UCS REPORTS

Briefing Papers from the Union of Concerned Scientists

Assessing Wind Resources

A Guide for Landowners, Project Developers and Power Suppliers

By Michael W. Tennis

Steven Clemmer

and Jonathan Howland

This report is intended to guide prospective wind farm developers through the process of site assessment. It provides practical information on how to develop reliable estimates of the wind resource and electricity production at a given site. This includes information on how to measure wind speeds and direction; how to qualify your land's potential for wind projects; how certain variables affect wind production costs and return on investment; what information is typically needed by banks and investors to finance a project; and where to look for additional information. While our examples are based on Minnesota, the principles discussed can be applied to any state, particularly other parts of the Midwest.

Wind Resource Information Funnel

Primary questions that anyone considering a wind project must answer are: how strong are the winds at my site and how much energy will my prospective wind turbine produce in these winds. In this report, we will guide potential developers through the steps necessary to estimate the wind resources at their sites.

These refinements are produced by examining data from local, short-term measurement sites and regional, long-term records; analyzing factors relevant to wind resources like site exposure and wind roses (also known as speed and direction distributions); and getting consulting support. You make use of the wind

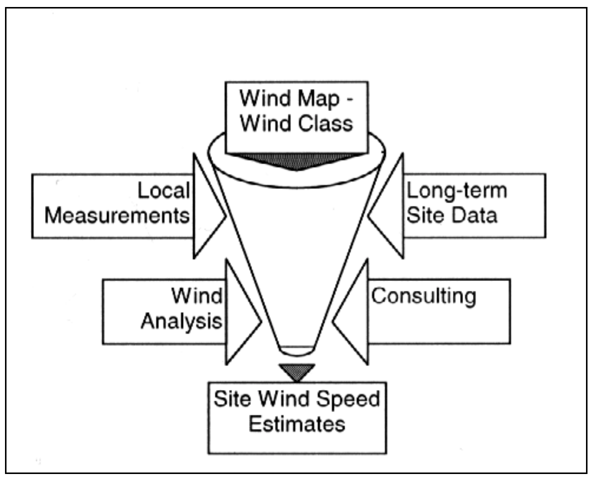


Figure 1. You might think of the wind assessment process as a funnel where rough estimates of wind power class from wind maps go in one end and more refined and precise estimates of site-specific wind speed come out the other end.

Scientists and citizens working for a healthy environment and a safe world.

resource data generated during the funneling process. The rough estimates at the beginning of the process are used to conduct a preliminary assessment of the feasibility of a wind project and determine whether further consideration of wind energy is warranted. The more refined estimates in the middle of the process can support your calculations of the cost and income potential from a wind project. The best estimates of site-specific wind speed can support a cash flow analysis of a wind energy investment, an investment prospectus for potential partners and a loan application to a lender.

Wind Resources

The wind resource powering a wind project is as fundamental to the project's success as rainfall is to alfalfa production. The objective of this report is to provide a concise body of wind resource data and information that will support the needs of wind trainers and potential wind project developers. This information is intended to clearly and effectively communicate what we really know and don't know about wind resources in Minnesota. Furthermore, we provide suggestions for how would-be project developers can use the data presented to perform a variety of critical assessments of their wind energy investment opportunities and how they might go about acquiring additional information that will increase the reliability of their assessments or increase their understanding of the specific wind resources available at their sites of interest. We present the material in a logical manner designed to allow you to quickly make the determination of whether wind projects are worth your detailed consideration.

The wind speed data for a site is critical to both the investor and the lender for a project. The investor must evaluate the long-term energy production and economic performance of the project to be assured that it generates an acceptable rate of return. The lender needs assurance that the revenues generated by the project month-to-month and year-to-year will be sufficient to cover the payment on any loan that is made. The project performance on the average is important to the investor, while project performance during poor wind months or years are important to the lender.

Impacts on a Wind Project

The power in the wind is the fundamental determinant of wind project success. Wind energy production from a particular wind turbine changes in proportion to approximately the square of the wind speed.[1] For this reason, if you over-estimate the wind speed at your site by 10 percent, you are over-estimating wind energy production from your project by 21 percent.[2] In more concrete terms, if you expect and need $10,000 of revenue per year to pay off your loan and earn some profit, you would only earn $8,100. At the very least, there goes your profit; at worst...

Fortunately, by developing a thorough understanding of the factors that influence the wind resource at a particular site—exposure, obstacles, height above the ground, etc.—you can include the inevitable uncertainties in your decision-making process and take action to get the most cost-effective performance from any project that you choose to develop.

What is the wind speed at my site?

Wind Speed and Project Value—the Critical Unknown

Just as good land is fundamental to successful farming, a good wind resource is essential to successful wind project development. Different locations across a state, county or section are likely to "possess" different wind resources. As a prospective wind project developer, one of your first priorities needs to be developing reliable estimates of the wind resources on the land that you control. Although wind data is not as readily available or as well understood as soil data, there is a reasonable and growing body of data that you can draw on to make this important determination.

In Minnesota and across the upper Midwest, public entities, usually state government, have been collecting measurements of wind speed and direction, air temperature and pressure data at prominent loca-

[1] The power in the wind is theoretically a function of the cube of wind speed. Wind turbines cannot extract all the power from the wind and, as a rule of thumb, actual power production is proportional to approximately the square of wind speed.

[2] If your estimate of wind speed is 110 percent of actual, then your estimate of wind energy production is 110 percent or 121 percent higher than actual. Therefore, your actual energy production will be approximately 83 percent of your estimates.

tions for a number of years. The number and sophistication of these measurements, as well as their usefulness in meeting the needs of a wind project developer, vary from state to state and from county to county.

The odds are that the existing measurement sites are not on or even near your property, so you will need to do some research to develop estimates of your wind resource that will satisfy yourself and your banker. The following sections will help you develop these estimates and give you suggestions on how to improve the reliability of the estimates, thus increasing your confidence in the rest of the analysis of a wind development opportunity.

The ideal wind project assessment data would be a decade long set of measurements of wind speed and direction along with air temperature and pressure taken above, below and at the exact height above the ground of the hub of the chosen wind turbine. Such a data set would allow you to estimate the energy production of a wind turbine at that site and to describe the variability in energy production, and ultimately revenue production, that you could expect from year-to-year and month-to-month and to do so with high reliability.

The wind resource assessment process described in this report is designed to allow you to take the less-than-ideal data that you are likely to have and develop reasonable and clearly explained estimates of all the wind parameters of interest. For example, if you have data for one or two years from a nearby measurement site, you need to determine what the long-term average wind year and "poor" wind years might look like. Alternatively, if you have long-term measurements taken 10 feet above the ground, you need to estimate how much faster the wind blows at 150 feet (wind turbine hub height) above the ground. Reliable and proven techniques are readily available to make the kinds of estimates that might be required, so don't despair.

Is the wind resource in my area sufficient to warrant serious consideration of a wind project?

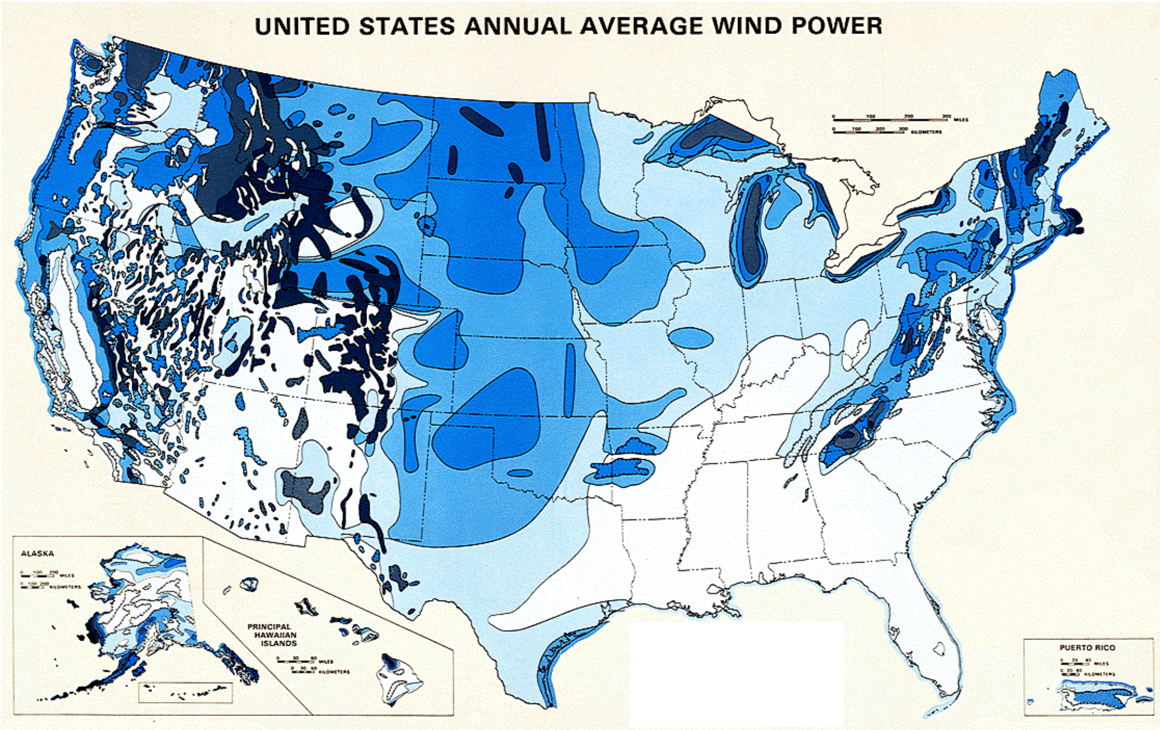
Using Existing Wind Maps to Estimate Wind Resource. Research performed and measurements taken over the last 25 years have shown that wind resources vary considerably over the upper Midwest and that some areas are just not appropriate for wind development at the current time. This information has been condensed into a number of wind resource maps or atlases which can give you a quick but general sense for the wind resource in your area.

