Small Wind Site Assessment Guidelines

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1 Introduction

Site assessment for small wind energy systems is one of the key factors in the successful installation, operation, and performance of a small wind turbine. A proper site assessment is a difficult process that includes wind resource assessment and the evaluation of site characteristics. These guidelines address many of the relevant parts of a site assessment with an emphasis on wind resource assessment, using methods other than on-site data collection and creating a small wind site assessment report.

The small wind site assessment report should include recommendations on suitability of the site, best locations for the installation, and appropriate turbine and tower options. In many cases, the recommendation will be that the site is not suitable for a wind generator. As a result, supporting information should be provided. In addition information on energy efficiency, incentives, economics, operation and maintenance (O&M) requirements, and off-grid or back-up power systems should be provided. Guidelines for the compilation and analysis of information for the report and sample reports follow. Several Case studies are also provided at the end of this document.

On-site data collection is always preferable to the simplified methods addressed here, but for small residential wind systems (usually less than 20 kilowatts [kW] in size) the time and cost is often not justified by the risk reduction available from this type of data collection and analysis. In cases in which this approach may be justified, these simplified methods can be useful as a preliminary filter to qualify a site for further evaluation.

A glossary of terms used as part of a small wind site assessment are provided at the end of this document along with several case studies that demonstrate the importance of proper site assessment in the implementation of any small wind project.

This document serves as a resource that describes the elements of a small wind site assessment and highlights the guiding principles using currently available tools and experience. The methods presented were compiled from leading experts in small wind site assessment.

2 Background and Importance

Historically, there has been a large variation in the accuracy of energy projections for small wind generators. There were two basic factors that impacted the accuracy of the energy estimates produced in site assessments performed before 2000, inaccurate power curves and wind resource assessments.

The first factor was that there were no certified power curves for small wind generators, and manufacturer-supplied power curves were often "optimistic." To help resolve these issues, the American Wind Energy Association's (AWEA's) Standards Committee developed a U.S. certification standard (AWEA 9.1) that included the International Electrotechnical Commission (IEC) 61400-2 standard with minor modifications. Part of this standard covered the third-party certification of power curves and specifications on how the data must be gathered and processed to produce a certified power curve. To date, 13 small wind generators have been completely certified, with many more in process. Most of the wind generators that are currently in the certification process have certified power curves available.

The second factor was that existing resource assessment efforts were often unrealistic. Although various nonprofit organizations had been offering site assessor training since the early 1990s, there were no consistent and systematized resource estimate processes widely published, few training programs for site assessors, and limited certification programs. The exceptions to this were the Midwest Renewable Energy Association in Wisconsin, Solar Energy International in Colorado, and various other nonprofits that offered site assessor trainings. In 2002, Wisconsin's Focus on Energy funded formal site assessor training and certification, which was housed at the Midwest Renewable Energy Association. At the time, small wind installation rebates in Wisconsin required that the application include a site assessment from a certified site assessor. In 2004, the small wind industry worked with the North American Board of Certified Energy Practitioners (NABCEP) to establish a national program of site assessor certification. Much of the required preparation was done before NABCEP decided that certifying site assessors was not a profitable business opportunity and halted work toward creating a certification program. To date, no sponsor for a site assessor certification program has been found.

The guidelines in this document are the result of conversations within the U.S. small wind industry, attempting to synthesize a diverse set of experiences into common, effective practices. It is not intended to serve as a training program or comprehensive text on the subject, but as a guiding framework to help site assessors, state program managers, and the general public better understand what to expect when conducting or reviewing a small wind turbine site assessment.

For the purpose of this discussion, small wind turbines are defined as having a power rating ranging from 1 kW up to 100 kW, as determined by the U.S. Department of Energy (DOE). It is important to note that the levels of detail and analysis in site assessment typically increase with turbine size and cost. On the upper end of even the small wind generator range, a site assessment based on a simplified wind resource assessment might be followed by a more detailed wind analysis and feasibility study that includes on-site data collection to reduce risk. In the end it is usually a balance between the cost of assessments, the cost of the turbine installation and potential risk profile of any error in the prediction of long term energy production.

3 Small Wind Site Assessor Qualifications

A practicing site assessor is expected to go well beyond the guidelines in this document in skill development, including formal training and experience, usually through apprenticeship and/or extended field practica.

Many practicing site assessors have taken 40 hours or more of site-assessment-specific training, plus field work under the mentorship of experienced practitioners. Such training should include the range of challenges, practices, and tools for site assessment, including an examination of ethics and safety, with the goal of ensuring effective assessments for clients that will serve to solidify the reputations of practitioners and the industry.

According to NABCEP's Small Wind Site Assessors Job Task Analysis [1], a site assessor must be competent in the following areas:

- Basic mathematics, including basic algebra and geometry
- Spreadsheets (e.g., wind speed calculators, output calculators, and economic calculators)
- Computer skills (e.g., Microsoft Excel and Microsoft Word)
- Basic documentation, photography, and drawing
- Listening, writing, and verbal communication
- Organization
- The Internet (e.g., Google Earth, wind maps, and incentives)
- Map interpretation (e.g., topography, location, and terrain)
- Compass and Global Positioning System (GPS) use
- Erection techniques for towers (including the anchors and foundations) and wind systems
- Report interpretation (e.g., utility bills, wind reports, and manufacturers' specifications)
- Elements of basic electricity (e.g., AC, DC, and power conversion systems)
- Fundamentals of wind energy and wind behavior
- Basic identification of tree types and mature heights
- Height and distance estimations
- Local, state, and federal energy policies and regulations
- Zoning ordinances and permitting and inspection requirements
- Wind turbine technology, performance, operation, and economics
- O&M practices and basic turbine/tower repair
- Basic financial knowledge
- Small wind installation process.

4 Site Evaluation and Description

Because the site evaluation and wind resource evaluation are interrelated, it is valuable to understand as much as possible about both before the initial visit. Assessors need to obtain the average wind speed and direction information for the area, because it is essential in determining which micro sites to document and analyze based on terrain and obstacles. A site assessor should also understand local zoning and permitting regulations if available to help understand local siting concerns.

Although understanding both site characteristics and wind resource is essential to successful wind turbine siting, site characteristics will be addressed first, because that information will help determine which site locations to analyze for the wind resources. The site assessor will guide the client through a rough optimization of land-use issues, constructability, good wind exposure, and the client will help the assessor understand their personal needs, motivations, expectations, and goals. One of the most important aspects of a site assessment is a physical visit to the location, allowing for an accurate evaluation of potential obstructions to the wind resource, including ground clutter (e.g., surrounding buildings and trees), as well as an overall grasp of location-specific characteristics, such as overhead and/or underground utilities, the best location for electrical interconnection, and site access.

4.1 Land-Use Considerations

The ability to site a wind turbine and tower in an ideal location that is completely free of obstacles and has access to unobstructed wind flow often clashes with the realities of land-use limitations, such as:

- Property boundaries
- Zoning setbacks and height limits
- Owner or neighbor view impact
- Soil conditions
- Construction access
- Interconnection requirements and wire run routing
- Safety.

These issues tend to be non-negotiable, and they must be addressed for any project that is expected to meet legal, technical, and owner requirements.

The zoning and permitting processes seek to address safety, aesthetics, and community interests and concerns. Some of these concerns might include sound level, visual impact, wildlife impact, TV/radio interference, ice shedding, or broken equipment. Although some of these issues may be perceived rather than actual, the installer and owner must be ready to address them all—and the site assessor needs to understand them well enough to provide sound advice on the turbine location.

Additionally, the site assessment must cover roads, obstacles, and site accessibility for the delivery of the wind turbine, tower, and construction equipment, as well as for the actual installation. Although the site assessment does not normally include a soils test, it is important to include at least some information about obvious soil issues that could affect foundation design and construction, such as intermittent water, sand, unstable slopes, rocks, expansive clay, and frost depth. A first estimate of soil type and condition can be found at the U.S. Department of Agriculture's Natural Resources Conservation Service at http://soils.usda.gov. This information is focused on the agricultural value of the top few feet of soil, yet most tower footings extend deeper than this characterization. A project may still need actual soils testing if required by the turbine or tower manufacturer or permitting authority, or if there are potential issues with the subsoil.

4.2 Interconnection and Utility Policies

In most cases, it is quite advantageous to interconnect a small turbine with the customer's utility service, thereby using the utility for backup power to cover the variability of the turbine's energy production as well as storage of excess energy. Such interconnection typically requires utility permission, which is usually in the form of an interconnection agreement. This agreement will address metering and billing arrangements with the utility, and may include requirements for additional safety equipment or procedures, protection devices, and inspections. The site assessor should be knowledgeable about these requirements and help educate the client. As described below, an off-grid-capable system may be recommended if no utility is available, the cost to bring grid power to the property is too expensive, the utility refuses interconnection, or the customer requires back-up power or utility independence.

4.3 Site Information and Administrative Data

As a basic framework, it is useful to note the site address, GPS coordinates, location maps (general area, or macro scale, and close-in, or micro scale), a site plan, and site photographs. Panoramic shots of the proposed wind turbine sites will help to document topography, landscape, and obstacles (typically start facing north and rotate 45° for each subsequent photo).

4.4 Safety and Environmental Concerns

Of critical importance is an assessment of potential hazards to project success, such as safety or the environment, including overhead and underground utilities, which affect excavation and trenching, and uneven terrain. Environmental concerns include potential avian and wetlands impacts and the potential impact of erosion on the installation. Again, the site assessor should understand these issues well enough to steer clear of a major problem with the turbine location.

4.5 Topography

Hills and many other topographic features alter air flow. The changes in air flow can increase, decrease, or even reverse flow, and intensify turbulence. In addition, uneven ground features can cause a wide range of local wind flow effects. As a result, if the surrounding area of a potential site is not relatively flat for several miles, then a description of the main topographic features is necessary, both nearby (macro siting) and at the proposed turbine site (micro siting). The topographical description should include shape, height, length, width, and distance and direction away from the proposed turbine site of any landforms. "Nearby" could include influences from large objects such as hills, groves of trees, or high wind breaks up to a mile away, and smaller objects could include single trees and buildings, especially within 500 feet (ft) of the proposed turbine location. If wind data used for the site evaluation are from a location several miles away, then it is important to have topographic maps of the area around both sites and between the sites. This information is essential in evaluating if the reference wind data are likely to be well-correlated with the wind resource on the site and if it needs to be adjusted up or down.

