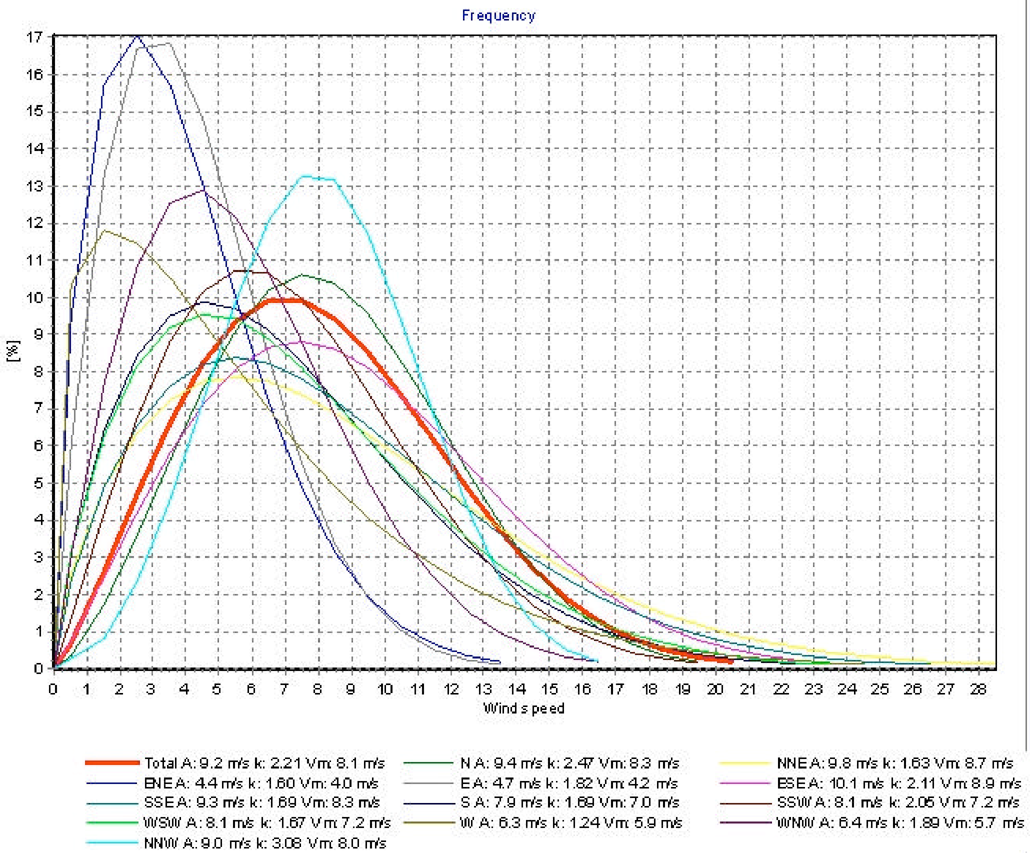
Meteo data report, height: 30.0

Name of meteo object: IYTE Met mast 30m

Weibull Data

k-parameter correction: 0.0080/m

Sector	A- parameter [m/s]	Mean wind speed [m/s]	k- parameter	Frequency	Frequency [%]	Wind shear
0-N	9.41	8.35	2.473	74.86	74.9	0.14
1-NNE	9.77	8.74	1.633	5.25	5.3	0.13
2-ENE	4.45	3.99	1.596	0.80	0.8	0.08
3-E	4.73	4.20	1.820	0.81	0.8	0.07
4-ESE	10.09	8.94	2.111	1.70	1.7	0.13
5-SSE	9.31	8.31	1.693	3.92	3.9	0.13
6-S	7.87	7.03	1.690	3.48	3.5	0.13
7-SSW	8.08	7.16	2.052	2.86	2.9	0.21
8-WSW	8.10	7.23	1.668	0.99	1.0	0.10
9-W	6.29	5.88	1.235	0.92	0.9	0.05
10-WNW	6.40	5.68	1.886	1.66	1.7	0.07
11-NNW	8.99	8.04	3.082	2.75	2.8	0.13
mean	9.19	8.14	2.211	100.00	100.0	0.13



WindPRO is developed by Energi- og Miljødata, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

Figure 7.6 Weibull parameters and Weibull distributions of the wind speed for 12 sectors according to measured data at 30 m height.

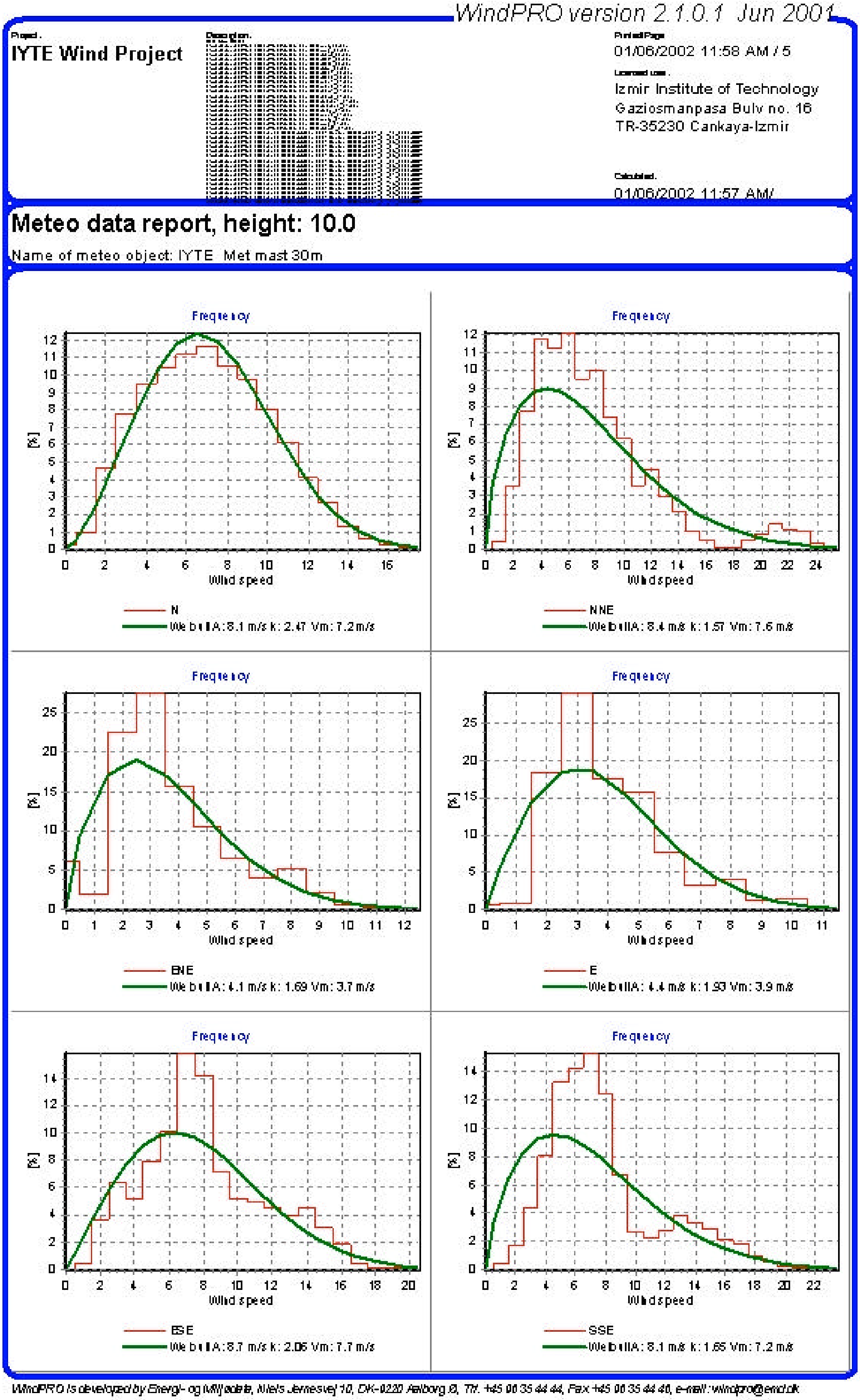


Figure 7.7 Weibull and turbulence histograms of the easterly 6 sectors according to measured data at 10 m height.

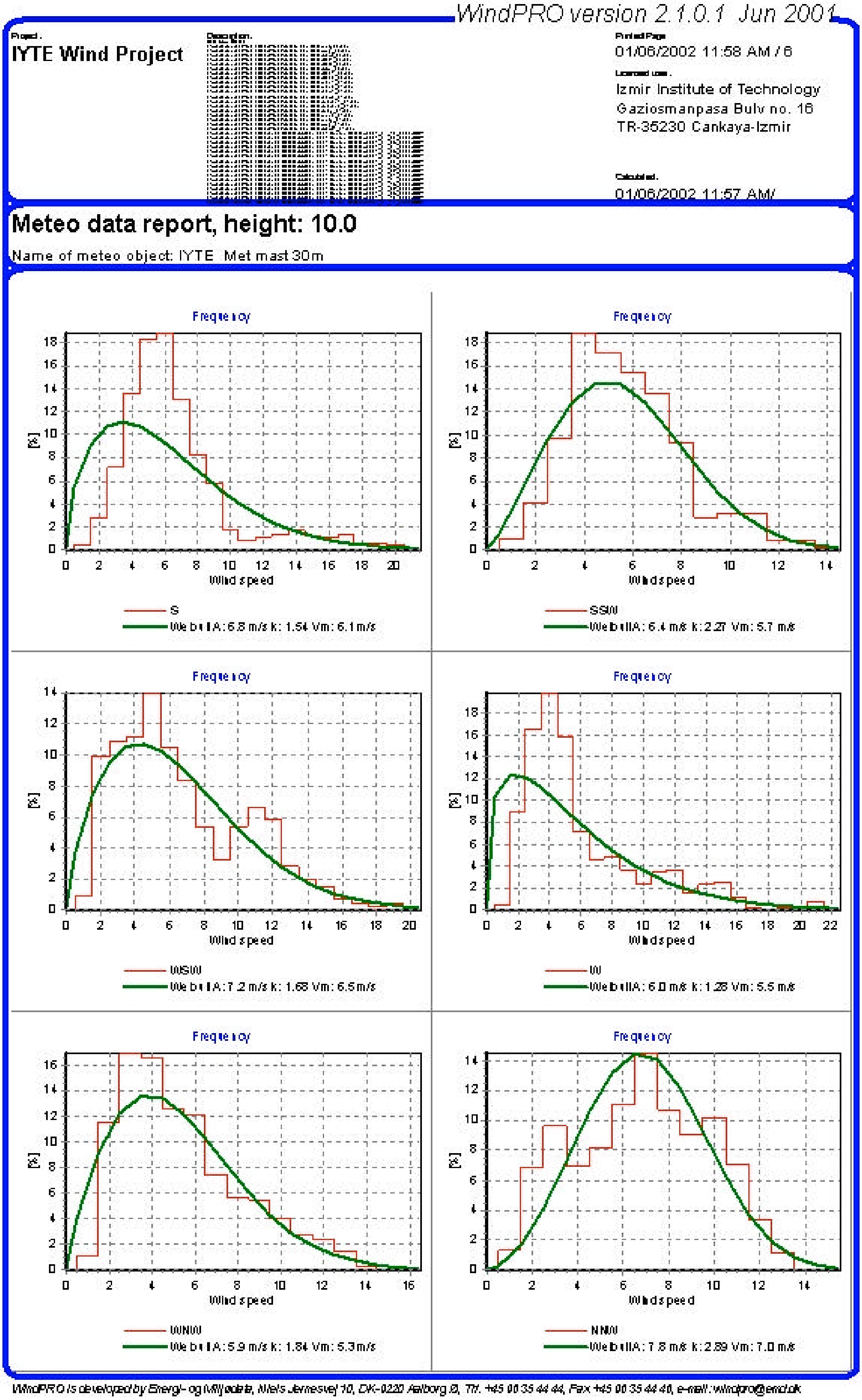


Figure 7.8 Weibull and turbulence histograms of the westerly 6 sectors according to measured data at 10 m height.