The oldest of these wind maps was produced by Battelle Pacific Northwest Laboratory (PNL) for the US Department of Energy in the early 1980s (see figure 2). Even after a dozen or more years, this assessment remains the best indicator of wind resource potential for much of the United States. As you can see from the map, wind resources appear to be highest (Wind Class 4) in the northwest and western parts of the Midwest, declining to Class 3 in the central part of the region and ultimately to Class 2 in the eastern part of the Midwest.[3] The zone of transition between the most promising wind areas and those with less promise occurs quite abruptly in western Minnesota and northern Iowa, making the task for a project developer in that area quite challenging.

Fortunately, there are newer and somewhat more refined estimates of wind resources available in the Midwest which can give developers additional guidance regarding the wind resources in this area.

Project developers in Minnesota are very fortunate to have the results of more than a decade of the Minnesota Wind Resource Assessment Program (MNWRAP), sponsored by the Minnesota Department of Public Service (DPS)[4], and the state's electric utilities to draw upon. In 1981, the Western Area Power Administration (WAPA) began providing DPS with wind data that was collected in the WAPA service area. Later, in 1983, Northern States Power Company (NSP) began recording wind data at loca-

[3] Wind power class is defined as a range of wind power densities (in watts per square meter of swept rotor area, or area perpendicular to wind flow), at a given height above the ground.
[4] The DPS was merged into the Minnesota Department of Commerce on September 15, 1999.



CLASSES OF WIND POWER DENSITY

Wind Power Class		Density at 10m (33ft) W/m²	Speed at 10m(33ft) m/s	Speed at 10m(33ft) mph	Density at 50m (164ft) W/m²	Speed at 50m(164ft) m/s	Speed at 50m(164ft) mph
1		0-100	0-4.4	0-9.8	0-200	0-5.6	0-12.5
2		100-150	4.4-5.1	9.8-11.5	200-300	5.6-6.4	12.5-14.3
3		150-200	5.1-5.6	11.5-12.5	300-400	6.4-7.0	14.3-15.7
4		200-250	5.6-6.0	12.5-13.4	400-500	7.0-7.5	15.7-16.8
5-7		250-1000	6.0-9.4	13.4-21.1	500-2000	7.5-11.9	16.8-26.6

Figure 2. Source: *Wind Energy Resource Atlas of the United States,* Pacific Northwest Laboratory, March 1997

tions in Minnesota expected to have high wind potential. In March, 1994, data from all sites monitored by NSP was transferred to DPS. For each of these sites, DPS created databases of the available information to facilitate analysis.

In 1986, advanced equipment to monitor and record wind measurements (data loggers) were purchased by utilities and DPS and installed throughout the state. All loggers recorded wind speeds measured at the 30-meter level. In addition, some of the sites collected wind direction data. In retrospect, we have learned that many of these sites were not in ideal locations. In addition, the data loggers, advanced as they were for the time, did not operate as reliably as expected. As a result, the recorded data may not be as representative of the local wind resources as we would prefer. This phase of the WRAP program ended on December 31, 1995 and the results of the entire monitoring program are summarized in *Minnesota Wind Resource Assessment Program—October 1996 Report*, available from DPS.

A special study of wind and solar resources on and near Buffalo Ridge in southwest Minnesota was conducted by DPS between October 1993 and December 1995. The objective of the study was to collect wind and solar data simultaneously in order to study the possible benefits of combining wind and solar facilities to meet the demand for electricity in Minnesota. The Wind/Solar study was carried out with five more advanced data loggers that monitored wind speeds at 10, 20 and 30- meter levels. They also recorded wind direction, site temperature and solar radiation. The data from this program was much more reliable in large part because the data recorded on-site could be checked and collected via a cellular telephone link built in to the data loggers.

In January 1995, DPS began installing NRG 9300 cellular data loggers at various locations throughout the state. (See figure 3.) There are currently 24 active sites. At these sites wind speed data is collected at 30, 50 and 70-meter levels. Due to improved siting techniques, collection methods and equipment, the data collected at these sites and the Wind/Solar sites is superior to the data collected in the previous projects. This data forms a more reliable basis for the evaluation of wind energy projects.

The Tall Tower Wind Shear Study, a detailed study of the wind shear (the change in wind speed at different heights above the ground) began in May 1996. The purpose of the study is to develop computational methods for determining wind power potential at all levels of interest to the wind energy industry. The data from the Tall Tower Study will be correlated with data from the 14 active WRAP sites to determine the wind shear for regions surrounding the project sites. Each of the four Tall Tower sites monitors wind speeds at 10, 30, 40, 50, 60 and 70 meters and wind direction at 10, 30, 60 and 70 meters.

WRAP supports the development of Minnesota's wind resources by establishing and maintaining wind data collection sites in various locations throughout the state. WRAP collects and organizes the data for use by developers and others interested in Minnesota's wind resources, and provides an overall assessment of the state's wind resources as well as a map defining Minnesota areas on the basis of their wind energy availability.

Figure 3 shows the sites where the DPS has its most reliable wind measurement stations. The closer your site is to these measurement locations, the more reliable your estimate of local wind resources will be. In 1994, DPS contracted with Minnesota's Land Management Information Center (LMIC) to assist in mapping the wind resource information analytically. Figure 4 is based on this analysis of wind energy values from 24 WRAP sites for data collected through 1998. The map supports previous estimations that a large area of southwest Minnesota contains Class 4 and Class 5 winds. The energy values for the Red River Valley area, however, are lower than expected; Class 2 and Class 3 winds rather than the expected Class 3 and Class 4 winds (see map legend for wind class ratings.) In addition, some areas of the state, such as the north central, have not been monitored at all and could cause the interpolation process to produce less than meaningful results. Further wind resource monitoring is clearly necessary, especially in the Red River Valley area. You should locate your particular wind development site on this wind power map to obtain a rough estimate of the wind class for your project. If your land is Wind Class 5 or better on the map and your property is clear of trees in all directions and higher than its surroundings (i.e. 1-2 miles), then you are justified in looking further into wind project development. Conversely, if your area shows up as Wind Class 2 or less and your property is in a valley, surrounded by hills or tree covered, it is unlikely that a wind development on your site will be cost-competitive. If your area shows up as Class 4 on the map and is well exposed to the winds, you might have a viable wind project opportunity; however, you may need to invest extra resources in estimating the wind speeds at your site.

Qualifying Your Land's Potential for Wind Projects. It is important to remember that the wind resource at a particular spot is strongly influenced by local terrain, vegetation cover and man-made structures. Once you have a sense for the Wind Class in your local area, you should assess the exposure of your land to winds. Terrain features like valleys, bluffs and near-by hills can block or disturb wind flow, reducing the winds that reach your property. Tree cover or buildings on or near your property are also likely to reduce wind flow (more on this later). Since you will ultimately have to connect your wind project to the utility distribution or transmission system or, for a small project, to your home or farm, you should also consider the location of existing utility lines to your property.

The Union of Concerned Scientists used a computer-based mapping system to take better account of terrain elevation in the Midwest and produced the map in figure 5 as part of their *Powering the Midwest* project.[5] This map shows numerous locations across

[5] In UCS's analysis, the exposure of a particular location was determined compared to average elevation in a 7.5-mile (12-km) radius. Twelve kilometers was chosen because it is larger than the scale over which winds may be affected by major features such as an abrupt transition from water to land or an abrupt increase in terrain elevation but not so large that significant details of geography are lost. A smaller radius would not distinguish the tops of hills from the surrounding terrain, whereas a larger radius might encompass several hills within the averaging area.