5 Wind Resource Data and Production Estimates

The following comprehensive set of steps address the most difficult cases of remote and/or low-resolution wind data and development of an estimate for energy production at a chosen project site. Background information for each of these steps is provided in the following sections:

1. Collect wind data. Use map estimates or actual wind data sets as described in Section 5.1.
2. Calculate the adjustment for topographic impact on speed and direction.
3. Adjust wind speed. Derive a sheer factor (alpha) and rationale to adjust the wind speed and direction from source data. Apply displacement height, vertical wind shear exponent (alpha), data height, and hub height to adjust wind speeds.
4. Adjust for obstacles. Set up a wind direction sector analysis to determine the effects of each nearby obstacle by applying its shade factor with a weighting for the amount of wind in that direction from the obstacle to the turbine. Summarize the composite results of the above steps to produce new estimates for the average wind speed, range, distribution, Weibull parameters, and other parameters at the selected site.
5. Estimate turbulence intensity. Use roughness and obstacles by sector to estimate the turbulence intensity of a site.
6. Estimate gross annual energy production. Apply the adjusted estimated wind distribution to the wind turbine power curve or several if different turbines are being considered and adjust for expected turbulence intensity to estimate the monthly and annual energy production.
7. Estimate net annual energy production. Determine other factors that could further reduce the actual energy produced and calculate the net annual energy production. Provide the customer with a range of expected values for wind speed and energy production to account for the uncertainties that may come from the previous steps in this process and the variation of wind speeds from year to year.

5.1 Wind Data Sources

Although there may be many methodologies for understanding the wind resource at a specific location, when conducting a site assessment, gathering on-site, measured wind data is typically preferred. Sources of local wind resource information include wind maps, wind data collected for other projects, data from local airports or weather stations, and modeled resource data which are based on sophisticated public and private weather assessment tools. Search for nearby data in online public or low-cost data banks intended for wind resource monitoring. Sample links to such data sources are provided in Section 5.1.3.

The best data sets for wind resource assessment tend to be those that underlie the state wind maps. Contact the state energy offices to learn how to access these data sets.

Local airport or weather stations are also attractive locations to find local data but often provide wind data that are less reliable than actual site data. If airport data (typically recorded at 30 ft or 10 meters [m] above ground) or weather station data (typically recorded at 5–20 ft above ground level) are used, the installation of the monitoring equipment should be checked. This equipment is not primarily intended for wind resource assessment; it is not always at an appropriate height or in a location that is free of obstructions. As a result, it is important to inquire not only about the site's current equipment and location, but also if it is historically consistent with the data collection equipment and siting. Unfortunately, airport and weather stations are usually far from the site of interest, with considerably different orography, tree cover, and monitoring height, making these data of questionable usefulness. Given the expertise required to effectively establish and correlate wind resource data, the data provided by airport and weather stations may only be useful to provide a rough screening assessment.

5.1.1 Wind Maps

Site assessors often use state wind maps to conservatively estimate the wind resource at turbine hub height by extrapolation using a conservative wind shear. Unfortunately, wind maps lack critical information such as wind speed distribution, direction distribution, and turbulence intensity, which is necessary for making accurate adjustments to account for the local site features. Despite this, multiple resources can be combined to improve data details and confidence in projection accuracy.

Wind maps continue to evolve and improve with better data and modeling techniques. A rough estimate usually starts with a state wind map, available for free at WINDExchange website (http://apps2.eere.energy.gov/wind/windexchange/windmaps/) and the Canadian Wind Atlas (http://www.windatlas.ca/en/index.php), and through a number of commercial providers for a fee. These maps can provide a general indication of good or poor wind resources, but may have very low site-specific accuracy, as they do not provide high enough resolution or include information on complex terrain, ground cover, and other local effects. Free wind maps are helpful, but maps or services that must be paid for can often provide higher resolution and more flexibility with zooming, orientation, and additional features. Specifically, attention should be given to a map's height above ground as it relates to the potential project's tower height. Adjusting the wind speed for the height difference between the map and the turbine height adds a potential source of error depending on the wind shear exponent that is selected, and the greater the height difference the greater the potential error. Therefore, for small wind generator applications, 30- to 40-m wind maps are far more useful than 10-, 60-, 80-, or 100-m wind maps. It is also important to understand the resolution of the wind map or model-generated data set. If the resolution is lower than the terrain features, adjustments will be needed to account for local terrain effects.

5.1.2 Measurement

On-site data measurement adds a new layer of confidence to the techniques discussed above, but with substantial additional costs, effort, and time, especially when the preferred methodology is to match turbine hub height and collect data for a minimum of 1 year. Obtaining several years of data is better, or 1 year that can be referenced to a longer-term data set if there is good correlation with the on-site data. A number of small, affordable wind data collection systems are available for on-site measurement and are best run for at least 1 year. These systems include anemometers, wind vanes, and temperature sensors that are mounted as close to hub height as possible. Calculating the wind shear exponent requires taking data at two different heights. Having wind shear data is essential for conducting an accurate analysis of the cost versus benefits of taller towers. In addition, analysis must be performed to determine wind speed averages and extremes, wind distribution, Weibull parameters, the wind direction rose, turbulence intensity, vertical wind shear exponent, and associated uncertainties. Low-to-medium cost measurement systems can be found at suppliers like, but not limited to Etesian, APRS World, Vaisala, Oregon Scientific, and Hobo, and advanced systems and tall towers can be found at suppliers such as SecondWind, NRG, MetOne, and several European and Canadian suppliers.

A helpful guide for setting up a monitoring tower and conducting a meteorological tower wind study is the *Wind Resource Assessment Handbook—Fundamentals for Doing a Successful Monitoring Program,* available at http://www.nrel.gov/wind/pdfs/22223.pdf.

5.1.3 U.S. wind maps and services

The following links can provide a starting point to find wind resource maps, data, and services to support the site assessment process.

- DOE-supported, National Renewable Energy Laboratory (NREL)/AWS True Power-generated 30-m state wind maps: http://apps2.eere.energy.gov/wind/windexchange/windmaps/residential_scale.asp
- AWSTruePower: www.awstruepower.com/ (Option of purchasing a day pass)
- 3Tier By Vaisala: www.3tier.com/en/ (Offers subscription services and data reanalysis)
- WindLogics: www.windlogics.com/ (Includes consulting services, but no apparent product offerings)
- Distributed Wind Site Analysis Tool: http://app.dsat.cadmusweb.com (annual subscription)
- National Aeronautics and Space Administration: https://eosweb.larc.nasa.gov/sse/
- University of Utah, national data sets from multiple sources: http://mesowest.utah.edu/
- Western Regional Climate Center national data sets: www.raws.dri.edu/
- Alternative Energy Institute: www.windenergy.org/datasites/
- University of Massachusetts Wind Energy Center: www.umass.edu/windenergy/resourcedata.php
- Wisconsin Wind Data: www.uwex.edu/sco/windex.html
- New Roots Energy Wind Report: http://www.newrootsenergy.com/
- Video of U.S. current flows: http://hint.fm/wind/.

5.2 Adjustments for Topography

This section includes a discussion of the effect of a variety of terrain features on wind flow, adapted from *A Siting Handbook for Small Wind Energy Conversion Systems* [2]. The site assessor should refer to this report and related references for more comprehensive information about the impact of terrain features on turbulence and wind resource with respect to turbine siting. Although many of the images included in the report help give a better sense of the wind flow patterns around various terrain elements, they do not quantify exact dimensions, distances, and amounts of wind impact. As a result, they are useful as general guidelines to help better understand wind flow, turbulence, and siting options, but the value of actual site data should become more apparent through this section.

Landforms, or orography, can influence wind speed, and as a result, the amount of electricity that a wind turbine can generate. Elevated areas not only experience increased wind speeds because of their increased height in the wind profile, but, given the size and shape of the landform, may cause local acceleration of the wind speed. Idealized cases have been shown to double the wind speeds over a ridge, but uncertainty is great without high-resolution computational fluid dynamics modeling or on-site data collection. An example of how wind flow is accelerated over a ridge, is illustrated in Figure 1.

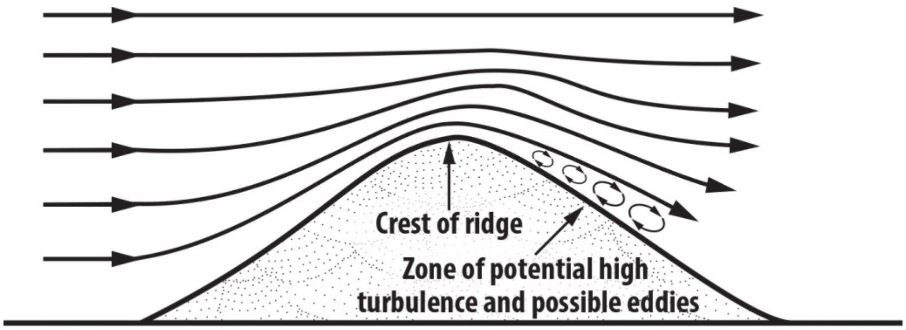

Figure 1. Acceleration of wind over a ridge. ***Illustration adapted from [2]***

Note in Figure 1 the potential area of turbulence behind the top of the ridge as well as in the lee of it. These are locations that should be avoided when siting a small wind turbine tower. Wind prospectors looking for sites for utility wind plant development are keenly aware of this phenomenon, and seek out elongated ridges perpendicular to dominant wind flow. The orientation of the ridge relative to the prevailing wind direction is critical to optimizing accelerated wind flow over the ridge. Note from the diagrams in Figure 2 that ridges are better than hills at accelerating wind flow.