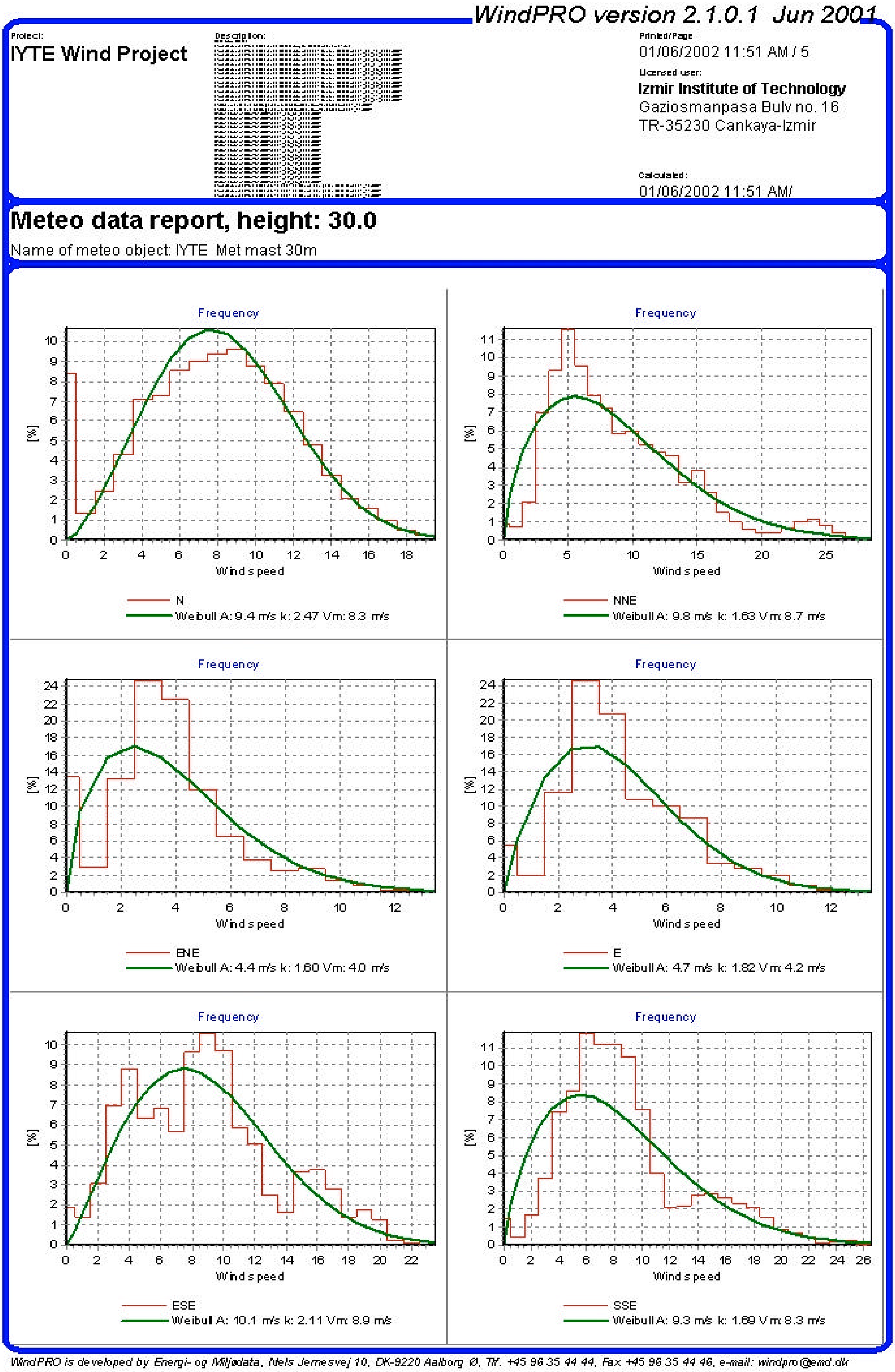


Figure 7.9 Weibull and turbulence histograms of the easterly 6 sectors according to measured data at 30 m height.

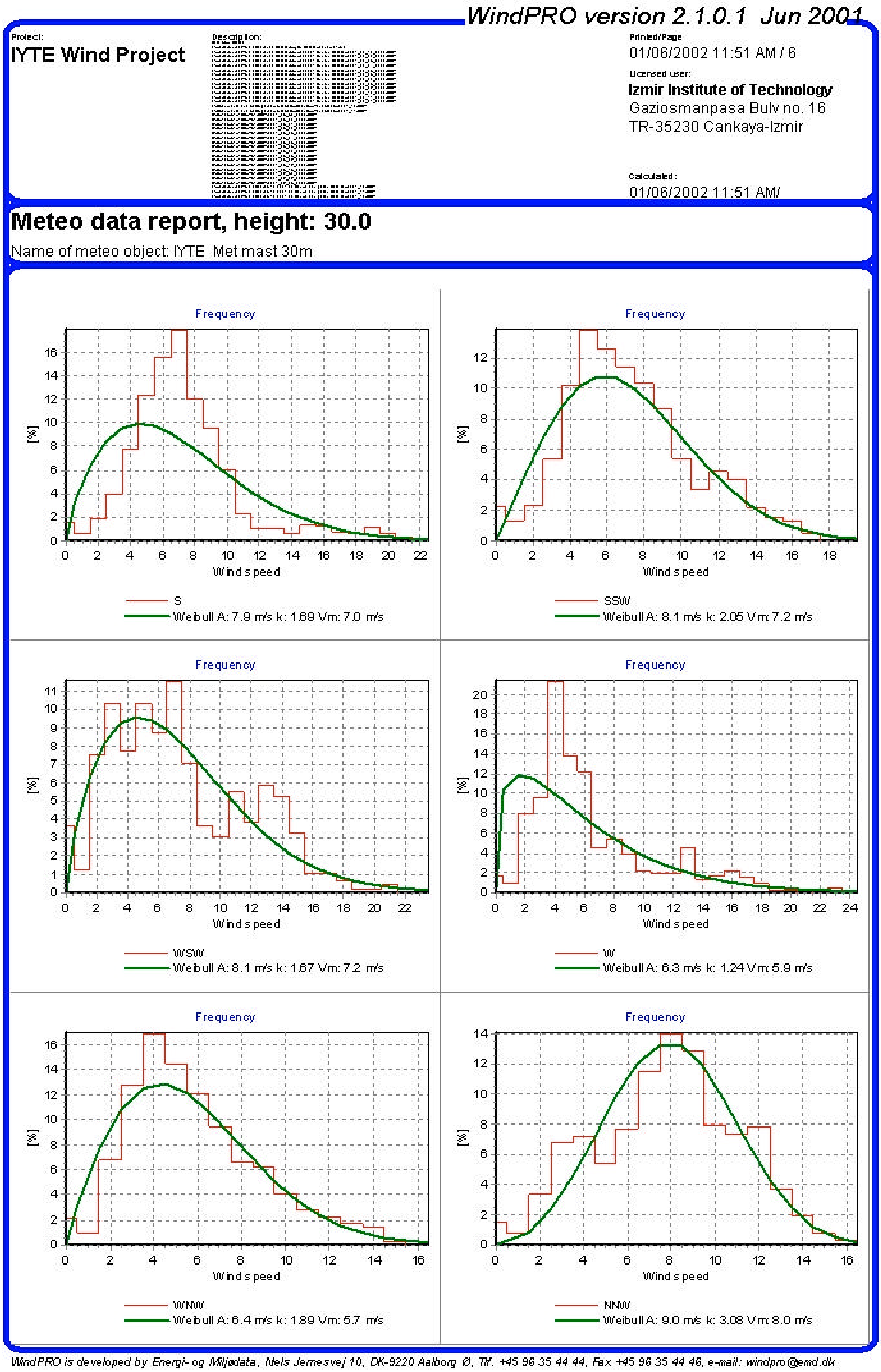


Figure 7.10 Weibull and turbulence histograms of the westerly 6 sectors according to measured data at 30 m height.

7.5 Wind Speed and Turbulence Analysis

North is the prevailing wind direction with 74.9% frequency, in IYTE campus area. Its mean wind speed and Weibull histogram are the most effective parameters in the wind analysis. Weibull parameters' lists in Figure 7.5 and 7.6 tell us mean wind speeds of north sector are 7.17 m/s at 10 m height and 8.35 m/s at 30 m height which are excellent values. Shape factor (k) for 30 m height is 2.473 which means that Rayleigh distribution does not fit to measured data. Some of the mean speeds of other sectors are even higher than mean speed of north sector. 8 sectors out of 12 sectors have mean speeds higher than 7 m/s at 30 m height. These are very important and very good results which mean IYTE campus area has large wind energy potential.

Sectors which have lowest mean wind speeds are E, ENE and W, WNW. E, ENE sectors have the lowest mean speed values which means that wind blowing from the main land is very weak. At W and WNW directions, terrain is very hilly and there are lot of cliffs and mountains. From the results, it is concluded that these mountains are blocking the wind in this direction. IYTE campus area is located in Çesme peninsula. North direction of the site is directly open to the sea. Sea is blocked by narrow land area at the south direction. Considering strong northerly and southerly winds, it can be said that most of the wind is blowing from the sea.

Turbulence intensity is very high in the north sector at 10 m height as shown in Figure 7.11. But, Figure 7.12 which graphs evaluation of the data measured at 30 m height, shows very low turbulence at north direction. These two contradictory results are normal because measurements collected at 10 m height are influenced by the surface roughness (refer to Figure 2.1). 30 m measurements are free of roughness influence and Figure 7.12 should be considered as the more realistic turbulence graph of the site.

According to Figure 7.12 turbulence is very low in north sector. It is an expected result because north is directly open to the sea which should get turbulence-free wind. Low turbulence in the prevailing direction means that site is getting clean and smooth wind 74.9% of the time. The Figure 7.12 points out big turbulence at NNW and SEE sectors. There is a high hill at NNW direction of the measurement site. It is the main reason of the turbulence at that sector. City center of Urla and many residential areas are located in SEE direction of the mast site, explains the high turbulence at this sector. Complex terrain and mountains with different heights cause turbulence at other sectors. The most important result of this analysis is wind from prevailing direction is turbulence-free.