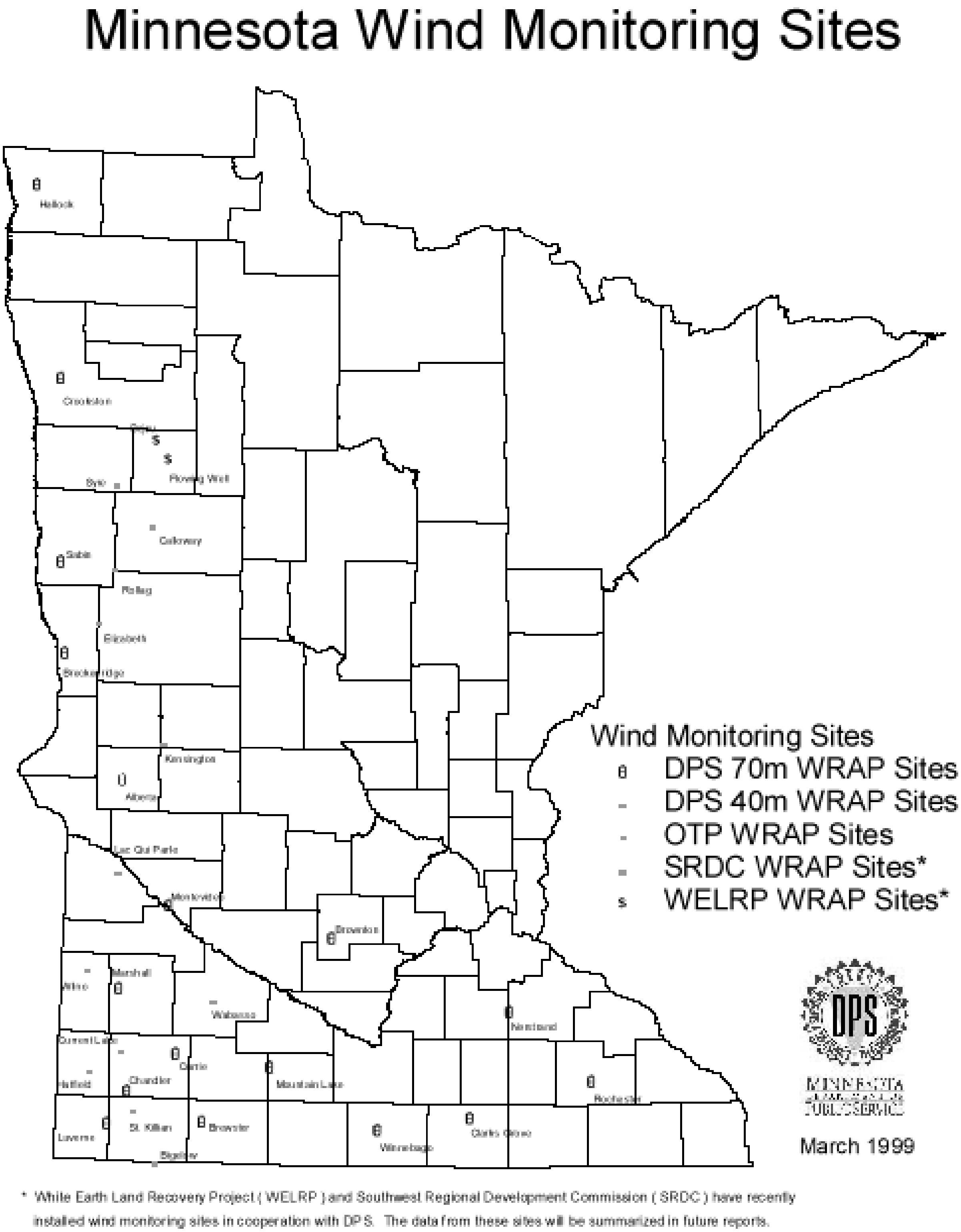


Figure 3.

Minnesota where local terrain is elevated above the surroundings and is well exposed to the wind classes shown in the DPS map above. Exceptional terrain exposure could produce local wind classes in excess of those shown in the DPS map. Again, locate your property on the terrain exposure map. If your site has good or better exposure, you would expect wind resources comparable to those mapped by the DPS. If your site is not well exposed, you may expect wind resources to be less than indicated by the DPS map.

The wind maps discussed earlier present wind resources in terms of wind power class. In order to develop estimates of the energy production and, ultimately, the economic benefits and costs of a wind investment, you need to translate your wind power class into a range of possible wind speeds. This wind speed range can then be used in the process and spreadsheets described later to generate a range for wind turbine energy production estimates. Table 1 shows the wind speed ranges at heights of 98 feet (30 meters) and 164 feet (50 meters) above the ground for each wind power class.

Your wind investment should make economic sense when you assume wind speeds at the low end of the wind power class range. For example, if your site

Union of Concerned Scientists Terrain Exposure Map

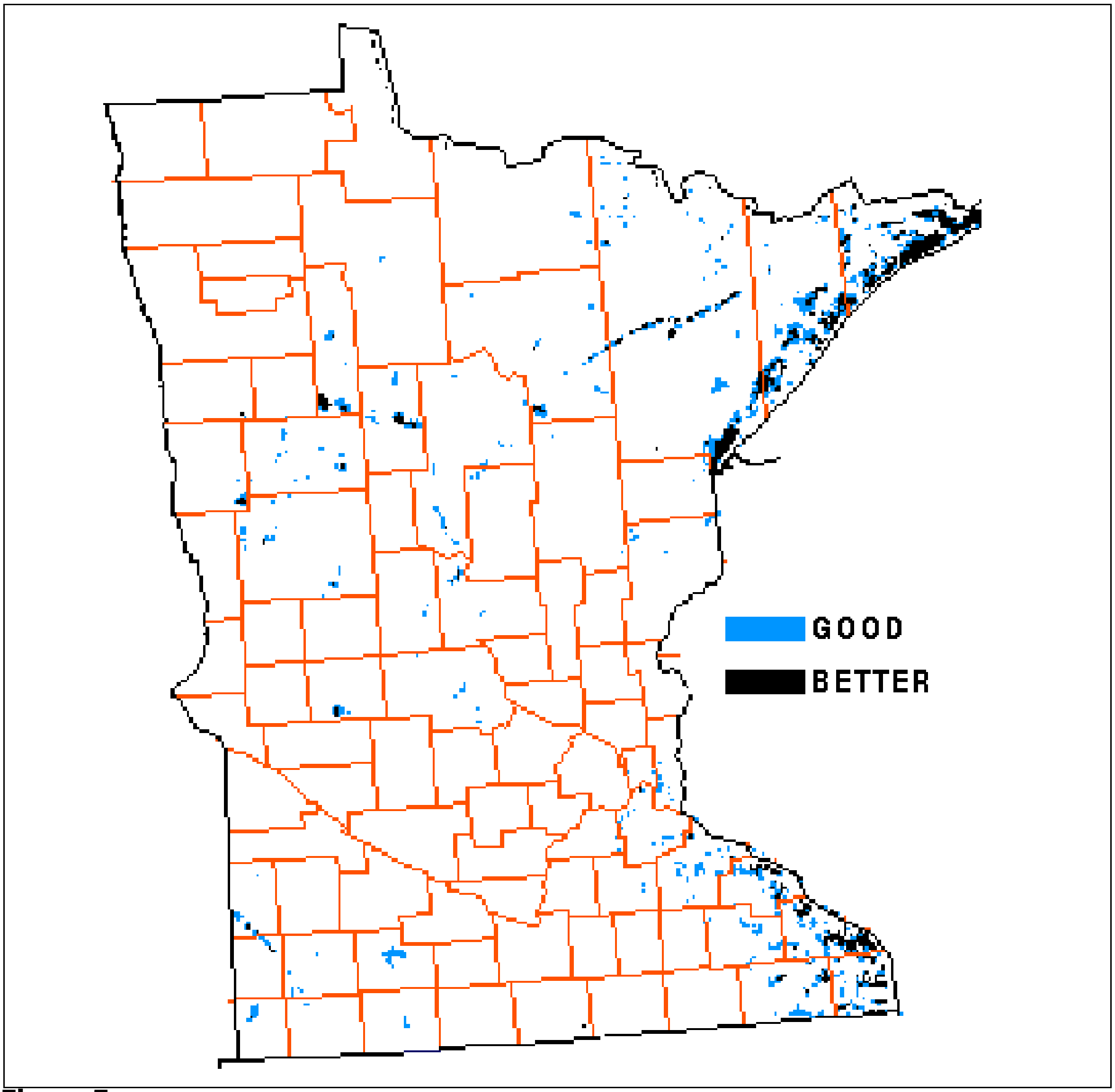


Figure 5.

Table 1. Conversions from Wind Power Class to Annual Average Wind Speed

Wind Class	At 98 ft (30m) Height		At 164 ft (50m) Height	
	Power*(W/m^2)	Speed (mph)	Power*(W/m^2)	Speed (mph)
1	0-160	0-11.4	0-200	0-12.5
2	160-240	11.4-13.2	200-300	12.5-14.3
3	240-320	13.2-14.6	300-400	14.3-15.7
4	320-400	14.6-15.7	400-500	15.7-16.8
5	400-480	15.7-16.6	500-600	16.8-17.9
6	480-640	16.6-18.4	600-800	17.9-19.7
7	>640	>18.4	>800	>19.7

*Wind power density is expressed in watts per square meter (W/m^2) of swept area, or area perpendicular to wind flow.

appears to be in Class 5, then the attendant annual average wind speeds at a height above the ground of 98 feet on your well-exposed site could range from as low as 15.7 mph to as high as 16.6 mph. In order to obtain a conservative, preliminary determination of the viability of a wind investment at your site, you should evaluate project economics at an average annual wind speed of 15.7 mph. It would be prudent to evaluate economics at a wind speed 10 percent or 1.6 mph lower 14.1 mph just to understand what the impact of over-estimating wind speeds can be. Evaluate project economics using wind speeds of 16.0 to 16.6, the upper half of the wind power class, only to get a sense for the potential up side of this investment. We are not doing you or wind energy any favors by overestimating the available wind resource.

Table 2. Desirable Data from Nearby Wind Measurement Sites

- Site elevation
- Monthly average wind speed
- Wind rose (wind speed and direction frequency data, showing directions from which the wind is strongest and weakest)
- Site exposure (local terrain—hills, valleys, etc., vegetation cover, and manmade structures)
- Height(s) above ground
- Data recovery (number of hours of valid data vs. total possible hours)
- Data record (year and months with measurements)
- Site location with respect to your property (wind speeds generally increase to north and

Collecting Wind Resource Information from Nearby Sites. Wind class information from wind maps is most useful in making a preliminary determination of the viability of your wind project. Once you convince yourself, based on wind map estimates, that you might go forward, you should then scour your area for good quality wind measurement information.

One of the simplest and least-costly ways to begin improving your estimate of the wind resources at your location is to collect information from nearby sites where wind resource measurements have been taken.[6] If you choose to have a consultant conduct this work for you, the following sections should assist you in defining the consultant's scope of work and evaluating the quality and reliability of the results. Table 2 provides a checklist of the data that you should try to acquire.

Once you have found wind measurement data from a nearby area, you need to determine if the data sets are valid and reliable and whether they are at least somewhat representative of your site. In general, if the measurement system accurately collected wind data 80 percent or more of the time and if the site is located on well-exposed terrain, well removed from hills, valleys, bluffs or trees, the data set is appropriate to help you make an informed decision. If the measurement location is near significant obstructions

[6] At this point in your evaluation, you might wish to solicit the services of an expert in wind resource assessment to develop estimates of the wind resource at your site. Independent consulting meteorologists are available to conduct this work. Alternatively, and with some caution, you might call on wind turbine marketers to assist you in this task. At some point in the future, we might expect common resources like the agricultural extension service or DPS to provide this type of consulting to interested project developers.