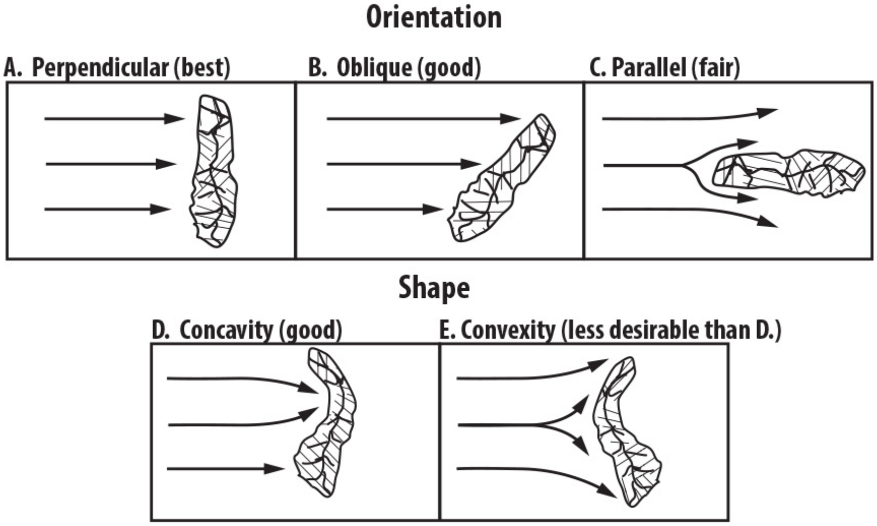

Figure 2. The effects of ridge orientation and shape on site suitability for wind generators.
Illustration adapted from [2]

Unique to elevated landforms are bluffs and cliffs (Figure 3), which create turbulence, including back eddies, as the wind passes up and over them. As a result, siting the tower to avoid the zones of turbulence created by the landform is critical. At minimum, the site assessor needs to understand the qualitative nature of these terrain effects, and perform more detailed modeling or site testing before siting a wind generator near a bluff.

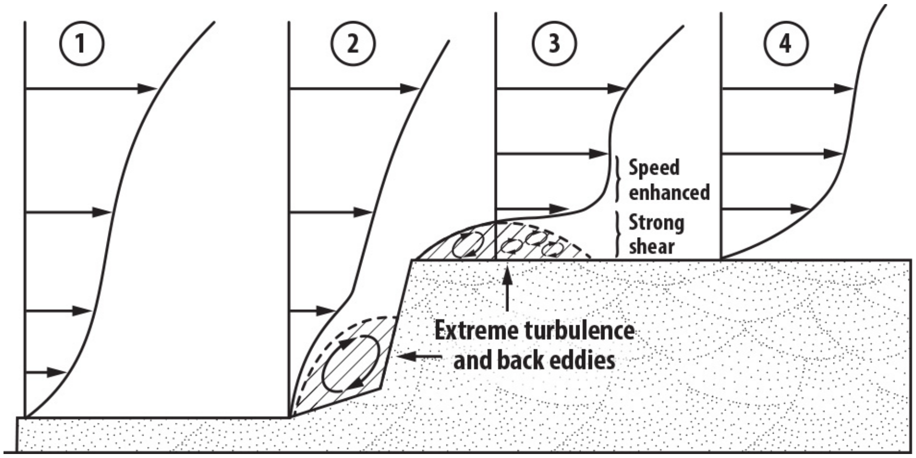

Figure 3. Vertical profiles of air flowing over a cliff. ***Illustration adapted from [2]***

Free topographic maps are available from Google Earth and the U.S. Geological Survey at www.nationalatlas.gov/mapmaker and http://store.usgs.gov/b2c_usgs/usgs/maplocator/(xcm=r3standardpitrex_prd&layout=6_1_61_48&uiarea=2&ctype=areaDetails&carea=%24ROOT)/.do, as well as www.listsofjohn.com (with some clever searching for mountainous areas). Free topographical data (often called digital elevation model data) are also available from the U.S. Geological Survey at http://data.geocomm.com/catalog/ and http://viewer.nationalmap.gov/viewer/, but these data require some proficiency with geographic information system (GIS) software to be useful.

5.2.1 Wind Rose

Knowing the prevailing wind direction(s) is essential to determining the impact of obstacles and landforms when seeking the best available site location and estimating the wind resource at that location. To help with this process, a wind rose can be used, which shows the wind direction distributions of a given area. The wind rose divides a compass into sectors (usually 8 or 16) and indicates the average wind speed, average percentage of time that the wind blows from each direction, and/or the percentage of energy in the wind by sector. Wind roses can be generated based on annual average wind speeds, or by season, month, or even time of day as needed. An example of a typical wind rose is shown in Figure 4.

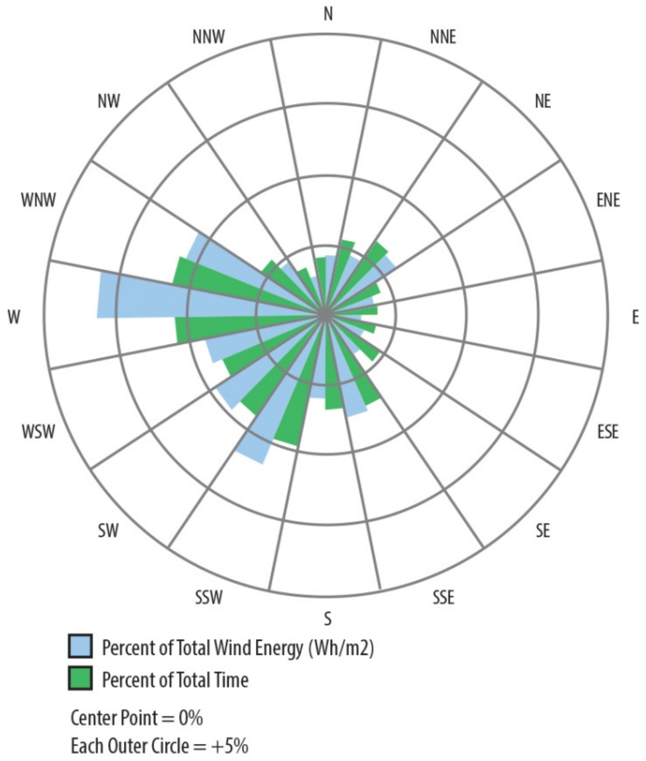

Figure 4. Sample wind rose

In this wind rose, for any of the 16 sectors, blue conveys the total wind energy available from that direction, whereas green indicates the total time the wind blows from that direction. It is important to recognize that sectors where the wind blows frequently may not provide the most energy if the winds from those sectors are relatively weak. For this reason, it is important to examine the wind roses for both the wind time and energy production.

Both common types of wind roses (percent of time and average wind speed or percent of time and percent of energy) help site assessors understand where to site a tower relative to landforms. The information from a wind rose is especially useful in determining a location for a tower that is upwind of any obstructions on a site and well exposed to the sectors that can produce the most energy.

In addition, if the wind rose data available is from a nearby site, it is important to review the topography at both sites and between the sites to determine if the wind direction data needs to be adjusted.

5.3 Adjustments Based on Wind Shear

5.3.1 Friction and surface roughness

Moving air experiences friction with the ground, ground cover and also between one air layer and another. This friction results in wind shear, which is the difference in wind speed at different heights above the ground. This change in wind speed with height is depicted in a wind profile, shown in Figure 5. The horizontal arrows represent wind speeds at their respective heights in the wind profile. Wind shear is an important factor in estimating wind speeds for turbine hub heights that are different from measured or modeled data heights.

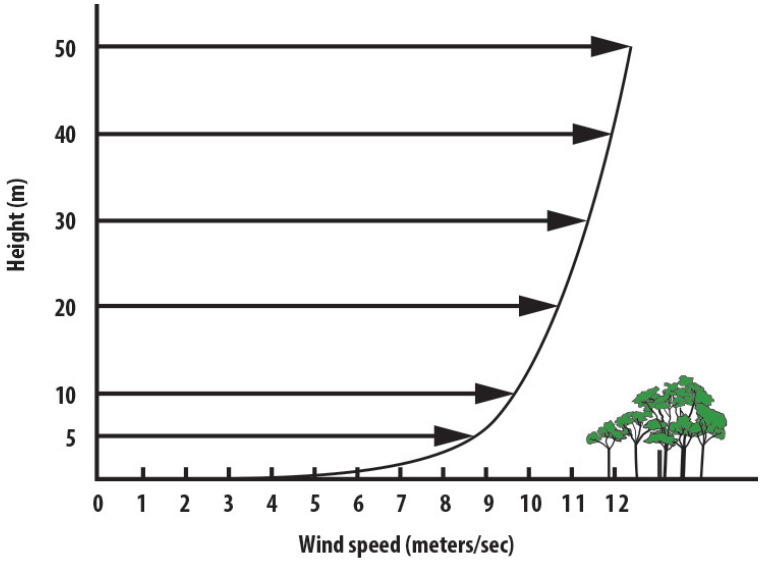

Figure 5. Effect of surface friction on low-level wind. ***Illustration adapted from [3]***

Rough topography and ground cover increases friction, adds turbulence to the air, and can even displace the effective ground level upward (called "displacement height"). Figure 6 shows how the wind profile is displaced upwards from the ground level by the grove of trees. This displacement height is called the "level of effective zero wind" since the wind below that level is nearly zero. Displacement height (d) is defined as a percentage of canopy height depending on vegetation or forest density, and often is approximated at 67% of canopy height for dense deciduous forests and 75% of canopy height for dense evergreen forests.

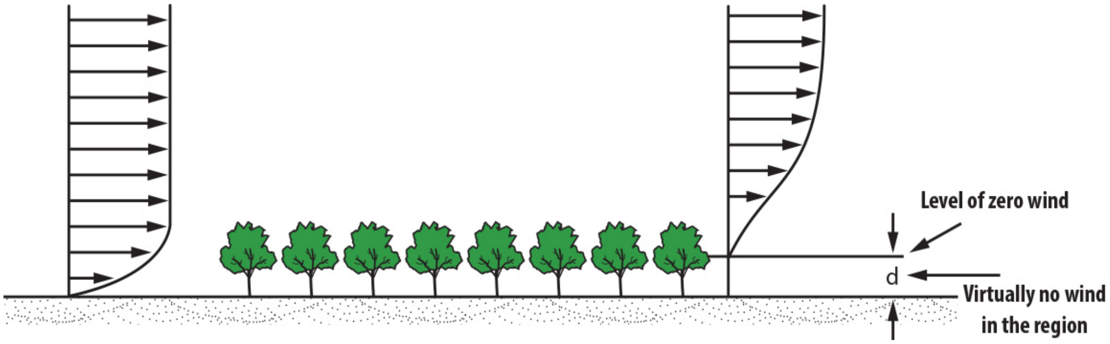

Figure 6. Formation of a new wind profile above ground level. ***Illustration adapted from [3]***

The effects of surface roughness from ground cover can extend as much as 1,650 ft above ground, strongly impacting the first 60 ft—which can have a significant effect on residential-scale wind turbines.