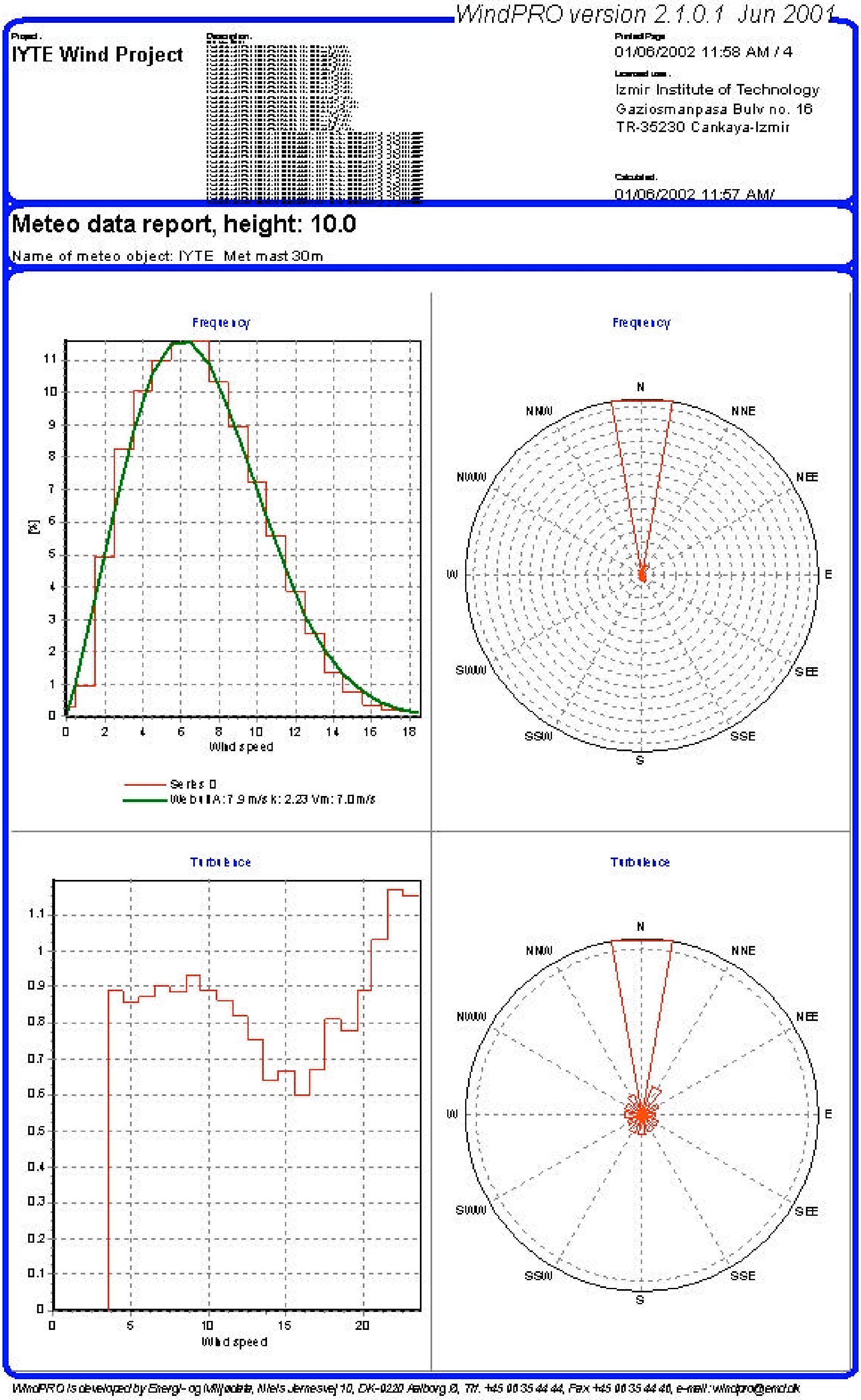


Figure 7.11 Windrose and histograms of wind speed and turbulence at 10 m height.

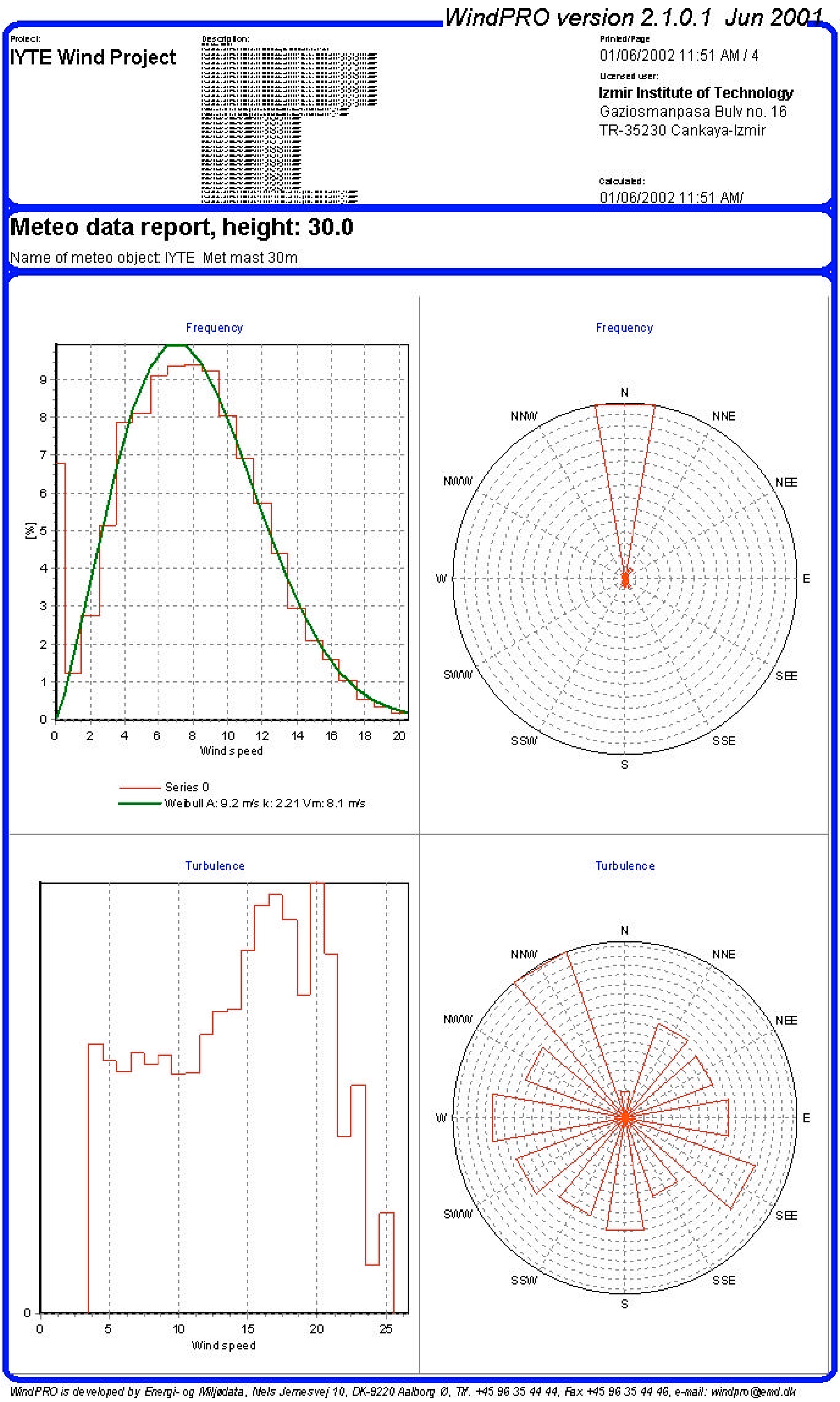


Figure 7.12 Windrose and histograms of wind speed and turbulence at 10 m height.

7.6 Mean Wind Speed Map of the Campus Area

Collected data from IYTE mast has been evaluated by WindPRO and WAsP programs to create wind speed map of the campus area. Roughness map of the measurement site with 20 km radius and orography map with 5 km radius have been used by WAsP to predict mean speeds of other locations of the campus area. Created map is covering 177.7 km^2 area with a resolution of 50 m.

Colors are used to indicate the wind speed intervals. Yellow colored areas are indicating locations with mean speeds between 5-6 m/s which is classified as class 2 or "poor" (refer to Table 5.1). Light green colored zones are indicating mean speeds between 6-7 m/s which is class 3 or "marginal". Green color stands for mean speeds between 7-7.5 m/s which is class 4 or "good". Dark green color stands for mean speeds 7.5-8 m/s which is class 5 or "very good" and very dark green and red colored areas are indicating class 6 or "excellent" zones which have mean speed of 8-9 m/s or higher.

Wind speed map of Campus area is indicating some "excellent" zones as well as lot of "very good" areas. IYTE mast site is also in class 6 which is "excellent" because its calculated mean speed was 8.14 m/s. Four site locations are found which are large areas in class 6 and very suitable for energy production.

7.7 Wind Energy Maps of Campus Area

Wind energy maps are created by WindPRO and WAsP programs which evaluated collected data, orography and roughness maps. Two maps are prepared with different units. The map shown in Figure 7.13 is determined in W/m^2 and second map in Figure 7.14 is determined in kWh/m^2/year. Difference between these two maps is map in W/m^2 is considering only mean wind speed values, but map in kWh/m^2/year is more valuable because it considers whole values of Weibull histogram.

In Figure 7.13, eight locations have energy more than 700 W/m^2 which are in class 6^+. There are several zones which have annual energy production more than 6000 kWh/m^2/year, shown in Figure 7.14.

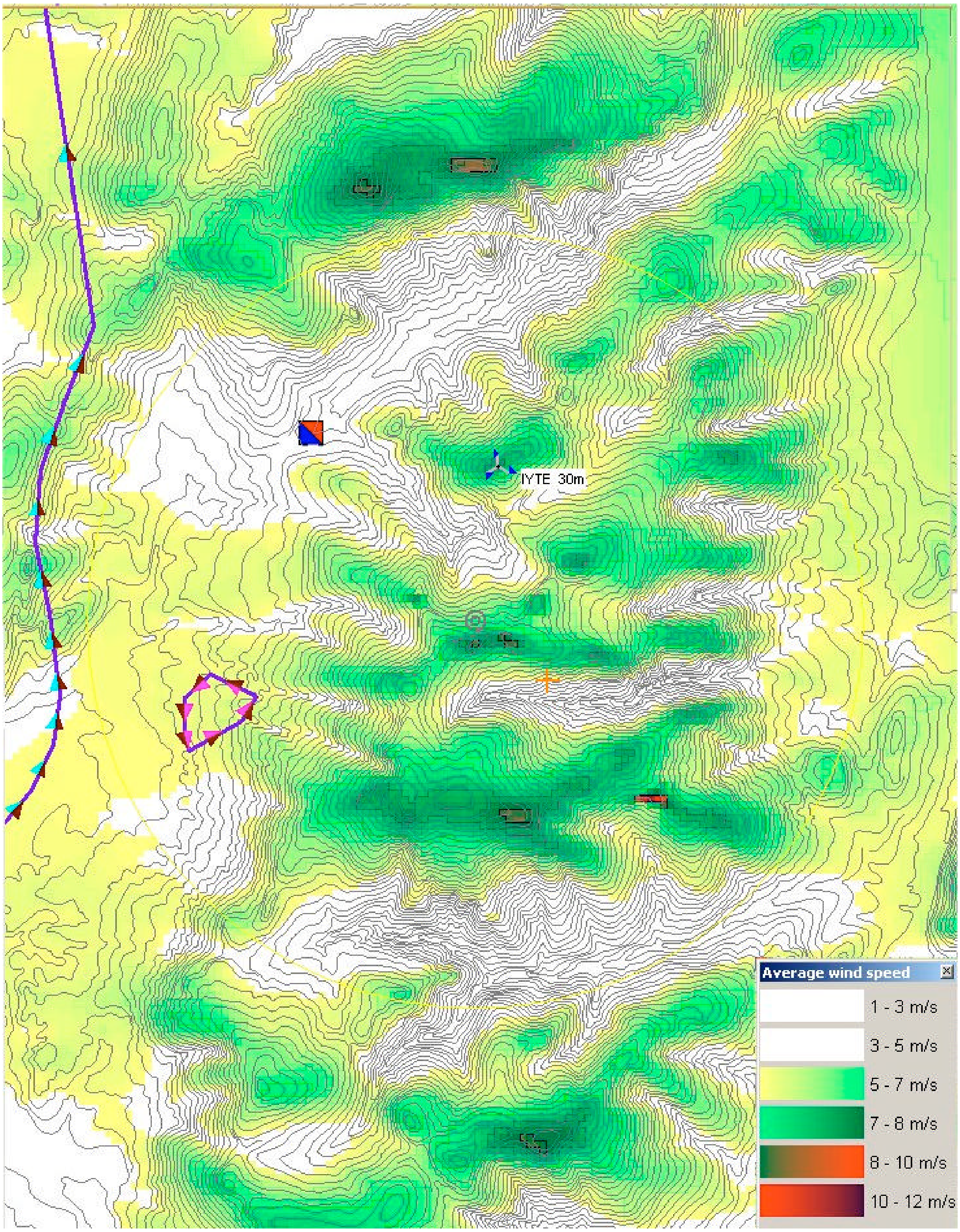


Figure 7.13 Average wind speed map of campus area.