Wind Assessment for Smaller Systems

In Europe, the WINDATLAS-SYSTEM is used to project the performance of turbines having standardized power curves, for areas between locations with well-documented wind resources. This software system has essentially eliminated the need for wind resource measurements at prospective turbine sites. Site projections and economic decisions can be made with the help of the WINDATLAS-SYSTEM in a matter of hours, instead of the months or years that might be required to perform conventional wind resource measurements at a prospective wind turbine site.

The WINDATLAS-SYSTEM depends on two key elements: wind statistics from long term monitoring stations and accurate mapping of the terrain and barriers surrounding the prospective turbine sites. It is hoped that data from existing and on-going wind resource assessment programs in the United States can be utilized for wind statistics in the upper Midwest. Once these wind statistics are in place, a Wind Atlas can be made for the upper Midwest and we will be able to take advantage of the WINDATLAS-SYSTEM.

(Some wind turbine suppliers offer this type of assessment to prospective buyers.)

to wind flow or the monitoring equipment captured less than 50 percent of the data, it is not appropriate to use in the assessment of your own site.

Once you have validated the data, you use it to estimate the wind resource at your site. This task is critical to your overall evaluation of the wind investment and should receive considerable attention. The larger the project or investment under consideration, the larger and more expensive the effort that is warranted.

There are a number of factors that influence the complexity of this task and the ultimate reliability of the result. The complexity or roughness of the terrain at your site and at the site where measurements were taken is very important. In California, where wind projects are constructed along the ridgetops of some very rugged terrain, developers of large projects have reported installing one wind measurement system (anemometer) for every two or three turbines to acquire wind resource data reliable enough to satisfy lenders and investors. In the Buffalo Ridge area, you might have seen five or six wind measurement systems operating across the area that was ultimately occupied by the 73 turbines of the first development in 1994. For installations of single, small machines, site specific measurements are often forgone and decisions are made based on measurements taken at other sites and the judgment of the developer and a local wind turbine sales person.

In the upper Midwest, particularly away from river valleys or prominent geological features, we anticipate that reliable wind estimates can be developed using relatively simple averaging or extrapolation techniques.

One promising technique has been developed and used extensively in Europe to assist local landowners in evaluating the feasibility of clusters of community-owned wind turbines. This computer-based assessment basically takes site data like that listed in the table on the previous page for both the wind project site of interest and wind measurements of nearby sites and generates wind resource estimates at the target site based on the principles developed in the European Wind Atlas. In Europe, where the wind community has been using this approach for some time, prospective owners, wind turbine sales persons and lenders have come to trust and rely on this technique. In the early stages of wind development in the Midwest, this and other techniques will need to be tested and proven so that buyers and lenders can achieve the same level of confidence as their European counterparts.

Should I take measurements at my site?

Site-specific measurements give the most reliable estimates of the wind resources for a project; however, they can be quite costly and require, at a minimum, six months to several years to complete. As a result, deciding whether or not to undertake a measurement program hinges on an assessment of the costs and benefits of such an effort.

Discussions with wind resource assessment experts suggest that you might be able to contract for four to six months of measurements from a tower of approximately 100 feet (30 meters), along with some consulting to evaluate this short measurement record with respect to long-term data for a cost of $1,500 to $3,000. For individuals considering single-farm wind turbines, it might cost $20,000 to $35,000 and generate $600 to $1,680 per year in revenue. This investment, amounting to 5-15 percent of your wind turbine investment, might be burdensome. On the other hand, for larger wind turbines and clusters of wind turbines where investments would be at least several hundred thousand dollars and annual revenues would be at least tens of thousands of dollars, an added expense of $1,500 to $3,000 may be better justified.[7] A systematic assessment of the monetary benefit of conducting on-site measurement programs is difficult to conduct.

Indeed, many of the benefits might be difficult to value in monetary terms (e.g., getting faster approval and a more favorable interest rate on a bank loan).

Measurement Programs.

Large Wind Projects: Multimillion Dollar Investments. The measurement program that you undertake should carry a cost that is consistent with the overall size of your potential investment and with the uncertainty of the resource in your area. If you are contemplating a multi-million dollar wind project in an area where no wind measurements have been taken, it would be wise for you to take at least two years of measurements with a multilevel meteorological tower in order to confirm your wind resource. If the terrain surrounding your site is rugged, it may be appropriate to install several anemometers across the site at wind turbine hub height to assure yourself that you have a reliable estimate of the variation of wind speed across your site. [8] In fact, it is quite common for the lenders to large wind projects to require rigorous wind resource assessment efforts before approving loans.

Medium Wind Projects: $1–3 Million Investments. For projects of this scale (1-4 MW or 2-6 wind turbines), you should seriously consider a short-term measurement program including anemometers at several heights and a measurement period lasting at least a year, combined with a careful wind data interpolation effort. Such an effort would eliminate a great deal of uncertainty in your estimate of wind resources and give you and your banker data that can confidently be used to evaluate an investment of this magnitude. The closer, more representative and more reliable the nearby measurements are, the more confidence you can have in your assessment of wind resources.

Small Wind Projects: Less $1 Million. For small projects (one or two machines in the 250 kW to 750 kW size range), large investments in on-site measurements are more difficult to justify. However, the revenue generated by projects this size could range from $25,000 to $100,000 per year or more based on capital investments of $200,000 to $800,000; investments of a few thousand dollars in wind resource assessment and validation are, therefore, certainly warranted. For less than $5,000, you should be able to have a contractor install an anemometer on a tilt-up tower at or near hub height, collect up to six months of wind data and carry out a careful interpolation with existing wind measurements from other representative sites.

Home or Farm Sized Wind Projects: $5,000–40,000. If your intent is to install a small wind turbine sized to supply a portion of the energy needs of your home or farm, on-site wind measurements are less common. In this case, you must rely on extrapolation or projections of the wind speed at your site. You should consider investing $500 or more in a consultation with a wind assessment consultant with a track record in your part of the state. These practitioners are not certified as yet, so you should be advised to carefully review their credentials and references before hiring them.

Measurement Program Help. Many contractors offer measurement programs as part of their services. As wind projects become more common in the Great Plains, it is possible that local economic development or agricultural extension services will add wind measurement planning and support to their lists of services. It is also possible that utilities or public agencies interested in promoting wind energy will offer anemometer loan programs whereby interested

[7] For representative project costs and revenue figures for wind turbine installations 7 meter/10 kW, 30 meter/225 kW and 40 meter/500 kW in size see Nancy Lange and William Grant, Izaak Walton League of America, *Landowner's Guide to Wind Energy in the Upper Midwest*, 1995, pages 15-26, online at http://www.me3.org/issues/wind/iwlaguid.html.

[8] Lenders to large wind projects often hire independent meteorologists to validate the developer's estimates of the available wind resources.

would-be developers would borrow relatively simple equipment and take site-specific measurements.

As the wind energy market develops in the Midwest, we expect some of the more traditional rural economic development agencies or agricultural extension services to develop or acquire expertise in this type of assessment.

Site Inspection. In California where wind projects have been developed for 15 years or more, a number of meteorologists, engineers and others have developed expertise in evaluating the wind resources at potential wind project sites. Several of these practitioners have been brought to the Midwest to support the development of the large projects on Buffalo Ridge. Some Minnesotans have also begun to offer site evaluation and inspection services to prospective project developers. Wind turbine sales organizations are also likely to offer this type of service; however, the prospective buyer should understand the biases that a company marketing the equipment might have.

What information do my banker and I need?

Average Annual Versus Year-to-Year Variations. Wind turbines will be like crops and have good years and bad years. Your banker will want a realistic assessment of the energy production, and revenue production of your project during a poor wind year, in order to be sure that you can cover any loan payment that you have. Different bankers are likely to have different perspectives on this issue; however, all evaluations need to rest on an assessment of the year-to-year variations in wind availability over the long term.

Because we do not yet have 20 or 30 years of wind measurements in good wind energy areas around the state, we must take an indirect approach to determining how much the winds at our wind site vary year to year. This approach relies on a comparison of short-term wind records at promising sites with those at reference sites where wind measurements have been taken for many years, often airports or National Weather Service installations. Ideally, the year-to-year changes seen at wind sites will be mirrored by changes at the reference sites.

As an example, consider figure 6 showing the annual average wind speed for the years 1961 to 1995 for the Minneapolis airport along with comparable averages for more recent years from Holland, St. James, and Rochester, Minnesota. All data is normalized; that is, each annual average wind speed value is divided by the long-term average from the site. The resulting chart shows how much, in percent,

Minimum Requirement—Site and Wind Resource Evaluation Report

At a minimum, you should expect the following from a site evaluation contractor:

1. Site description—including property description, site elevation above sea level.

2. Site map—including property lines, topographic contours, locations of existing electricity distribution and transmission lines and roads, obstacles to wind flow—trees, terrain, buildings, etc.

3. Wind statistics from nearby representative wind monitoring stations—including:

- Measurement site description, including location relative to proposed site, elevation above sea level and exposure;
- Annual average wind speed for as many years as possible up to twenty;
- Monthly annual winds based on as long a record as possible;
- Wind speed and wind power roses showing frequency of winds over range of wind speeds or power levels from different directions; and
- Wind shear coefficient or annual average wind speeds at all anemometer levels.

