All renewable energy (except tidal and geothermal power), and even the energy in fossil fuels, ultimately comes from the sun. About 1–2 % of the energy coming from the sun is converted into wind energy. This chapter explains the cause of wind flow and factors that affect the flow pattern. Understanding these is necessary for selecting proper locations for wind turbines.

2.1 Origin and Global Availability

The regions around the equator, at 0° latitude, are heated more by the sun than the rest of the globe. Hot air is lighter than cold air; it will rise into the sky until it reaches approximately 10 km altitude and will spread to the North and the South. If the globe did not rotate, the air would simply arrive at the North Pole and the South Pole, sink down, and return to the equator.

Since the globe is rotating, any movement on the Northern hemisphere is diverted to the right, if we look at it from our own position on the ground. (In the Southern hemisphere it is bent to the left). This apparent bending force is known as the Coriolis force, named after the French mathematician Gustave Gaspard Coriolis.

In the Northern hemisphere, the wind tends to rotate counterclockwise as it approaches a low pressure area. In the Southern hemisphere, the wind rotates clockwise around low pressure areas.

The wind rises from the equator and moves north and south in the higher layers of the atmosphere. Around 30° latitude in both hemispheres the Coriolis force prevents the air from moving much farther. At this latitude, there is a high pressure area, as the air begins to sink down again. As the wind rises from the equator there is a low pressure area close to ground level attracting winds from the North and South. At the Poles, there is high pressure due to the cooling of the air. Table 2.1 shows the prevailing direction of global winds.
The prevailing wind directions are important when siting wind turbines, since one would obviously want to place them in areas with the least obstacles from the prevailing wind directions.

### 2.2 Local Effects on Wind Flow

Winds are very much influenced by the ground surface at altitudes up to 100 m. The winds are slowed down by the earth’s surface roughness and obstacles. There may be significant differences between the direction of the global or geostrophic winds because of the earth’s rotation (the Coriolis force), and the wind directions near the surface. Close to the surface of the earth, the following effects influence the flow pattern of wind:

(a) **Sea Breeze**

Land masses are heated by the sun more quickly than the sea in the daytime. The air rises, flows out to the sea, and creates a low pressure at ground level which attracts the cool air from the sea. This is called a sea breeze. At nightfall there is often a period of calm when land and sea temperatures are equal. At night the wind blows in the opposite direction. The land breeze at night generally has lower wind speeds, because the temperature difference between land and sea is smaller at night.

The monsoon (specific period of the year the when majority of rainfall occurs) in India and all of South-East Asia is in reality a large-scale form of the sea breeze and land breeze, varying in its direction between seasons, because land masses are heated or cooled more quickly than the sea.

(b) **Mountain Breeze**

Mountain regions display many interesting weather patterns. One example is the valley wind which originates on South-facing slopes (North-facing in the Southern hemisphere). When the slopes and the neighboring air are heated, the density of the air decreases, and the air ascends towards the top following the surface of the slope. At night the wind direction is reversed, and turns into a down-slope wind. If the valley floor is sloped, the air may move down or up the valley, as a canyon wind. Winds flowing down the leeward sides of mountains can be quite powerful.

(c) **Wind Rose**

It can be noticed that strong winds usually come from a particular direction. To show the information about the distributions of wind speeds, and the frequency of the varying wind directions, one may draw a so-called wind rose as shown in Fig. 2.1 on the basis of meteorological observations of wind speeds and wind directions.
The wind rose presents a summary of annual wind data. The circular space can e.g., be divided in 16 sectors representing major directions from which wind might come. The number of segments may be more but it makes the diagram difficult to read and interpret. The concentric circles having percent values represent the probability of wind coming from any particular direction. In Fig. 2.1, the polygon in north direction goes slightly ahead of the 10 % circle, hence it can be concluded that at this location, the probability of wind coming from the North is roughly 12 %. The bars going up to the border of the polygon have a value tag with them. This value represents the mean velocity of wind when it comes from that particular direction. Again, in Fig. 2.1, the bar in the North direction says that when wind comes from the North it has an average velocity of 4.1 m/s. This graph shows that the strongest wind comes from the westward directions.

It should be noted that in popular terms, when we say that some site has ‘North wind’, this means that wind is coming from the North and not going to the North. Further to note is that wind patterns may vary from year to year, and the energy content may vary (typically by some 10 %) from year to year, so it is best to have observations from several years to calculate a credible average. Planners of large wind parks will usually rely of local measurements, and use long-term meteorological observations from nearby weather stations to adjust their measurements to obtain a reliable long term average.

2.3 Attractive Locations for Wind Energy

In Europe, the area close to the North Sea has the strongest winds. In the extreme North, a wind velocity of the order of 10–11 m/s is available at a height of 50 m. This velocity is very attractive for installation wind machines. The Southern part
of Europe also has wind energy potential but it has relatively less wind velocities, in the range of 3–8 m/s at the height of 50 m above the ground.