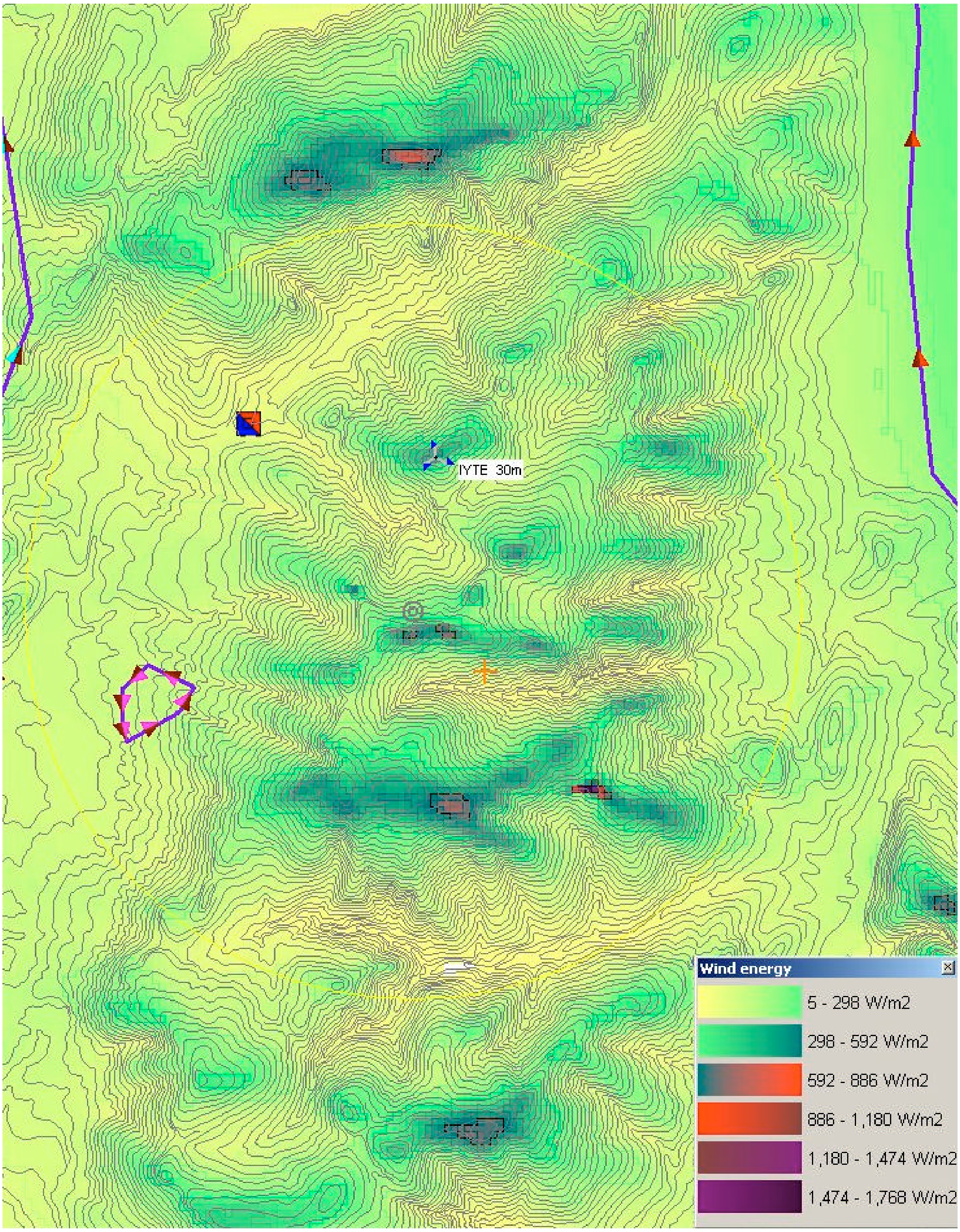


Figure 7.14 Wind energy map of campus area (W/m^2).

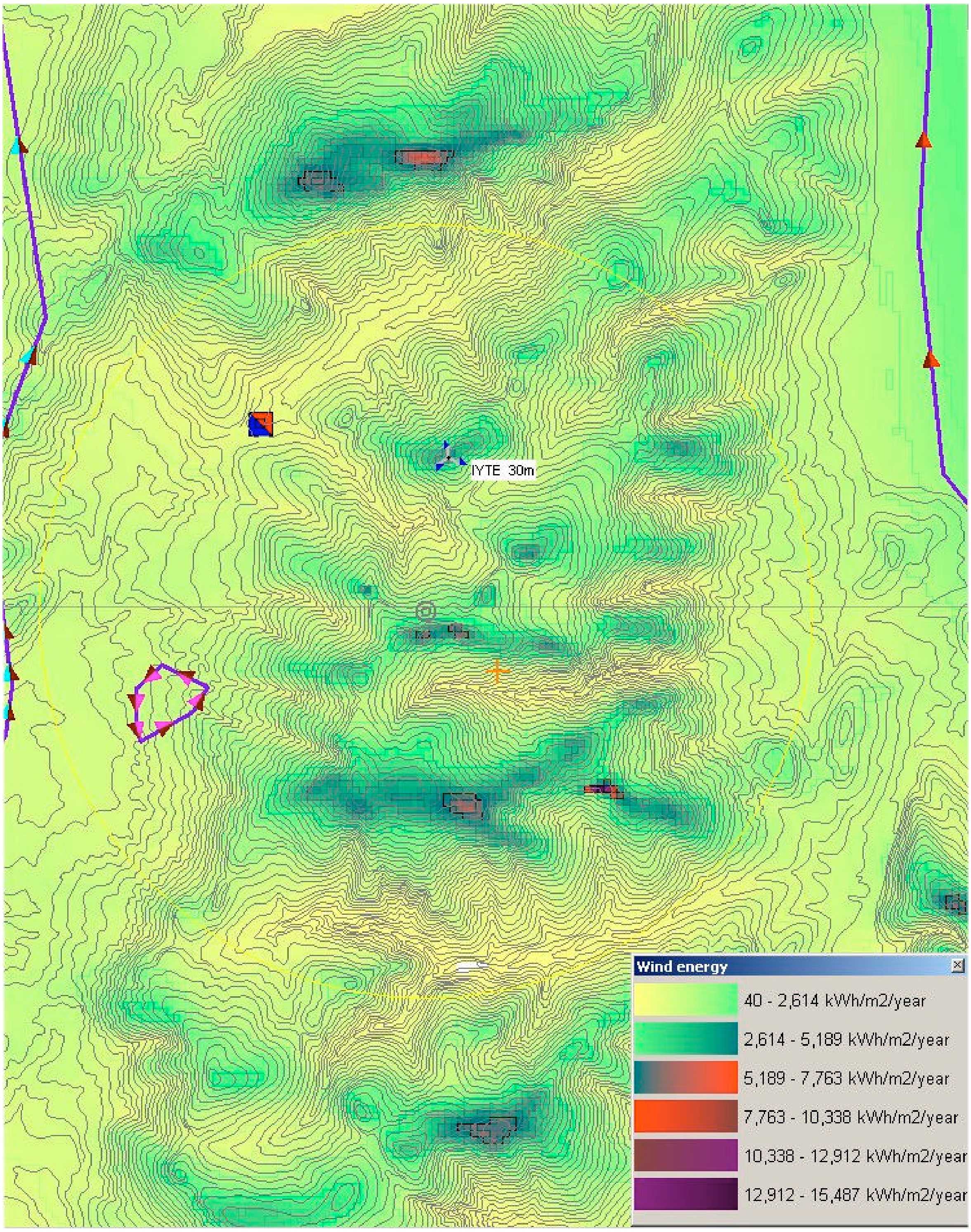


Figure 7.15 Wind energy map of campus area (kWh/m^2/year).

7.8 Orography Map of IYTE Campus Area

Digitized height contours have been evaluated to create orography map of IYTE campus area by WindPRO and WAsP programs. Map is colored to indicate elevation of the area. Highest location is 515 m high and colored by dark red. Red locations are indicating mountains (Figure 7.16). Dark green colored areas are showing elevations between 300-370 m. Light green areas indicating elevation of 200-300 m. Yellow and blue colors are showing lower elevations.

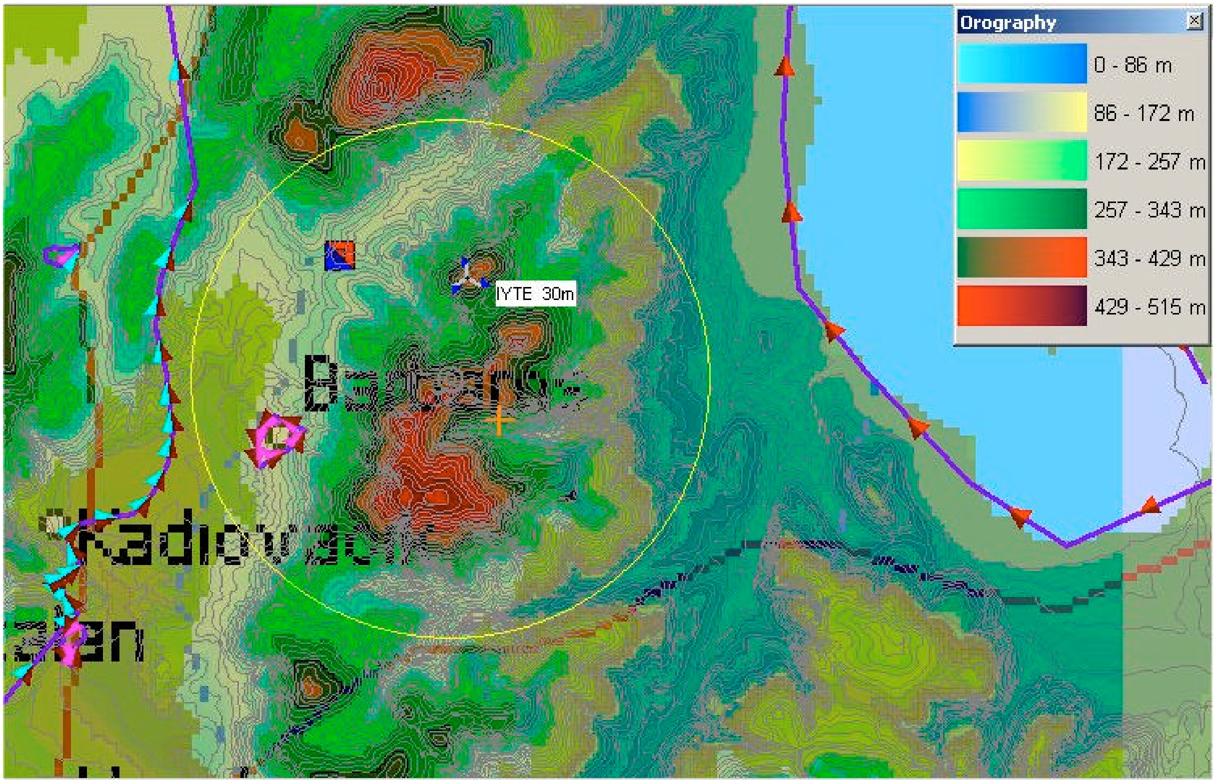


Figure 7.16 Orography map of IYTE campus area.

7.9 Selecting Best Fit Turbine for the IYTE Campus Area

Annual energy productions of five turbines with different energy capacity, are calculated by WindPRO software by using measured data of the IYTE mast. These turbines were: Enercon 600 kW, Vestas 660 kW, Vestas 850 kW, Nordex 1000 kW and Nordex 1500 kW Orography and roughness are not taken into considerations in the calculation.