4. Projected annual wind speed at the site, along with an explanation of how the projection was determined.

5. Annual average wind speed that will be exceeded 70%, 80%, and 90% of the time, along with a description of the method for determining the distribution of wind speeds.

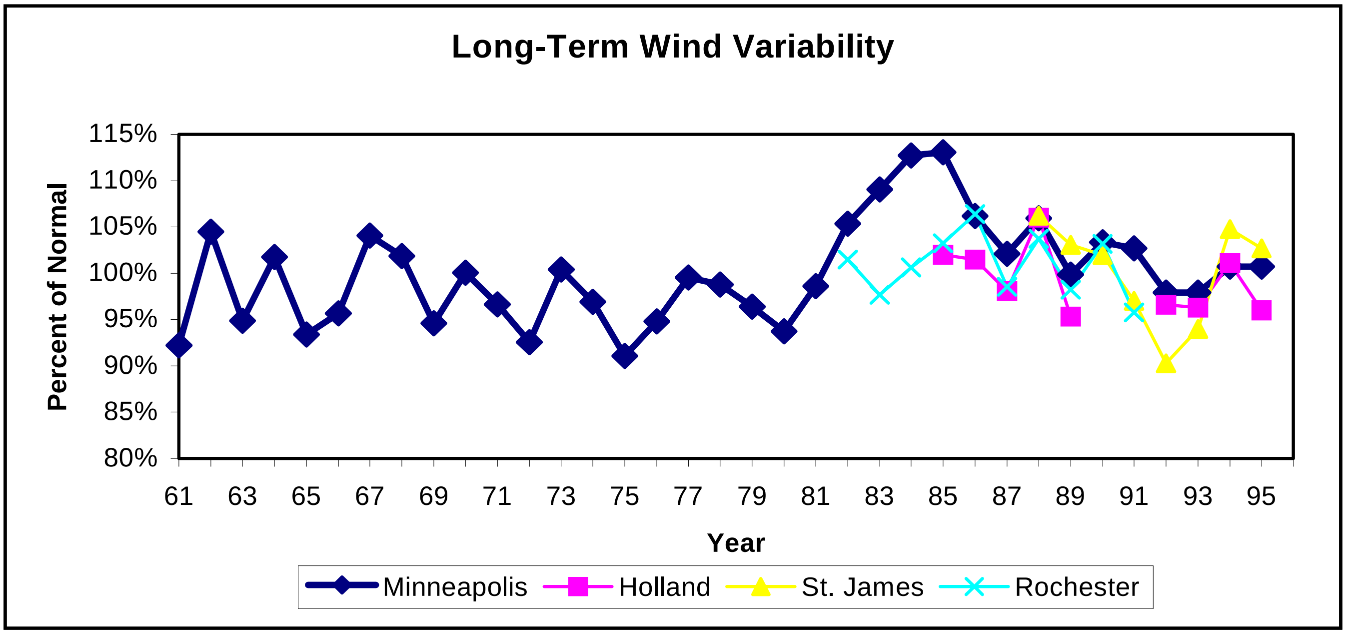


Figure 6.

the annual average wind speed in any year might vary from the long-term average.

Then, let's take a closer look to explore whether the wind resources at other sites follow a similar long-term pattern as those at Minneapolis. See figure 7, which shows the years 1982 through 1995 from figure 6.

When we compare the record from Minneapolis with wind measurements taken for wind power purposes across the state, we can see that the annual average wind speeds at diverse sites including Holland, St. James and Rochester follow a similar pattern to those at Minneapolis. The wind speeds at the other sites drop in 1987, 1989 and 1992, when wind speeds in Minneapolis drop, and increase in 1985, 1988 and 1994, when they climb.

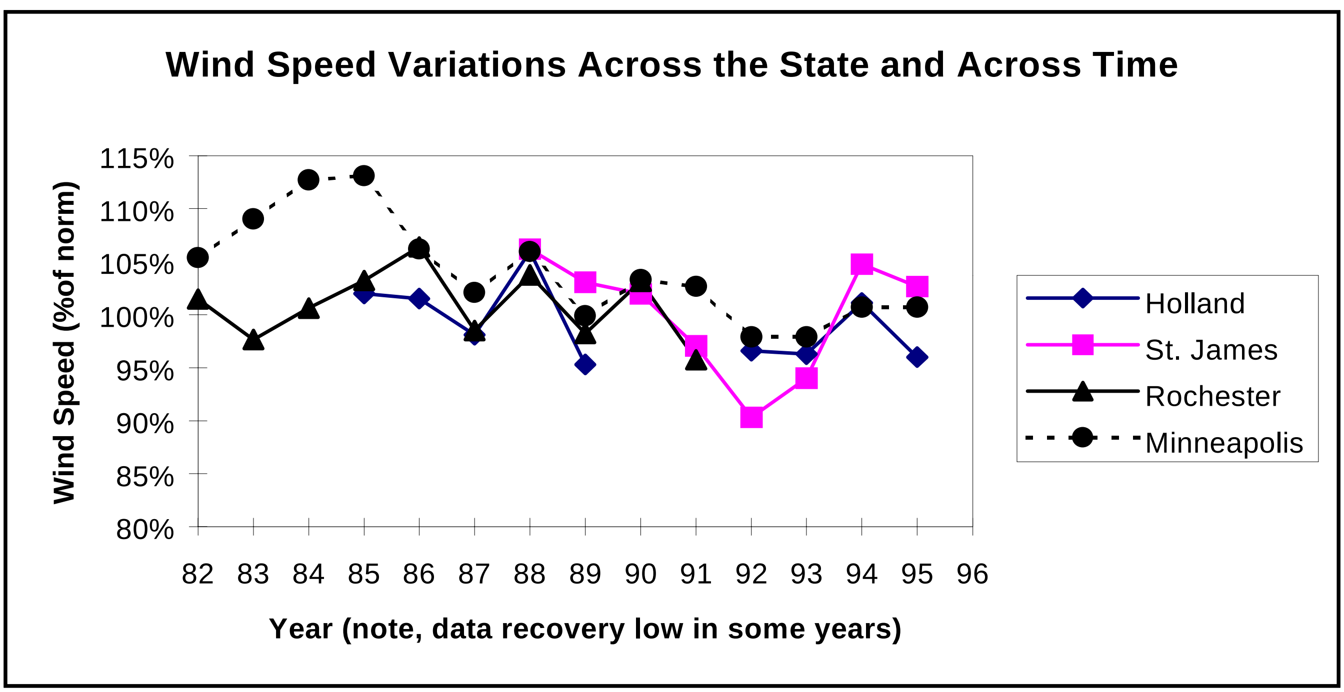


Figure 7.

This indirect assessment of good and bad wind years at our specific sites requires two steps. In the first, we attempt to determine whether the years of measurement at the windy sites represent the long-term averages at those sites or whether they are, on balance, better than average or worse than average. If they are not representative, we should make adjustments so that they are. This step is intended to avoid over or under-estimating the long-term average wind resource at the site because the nearby measurements upon which we rely do not accurately reflect a long-term data record. It will also allow us to adjust the local site data up or down to better reflect the long-term average.

The data since 1961 for Minneapolis show that annual average wind speed tends to cycle through several years with above-average values and several years of below-average values. The lowest value in the entire record for Minneapolis is 91 percent of the long-term annual average, while there are six years when the average annual wind speed was 95 percent or less of the long-term average.

Another way of expressing this information is as a frequency distribution showing the percent of the time or probability that annual wind speeds will deviate from the long-term average by more than a certain amount. Your loan officer will be concerned about the lowest winds thus, electricity generation and gross revenue from power sales that your project will experience once or twice over the term of the loan? For example, on a ten-year loan, the question is: what is the worst wind year to be expected over the entire loan? In terms of probabilities, the question is: what wind speed is likely to be exceeded 90 percent of the time?

Figure 8 shows the probability distribution of all the measurements at the Minneapolis airport for the period from 1961 through 1995. If the loan officer wants to base the loan "coverage ratio" on the worst year in 10 percent probability, this chart would suggest that the annual average wind speed would be between 91 percent of the long-term average the worst year in the measurement record to 94 percent of the long-term average. In other words, a bank might base its determination of loan coverage ratio considering annual average wind speeds that are 91–94 percent of the long-term average at a site. As long-term data records accumulate at the more representative sites maintained by the DPS, we would encourage wind developers to refer to this data in answering this