The Centre for Wind Energy Technology, India, has estimated a 50 GW potential of wind energy in India. This estimate is based on the current technologies and economics of wind energy for 50 m and 100 GW for 80 m hub heights. The Southern part of India is most attractive for wind energy. The wind energy map of India reveals that the maximum wind energy potential lies either in the Southern or Western part of India. In the states of Tamilnadu and Karnataka, there are sites having velocities in the range of 6–8 m/s at a 50 m height above the ground. But in the Western parts of India, close to the Arabian Sea as well as in the desert of Rajasthan, attractive wind energy locations also exist.

The wind data available from various agencies give a fairly good idea about attractive locations for wind energy installations. However, to get exact knowledge about certain locations, measurement of wind availability over several years would be appropriate. The reasons for this are explained in the next section.

2.4 Local Effects on Wind Flow

For the purpose of wind turbines, local wind is perhaps more important, since due to local effects, a site may have very low wind even if it is situated in a predominantly windy area. Major factors that govern local winds are, therefore, described in this section.

2.4.1 Roughness Length and Wind Shear

High above ground level the wind is influenced by the surface of the earth at all. In the lower layers of the atmosphere, however, wind speeds are affected by the friction against the surface of the earth. In the wind industry one distinguishes between the roughness of the terrain, the influence from obstacles, and the influence from the terrain contours, which is also called the orography of the area.

The more pronounced the roughness of the earth’s surface, the more the wind will be slowed down. In the wind industry, wind conditions in a landscape are referred through roughness classes or roughness lengths. The term roughness length is the distance above ground level where the wind speed theoretically should be zero. A high roughness class of 3 to 4 refers to landscapes with many trees and buildings, while a sea surface is in roughness class 0. Concrete runways in airports are in roughness class 0.5.
2.4.2 Wind Speed Variability

The wind speed is always fluctuating, and thus the energy content of the wind is always changing. Exactly how large the variation is depends both on the weather and on local surface conditions and obstacles. Energy output from a wind turbine will vary as the wind varies, although the most rapid variations will to some extent be compensated for by the inertia of the wind turbine rotor. Figure 2.2 shows short term variations in wind.

In most locations around the globe it is more windy during the daytime than at night. This variation is largely due to the fact that temperature differences, e.g., between the sea surface and the land surface, tend to be larger during the day than at night. The wind is also more turbulent and tends to change direction more frequently during the day than at night.

From the point of view of wind turbine owners, it is an advantage that most of the wind energy is produced during the daytime, since electricity consumption is higher than at night. Many power companies pay more for the electricity produced during the peak load hours of the day (when there is a shortage of cheap generating capacity).

At most locations, the wind may not be sufficient for producing power continuously for 2–3 days and sometimes even for 1 week.
2.4.3 Turbulence

It is normally experienced that hailstorms or thunderstorms in particular, are associated with frequent gusts of wind which both change speed and direction. In areas with a very uneven terrain surface, and behind obstacles such as buildings, a lot of turbulence is similarly created, with very irregular wind flows, often in whirls or vortexes in the neighborhood.

Turbulence decreases the possibility of using the energy in the wind effectively for a wind turbine. It also imposes more tear and wear on the wind turbine, as explained in the section on fatigue loads. Towers for wind turbines are usually made tall enough to avoid turbulence from the wind close to ground level.

2.4.4 Obstacles to Wind Flow

Obstacles to the wind such as buildings, trees, rock formations etc. can decrease wind speeds significantly, and they often create turbulence in their neighborhood. It can be seen in Fig. 2.3 that in case of typical wind flows around an obstacle, the turbulent zone may extend to some three times the height of the obstacle. The turbulence is more pronounced behind the obstacle than in front of it. Therefore, it is best to avoid major obstacles close to wind turbines, particularly if they are upwind in the prevailing wind direction, i.e., “in front of” the turbine.

However, every tower of a wind converter will work as such an obstacles and will have influence on the blade when it is coming before or behind the tower.

Obstacles will decrease the wind speed downstream. The decrease in wind speed depends on the porosity of the obstacle, i.e., how “open” the obstacle is. Porosity is defined as the open area divided by the total area of the object facing the wind. A building is obviously solid, and has no porosity, whereas a fairly open tree may let more than half of the wind through. In case of very dense trees, the porosity is less, say one third. The slowdown effect on the wind from an obstacle
increases with the height and length of the obstacle. The effect is obviously more pronounced close to the obstacle, and close to the ground.

(a) Reduction in Obstacles with Turbine Hub Height
The higher a turbine is above the top of the obstacle, the less wind shade will be produced. The wind shade, however, may extend to up to five times the height of the obstacle at a certain distance. If the obstacle is taller than half the hub height, the results are more uncertain, because the detailed geometry of the obstacle, (e.g., differing slopes of the roof on buildings) will affect the result.