Figure 7.16 shows calculated annual energy production of the these five turbines and Table 7.3 shows their AEP (Annual Energy Production) efficiencies of the turbines. Nordex 1500 kW has the highest efficiency of 45.1% comparing other four turbines. Enercon 600 kW has the second best efficiency of 41.8%. Enercon 600 kW is a turbine which is very common used commercially and Nordex 1500 kW has the highest efficiency comparing other four but new generated and not commonly used so far. Thus, both turbine types are chosen as the most suitable wind turbine type for the IYTE campus area.

Final decision can be made only after advanced investment analysis which should be done definitely in the future studies.

Table 7.2 Comparison of AEP of five turbines and their capacity factors.

Turbine Type	Nominal AEP (MWh)	Estimated AEP (MWh)	Capacity Factor
Enercon 600 kW	5256	2196	41.8%
Vestas 660 kW	5781.6	2405	41.6%
Vestas 850 kW	7446	3076	41.3%
Nordex 1000 kW	8760	3478	39.7%
Nordex 1500 kW	13140	5927	45.1%

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TR-35230 Cankaya-Izmir

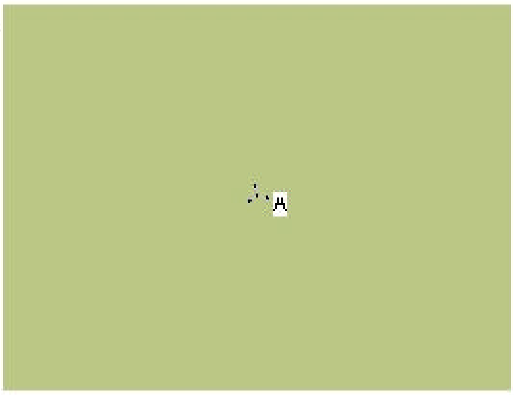
Calculated:
01/06/2002 12:07 PM/2.1.0.1

METEO - Main Result

Calculation: Calc 1

Name	IYTE Met mast 30m
Site Coordinates	UTM ED50 Zone: 35 East: 465,684
Air density	1.225 kg/m3

Calculation is based on "IYTE Met mast 30m", giving the measured distribution for the wind speed on the site. Using the selected power curve, the expected annual energy production is calculated.



Scale 1:25,000
Meteorological Data

Measure data 30 m above ground level

Wind speeds in m/s

Sector	Wind gradient exponent	Sum	0.00 - 0.50	0.50 - 1.50	1.50 - 2.50	2.50 - 3.50	3.50 - 4.50	4.50 - 5.50	5.50 - 6.50	6.50 - 7.50	7.50 - 8.50	8.50 - 9.50	9.50 - 10.50
0 N	0.133	37519	1563	507	333	1622	2843	2791	3302	3331	3563	3304	3333
1 NNE	0.133	2333	11	20	55	134	244	304	251	207	191	153	153
2 ENE	0.073	401	27	12	53	33	30	43	28	15	10	11	5
3 E	0.072	407	11	3	47	100	34	44	41	35	14	11	3
4 ESE	0.134	351	3	12	28	53	73	54	53	43	32	30	33
5 SSE	0.123	1384	15	3	33	74	148	163	232	220	220	208	143
6 S	0.123	1745	13	10	33	63	135	218	273	312	210	187	105
7 SSW	0.214	1433	18	13	33	78	148	133	130	163	143	124	73
8 WSW	0.102	434	3	6	37	51	33	51	43	57	35	13	15
9 W	0.054	480	4	4	37	44	33	63	58	21	25	13	10
10 WNW	0.087	384	3	3	57	107	141	121	101	73	55	52	34
11 NNW	0.128	1373	10	11	48	33	33	75	106	153	133	173	103
Sum		50114	1102	625	1330	2573	3345	4073	4563	4636	4716	4602	4036

Sector	10.50 - 11.50	11.50 - 12.50	12.50 - 13.50	13.50 - 14.50	14.50 - 15.50	15.50 - 16.50	16.50 - 17.50	17.50 - 18.50	18.50 - 19.50	19.50 - 20.50	20.50 - 21.50	21.50 - 22.50	22.50 - 23.50	23.50 - 24.50	24.50 - 25.50	25.50 - 26.50	26.50 - 27.50
0 N	2350	2438	1319	1220	733	535	384	133	38	44	15	5	3	1			
1 NNE	133	127	122	34	101	63	41	28	18	10	12	17	25	30	21	12	4
2 ENE	3	1												1			
3 E	3	1															
4 ESE	50	43	21	14	31	32	24	12	15	11	2	1					
5 SSE	73	42	43	54	57	51	45	40	31	17	14	3	3	4	5	1	
6 S	40	13	13	11	23	21	14	10	13	10	5	3	3	1	1		
7 SSW	43	65	53	31	22	13	7							1	1		
8 WSW	27	13	23	28	18	5	5	3	1	1	2						
9 W	3	3	21	6	3	10	7	4	1	1		1	2		1		
10 WNW	23	13	14	12	2												
11 NNW	101	103	51	27	10	4											
Sum	3471	2333	2136	1435	1053	736	507	273	163	94	50	35	41	33	23	13	4

Calculation Results

Key results for height 50.0 m above ground level
Wind energy: 6,190 kWh/m2; Mean wind speed: 8.6 m/s;

Key results for height 40.0 m above ground level
Wind energy: 5,676 kWh/m2; Mean wind speed: 8.3 m/s;

Calculated Annual Energy

WTG type						Power curve		Annual Energy		
Valid	Manufact.	Type	Power	Diam.	Height	Creator	Name	Result	Result-10%	Mean wind speed
			[kW]	[m]	[m]			[MWh]	[MWh]	[m/s]
Yes	ENERCON	E-40/6.44	600	44.0	46.0	EMD	Windtest 06/01 1.225 25 0.00	2,439.2	2,195	8.5
Yes	NEG MICON	NM 72-1500C	1,500/400	72.0	64.0	EMD	Risoe 03/01 1,225 25 0,00	6,585.8	5,927	8.9
Yes	NORDEX	N-54/1000	1,000/200	54.0	60.0	EMD	Windtest 03/96 1.225 25.00 -1.00	3,864.1	3,478	8.8
Yes	VESTAS	V47	660	47.0	45.0	EMD	Man. 24-08-00 1.225 25.00 0.00	2,672.6	2,405	8.5
Yes	VESTAS	V52	850	52.0	50.0	EMD	Noise opt. 104.2 dB(A) 8m/s Man. 03-04-01 1.225 25.00 0.00	3,417.7	3,076	8.6

Figure 7.17 Calculated AEP of five turbines using IYTE mast measurements.

7.10 Annual Energy Productions of Selected Sites

Wind speed and wind energy maps have been used to select suitable sites to locate wind turbines. Four sites were selected to install Enercon 600 kW turbines (46 m hub height and 44 m rotor diameter). These sites have mean speeds more than 8m/s and enough area to locate these turbines. Turbines have been located 150 m distance apart each other to prevent energy production loses of park effect. 47 turbines have been located as aligned position in four sites according to the prevailing direction (Figure 7.18). WindPRO software calculated annual energy production of every individual turbine and total production of four sites as well (Figures 7.20, 7.21, 7.22). Calculated energy production of located 47 turbines with total capacity of 28.2 MW, is 100.3 GWh. Technical data about Enercon 600 kW turbine and power and efficiency values used in calculations can be seen in Figure 7.23 and Figure 7.24.

Two sites were selected to install Nordex 1500 kW (60m hub height and 64m rotor diameter). These sites have mean speeds more than 8 m/s and enough area to mount these huge turbines. 26 turbines have been located 250 m distance apart and aligned according to prevailing wind direction to prevent from park effect production loses (Figure 7.19). WindPRO software calculated annual energy production of every individual turbine of two sites and total production of 26 turbines as well (Figures 7.25 and 7.26). Calculated energy production of 26 turbines with total capacity 39 MW, is 122.4GWh. Technical data about Nordex 1500 kW turbine and power and efficiency values used in calculations can be seen in Figure 7.27 and Figure 7.28.

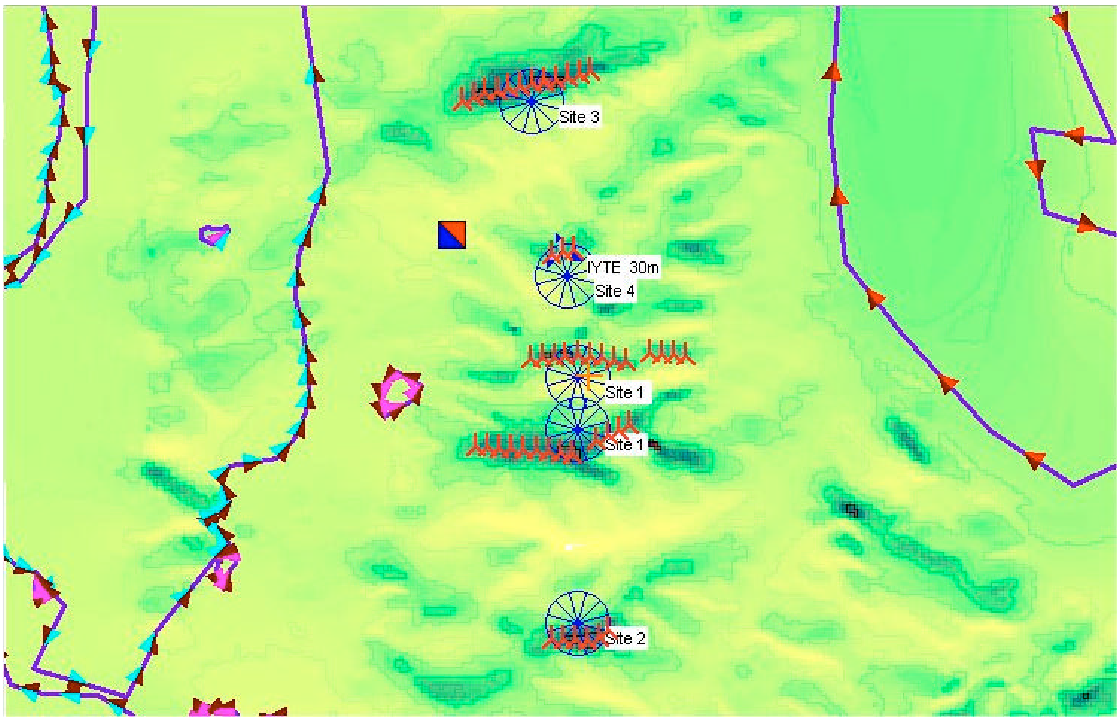


Figure 7.18 Location of the Enercon 600 kW turbines located on the IYTE campus area.

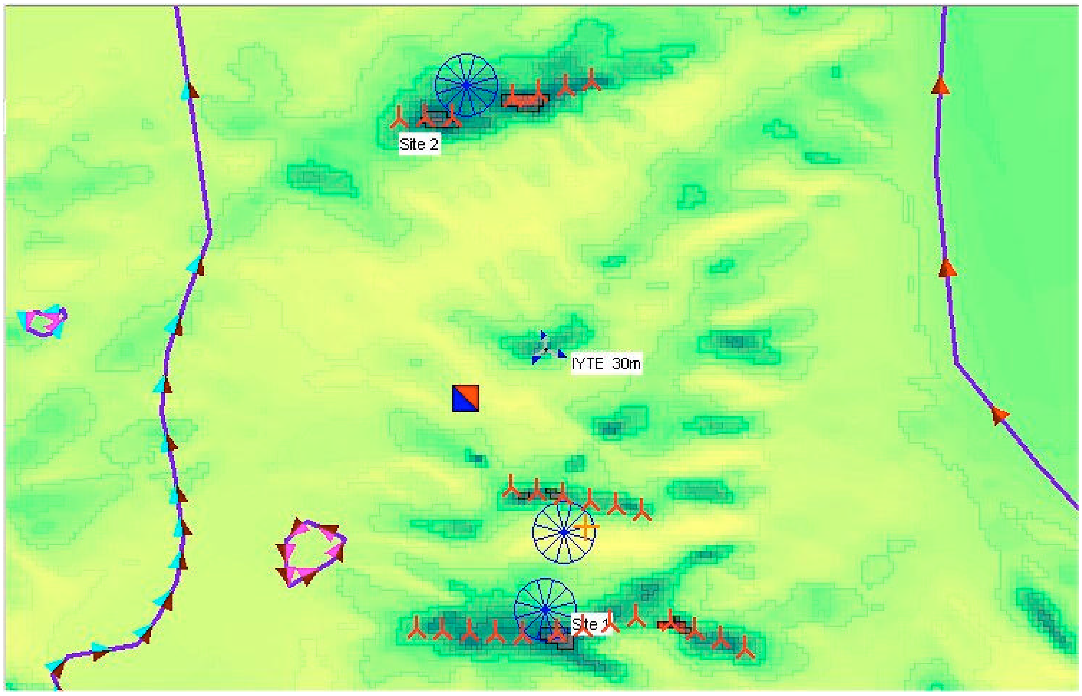


Figure 7.19 Location of the Nordex 1500 kW turbines located on the IYTE campus area.