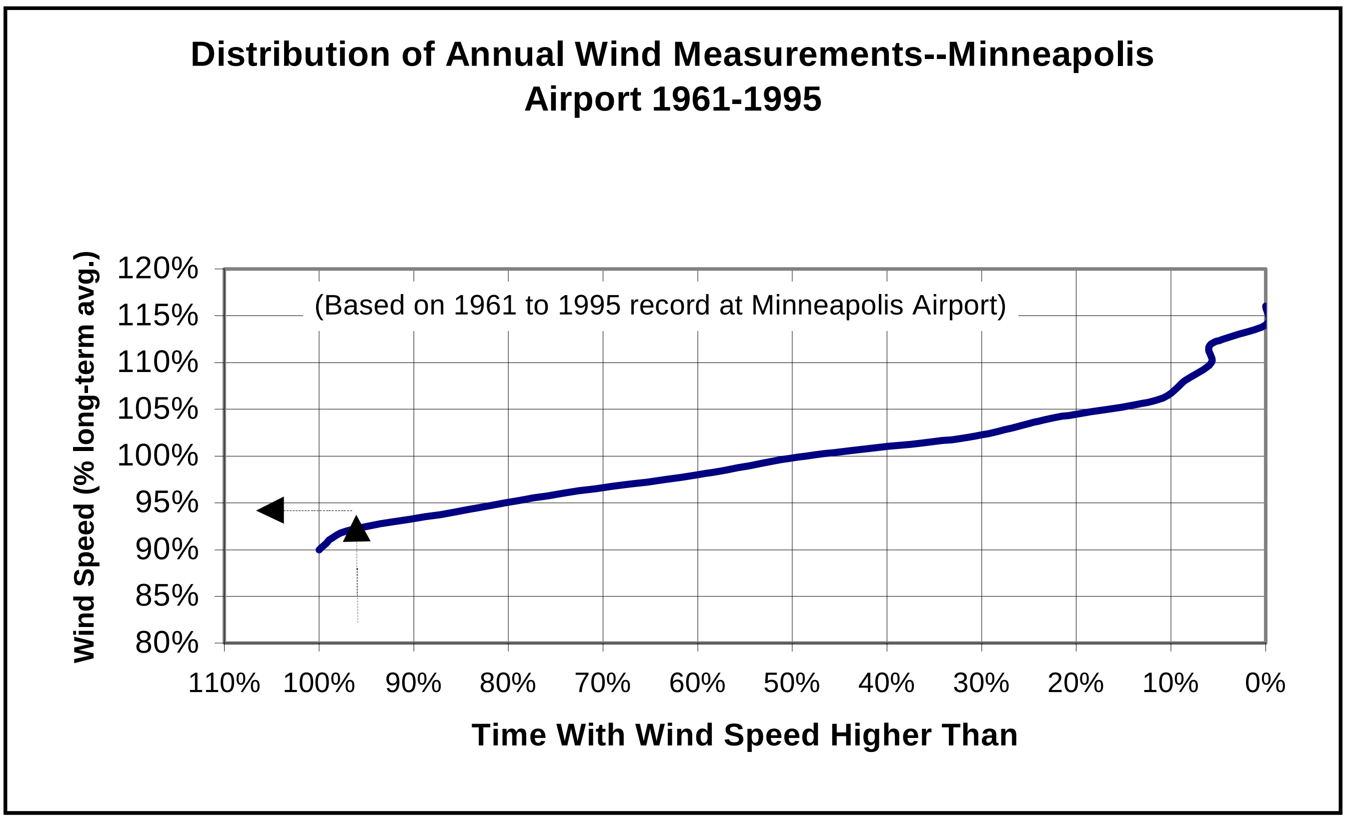


Figure 8.

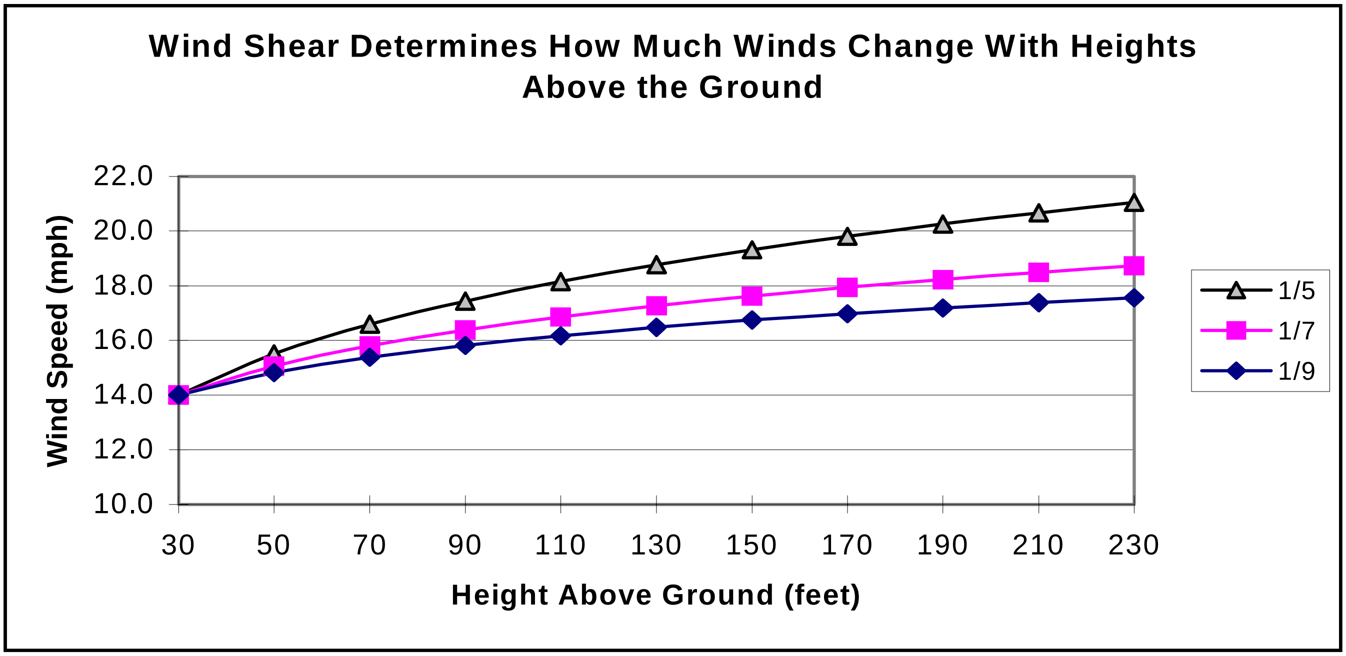


Figure 9.

question.

Although the lender on a project will be particularly concerned with the "downside" of annual wind performance, there is an "upside" to this situation as well. Based on the Minneapolis wind record, a project operator could expect wind speeds five percent higher than the average 17 percent of the time or nearly two years out of every 10.

Wind speed and tower cost increase with height. How high should my tower be?

The Benefits/Costs of Increasing the Height of Your Wind Turbine Tower. One of the first things that wind researchers learned when they began measuring wind speed for wind projects was that wind speed generally increases as you get higher above the ground. Basically, the wind is slowed down by friction where it comes in contact with the ground or ground cover. As a result, wind speeds increase at increased heights above the ground at wind sites. This phenomenon, known in the wind industry as wind shear, presents wind developers with an opportunity to improve the overall economics of their investment by putting their wind turbines on taller towers. As a developer, your task is to determine if the extra cost associated with a taller tower will pay off in increased wind energy production and revenue. In this section, we will describe wind shear, its effect on wind energy investments and the uncertainties surrounding estimating wind shear.

For years, wind developers used the rule-of-thumb that wind speed increased over a site according to the one-seventh power law. The mathematical equation for this rule-of-thumb is:

$$\text{Velocity}_{\text{hub ht.}} = \text{Velocity}_{\text{anem.ht.}} \times (\text{hub ht./anem.ht.})^{1/7}$$

Figure 9 shows a graph of wind speed as a function of height above the ground, assuming the wind speed at 30 feet is 14 mph and different power law coefficients.[9]

These coefficients—1/9 (0.111), 1/7 (0.143) and 1/5 (0.200)—are all consistent with measurements that have been taken at wind sites across the country. For reference, the impact on average wind speed of increasing the height of your wind turbine tower from 100 feet (approximately 30 meters) to 130 feet (approximately 40 meters) would be 4.2 percent, under

[9] The coefficient of a power law expression is the exponent of the equation, $V^2/V^1 = (H^2/H^1)^{\text{coefficient}}$.

the 1/7th power law. If wind shear is greater than 1/5th power, average annual wind speeds increase by 5.9 percent. If on the other hand, wind shear is lower than typical 1/9 power, the wind speed increase would only be 3.3 percent. Remember that wind turbine energy production increases by approximately the wind speed increase squared, meaning that wind energy increases associated with the tower height increase from 100 feet to 130 feet would be 6.6 percent, 8.6 percent and 12.2 percent respectively. If the cost of increasing the wind turbine tower height from 100 feet to 130 feet increases the total project cost by less than eight percent, then the extra investment in the tower is justified by the increase in wind energy production if wind shear follows the 1/7th power law or higher. (This information should be used in specifying the wind turbines for a project and in estimating their annual energy production.)

How does wind speed change with height (wind shear) at my site?

During the last few years, researchers have been making measurements of wind shear at promising wind energy locations using meteorological towers with several levels of wind measuring equipment. We can get estimates of the wind shear coefficient in the area near the meteorological tower by comparing the wind speed measurements hourly and monthly or annual averages at different heights above the ground.

Figure 10 shows the calculated wind shear (alpha) coefficient for 12 Minnesota WRAP sites that have been in operation since 1995 or earlier. This figure shows that instead of the 1/7 coefficient so often referred to for determining the wind shear in an area, it might be more appropriate to use a 1/5 or 1/4 coefficient for wind shear calculations in Minnesota. This figure also indicates considerable variation in wind shear from location to location and at different heights above the ground. In general, the more open and flat the area surrounding a potential turbine site is, the less wind shear there will be. Sites with significant nearby obstructions will show greater wind shear values at heights just above these obstructions.