5.3.2 Calculating Wind Shear Effect on Wind Speed

Analysts typically use the power law equation to characterize the measured wind shear profile.

Power Law

The power law equation is: $V = V_{ref} * (h / h_{ref})^{\alpha}$

V = wind speed at height of interest (e.g., hub height)
V_{ref} = wind speed measured at height h_{ref}
h = height of interest (e.g., hub height)
h_{ref} = height of measured data
α = wind shear exponent

The wind shear exponent, α, defines how the wind speed changes with height. When wind speed data are available at multiple heights, the wind shear factor can be calculated using the power law equation.

The wind shear exponents from several heights with known wind speeds are used to estimate the wind speed at other heights of interest (e.g., turbine hub height). Depending on the type of terrain and surface roughness features, typical wind shear exponents may vary from 0.2 to 0.5.

Much work has been done to quantify the wind shear exponent based on various levels of surface roughness. As a result, the site assessor should be able to estimate an appropriate wind shear exponent from the surrounding land cover. A sample of these factors can be seen in Table 1. Note the two columns for wind shear exponent: one based on classic textbook calculations, and another based on extensive empirical data collected by several sources tied to Wisconsin's Focus on Energy and the Wisconsin Energy Bureau described in [4].

Table 1. Textbook Versus Measured Wind Shear by Terrain Type

Terrain Type	Wind Shear Exponent α (Textbook)	Wind Shear Exponent α (Wisconsin)
Ice	0.07	0.20
Snow on flat ground	0.09	0.20
Calm sea	0.09	0.20
Coast with onshore winds	0.11	
Snow-covered crop stubble	0.12	
Open, smooth surface (i.e., concrete)		0.20
Cut grass	0.14	0.25
Short-grass prairie	0.16	0.25
Open agriculture without hedges/fences		0.30
Crops, tall-grass prairie	0.19	0.30
Agriculture with homes, hedges at 1,250 m		0.35
Hedges	0.21	
Scattered trees and hedges	0.24	0.35
Agriculture with homes, hedges at 250 m		0.40
Trees, hedges, a few buildings	0.29	0.45
City suburbs, villages, scattered forests	0.31	
Larger cities with tall buildings		0.60
Woodlands	0.43	0.50
Very large cities, skyscrapers		Measure

Source: Adapted from [4].

5.4 Wind Shade Adjustment

Strong wind “shadows” are present behind obstacles such as buildings and trees. For example, for a 20-ft building, turbulence bubbles (wind shadows) can extend up to 40 ft above the ground, up to 400 ft downwind, and 40 ft upwind of the obstacle, as illustrated in figure 7. The prevailing simplified recommendation is to ensure that the lower blade tip of the wind turbine rotor is installed at least 30 ft above obstacles within 500 ft. A more complex analysis requires information on the height, width, type, distance, direction, and porosity of individual obstacles, and then for multiple obstacles in different directions. The Danish Wind Shade Calculator is a free tool that can be used to run this analysis. It is available at http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/shelter/index.htm. Although the calculator provides a good picture of the obstacle impact on wind flows, it is still an approximation, and is not accurate for close obstructions (which should be avoided in any case).

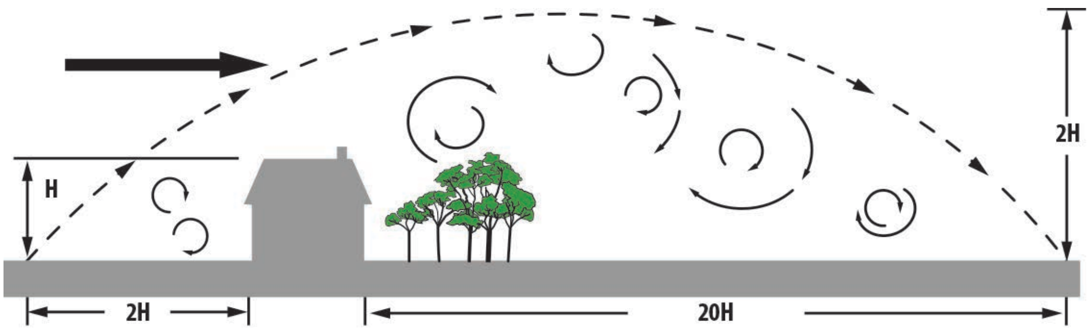

Figure 7. Zone of disturbed flow over a small building. ***Illustration adapted from [3]***

5.5 Turbulence Intensity

Experience indicates that turbulence intensity is a major issue for small turbines because of their tower height and location around ground clutter. Turbulence can reduce the annual energy output estimate anywhere from 15% to 25% because wind turbine power curves are typically developed based on measurements taken at sites with relatively low turbulence intensity compared to typical small wind project sites. Most assessors include a reduction for turbulence in their annual energy production estimates, and explain why. Sagrillo and Taivalkoski have developed guidelines for turbulence intensity that are based on terrain cover, available at www.smallwindtraining.org/wp-content/uploads/2011/12/12-Turbulence-Intensity.pdf.

5.6 Gross Annual Energy Production Estimate

The gross annual energy production estimate is developed by applying the adjusted estimated wind distribution to the wind turbine power curve (and possibly multiple options), and then adjusting the energy production for expected turbulence intensity to estimate the monthly and annual energy production. The process of adjustment should be done by sector so that the wind shade and turbulence intensity factors for each sector can be applied.

Turbine manufacturers usually provide energy production curves that are based on average wind speeds and Weibull shape factors of 2.0 (a special case called a Rayleigh distribution), and these energy production values should use power curves validated by third-party agencies. These energy production values can be used as a first approximation; however, deviations in the Weibull shape factor can have strong impacts on energy production. If possible, measurements or estimates of the wind speed distribution should be used. If there are no data available to establish a site- or area-specific distribution, a strong written caveat should be provided in the assessment report and include an estimate of the potential impact on annual energy production.

5.7 Net Annual Energy Production Estimate

To calculate the net annual energy production estimate, it is necessary to first determine or estimate other factors that could further reduce the actual energy produced, including downtime for faults and servicing, blade soiling, turbulence intensity causing control error/hysteresis and yaw error losses, icing losses, grid outages, wire losses, and inverter losses. In most cases, wire and inverter losses for small wind turbines are included in the certified power curve because power delivered is measured at the connection to the breaker panel. Likewise, control and yaw error losses are also included in measured power curves unless the site under consideration has extreme turbulence. The other losses are very dependent on the turbine or local environment with a likely range of 5% to 15%. The high end of this range would be for remote sites in which a long lead time can be expected for service. To estimate the net annual energy production, reduce the gross annual energy production by the estimated losses.

6 Other Site Issues

Issues other than wind resource and obstructions can affect site selection, suitable turbines and project cost.

6.1 Zoning and Permitting

Zoning refers to the general local regulations that allow and restrict various types of projects, whereas permitting refers to acquiring permits for a specific project within the scope of those zoning rules. By drafting a project site plan, an element of a site assessment report that provides a pictorial representation of the potential installation of the turbine at the preferred location, the site assessor provides an important first step to developing the permit package.

Zoning and permitting practices vary dramatically across the country so it is very valuable for the site assessor to be familiar with the local regulations, authorities, and general requirements. In some cases, zoning and permitting expectations are consistent and straightforward, allowing the assessor to provide the customer with a clear understanding of what is required. In other cases, hearings may be required and the process is uncertain. When zoning and permitting practices are clear, a project designed within the existing limitations will experience a much smoother permitting process and will be more likely to be granted a permit. But for a project that falls outside of defined limits, the customer will usually be sent through a special review process to obtain a variance from the existing rules and regulations—a potentially expensive and time-consuming process that often involves at least one public hearing and has no guarantee of success.

For more information on state and local wind zoning policies and permitting issues, visit:

- DOE's Database of State Incentives for Renewables & Efficiency: www.dsireusa.org
- WINDExchange – Wind energy ordinances: http://apps2.eere.energy.gov/wind/windexchange/policy/ordinances.asp
- Windustry – Planning a Small Wind Project: http://www.windustry.org/small_wind_toolbox.

If no zoning ordinances exist for a specific location, it might be worthwhile to help create one. Several DOE sponsored Regional Wind Resource Centers (http://apps2.eere.energy.gov/wind/windexchange/regional.asp) have developed regionally appropriate model ordinances and the WINDExchange provides a database of existing ordinances (http://apps2.eere.energy.gov/wind/windexchange/policy/ordinances.asp). Additionally the Distributed Wind Energy Association provides some resources at http://distributedwind.org/assets/docs/PandZDocs/dwea-model-zoning-ordinance-passed-01-07-12.pdf, and Wisconsin's model Small Wind Energy System Ordinance developed by Focus on Energy, is available at http://www.renewwisconsin.org/wind/Toolbox-Zoning/Small%20Wind%20System%20Model%20Ordinance%2012-06.pdf .

Although the permitting process generally falls in the purview of the installer, the site assessor can provide a great service by apprising the client of permits that are required with local, state, and federal agencies, such as for proximity to military bases, shoreline management areas, designated scenic areas, stream protection zones, or sensitive government lands.

6.2 Federal Aviation Administration Considerations

If a project is anywhere near an airport, then a Federal Aviation Administration (FAA) review and "no hazard determination" may be needed, which requires knowledge of the distance and direction from the site to the airport, and the associated FAA class. Frequently asked questions about the FAA and wind turbines can be found at https://oeaaa.faa.gov/oeaaa/external/searchAction.jsp?action=showWindTurbineFAQs. Information on FAA notification can be found via the FAA Notice Criteria Tool at https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showNoNoticeRequiredToolForm. If FAA notification is required, then a Form 7460-1 must be filed online after setting up an account at https://oeaaa.faa.gov/oeaaa/external/userMgmt/permissionAction.jsp?action=showRegistrationForm.