(b) Distance between Obstacle and Turbine
The distance between the obstacle and the turbine is very important for the shelter effect. In general, the shelter effect will decrease as one moves away from the obstacle, just like a smoke plume becomes diluted as we move away from a smokestack. In terrain with very low roughness (e.g., water surfaces), the effect of obstacles (e.g., an island) may be measurable up to 20 km away from the obstacle. If the turbine is closer to the obstacle than five times the obstacle height, the results will be more uncertain, because they will depend on the exact geometry of the obstacle.

2.4.5 The Wind Wake and Park Effect
Since a wind turbine generates electricity from the energy in the wind, the wind leaving the turbine must have a lower energy content than the wind arriving in front of the turbine. There will be a wake effect behind the turbine, i.e., a long trail of wind which is quite turbulent and slowed down, as compared to the wind arriving in front of the turbine. The expression wake is obviously derived from the wake behind a ship. Wind turbines in parks are usually spaced at least three rotor diameters from one another in order to avoid too much turbulence around the turbines downstream.

As a result of the wake effect, each wind turbine will slow down the wind behind it as it pulls energy out of the wind and converts it to electricity. Ideally, therefore turbines should be spaced as far apart as possible in the prevailing wind direction. On the other hand, land use and the cost of connecting wind turbines to the electrical grid would force to space them closer together.

As a guideline for wind park design turbines in wind parks are usually spaced somewhere between 5 and 9 rotor diameters apart in the prevailing wind direction, and between 3 and 5 diameters apart in the direction perpendicular to the prevailing winds. In Fig. 2.4, three rows of five turbines each are placed in a fairly typical pattern. The turbines (the dots) are placed 7 diameters apart in the prevailing wind direction, and 4 diameters apart in the direction perpendicular to the prevailing winds.
2.4.6 The Tunnel Effect and Hill Effect

(a) Tunnel Effect

While walking between tall buildings or in a narrow mountain pass, it can be noticed that wind velocity increases. The air becomes compressed on the windy side of the buildings or mountains, and its speed increases considerably between the obstacles to the wind. This is known as a “tunnel effect”. So, even if the general wind speed in open terrain may be, say, 6 m/s, it can easily reach 9 m/s in a natural “tunnel”. Placing a wind turbine in such a tunnel is one clever way of obtaining higher wind speeds than in the surrounding areas. To obtain a good tunnel effect the tunnel should be “softly” embedded in the landscape. In case the hills are very rough and uneven, there may be lots of turbulence in the area, i.e., the wind will be whirling in a lot of different (and rapidly changing) directions. If there is much turbulence it may negate the wind speed advantage completely, and the changing winds may inflict a lot of useless tear and wear on the wind turbine.
(b) Hill Effect

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.

2.5 Selecting a Turbine Site

Looking at nature itself is usually an excellent guide to finding a suitable wind turbine site. However, some typical considerations are as follows:

(a) Wind Conditions

If there are trees and shrubs in the area, one may get a good clue about the prevailing wind direction. While moving along a rugged coastline, centuries of erosion which have worked in one particular direction can also be noticed. Meteorology data, ideally in terms of a wind rose calculated over 20–25 years is probably the best guide, but these data are rarely collected directly at the site, and there are many reasons to be careful about the use of meteorology data. Meteorologists 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. Unless calculations are made which compensate for the local conditions under which the meteorology measurements were made, it is difficult to estimate wind conditions at a nearby 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. In countries like Denmark, Germany, Spain, and in the Southern part of India, where a large number of turbines are found scattered around the countryside, manufacturers can offer guaranteed production results on the basis of wind calculations made on the site.

(b) Look for a View

It is often preferred 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 a rounded hill can be found to place the turbines, one may even get a speed up effect in the bargain.

(c) Soil Conditions and Transportation Facilities

Both the feasibility of building foundations for the turbines and road construction to reach the site with heavy trucks must be taken into account with any wind turbine project. Due to the large size of equipment and machinery, these sometimes become bottlenecks for the installation of systems.
To sum up the coverage on wind, it may be said that for taking a macro level decision such as around which city the installation should be planned, the global wind availability and published wind data may be used. However, for an exact siting of wind energy system, a micro level analysis would be necessary due to large variations caused by the local geographical details. Only in case of very high turbines, e.g., 130 m high, where local disturbances have nearly no effect, it may not be necessary to go into micro level detail. The exercise of finding an exact location for installation is termed as ‘micro-siting’ which requires actual measurement of wind data at the site.

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Basics, Technology and Operation
Wagner, H.-J.; Mathur, J.
2013, X, 106 p., Hardcover
ISBN: 978-3-642-32975-3