Wind turbine vendors most often offer towers that place turbine hub height in the range of 98–164 feet (30–50 meters), so you should use the coefficients shown by the white bars for your calculations. However, in recent years, wind developers

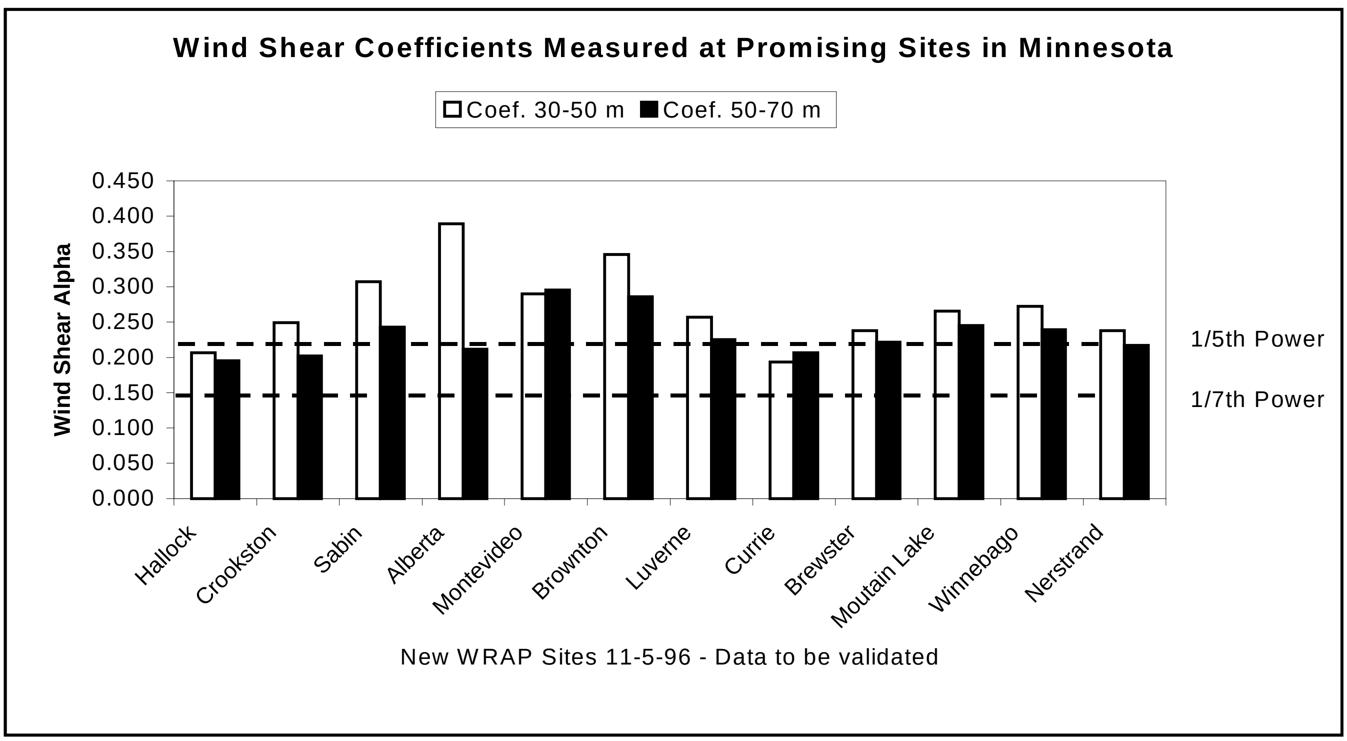


Figure 10.

have installed turbines on towers as high 230 feet or 70 meters, and towers as high as 100 meter towers are being developed. Under those circumstances, you might need both coefficients to estimate the increase in wind speed produced by increasing wind turbine tower height.

If there are meteorological towers nearby and comparable to your site, you should use the average of the wind shear coefficients from these sites in your calculations of average annual energy production and in assessing whether increasing wind turbine tower height increases the pay-off for the investment. If the terrain or ground cover around your site is less favorable than that around the meteorological towers, you should use a conservative value for the power law coefficient 1/7 or smaller unless a wind resource specialist can argue persuasively for a higher, less-conservative value.

For the purposes of obtaining a bank loan, you might be justified in using one of the lower wind shear coefficients measured at representative sites. In the absence of comparable measurements, you should use the 1/7th power law expression because it is widely accepted and likely a bit conservative at a well-exposed site in the Great Plains.

How do I choose the specific spot for my wind project?

Choosing the actual spot on your property for your wind project may be a tradeoff between the most windy and well-exposed location and the distance that location is from either the utility distribution lines or your home or farm electrical service. In this section, we will give you a number of pointers to help assure that you can identify pluses and minuses of any specific location and avoid selecting sites where wind flow to your project is severely compromised.

Obstacles and Wind Roses. In an ideal world, your project site would be the most prominent piece of property for miles and would have no obstructions to wind flow nearby hills, valleys, trees or buildings within 2,000 feet. As a practical matter, your site might not be perfect so you need guidelines to avoid bad sites and highlight your best options. Fundamental data to support this process comes from a wind speed rose or wind power rose, a chart that conveniently shows where the strong and weak winds come from over the course of a year. In the upper Midwest, winds are generated by large-scale weather patterns which move in predictable patterns across the region. As a result, the strongest winds are most likely to come from the westerly directions northwest, west and southwest. Figure 11 shows both a wind speed rose and a wind power rose for the Ruthton/Holland site in southwest Minnesota.

Clearly, during the period of record for the Holland site, the strongest winds were observed coming from the south/southwest direction with additional strong winds from the southwest, northwesterly, and north directions. In areas of the Midwest subject to similar wind regimes, it is essential that wind project sites be very well exposed to these dominant directions. Conversely, winds are infrequent and weak from the easterly directions, suggesting that wind flow obstructions in those directions will have little adverse effect on energy production at a site.

Wind Turbine Wake Effects If Siting More than One Machine

If you are considering a project with several wind turbines, you should use the wind roses to assess how much space to leave between wind turbines. Since wind turbines are themselves obstacles to wind flow, they leave "wakes" in downwind directions where wind energy is depleted for considerable distances. Rules of thumb suggest that wind turbines in the dominant wind power directions should be at least 8–10 wind turbine diameters apart.[10] In the directions where winds are weak, spacing of 3–5 diameters can be acceptable. This means that wind turbines with rotors that are 82 feet (25 meters) in diameter should be placed 650–820 feet apart in the dominant wind directions.[11]

[10] Researchers have shown that the size of the downwind disturbance to wind flow created by a wind turbine proportional to the wind turbine's rotor diameter. For this reason, wind turbine spacing to avoid unacceptable losses in the performance of downwind machines is defined in "rotor diameter" terms rather than simply in feet or meters.

[10] Wind projects to date in Minnesota and Iowa do not appear to

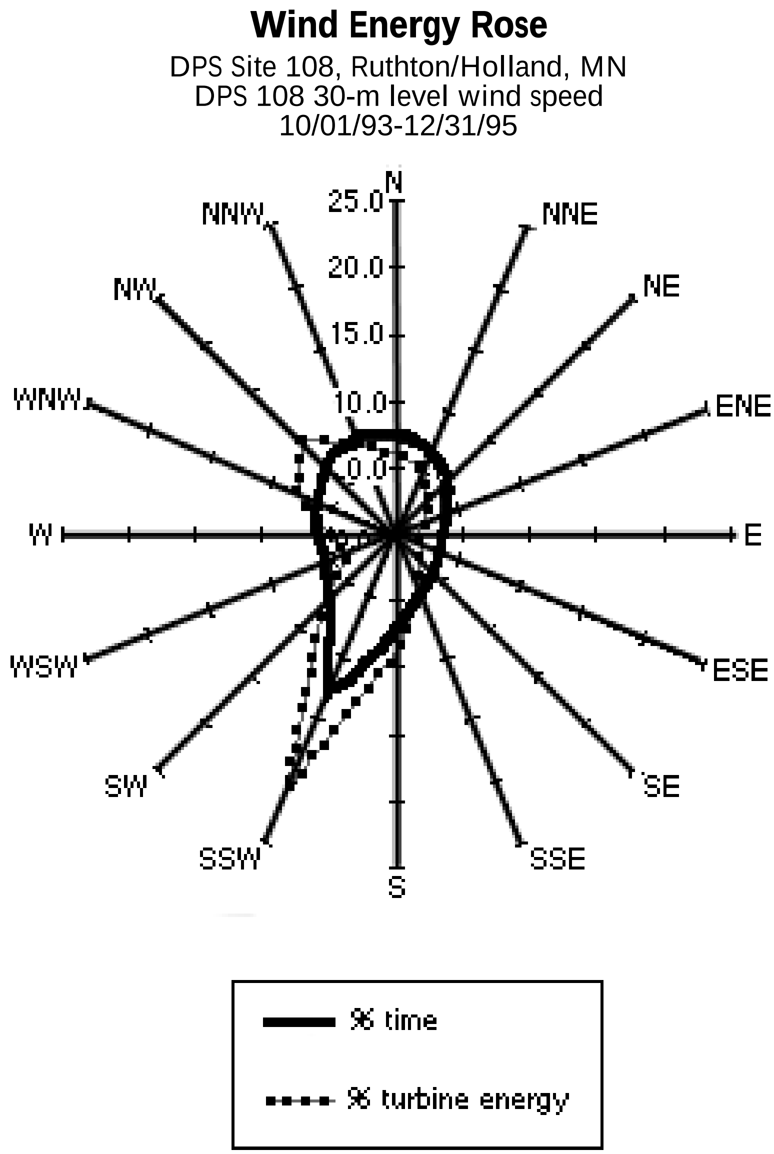


Figure 11.

Again referring to figure 11 showing the wind rose for the Ruthton/Holland site, it would clearly be critical to multiple wind turbines spaced at least eight rotor diameters apart in the south southwest/north northeast direction. Based on the important secondary wind directions shown on the wind rose, turbines should also be spaced eight or more rotor diameters apart in the northwest/southeast direction. This wind rose, with strong winds from essentially perpendicular directions, does not leave much opportunity for wind developers to reduce the spacing between machines, in any direction, below 8-10 rotor diameters.

---

have strictly followed this siting guidance and we would expect that energy production from these sites is compromised somewhat due to wake losses between machines.

Wind Turbine Spacing at Lake Benton

At the 1994 Lake Benton wind project, several strings of turbines are closer than eight diameters in the north/south direction while the different strings of turbines are separated by a much larger distance from the east/west direction. This spacing represents the economic compromise that the developer chose considering impact of turbine spacing on turbine energy production when the winds were from the north versus the added costs of land and machine interconnection. If you are considering placement of several machines, you will be faced with a similar choice. Remember that a wind rose for your site will give you the information that you need to estimate the cost and benefit of different arrangements.