WindPRO version 2.1.0.1 Jun 2001

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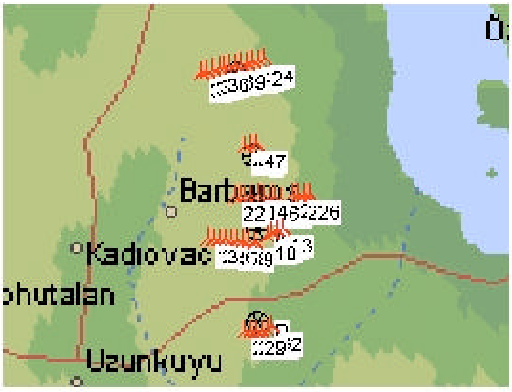
Calculated:
01/03/2002 1:21 PM/2.1.0.1

PARK - Main Result

Calculation: Park Calc for Site 1-2-3-4

Air density		1.165 kg/m3
Wake Decay Constant		0.075
Wind statistics	TR 30.0 m IYTE	Met mast 30m.lib



Scale 1:200,000
New WTG
Site Data

Key results for height 40.0 m above ground level

Terrain UTM ED50 Zone: 35

Terrain	East	North	Name of wind distribution	Type	Wind energy [kWh/m2]	Mean wind speed [m/s]	Mean roughness
A	465,914	4,241,469	Wind sta for Site 1 _ 2	WAsP (RVEA0011 1, 0, 0, 9)	3,348	7.3	0.2
B	465,917	4,242,168	Wind Sta for Site 1	WAsP (RVEA0011 1, 0, 0, 9)	1,138	5.1	2.6
C	465,310	4,245,864	Wind Sta for Site 3	WAsP (RVEA0011 1, 0, 0, 9)	2,755	6.9	0.5
D	465,903	4,238,873	Wind Sta for Site 2	WAsP (RVEA0011 1, 0, 0, 9)	3,758	7.6	0.0
E	465,782	4,243,526	Wind Sta for Site 4	WAsP (RVEA0011 1, 0, 0, 9)	1,803	5.7	1.7

Main Result for Windfarm Calculation

WTG combination	Windfarm energy [MWh]	Windfarm energy - 10 % [MWh]	Windfarm efficiency [%]	Mean WTG energy [MWh]
Windfarm	111,480.0	100,332.0	98.3	2,371.9

Calculated Annual Energy for new WTG's

	Terrain	WTG type Valid	Manufact.	Type	Power [kW]	Diam. [m]	Height [m]	Circle radius [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Result-10% [MWh]	Park Efficiency [%]	Mean wind speed [m/s]
1	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,261.6	2,036	99.0	8.3
2	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,381.1	2,143	98.8	8.6
3	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,477.8	2,230	98.5	8.8
4	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,445.0	2,200	97.8	8.8
5	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,420.3	2,178	97.2	8.8
6	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,427.3	2,185	96.4	8.9
7	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,455.0	2,209	96.1	9.0
8	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,588.5	2,330	96.4	9.3
9	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,682.0	2,414	96.7	9.5
10	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,269.3	2,042	95.3	8.5
11	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,295.9	2,066	95.2	8.6
12	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,166.8	1,950	95.2	8.3
13	A	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,252.5	2,027	96.0	8.5
14	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,138.1	1,924	97.4	8.1
15	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,065.8	1,859	97.8	8.0
16	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,100.7	1,891	98.4	8.0
17	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,262.6	2,036	98.9	8.4
18	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,196.8	1,977	99.0	8.2
19	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,484.3	2,236	97.5	8.9
20	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest06/01 1.225 25 0.00	2,281.0	2,053	97.4	8.4

WindPRO is developed by Energi- og Miljødata, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

Figure 7.20 WindPRO report of calculated annual energy production of Enercon 600 kW turbines.

WindPRO version 2.1.0.1 Jun 2001

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Calculated:

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PARK - Main Result

Calculation: Park Calc for Site 1-2-3-4

	Terrain	WTG type Valid	Manufact.	Type	Power	Diam.	Height	Circle radius	Power curve Creator	Name	Annual Energy Result	Result-10%	Park Efficiency	Mean wind speed
					[kW]	[m]	[m]	[m]			[MWh]	[MWh]	[%]	[m/s]
21	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,346.3	2,112	97.8	8.6
22	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	1,984.2	1,786	97.9	7.8
23	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	1,874.9	1,687	99.3	7.5
24	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,073.9	1,867	99.4	7.9
25	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,107.7	1,897	99.5	8.0
26	B	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,007.5	1,807	99.7	7.8
27	D	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,198.2	1,978	98.3	8.2
28	D	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,457.3	2,212	98.3	8.8
29	D	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,630.7	2,368	98.5	9.2
30	D	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,625.3	2,363	98.5	9.2
31	D	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,553.5	2,298	97.7	9.1
32	D	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,344.8	2,110	98.2	8.6
33	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,290.2	2,061	99.8	8.4
34	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,612.6	2,351	99.6	9.1
35	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,782.9	2,505	99.5	9.5
36	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,594.1	2,335	99.6	9.0
37	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,477.5	2,230	99.6	8.8
38	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,403.8	2,163	99.7	8.6
39	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,624.0	2,362	99.7	9.1
40	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,907.1	2,616	99.7	9.8
41	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,769.9	2,493	99.6	9.5
42	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,545.3	2,291	99.6	8.9
43	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,463.8	2,217	99.6	8.7
44	C	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,464.6	2,218	99.8	8.7
45	E	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,229.4	2,007	98.1	8.3
46	E	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,372.1	2,135	98.1	8.6
47	E	Yes	ENERCON	E-40/6.44	600	44.0	46.0	90.0	EMD	Windtest0601 1.225 25 0.00	2,086.1	1,878	98.1	8.0

WTG siting

UTM ED50 Zone: 35

		East	North	Z	Row data/Description
				[m]	
1	New	464,534	4,241,255	391	93.5°, 160.0 m
2	New	464,694	4,241,245	429	
3	New	464,853	4,241,235	460	
4	New	465,013	4,241,226	470	
5	New	465,173	4,241,216	465	
6	New	465,355	4,241,203	468	96.2°, 160.0 m
7	New	465,514	4,241,186	463	
8	New	465,673	4,241,168	450	
9	New	465,832	4,241,151	440	
10	New	466,163	4,241,332	374	64.3°, 160.0 m
11	New	466,307	4,241,401	350	
12	New	466,451	4,241,471	335	
13	New	466,596	4,241,540	330	
14	New	465,925	4,242,495	400	100.6°, 160.0 m
15	New	466,082	4,242,465	390	
16	New	466,239	4,242,436	372	
17	New	466,397	4,242,407	365	
18	New	466,554	4,242,377	353	
19	New	465,747	4,242,470	0	265.2°, 160.0 m
20	New	465,588	4,242,457	0	
21	New	465,428	4,242,443	0	
22	New	465,269	4,242,430	0	
23	New	466,893	4,242,503	0	94.2°, 160.0 m
24	New	467,053	4,242,491	0	
25	New	467,212	4,242,480	0	
26	New	467,372	4,242,468	0	
27	New	465,538	4,238,671	341	91.0°, 160.0 m

Figure 7.21 WindPRO report of calculated annual energy production of Enercon 600 kW turbines.

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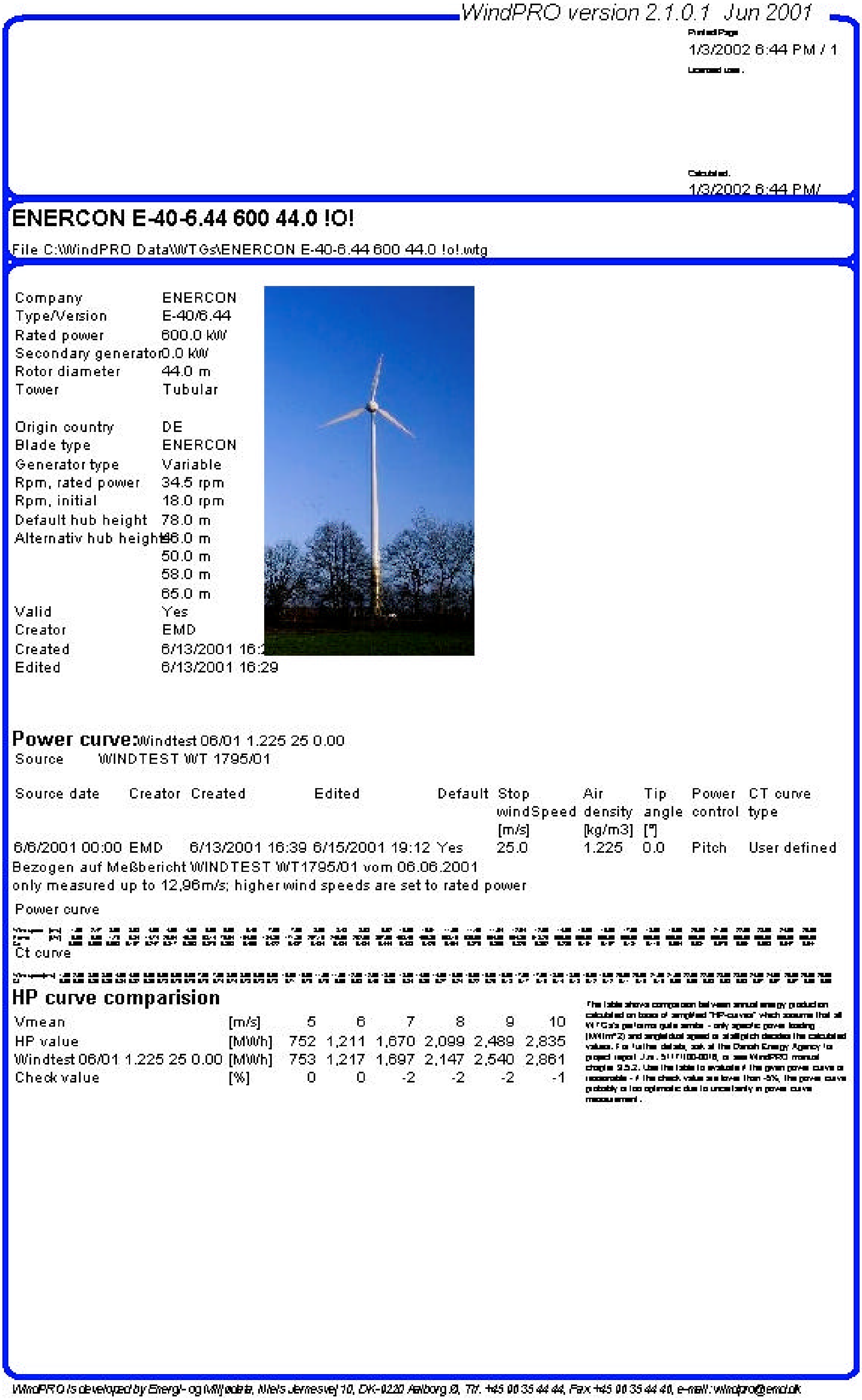
PARK - Main Result

Calculation: Park Calc for Site 1-2-3-4

		UTM ED50 Zone: 35 East	North	Z [m]	Row data/Description
28	New	465,698	4,238,668	335	
29	New	465,858	4,238,665	335	
30	New	466,018	4,238,663	340	
31	New	466,186	4,238,692	331	50.0°, 160.0 m
32	New	466,309	4,238,795	318	
33	New	464,373	4,245,898	0	71.8°, 160.0 m
34	New	464,525	4,245,948	0	
35	New	464,677	4,245,998	0	
36	New	464,841	4,246,036	458	80.4°, 160.0 m
37	New	464,999	4,246,063	431	
38	New	465,157	4,246,089	410	
39	New	465,314	4,246,116	405	
40	New	465,472	4,246,143	420	
41	New	465,638	4,246,166	410	75.6°, 160.0 m
42	New	465,793	4,246,206	368	
43	New	465,948	4,246,246	341	
44	New	466,103	4,246,285	313	
45	New	465,560	4,243,828	368	79.0°, 160.0 m
46	New	465,717	4,243,859	400	
47	New	465,874	4,243,889	380	

Figure 7.22 WindPRO report of calculated annual energy production of Enercon 600 kW turbines.