6.3 Environmental

It is essential to consider the environmental impacts and benefits of a small wind installation to the extent required by permitting agencies. Such impacts could include but are not limited to ground restoration after excavation and trenching, and avian and wildlife impacts. The U.S. Fish & Wildlife Service now requires voluntary compliance with their screening process for all wind turbine installations and has provided guidance on the tiered approach. Distributed wind projects are expected to complete only the first two tiers: land-scale level assessment and project level assessment.[1] Water runoff and erosion control are important to both minimize environmental impact and safeguard the structural integrity of the turbine foundation. Avoid building in obvious wetlands for environmental reasons, tower foundation stability, and structural and electrical integrity. Most foundation designs preclude use in standing water or potential flood situations so proper site drainage should be understood.

Providing an objective assessment of impacts includes reviewing development benefits as well documenting the potential impacts of the project. Calculators for estimating emissions and pollutants avoided by using a wind generator can be found at the following websites:

- www.epa.gov/cleanenergy/energy-resources/calculator.html#results (Carbon dioxide only)
- www.cleanerandgreener.org/resources/pollutioncalculator.html
- www.abraxasenergy.com/energy-resources/toolbox/emissions/
- www.csgnetwork.com/elecpowerpolcalc.html.

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[1] For more information, visit http://www.fws.gov/windenergy/wind_training/wind_training.html, http://ecos.fws.gov/ipac/, http://www.fws.gov/endangered/, http://www.wind.tnc.org/, and http://www.natureserve.org/.

6.4 Other Siting Issues

Although the available wind resource at a specific site is a critical element of site assessment, there are many other factors that will impact the development process. If a site has access to a viable wind resource, the considerations described in this section will influence where a wind turbine could be located and what additional restrictions may be placed on the project.

The site assessment should include notes on the following:

- The location of the utility meter, main service panel, and any subpanels
- The voltage of the main service panel and whether it is single or three-phase
- The rating of the panels or main breakers and whether or not there is room for a breaker or breakers for the wind turbine system, or if a subpanel needs to be installed to accommodate the breaker(s).

The site assessor needs to have sufficient understanding of these issues to recommend compatible wind turbines, as modifying the electrical infrastructure can incur considerable costs.

7 Site Assessment Report

After compiling all of the information provided in the previous sections, the resulting site assessment report should present two key recommendations:

1. A simple yes, no, or maybe statement on the efficacy of installing a wind turbine, with explanation
2. If yes, the preferred (and an alternate) location for the turbine, with justification.

The site assessment should conclude with one or more wind energy production estimates, based on the expected wind resource, tower height options, and turbine selections. Turbine recommendations should be appropriate to the customer's needs and goals as well as available in the area with O&M support. If there is no data available to establish a site- or area-specific power production estimate, a strong written caveat should be provided in the assessment report and include an estimate of the potential impact on annual energy production.

Examples of good site assessments can be found here:

- http://www.smallwindtraining.org/wp-content/uploads/2014/05/Faller-Residential-Wind-Assessment.pdf
- http://www.smallwindtraining.org/wp-content/uploads/2014/05/Taivalkoski-Business-Wind-Assessment.pdf
- http://www.smallwindtraining.org/wp-content/uploads/2014/05/West-Agricultural-Wind-Assessment.pdf.

Appendix A of this document also provides several example check lists that may be helpful in the development of a site assessment report and appendix B provides some project case studies that highlight different aspects of the site assessment process. Additional information to be included in a site assessment report includes, but should not be limited to, the following:

7.1 Energy Efficiency

Although an energy efficiency audit is a different project, it is certainly appropriate for a small wind site assessor to recommend taking this additional step. It is often most cost-effective to address energy efficiency issues first, and then provide wind generation for the essential energy needs that remain. Despite the fact that the site assessor is not expected to be an expert in this area, he/she should be ready to acknowledge its relevance and recommend consultation. It is also prudent to discuss replacing existing natural gas, propane, or fuel oil appliances with electric appliances if the wind turbine can be sized to serve those loads.

7.2 Turbine and Tower Options

The assessment report should provide turbine and tower recommendations that meet site and owner requirements. Recommendations should be for products that are third-party certified, such as from the Small Wind Certification Council, or Intertek, or that are recommended by the Interstate Turbine Advisory Council. The site assessor should be able to explain the various tower types, what is appropriate for the site under consideration, and why.

7.3 Minimum Acceptable Turbine Tower Height for a Site

Based on the obstructions and ground clutter within at least 500 ft of the site or a tree line in the surrounding area, the site assessor should specify the minimum turbine tower height with a minimum of 30 ft additional clearance for the lowest point of the rotor. This specification should also include estimated tree growth for the 20+ year life of the wind system. Although this is the minimum acceptable height, the report should consider the economics of higher towers that will provide more energy.

7.4 Economics and Incentives

A preliminary financial analysis may be included in a site assessment based on typical installed costs. Site-specific quotes are usually done by the installer, sales person, or feasibility assessment consultant(s). Financial analysis should include upfront and ongoing costs, such as maintenance, performance, electricity rates, incentives, and economic factors (e.g., interest, discount rates, and inflation) to estimate simple paybacks and internal rates of return. The site assessor needs to check www.dsireusa.org for federal incentives, such as the Investment Tax Credit and U.S. Department of Agriculture grants, loans, and loan guarantees, and state incentives, such as net-metering, rebates, feed-in-tariffs, Renewable Energy Credits, and be able to understand and explain them. In addition, state incentive programs may be limited to a list of specific turbines as listed by the Interstate Turbine Advisory Council. More subtle incentives are also very important, including laws permitting the use and interconnection of wind, and net- or dual-metering rules that allow for a financial exchange of excess energy with a utility.

7.5 Operation and Maintenance Expectations

Ultimately, O&M is the responsibility of the turbine installer and owner, but the site assessor should be able to advise the customer that maintenance is required. Turbine and tower manufacturers should provide their own O&M plan; however, turbine owners should be aware that all rotating equipment will require some maintenance. Many turbines require periodic lubrication, oil changes, and replacement of wear surfaces such as brake pads.

7.6 Off-Grid Systems

If a customer wants or needs full independence from the utility or battery backup in the event of power outages, the site assessor should be able to discuss the extra challenges, costs, and O&M requirements of a battery backup system and potential hybrid blends with solar, hydro, fossil, or other energy resources. Design and sizing of the components for an off-grid system is beyond the scope of site assessment.

7.7 Building Integration

Most experts in the wind industry discourage building integration because of insufficient wind resource at building height, potentially damaging turbulence, and excessive costs from additional building engineering and reinforcement. Building integration has strong implications for aesthetics, very difficult wind resource prediction challenges, and building-scale structural impacts that may require extensive engineering, building reinforcement, noise management, and system safety analysis. Given these complications a site assessor should avoid conducting an assessment for a building-integrated wind generator.

7.8 Electrical Load Usage Analysis

For a potential small wind site, turbine size, performance, and project economics must relate to the customer's energy needs and expenditures. Often customers have very little understanding of those needs and costs, so they should be included in the site assessment, along with some customer education on their energy needs. For residential customers, the bill is based on kilowatt-hours (kWh), or energy consumption, and may have charges that are fixed (e.g., a meter charge, billing charge, or customer service charge). Residential utility bills may also note the energy cost (retail rate for the electricity itself) as well as the delivery cost (retail rate to deliver it to the site). In some locations the energy billing rate will vary based on the level of consumption (tiered rates) or time of day. Commercial customers—usually, but not always, using three-phase electric service—may have other charges, with the most common being a demand charge. The demand charge can be a significant part of the bill and is commonly based on the peak demand in any 15-minute period of the month or quarter. Demand charges are not reliably reduced by adding a wind generator. For existing facilities, the quickest way to determine the energy consumption is to review the electric bills. For new facilities or off-grid installations, a more involved estimate process is needed and will require tallying up all of the electrical equipment and expected operating hours.

8 Conclusions

This document is intended to provide guidelines in conducting and writing a small wind site assessment, highlighting common guiding principles using currently available tools and experience. These guidelines present a basic set of expectations for site assessors, customers, local agencies, and incentive programs, and are not intended as a substitution for site assessor training, which is strongly recommended and available from many sources.

9 Glossary

The following provides a glossary of terms commonly used in the site assessment process. An expanded online glossary of small wind specific terms can be found as part of the small wind guidebook at http://en.openei.org/wiki/Small_Wind_Guidebook/Glossary_of_Terms.

Anemometer: An instrument that measures wind speed, which usually produces an electrical signal for logging data over time.

Beaufort scale: A scale of wind forces, described by name and range of velocity, and classified from force 0 to 12, with an extension to 17. The initial (1805) Francis Beaufort wind force scale of 13 classes (0 to 12) did not reference wind speed numbers but related qualitative wind conditions to effects on the sails of a frigate, then the main ship of the Royal Navy, from "just sufficient to give steerage" to "that which no canvas sails could withstand." Although the Beaufort scale has little use in site assessments, a system of tree flagging observations has been used to estimate prevailing wind directions and levels on the scale over time.

Displacement height: The height above ground level where wind speed is theoretically zero based on the effects of ground cover.

Diurnal: Having a daily cycle or pattern. It may be useful to average many daily cycles of wind speed or wind energy production to understand a typical daily pattern, by month, season, or year.

Downwind: To the lee, as in located behind an obstacle relative to the prevailing wind direction. A downwind turbine has wind passing the tower first and then through the blades.

Dual-metering: Buying electricity from the utility and selling it to the utility with two different energy rates, typically retail (buying) and wholesale (selling).

Energy curve: A diagram showing the annual energy production at different average wind speeds, typically assuming a Rayleigh wind distribution (with a Weibull shape factor of 2.0).

Flagging: Is the deformation of local vegetation toward one direction, indicating the prevailing wind direction and relative strength (more formally called Krummholtz formation). Flagging is sometimes used with the Beaufort scale to generate an initial estimate of local site conditions. (Note: flagging does not determine the wind resource, but is a confirming indicator of it. For example, sometimes flagging is the result of sunlight availability, or trimming of tree branches near electrical lines. The assessor needs to understand when flagging is relevant, or when it is a confirming indicator of another condition at the site.)

Frequency distribution: A statistical function presenting the amount of time at each wind speed level for a given data set and location, usually in percent of time or hours per year.