Set-Backs—Protecting Your Wind Access

Since obstacles at considerable distances can obstruct the flow of wind to a wind turbine, it is important to control the property surrounding your site so that unobstructed wind flow is assured over the life of the project. In the terminology of county and state planners, this is described as using set-backs from property lines to assure unobstructed wind flow. The turbine wake effects described above and the guidelines described in the *Landowner's Guide to Wind Energy in the Upper Midwest*, provide valuable guidance in this regard.[12] In general, your wind project should be set back sufficient distance from property lines to assure that developments or buildings on adjacent property do not reduce the wind flow and thus reduce the economic performance of your wind project.

Some local planning boards may have set-backs for wind turbines documented in their codes. However, these requirements may reflect safety and noise rather than wind access considerations. As a result, you should always do your own evaluation to determine the set-backs that protect your access to the wind.

If your property is not large enough to provide the necessary distances, you might consider purchasing wind easements from your neighbors to assure the same protection as set-backs. The participants in large-scale wind projects, including the ongoing NSP projects, often acquire easements from neighbors for this purpose. The location and size of these easements should be determined considering the dominant wind power directions at your site and your expectations as to the potential scale of obstacle. If your primary concern is the construction of wind projects in upwind directions, then set-backs and easements that provide you with a buffer of around 1,600 feet should be sufficient.[13]

Who can help me?

In Minnesota and a number of other states, publicly accessible wind measurement programs have been going on for several years. As a result, you can expect to find a rich and growing set of wind statistics to help you assess your site.

Conclusion

Wind energy is a new "crop" for rural America and, as a result, wind project developers need to work hard to assure themselves and their bankers that wind investments make sense. This work is especially necessary in assessing the wind speeds at a promising site for development. As with other crops, wind farmers should understand what the cash flow implications of good and bad wind years might be and resist the temptation to pin their investment analysis to a single site wind speed value. With this in mind, this report was designed to define a range of wind speeds upon which decisions can be based.

We have attempted to provide numerous approaches for wind farmers to improve the reliability of the wind resource estimates on which they base their decisions by conducting on-site wind measurements or obtaining consultation and analysis of their situation from qualified outsiders. In time, we expect much of this support to come from the institutions that farmers already rely on, such as the agricultural

[12] Nancy Lange and William Grant, Izaak Walton League of America, *Landowner's Guide to Wind Energy in the Upper Midwest*, 1995. A summary is available online at http://www.me3.org/issues/wind/iwlaguid.html.

[13] This distance is approximately 10 diameters on a 50-meter (164 feet) diameter turbine. Wind machines larger than this are unlikely in the next five to 10 years.

extension service and county or state government. But for today, wind farmers must do their homework and seek out the consultation and other support they need on their own. Hopefully, this wind resource assessment report will help support these pioneering efforts.

ACKNOWLEDGMENTS

This report was originally published as a chapter in the curriculum, *Harvest the Wind* released by the Windustry Project in Minneapolis. UCS is grateful to Lisa Daniels of the Windustry project and Rory Artig of the Minnesota Department of Public Service for their continued support and invaluable contributions to this project.

This report was supported by grants from the Energy Foundation, the Joyce Foundation, the McKnight Foundation, and the Office of Utility Technologies, United States Department of Energy under grant number DE-FG41-95R110853. The Union of Concerned Scientists is solely responsible for its contents.

DECEMBER 1999

Further Information on Wind Power

Minnesota

Minnesota Department of Commerce
85 7th Place East, Suite 500
St. Paul, MN 55101
Phone: 651-296-5175
Toll-Free: 1-800-657-3710
E-mail: energy.info@state.mn.us
http://www.commerce.state.mn.us/pages/Energy/ModTech/windmain.htm

Provides a wide variety of information and technical assistance on wind power, including wind monitoring data; contact information for local wind dealers, developers and utilities; guides for purchasing small wind turbines and calculating wind power production; and information to ease potential developers through property and zoning issues. Operates state Wind Resource Assessment Program (WRAP).

Windustry™ Project
2105 First Avenue South
Minneapolis, MN 55404
Phone: 612-374-2261
Toll Free: 800-365-5441
Fax: 612-374-2601
E-mail: info@windustry.org
http://www.Windustry.org/

Non-profit organization that provides information on the economic development benefits of wind power and analytic models to assess the costs and benefits of locally owned wind projects.

Minnesotans for An Energy Efficient Economy
Minnesota Building, Suite 600
46 East Fourth Street
St. Paul, MN 55101
Phone: 651/225-0878
Fax: 651/225-0870
E-mail: info@me3.org
http://www.me3.org/

Non-profit organization that provides information on a wide variety of wind energy topics, including reports, analysis, local projects and legislation.

Wisconsin

Wisconsin Department of Administration, Division of Energy
101 E. Wilson, 6th Floor
PO Box 7868
Madison, WI 53707-7868
Phone: 608-266-8234
Fax: 608-267-6931
E-mail: energy@doa.state.wi.us
http://www.doa.state.wi.us/depb/boe/index.asp

1996 Wind Resource Map for Wisconsin:
http://www.baywinds.com/new/wiscpot.html

Provides general information, programs, technical assistance, and wind monitoring data. Publishes Wisconsin Renewable Energy Yellow Pages with information on wind energy businesses

Renew Wisconsin
222 South Hamilton Street
Madison, WI 53703
Phone: 608-255-4044
E-mail: mvickerman@renewwisconsin.org
http://www.renewwisconsin.org/

Non-profit organization that promotes clean energy strategies for powering the state's economy in an environmentally responsible manner. Provides information on legislative issues, purchasing renewable energy from your local utility, and local wind projects.

Midwest Renewable Energy Association
7558 Deer Park Road
Custer, WI 54423
Phone: 715-592-6595
Fax: 715-592-6596
E-mail: mreainfo@wi-net.com
http://www.the-mrea.org/

Holds workshops on renewable energy application. Hosts annual Midwest Renewable Energy Fair, which offers workshops and displays small wind turbines.

Further Information on Wind Power

Iowa

Energy Bureau, Energy and Geological Resources Division, Iowa Department of Natural Resources
Wallace State Office Building,
Des Moines, Iowa 50319
Phone: 515-281-8681
Fax: 515-281-6794
http://www.state.ia.us/dnr/energy/index.htm

Provides general information and education on wind power.

Iowa Energy Center
2521 Elwood Drive Suite 124
Ames, Iowa 50011-8299
Phone: 515-294-8819
Fax: 515- 294-9912
E-mail: iec@energy.iastate.edu
http://www.energy.iastate.edu/renewable/

Publishes Iowa specific wind resource, ground cover, and wind speed maps. Created a wind energy production calculator that can determine wind speed and potential turbine generation for any area in the state.

Iowa Renewable Energy Association
P.O. Box 466
North Liberty, IA 52317-0466
Phone: 319-338-3200
Fax: 319-351-2338
E-mail: irenew@igc.apc.org
http://www.avalon.net/~laugh/index.html

Provides information on local renewable energy businesses.

Nebraska

Nebraska Energy Office
Box 95085
Lincoln, NE 68509-5085
Phone: 402-471-2867
Fax: 402-471-3064
E-mail: energy@neo.state.ne.us
http://www.nol.org/home/NEO/

Provides general information on wind power.

High Plains Climate Center
University of Nebraska
830728 Chase Hall
Lincoln, NE 68583-0728
Phone : 402-472-6706
Fax : 402-472-6614
E-mail: online@hpccsun.unl.edu
http://hpccsun.unl.edu/wind/

The High Plains Climate Center offers statewide weather data and four years of wind monitoring data collected from eight sites around the state.

National

American Wind Energy Association
122 C Street, NW, 4th Floor
Washington, DC 20001
Phone: (202) 383-2500
Fax: (202) 383-2505
windmail@awea.org
www.awea.org

Provides a wide variety of information on wind power, including the status of projects operating in different states, a directory of U.S. wind energy companies, and policy developments.

Department of Energy Wind Program
Forrestal Building
1000 Independence Avenue, S.W.
Washington, DC 20585
http://www.eren.doe.gov/wind/

Provides a wide variety of information, programs, education and assistance on wind power. Administer's DOE's Wind Powering America initiative.

Energy Efficiency and Renewable Energy Network (EREN)
Forrestal Building
1000 Independence Avenue, S.W.
Washington, DC 20585
http://www.eren.doe.gov/RE/wind.html
http://www.eren.doe.gov/state_energy/states.cfm

Provides extensive information on various state resources and incentives for developing wind projects.

National Renewable Energy Laboratory's National Wind Technology Center
18200 State Highway 128
Golden, CO 80403
http://www.nrel.gov/wind/

Provides technical information and research on a wide variety of wind energy topics including U.S. wind resource data and maps, environmental issues, and turbine technology.

National Wind Coordinating Committee
c/o RESOLVE
1255 23rd Street NW, Suite 275
Washington, DC 20037
Phone: (888) 764-9463; (202) 965-6398
fax: (202) 338-1264
nwcc@resolv.org
http://www.nationalwind.org/

Multistakeholder organization that publishes reports and conducts outreach dealing with a wide variety of wind energy topics including siting, transmission, policy, economic development and environmental issues.

Union of Concerned Scientists
2 Brattle Square, 6th Floor
Cambridge, MA 02238-9105
Phone: 617-547-5552
Fax: 617-864-9405
ucs@ucsusa.org
http://www.ucsusa.org/

Non-profit organization that provides a wide variety of information on wind power, including technical research reports, policy analysis, updates on state and federal efforts to promote wind development, and links to other resources.