WindPRO version 2.1.0.1 Jun 2001

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Calculated:
1/3/2002 6:44 PM/

ENERCON E-40-6.44 600 44.0 !O!

File C:\WindPRO Data\WTGs\ENERCON E-40-6.44 600 44.0 !o!.wtg

Company	ENERCON
Type/Version	E-40/6.44
Rated power	600.0 kW
Secondary generator	0.0 kW
Rotor diameter	44.0 m
Tower	Tubular
Origin country	DE
Blade type	ENERCON
Generator type	Variable
Rpm, rated power	34.5 rpm
Rpm, initial	18.0 rpm
Default hub height	78.0 m
Alternativ hub height	46.0 m
	50.0 m
	58.0 m
	65.0 m
Valid	Yes
Creator	EMD
Created	6/13/2001 16:2
Edited	6/13/2001 16:29

Power curve: Windtest 06/01 1.225 25 0.00
Source WINDTEST WT 1795/01

Source date	Creator	Created	Edited	Default	Stop windSpeed [m/s]	Air density [kg/m3]	Tip angle [°]	Power control	CT curve type
6/6/2001 00:00	EMD	6/13/2001 16:39	6/15/2001 19:12	Yes	25.0	1.225	0.0	Pitch	User defined

Bezogen auf Meßbericht WINDTEST WT1795/01 vom 06.06.2001
only measured up to 12,96m/s; higher wind speeds are set to rated power

Power curve

Ct curve

HP curve comparision

Vmean	[m/s]	5	6	7	8	9	10
HP value	[MWh]	752	1,211	1,670	2,099	2,489	2,835
Windtest 06/01 1.225 25 0.00	[MWh]	753	1,217	1,697	2,147	2,540	2,861
Check value	[%]	0	0	-2	-2	-2	-1

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Figure 7.23 Technical information sheet of Enercon 600 kW wind turbines.

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PARK - Power Curve Analysis

Calculation: Park Calc for Site 1-2-3-4 **WTG:** 1 - ENERCON E-40/6.44 600 44.0 !O! Windtest 06/01 1.225 25 0.00, Hub height: 46.0 m

Name: Windtest 06/01 1.225 25 0.00
Source: WINDTEST WT 1795/01

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type
06/06/2001	EMD	06/13/2001	06/15/2001	25.0	Pitch	User defined

Bezogen auf Meßbericht WINDTEST WT1795/01 vom 06.06.2001
only measured up to 12,96m/s; higher wind speeds are set to rated power

Power curve

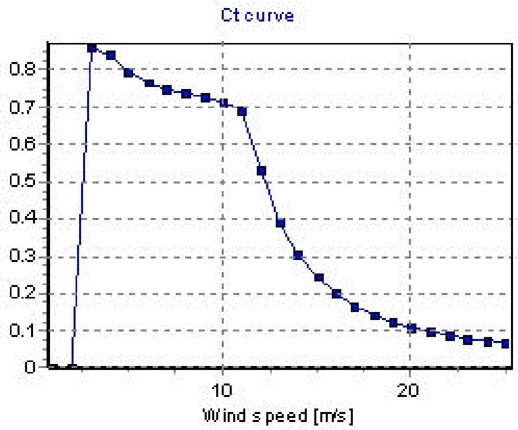
Original data from Windcat, Air density: 1.225 kg/m3

[illegible]

Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 1.165 kg/m3

Wind speed [m/s]	Power [kW]	Ce	Interval [m/s]	Energy [MWh]	Acc.Energy [MWh]	Relative [%]
1.0	0.0	0.00	0.50- 1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50- 2.50	0.0	0.0	0.0
3.0	1.6	0.07	2.50- 3.50	1.6	1.6	0.1
4.0	14.0	0.25	3.50- 4.50	9.9	11.5	0.5
5.0	39.1	0.35	4.50- 5.50	29.5	41.0	1.8
6.0	76.2	0.40	5.50- 6.50	63.2	104.2	4.6
7.0	128.2	0.42	6.50- 7.50	113.7	217.8	9.6
8.0	197.0	0.43	7.50- 8.50	173.4	391.3	17.3
9.0	280.5	0.43	8.50- 9.50	236.8	628.1	27.8
10.0	383.6	0.43	9.50-10.50	290.4	918.4	40.6
11.0	487.3	0.41	10.50-11.50	309.0	1,227.4	54.3
12.0	550.7	0.36	11.50-12.50	291.9	1,519.3	67.2
13.0	612.7	0.31	12.50-13.50	243.3	1,762.7	77.9
14.0	600.0	0.25	13.50-14.50	178.5	1,941.2	85.8
15.0	600.0	0.20	14.50-15.50	122.8	2,064.0	91.3
16.0	600.0	0.17	15.50-16.50	80.7	2,144.7	94.8
17.0	600.0	0.14	16.50-17.50	50.4	2,195.0	97.1
18.0	600.0	0.12	17.50-18.50	30.0	2,225.0	98.4
19.0	600.0	0.10	18.50-19.50	17.1	2,242.1	99.1
20.0	600.0	0.08	19.50-20.50	9.4	2,251.5	99.6
21.0	600.0	0.07	20.50-21.50	5.0	2,256.5	99.8
22.0	600.0	0.06	21.50-22.50	2.7	2,259.2	99.9
23.0	600.0	0.06	22.50-23.50	1.4	2,260.6	100.0
24.0	600.0	0.05	23.50-24.50	0.7	2,261.4	100.0
25.0	600.0	0.04	24.50-25.50	0.3	2,261.6	100.0



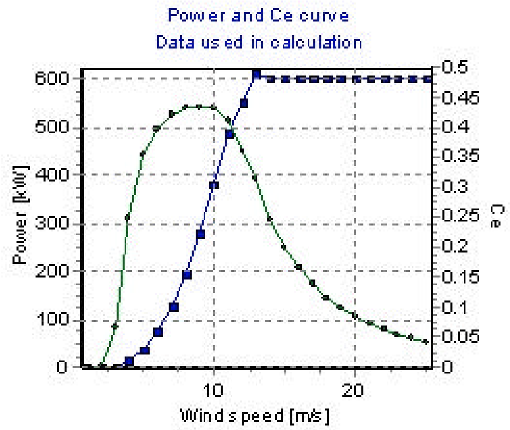


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Figure 7.24 Power curve and efficiency values of Enercon 600 kW wind turbine.

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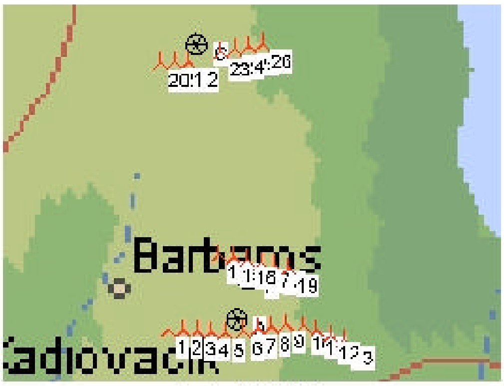
PARK - Main Result

Calculation: Calc for Site 1-2

Air density 1.165 kg/m3
Wake Decay Constant 0.075



Scale 1:125,000
New WTG Site Data

Key results for height 40.0 m above ground level

Terrain UTM ED50 Zone: 35

	East	North	Name of wind distribution	Type	Wind energy [kWh/m2]	Mean wind speed [m/s]	Mean roughness
A	465,673	4,241,410	Wind sta for Site 1_1	WAsP (RVEA0011 1, 0, 0, 9)	4,138	7.8	Not calculated
B	465,857	4,242,128	Wind sta for Site 1	WAsP (RVEA0011 1, 0, 0, 9)	659	4.2	3.8
C	464,970	4,246,285	Site data 12 sectors; Radius: 20,000 m	WAsP (RVEA0011 1, 0, 0, 9)	4,444	8.1	Not calculated

Main Result for Windfarm Calculation

WTG combination	Windfarm energy [MWh]	Windfarm energy - 10 % [MWh]	Windfarm efficiency [%]	Mean WTG energy [MWh]
Windfarm	135,991.7	122,392.5	98.4	5,230.4

Calculated Annual Energy for new WTG's

	Terrain	WTG type Valid	Manufact.	Type	Power [kW]	Diam. [m]	Height [m]	Circle radius [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Result-10% [MWh]	Park Efficiency [%]	Mean wind speed [m/s]
1	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	4,910.7	4,420	98.9	8.4
2	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,387.6	4,849	98.7	8.9
3	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,640.2	5,076	98.2	9.2
4	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,534.8	4,981	97.2	9.1
5	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,550.6	4,996	96.4	9.2
6	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,861.1	5,275	96.3	9.6
7	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,401.2	4,861	96.0	9.1
8	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	4,782.3	4,304	95.4	8.4
9	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	4,656.9	4,191	95.9	8.3
10	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	6,370.2	5,733	98.9	10.1
11	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,127.4	4,615	99.5	8.7
12	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,465.9	4,919	99.5	9.0
13	A	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,100.6	4,591	99.7	8.6
14	B	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	4,433.5	3,990	98.1	8.0
15	B	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,330.5	4,797	98.5	8.8
16	B	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,305.4	4,775	98.5	8.8
17	B	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	4,907.3	4,417	98.4	8.4
18	B	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	4,855.9	4,370	98.6	8.4
19	B	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	4,763.0	4,287	98.8	8.3
20	C	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	4,453.6	4,008	99.8	7.9
21	C	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,470.7	4,924	99.7	8.9
22	C	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,408.1	4,867	99.7	8.8
23	C	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,695.9	5,126	99.8	9.1
24	C	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,371.3	4,834	99.7	8.8

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Figure 7.25 WindPRO report of calculated annual energy production of Nordex 1500 kW turbines.