Electric cost adjustment (sometimes referred to as fuel cost adjustment): An energy charge (dollars per kilowatt-hour) on a utility bill in addition to the standard rate in the tariff, which is associated with extra costs to purchase fuel, control emissions, construct transmission upgrades, and so on. These various costs may be itemized or rolled into one electric cost adjustment rate.

Geographic information system (GIS) software: GIS software is used for managing map-based information and data. It may also be used to visualize the relationships between terrain, wind data, land-use boundaries, obstacles, and potential wind turbine locations.

Global Positioning System (GPS): GPS is a satellite-based navigation system that uses handheld receivers to identify the location of the receiver and coordinate with mapping system locations.

Gross annual energy production: The amount of annual energy (usually in kilowatt-hours) estimated for a given wind turbine at a given location, before adjusting for losses (see net annual energy production).

Horizontal-axis wind turbine (HAWT): A wind turbine designed with the axis of rotation around a horizontal shaft, typically with a propeller-like configuration.

Hub height: For a HAWT, this typically refers to the height above ground of the center of the rotor that consists of blades mounted to a hub connected to the turbine's main shaft.

Interannual variability: The variation from year to year in average wind speed, distribution, and patterns.

Micrositing: The process of selecting a wind turbine location and determining the likely wind resource available after considering all of the possible impacts, such as topography, ground cover, and obstacles, and their location relative to the tower's location, turbulence, and land-use restrictions.

Microturbine: A very small wind turbine, usually under a 1,000 Watt rating, which is appropriate for small energy needs (e.g., for cabins, campers, sailboats, very small communication stations, or other small off-grid loads).

Net annual energy production: The amount of annual energy (usually in kilowatt hours) produced or estimated for a given wind turbine at a given location, after subtracting losses from the gross annual energy production. A variety of losses may be estimated for obstacle wind shadows, turbulence, turbine wake effects, turbine availability, high-wind hysteresis effects, electrical efficiency, blade icing, blade soiling and surface degradation, idling parasitic losses, control errors, low temperature shutdown, utility system maintenance, and other issues specific to a given turbine installation.

Net-metering: Buying electricity from the utility and selling the excess generation to the utility at the same energy rate, typically retail, which includes the generation rate, delivery cost, and all additional costs. Demand charges, if applicable, are not included. Credits may or may not be carried forward from windy months to calm months and excess energy may be paid at a lower rate than retail—or not at all—depending on the local utility and state regulations.

Peak demand (otherwise known as "demand"): The maximum electricity consumption level (in kilowatts) reached during the month or billing period, usually for a 15- or 30-minute duration. The definition of peak demand may vary by electric utility. This is a simplified definition of a complex topic.

Permitting: The process of obtaining legal permission to build a project, potentially from a number of government agencies, but primarily from the local building department (i.e., the city, county, or state). During this process, a set of project plans is submitted for review to assure that the project meets local requirements for safety, sound, aesthetics, setbacks, engineering, and completeness. The permitting agency typically inspects the project at various milestones for adherence to the plans and building safety standards.

Power curve: The table or graph showing the expected power versus wind speed for a given turbine design and air density.

Prevailing wind direction: The direction or directions from which the wind blows most consistently, most often, or with the most energy.

Reactive power: When the voltage and current waveforms for AC power are out of phase the resulting instantaneous power flow is modeled as real power and reactive power. The presence of reactive power increases the instantaneous current flow required to do work. The increase in current flow results in additional line losses. The utility tariff for larger customers may include a charge for reactive power compensation, measured in kilo-volt-amp-reactive.

Shadow flicker: A moving shadow that occurs when rotating turbine blades come between the viewer and the sun.

Site assessment: The act of evaluating a site to determine a favorable location for a wind turbine, which includes assessing the expected wind resource and potential turbine performance at that location.

Siting: See micrositing and site assessment.

Small wind turbine: A wind turbine that has a rating of up to 100-kilowatts, and is typically installed near the point of electric usage, such as near homes, businesses, remote villages, and other kinds of buildings.

Tariff: An official schedule of rates or charges from a utility, usually with different rate schedules by customer classification (e.g., residential, commercial, industrial, farm, or other designation) and/or a service or meter rating for the customer.

Topography: The surface configuration and relief features of an area, such as hills and bluffs, and the detailed mapping and description thereof.

Turbulence bubble: A region of excessive turbulence around an obstacle.

Turbulence intensity: A basic measure of turbulence that is defined by the ratio of the standard deviation of the wind speed to the mean wind speed. For wind energy applications this is typically defined as a 10-minute average wind speed and standard deviation based on 1-second samples. Turbulence intensity is important for wind energy applications because it has implications for both power performance and turbine loading. Experience indicates that it can be a significant issue for small turbines because of their tower height and location around ground clutter, which puts them in the most turbulent area of the atmospheric boundary layer. The effects of turbulence on distributed wind turbines can be seen in both power production and loading.

Upwind: Toward the windward direction, as in located in front of an obstacle relative to the prevailing wind direction. An upwind turbine has wind hitting the blades first and then the tower.

Vertical-axis wind turbine (VAWT): A turbine designed with the axis of rotation around a vertical shaft, with two prevalent configurations: Darrieus, which is an egg-beater style with primarily lift aerodynamics, and Savonius, a split-barrel style with primarily drag-based aerodynamics.

Vertical wind shear exponent: The parameter that defines the rate at which the wind speed increases with height above ground (see equation in Section 5.3.2).

Weibull scale factor (or parameter): Parameter of a wind distribution as approximated by the Weibull statistical function that is closely related to the average wind speed.

Weibull shape factor (or parameter): Parameter describing the shape or “fatness” of a wind distribution as approximated by the Weibull statistical function. A fairly median value of 2.0 defines a special case called the Rayleigh distribution; lower values indicate a wider, flatter distribution, and higher values indicate a narrower, high-peaked distribution.

Wind direction: The direction from which the wind is blowing and a wind vane points. (This is sometimes confusing because it is not the direction the air is moving in).

Wind shadow: A turbulent and/or low-wind-speed region downwind of (behind) an object such as a building, tower, or trees.

Wind turbine: A machine that harnesses the energy of the wind, also called a wind generator, when used to produce electricity.

Wind rose: A diagram that indicates the average wind speed, average percentage of time that the wind blows, and/or the percentage of energy in the wind from different directions, on a monthly or annual basis.

Wind shear: The difference in wind speed and direction over a relatively short distance in the atmosphere. Wind shear can be broken down into vertical and horizontal components, with horizontal wind shear seen across storm fronts and near the coast, and vertical shear seen typically near the surface (though also at higher levels in the atmosphere near upper-level jets and frontal zones aloft).

Wind vane: An instrument that measures the wind direction, usually producing an electrical signal to log data over time or provide input to the yaw control system for a wind turbine with an active yaw system.

Zoning: Most land has been delegated to various zones by a region's local government and building department officials (at the city, county, or state level [occasionally]). The zones control types of land use, such as agricultural, residential, commercial, and industrial, and include subcategories. Each type of zoning carries its own specific permitting restrictions, such as building height and property line offsets (required separation distance).

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Links for Further Information

1. Distributed Wind Energy Association: http://distributedwind.org/
2. Renewable UK: http://www.bwea.com/index.html
3. Wind Works: http://www.wind-works.org/articles/index.html
4. Wind Shade Calculator,
   Danish: http://www.motiva.fi/myllarin_tuulivoima/windpower%20web/en/tour/wres/shelter/index.htm
5. Met Office: http://www.metoffice.gov.uk/energy/vmm
6. Wind Shear: http://www.engineeringtoolbox.com/wind-shear-d_1215.html
7. Microgeneration Certification
   Scheme: http://www.microgenerationcertification.org/installers/installers
8. Small Wind Training Resources: http://www.smallwindtraining.org/?page_id=6
9. RENEW Wisconsin's Small Wind Toolbox (useful information for zoning and permitting issues): http://www.renewwisconsin.org/wind/windtoolbox.htm.

Appendix A

Sample Checklist

Wind Energy Site Assessment (Customer Name/Location)

1. **Motivation**

_____Specify customer goals and expectations
_____Reviewed electricity usage and costs (including rate structure)

2. **Site Description**

_____Documented location(s)
_____Reviewed topography, landscape, surface roughness, and ground clutter
_____Estimated displacement height (if applicable)
_____Documented obstacles
_____Reviewed construction and delivery access
_____Estimated soil conditions
_____Documented potential safety hazards

3. **Wind Characteristics**

_____Acquired wind maps and wind data
_____Considered wind measurement
_____Estimated wind characteristics (e.g., speed, direction, Weibull, turbulence, shear, uncertainty)

4. **Micrositing and Analysis**

_____Completed micrositing
_____Adjusted for topography
_____Adjusted wind direction
_____Adjusted for wind shear
_____Adjusted for displacement height
_____Adjusted for obstacles and wind shading
_____Completed adjusted wind speeds
_____Completed energy estimation
_____Adjusted energy estimation for losses

5. **Other Requirements**

_____Reviewed interconnection and examined service panel
_____Checked zoning and permitting requirements (to the extent established for the area)
_____Checked for Federal Aviation Administration/aviation impact
_____Checked environmental requirements (if established for the area), observed potential issues
_____Prepared U.S. Fish & Wildlife Service materials for review

6. **Report**

_____Recommended turbine options and tower options with estimated net annual energy production for each scenario
_____Recommended prime location with secondary options
_____Completed checklist and report information
_____Included educational section.

Sample Report Outline

Wind Energy Site Assessment (Customer Name/Location)

1. Motivation

Customer goals: __Energy __Independence __Marketing __Save World __Other ________
Electricity usage: ____Low ____High ____Avg kWh/mo ____Peak demand (kW) ____kVAR
Electricity rate (as appropriate): ____Tariff ____Base $/kWh ____Electric cost adjustment/Fuel cost adjustment $/kWh \_\_\_\_$/kW-mo ____$/kVAR ____Fixed costs ____Taxes ____ Other

2. Site Description

Address: ____
GPS: ______________________
Location maps: (insert here: general area, close-in, site plan)
Photographs: (insert here – i.e., Dermandar panorama)
Topography features: ____
Main features: ______Shape______Height______Length ______Distance______Direction
Landscape description: ____
Displacement height: ______Mature Canopy Height (*0.67 or 0.75 =) ______Displacement Height
Obstacles: (e.g., number, height, width, type, distance, direction) List here:
Access: (e.g., roads, obstacles, installation layout) ____________________________________
Soils: ______Class ______Strength ______Water Depth____________________Description
Potential Hazards: (e.g., overhead, underground, terrain, weather, wetlands, agricultural operations) _________________
Existing utilities: (location, overhead, underground: water/well, electric, sewer/septic system, natural gas/propane, cable television, phone, other.)

3. Wind Characteristics

Wind maps: (source, insert here)
Wind data sources: ____ (see Section 5.1)
Wind measurement: ___Needed (yes/no)?______Scope ________Duration ________Cost
Wind speeds: ______Average _______________Weibull parameters (insert details here)
Wind directions: __________Prevailing __________Secondary (insert wind rose, energy rose)
Turbulence: ________Intensity
Wind shear: ________Exponent
Uncertainties: __________________________List, combine: ____________Wind-speed range
Others: ____

4. Micrositing and Analysis

Micrositing: (describe selected location and height, rationale, benefits, challenges, other options)
Topography adjustment:
____ (Factor to adjust wind speeds from source data, rationale) ____New average wind speed
Wind direction adjustment:
____ (Degrees to adjust wind rose from source data, rationale) ____New prevailing direction
Wind shear adjustment: ____displacement height ____ exponent ____ data height
____hub height ____New average wind speed
Wind shade adjustment: (Obstacle #, shade factor, direction (%), weighted factor)
List here:
Adjusted wind speeds: ____New average wind speed _______Range ____ Weibull parameters
Energy estimation: ____Avg __________Range (apply turbine power curve; multiple options)

5. Other Requirements

Because zoning and permitting requirements are local, there can be large variations in procedures and the amount of information available to the site assessor at the time an assessment is prepared. Reporting on these factors will have to be adjusted accordingly. Environmental requirements may also vary.
Interconnection: ______Utility ____Allowed ____________Location
_____________Requirements
Service Panel Specs: ____Voltage____Phases ____Current ____Power ____Spare breakers
Zoning: ______Zone ____Height Limit ____Setback__________________Other restrictions
Permitting: ______________Authority Having Jurisdiction (AHJ) ______Fees ______Lead time
Federal Aviation Administration (FAA): ________________________Distance, Direction to nearest Airport ______FAA class
Environmental requirements: (Any requirements by AHJ, state, or federal agencies?)
Environmental observations: (Any obvious wetlands, other issues known to customer or by the site assessor?)
U.S. Fish & Wildlife Service report for the area

6. Report

Recommendation: ____ (Yes/No, Explanation)
Preferred location: ________________________________Describe, add to site plan
Checklist: (Include checklist developed above)
Education: (Include discussion of energy efficiency, turbine and tower options, horizontal-axis and vertical-axis wind turbines, micro/small/large/multiple units, incentives, economics, operation and maintenance expectations, off-grid systems, and building integration).

Appendix B. Case Studies and Lessons Learned

The following case studies are intended to highlight the various site selection and assessment choices that can affect turbine performance, without regard to specific turbine types, sizes, certification, and installation.

Case Study #1: Comparison of Two Similar Turbines: Bassetti and Grim

Case Study #1 compares two similar turbines from the same manufacturer (Bergey Windpower Company) that were both properly installed. The primary factor contributing to a significant difference in the productivity of these turbines was the site selection. To better understand the potential impact that site selection can have on a given project, this case study looks into project-specific details to determine the contributing positive and negative siting impacts associated with the projects. Figure B-1 shows the Bassetti turbine installed in an open, agricultural setting, and Figure B-2 shows the Grim turbine installed in a forested setting. Table B-1 provides the system details for both the Bassetti and Grimm installations.

Figure B-1. Bassetti turbine in Klickitat County. ***Photo by Gwen Bassetti, NREL 26429***

Figure B-2. Grim turbine in Peshastin, Washington. ***Photo by Abigail Krich, NREL 13495***

Table B-1. Case Study #1 Turbine System Details

	BASSETTI	**GRIM**
Location	Klickitat County, Washington (Figure B-1)	Peshastin, Washington (Figure B-2)
Date Installed	September 2004	October 2002
Project Goal	Customer decided to install a turbine after seeing their neighbor's installation	Homeowners wanted to participate in the Sustainable Natural Alternative Power incentive program in the Chelan County Public Utility District service area, which would pay up to $1.50 per kilowatt-hour (kWh) for green electricity
Assessment Information	No formal site assessment prior to installation[2]	Assessment done in 2001, but it relied too much on the owner's estimate of the site wind speeds, which turned out to be incorrect.[3] Met installation was suggested, but owners did not want added expenses; they believed site was windy. Installer observed landscape and agreed.[4]
Turbine Information		
Model	Bergey Excel 10	Bergey Excel 10
Capacity	10 kilowatts (kW)	10 kW
Tower Height	120-ft guyed tower	100-ft lattice tower
Site Characteristics		
Elevation	632 meters (m)	610 m
Latitude/Longitude	45.83/-120.65	47.547/-120.639
Surrounding Terrain/Obstacles	Turbine installed in an open field behind the ranch	Site situated on the top of a hill, surrounded by trees[5]
Performance		
Estimate (kWh)	13,000 kWh annually[6]	8,000 kWh annually
Actual (kWh)	~13,000 kWh/year (yr)[7] (100% of estimate)	500 kWh during first year of operation (less than 10% of estimate)
Maintenance Issues	Inverter cut-outs caused by extra output from new turbine blades; no other maintenance issues[8]	Faulty inverter
Current Operating Status	Still operating; owner believes the turbine has paid for itself since the installation[9]	• After 4 years of operation, the turbine was taken down, sold, and relocated to a property in Ellensburg, Washington

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[2] Jennifer Grove email. August 23, 2013.

[3] Email correspondence with original installer. September 3, 2013.

[4] Woofenden, Ian. "A Second Wind." Home Power 130/April & May 2009.

[5] Sinclair, K. (2005). *Regional Field Verification – Case Study of Small Wind Turbines in the Pacific Northwest*. NREL/CP-500-38166. Golden, CO: National Renewable Energy Laboratory. Accessed approximately April 2013: http://www.nrel.gov/wind/smallwind/pdfs/sinclair_rfv_case_study.pdf.

[6] Sinclair, K. (2005*). Regional Field Verification – Case Study of Small Wind Turbines in the Pacific Northwest*. NREL/CP-500-38166. Golden, CO: National Renewable Energy Laboratory. Accessed approximately April 2013: http://www.nrel.gov/wind/smallwind/pdfs/sinclair_rfv_case_study.pdf

[7] Owner interview. June 5, 2013.

[8] Sinclair, K. (2005). Regional Field Verification – Case Study of Small Wind Turbines in the Pacific Northwest. NREL/CP-500-38166. Golden, CO: National Renewable Energy Laboratory. Accessed approximately April 2013: http://www.nrel.gov/wind/smallwind/pdfs/sinclair_rfv_case_study.pdf.

[9] Owner interview. June 5, 2013.

Wind Rose

Unlike Case Study #2 and #3, Case Study #1 does not include a wind rose because of the chosen assessment methodology for each project.

Lessons Learned

Prior to installing a small wind turbine, it is vital to assess the wind resource to reduce production uncertainties that can be associated with a project. Case Study #1 highlights the Bassetti and Grim installations as a paired example, because both installations used a minimal resource assessment methodology, yet had decidedly different outcomes.

Bassetti

The primary decision criterion for the Bassetti project was a neighbor's successful wind turbine installation. Though no formal site assessment was conducted for this project, it did end up producing at a high level.

The success of the Bassetti installation can likely be associated with not only a strong wind resource, but also a location that is free and clear of ground clutter, which would obstruct the wind resource. When deciding between locations on a property, sites with higher elevations and fewer obstructions are considered superior.

For the Bassetti case, not doing a wind resource assessment resulted in a successful installation; however, this approach results in high levels of uncertainty in terms of how the turbine will perform at a particular site. The Grim project that follows illustrates this risk.

Grim

The Grim project was heavily reliant on the owner's belief that the site had a strong wind resource. Project installers did use a wind resource map in their assessment, but the 2001 wind resource maps had limited resolution when compared to more recently developed versions. A 2009 article highlighting the Grim project indicated that one of the contributing factors to the project's failure was the lack of advanced wind resource maps. At the time of the article's publication, new resource maps indicated that the Grim site had an average wind speed of 4.8 mph at a 60-m height, which is insufficient for adequate production.[10]

The access to reliable wind data through higher resolution resource maps could have factored into whether or not the Grim turbine should have been installed. Though the installer suggested that collecting data using an on-site anemometer would provide a higher level of production certainty, the owners declined because of the added expense. Had an anemometer been utilized, the added cost to purchase the necessary equipment would have been between $500 and $1,500. This method of assessment would have shown that the location was not ideal for a wind turbine installation.

Another factor that may have contributed to the project's eventual failure and subsequent sale and relocation is the lack of clearance at the original location. Ground clutter creates an obstruction that can impact the strength of a site's wind resource. As a result, it is absolutely

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[10] Woofenden, Ian. "A Second Wind." Home Power 130/April & May 2009.

essential to fully consider the surrounding ground clutter of a potential project site, including the possible removal of trees, shrubs, or other vegetation to provide unobstructed wind flow.

Case Study #2: Comparison of Two Turbines: Kittery and Vosters

Case Study #2 compares two wind installations that feature similar sized turbines in which comparable resource assessments were conducted using wind resource maps. The primary factor contributing to a significant difference in the productivity of these installations was that one site had access to a relatively strong and uninterrupted wind resource, whereas the other did not. To better understand the potential impact that site selection can have on a given project, this case study examines specific project details to determine the contributing siting impacts, both positive and negative, associated with the projects. Figures B-4 through B-7 and Table B-2 and the following information provide insight into both of the projects and their results.