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PARK - Main Result

Calculation: Calc for Site 1-2

Terrain	WTG type Valid	Manufact.	Type	Power [kW]	Diam. [m]	Height [m]	Circle radius [m]	Power curve Creator	Name	Annual Energy Result [MWh]	Result-10% [MWh]	Park Efficiency [%]	Mean wind speed [m/s]
25 C	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,182.4	4,664	99.7	8.6
26 C	Yes	NEG MICON	NM 64/1500C	1,500/400	64.0	60.0	125.0	EMD	Man. 28-11-00 1.225 25.00 0.00	5,024.7	4,522	99.8	8.5

WTG siting

UTM ED50 Zone: 35

		East	North	Z [m]	Row data/Description
1	New	464,466	4,241,255	378	93.6°, 250.0 m
2	New	464,716	4,241,239	431	
3	New	464,965	4,241,224	470	
4	New	465,215	4,241,208	466	
5	New	465,464	4,241,192	466	
6	New	465,784	4,241,217	446	80.5°, 250.0 m
7	New	466,030	4,241,258	401	
8	New	466,277	4,241,300	336	
9	New	466,524	4,241,341	304	
10	New	466,839	4,241,305	339	109.6°, 250.0 m
11	New	467,075	4,241,221	266	
12	New	467,310	4,241,137	256	
13	New	467,546	4,241,053	203	
14	New	465,356	4,242,569	402	100.7°, 250.0 m
15	New	465,602	4,242,523	414	
16	New	465,847	4,242,476	406	
17	New	466,093	4,242,430	390	
18	New	466,339	4,242,383	358	
19	New	466,584	4,242,337	345	
20	New	464,326	4,245,989	410	88.4°, 250.0 m
21	New	464,576	4,245,996	475	
22	New	464,826	4,246,003	462	
23	New	465,394	4,246,180	420	79.1°, 250.0 m
24	New	465,639	4,246,227	403	
25	New	465,885	4,246,275	360	
26	New	466,130	4,246,322	310	

Figure 7.26 WindPRO report of calculated annual energy production of Nordex 1500 kW turbines.

WindPRO version 2.1.0.1 Jun 2001

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NEG MICON NM 64-1500C 1500-400 64.0 !O!

File C:\WindPRO Data\WTGs\NEG MICON NM 64-1500C 1500-400 64.0 !O!.wtg

Company	NEG MICON
Type/Version	NM 64/1500C
Rated power	1,500.0 kW
Secondary generator	400.0 kW
Rotor diameter	64.0 m
Tower	Tubular
Origin country	DK
Blade type	AL 31.2
Generator type	Two generator
Rpm, rated power	17.3 rpm
Rpm, initial	11.5 rpm
Default hub height	60.0 m
Alternativ hub height	42.8 m
	68.0 m
	80.0 m
Valid	Yes
Creator	EMD
Created	6/8/2001 14:1(
Edited	6/8/2001 14:1(

Power curve: Man. 28-11-00 1.225 25.00 0.00

Source Manufacturer

Source date	Creator	Created	Edited	Default	Stop windSpeed [m/s]	Air density [kg/m3]	Tip angle [°]	Power control	CT curve type
11/28/2000 00:00	EMD	4/18/2001 22:17	6/20/2001 17:36	Yes	25.0	1.225	2.0	Stall	User defined

According to TIC 323'008 DK NM 64/1500C dated 28-11-2000. Power curve is calculated.

Power curve

Wind speed [m/s]	[illegible]
Power [kW]	[illegible]
Cp	[illegible]

Ct curve

Wind speed [m/s]	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00	21.00	22.00	23.00	24.00	25.00
Ct	0.93	0.79	0.93	0.83	0.75	0.67	0.60	0.54	0.48	0.43	0.38	0.35	0.31	0.28	0.25	0.23	0.21	0.19	0.18	0.17	0.16	0.15

HP curve comparision

Vmean	[m/s]	5	6	7	8	9	10
HP value	[MWh]	1,544	2,557	3,640	4,684	5,622	6,442
Man. 28-11-00 1.225 25.00 0.00	[MWh]	1,587	2,599	3,683	4,719	5,629	6,365
Check value	[%]	-3	-2	-1	-1	0	1

[illegible]

Figure 7.27 Technical information sheet of Nordex 1500 kW wind turbines.

Project:

IYTE Wind Project

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Gaziosmanpasa Bulv no. 16
TR-35230 Cankaya-Izmir

Calculated:
01/03/2002 6:10 PM/2.1.0.1

PARK - Power Curve Analysis

Calculation: Calc for Site 1-2 **WTG:** 1 - NEG MICON NM 64-1500C 1500-400 64.0 !0! Man. 28-11-00 1.225 25.00 0.00, Hub height: 60.0 m

Name: Man. 28-11-00 1.225 25.00 0.00
Source: Manufacturer

Source/Date	Created by	Created	Edited	Stop wind speed [m/s]	Power control	CT curve type
11/28/2000	EMD	04/18/2001	06/20/2001	25.0	Stall	User defined

According to TIC 323'008 DK NM 64/1500C dated 28-11-2000. Power curve is calculated.

Power curve

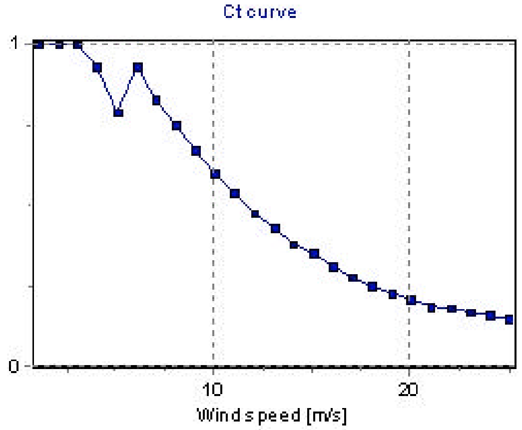
Original data from Windcat, Air density: 1.225 kg/m3

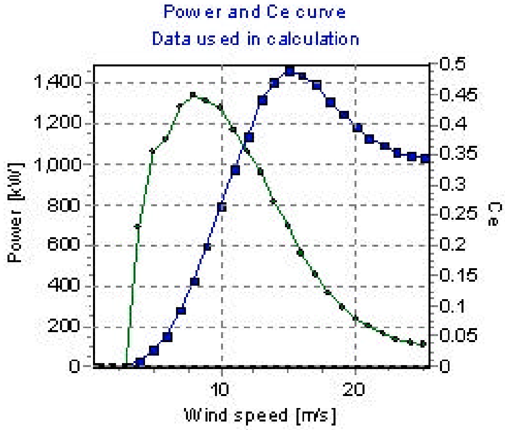
Wind speed [m/s]	Power [kW]	Ce	Wind speed [m/s]	Ct curve
3.0	0.0	0.00	4.0	0.93
4.0	29.0	0.23	5.0	0.79
5.0	87.0	0.35	6.0	0.93
6.0	160.0	0.38	7.0	0.83
7.0	291.0	0.43	8.0	0.75
8.0	452.0	0.45	9.0	0.67
9.0	632.0	0.44	10.0	0.60
10.0	840.0	0.43	11.0	0.54
11.0	1,025.0	0.39	12.0	0.48
12.0	1,203.0	0.35	13.0	0.43
13.0	1,391.0	0.32	14.0	0.38
14.0	1,480.0	0.27	15.0	0.35
15.0	1,542.0	0.23	16.0	0.31
16.0	1,518.0	0.19	17.0	0.28
17.0	1,465.0	0.15	18.0	0.25
18.0	1,382.0	0.12	19.0	0.23
19.0	1,309.0	0.10	20.0	0.21
20.0	1,246.0	0.08	21.0	0.19
21.0	1,193.0	0.07	22.0	0.18
22.0	1,150.0	0.05	23.0	0.17
23.0	1,117.0	0.05	24.0	0.16
24.0	1,094.0	0.04	25.0	0.15
25.0	1,081.0	0.04		
26.0	0.0	0.00		

Power, Efficiency and energy vs. wind speed

Data used in calculation, Air density: 1.165 kg/m3

Wind speed [m/s]	Power [kW]	Ce	Interval [m/s]	Energy [MWh]	Acc.Energy [MWh]	Relative [%]
1.0	0.0	0.00	0.50- 1.50	0.0	0.0	0.0
2.0	0.0	0.00	1.50- 2.50	0.0	0.0	0.0
3.0	0.0	0.00	2.50- 3.50	3.3	3.3	0.1
4.0	27.6	0.23	3.50- 4.50	20.7	24.0	0.5
5.0	82.7	0.35	4.50- 5.50	61.8	85.8	1.7
6.0	152.2	0.38	5.50- 6.50	135.4	221.2	4.5
7.0	276.7	0.43	6.50- 7.50	248.6	469.8	9.6
8.0	429.9	0.45	7.50- 8.50	385.7	855.6	17.4
9.0	601.0	0.44	8.50- 9.50	517.6	1,373.1	28.0
10.0	798.9	0.43	9.50-10.50	613.0	1,986.2	40.4
11.0	974.8	0.39	10.50-11.50	644.9	2,631.1	53.6
12.0	1,144.1	0.35	11.50-12.50	614.7	3,245.8	66.1
13.0	1,322.9	0.32	12.50-13.50	533.1	3,778.9	77.0
14.0	1,407.5	0.27	13.50-14.50	415.5	4,194.4	85.4
15.0	1,466.5	0.23	14.50-15.50	292.6	4,487.0	91.4
16.0	1,443.6	0.19	15.50-16.50	187.6	4,674.6	95.2
17.0	1,393.2	0.15	16.50-17.50	110.6	4,785.2	97.4
18.0	1,314.3	0.12	17.50-18.50	61.0	4,846.2	98.7
19.0	1,244.9	0.10	18.50-19.50	32.1	4,878.3	99.3
20.0	1,185.0	0.08	19.50-20.50	16.4	4,894.8	99.7
21.0	1,134.6	0.07	20.50-21.50	8.3	4,903.0	99.8
22.0	1,093.7	0.05	21.50-22.50	4.1	4,907.2	99.9
23.0	1,062.3	0.05	22.50-23.50	2.1	4,909.2	100.0
24.0	1,040.4	0.04	23.50-24.50	1.1	4,910.3	100.0
25.0	1,028.1	0.04	24.50-25.50	0.4	4,910.7	100.0





WindPRO is developed by Energi- og Miljødata, Niels Jernesvej 10, DK-9220 Aalborg Ø, Tlf. +45 96 35 44 44, Fax +45 96 35 44 46, e-mail: windpro@emd.dk

Figure 7.28 Power curve and efficiency values of Nordex 1500 kW wind turbine.

CHAPTER VIII
CONCLUSION

The study presented here is an attempt to promote wind energy in Turkey and to bridge the gap in order to create future Turkish Wind Atlas.

In order to utilize optimum wind power, a standard wind measurement mast was erected at the coordinates of 4243843 N and 465684 E (in UTM coordinate system) on the campus area of Izmir Institute of Technology. The mast height was 30 m and had two anemometers, one at 10 m and the other at 30 m, a wind vane at 30 m, and temperature, humidity and barometric pressure probes mounted on it. A data logger capable to collect and calculate wind speeds, wind direction and additional inputs for a thermometer, a barometer and a hygrometer was also mounted. Data were retrieved and transferred to a computer remotely. A solar panel and a battery were energy supplied sources for the equipments mentioned above.

Data collected from July 2000 to November 2001 on the measurement site. The measured data used for input into the WAsP and WindPRO programs were generally representative of the area. Mean speeds were 7.03 m/s at 10 m height and 8.14 m/s at 30 m height. It was found that prevailing wind direction was north (N) (on the campus area)

In addition to wind characteristics, wind probability distributions were found by using the proper models. Weibull approximation was found to be a better approximation than that of Rayleigh model.

Turbulence intensity was very low at north direction. This was very obvious result because of turbulence-free effect of open sea. The sectors that cover city center of Urla and surrounding hills had high turbulence. Turbulence-free character of the wind at prevailing direction was one of the most important results of the study.

The same softwares using collected data created wind energy and average wind speed maps of the campus area. The most convenient locations for utilizing wind power were determined. The most suitable turbines (600 kW and 1500 kW) have been selected and power productions of the turbines that are assumed to be installed at convenient locations were evaluated. The annual energy productions of the located forty-seven 600 kW turbines with a total capacity of 28.2 MW and twenty-six 1500 kW turbines with a total capacity of 39 MW have been calculated as respectively 100.3 GWh/year and 122.4 GWh/year.

The result derived from this study encourages the utilization of the wind energy potential on the Izmir Institute of Technology campus area. It's explicitly demonstrated the presence of high wind potential on this location.

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