Figure B-4. Turbine in Kittery, Maine. ***Photo by Donald Doval, NREL 28427***

Figure B-5. Vosters turbine in Appleton, Wisconsin. ***Photo by Kettle View Renewable Energy, LLC, NREL 28428***

Table B-2. Case Study #2 Turbine System Details

	KITTERY	**VOSTERS**
Location	Kittery, Maine (Figure B-4)	Appleton, Wisconsin (Figure B-5)
Date Installed	September 2008	2011
Project Goal	Town of Kittery installed the turbine near the transfer station and local middle school in an attempt to reduce energy costs	Reduction of costs and clean energy production
Assessment Information	Project developers conducted a site assessment using a 50-m map with the best available resolution at the time;[11] prior to contracting with Entegrity, the town installed an anemometer and began data collection in November 2006, which the client used as validation to move forward with the wind installation process;[12] it is unknown how the data were used by the developers in the final site evaluation for this project	Assessment was conducted in May 2010 using a 60-m wind resource map from 2007; the wind rose was provided through AWS Truewind[13]

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[11] Project developer interview. (May 3, 2013).

[12] Seacoastonline.com. (2008). "Kittery wind turbine pays dividends." Accessed June 2013: http://www.seacoastonline.com/article/20081223/BIZ/812230370

[13] Email correspondence with original site assessor. (August 2013).

	KITTERY	**VOSTERS**
Turbine Information		
Model	Entegrity EW50	Endurance E 3120
Capacity	50-kilowatts (kW) 177-m^2 swept area	50-kW 290-m^2 swept area
Tower Height	125-ft lattice tower	140-ft tower
Site Characteristics		
Elevation	~26.8 meters (m)	221 m
Latitude/Longitude	43.119/-70.749	44.3382/-88.3149
Surrounding Terrain/ Obstacles	Developed on the crest of a hill, above some trees at the town transfer station with a big gap facing the principal wind direction down by the river (see wind rose B-6); trees are 70 ft high in the area	The site had excellent access to the prevailing western winds with open farmland in that direction for over 2 miles (see wind rose B-7); open farmland stretches to the south and southeast for 3/4 mile[14]
Performance		
Estimate (kWh)	58,000 kilowatt-hours (kWh) annually[15]	111,830 kWh annually
Actual (KWh)	~35,000 kWh/year (yr.)[16] (approx. 60% of estimate)	100,000 kWh/yr (approx. 90% of estimate)
Maintenance Issues	Main brakes malfunctioned, locking the blades in place	Minimal downtime for various issues that are not considered to have had a significant impact on production
Current Operating Status	Turbine is still located at the transfer station, but does not currently generate energy[17]	Still operating

Note: The point here is not the difference in production between the two turbines. These are very different machines and even though they have the same rated power, they would generate very different annual energy even on the same site. The point is the difference between the expected and delivered energy—with one site experiencing impacts from obstructions that were not effectively accounted for and one experiencing fewer impacts from obstructions.

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[14] Vosters site assessment. (May 18, 2010).

[15] Project developer interview. (May 3, 2013).

[16] Project developer interview. (May 3, 2013).

[17] Email with Cameron Wake, member of the Kittery Energy Committee.

Wind Rose

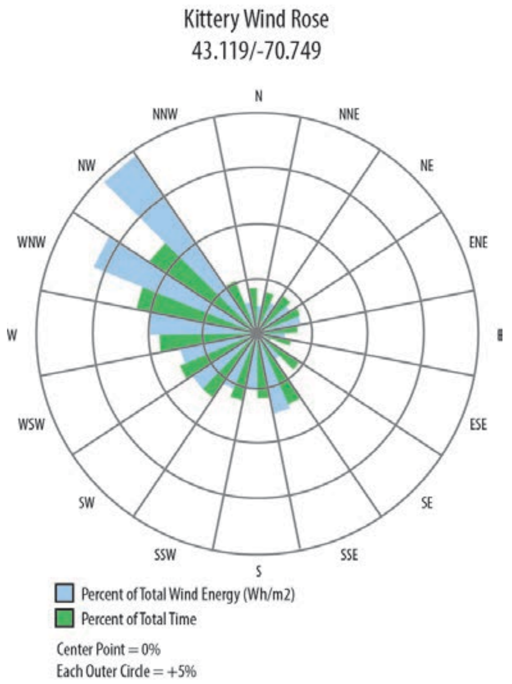

Figure B-6. Kittery wind rose

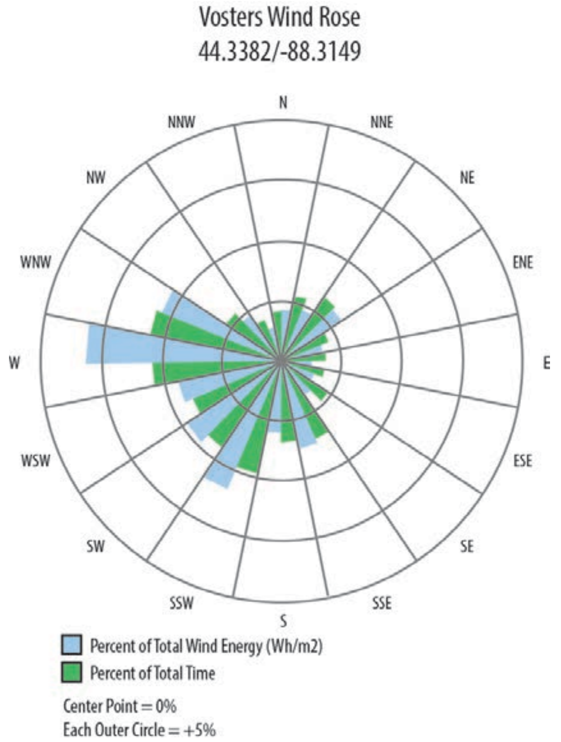

Figure B-7. Vosters wind rose

Lessons Learned

Case study #2 highlights the Kittery and Vosters installations as a paired example because both installations used a minimal resource assessment methodology, installed equal kilowatt-sized turbines, and had decidedly different outcomes.

Kittery

In the case of Kittery, project developers encountered a low but steady wind resource that was not adequate for a wind turbine installation. The estimated wind resource for the Kittery installation at hub height (~125 ft) was 4.6 m/s, or 10.39 mph, a resource that is characterized as a Class I wind site. In hindsight, with such a limited resource at that height, the project developers believe they could have potentially used a taller tower (~200 ft) with a larger turbine to reach a stronger wind resource.

An additional aspect of the wind resource that potentially affected the installation was that the project developers incorrectly overestimated the amount of flow recovery at the site. Flow recovery is the revitalization of the wind resource at a specific location after it has been interrupted by an obstacle. Seventy-foot trees were in the vicinity of the Kittery project and presented a level of ground clutter that was likely to play an important role in the underproduction of this project. In addition to the surrounding trees were buildings located to the west and northwest of the turbine, which may have also interfered with the wind resource. It is critical that both ground clutter and other potential wind resource obstacles be considered during site evaluation and selection.

In addition to the impact on wind speeds, ground clutter can create higher levels of turbulence that can influence a project's annual energy output. High levels of turbulence also have the ability to decrease a turbine's expected life span because of additional stresses on various components.

Projects that could be impacted by ground clutter should take additional steps during a resource assessment to understand how the obstacles will affect the wind resource. It is suggested that these projects follow the best practice of installing an on-site anemometer for data collection to reduce wind resource uncertainty and increase the likelihood of a successful project.

Vosters

Similar to the Kittery project, the Vosters installation used a 2007 wind resource map as a major part of the assessment. The map indicated that the proposed location had an average wind speed of 14 mph at a 60-m height. Although the project hub height was ~42 m, the project proponents predicted an average wind speed of 12.4 mph at that height and assumed the wind resource was adequate for the site.

The Vosters' assessment noted that the open space from the predominant wind direction made the site an ideal location. If there had been ground clutter in the form of large trees or man-made structures located in this area the site might not have had access to the necessary wind resource for a successful installation. Five hundred feet east of the installation is a barn with three 80-ft silos. The height and mass of the barn and silos were factored into the assessment.

Case Study #3: Hempstead Project

Case Study #3 examines a wind project in which various parties took different approaches in completing a wind resource assessment that used wind resource maps and supporting data sets, an online small wind assessment tool, publicly available data sets, and nacelle anemometer data each with slightly different values for Weibull shape and scale factors, vertical wind shear factors, losses, and so on. The different wind resource assessment techniques resulted in varied annual energy production projections which, of course, impacted the turbine performance evaluation and project economics.

The manufacturer's preliminary annual energy production estimate provides a range of Weibull scale factors, wind shear factors, wind speeds, and annual energy production (with and without estimated losses). This is a prudent approach as no on-site hub height wind data were collected and analyzed. The wind will vary year-to-year and so will the energy production; however, the rotor diameter (two sizes are available for this turbine) is not included in this document and has a significant impact (~13%–14% at these wind speeds) on the expected annual energy production.

For projects that are the same size as the one used in this case study (100 kW), the customer is often not willing to pay for a year-long wind resource assessment with a meteorological tower, so these multiple resource assessment techniques are prudent approaches to better frame the realm of possible outcomes and help reduce uncertainty in annual energy production projections. The different energy production projections are provided in Table B-3 along with site details.

New York State Energy Research and Development Authority (NYSERDA)[18] sponsors the Small Wind Explorer, an online tool linked to AWS Truepower's system, which can be used to estimate small turbine performance at various sites throughout New York. A free report can be generated that provides mean annual wind speed at three heights (80, 100, and 120 ft), annual energy range (kWh) for generic 5-, 10-, 20-, and 50-kW turbines[19] at each height, a color-coded wind speed map at 100 ft, and a wind energy rose. The site also provides a professional report that includes wind speeds at 60 and 140 ft.

During Case Study #3, NREL used long-term hourly data from Modern-Era Retrospective Analysis for Research and Applications (MERRA)[20] for two nearby sites (14 and 22 miles away) at both 10 and 50 m to generate synthetic wind speed and direction data at 37 m (hub height). Windographer[21] software was used to analyze this data, which has several advantages: it provides hourly data that can be used to improve the accuracy of energy production calculations; it provides estimated wind speeds at two heights (10 and 50 m) so synthetic data at other heights can be extrapolated; and modeled data are adjusted by actual recorded data so that a reasonable long-term data set can be created. Figure B-8 shows the locations of the MERRA data sets relative to the turbine locations.

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[18] Small Wind Explorer, NYSERDA. http://nyswe.awstruepower.com/

[19] Full turbine list can be found at: http://www.cleanenergystates.org/projects/ITAC/itac-unified-list-of-wind-turbines/

[20] Cullather, Richard & National Center for Atmospheric Research Staff (Eds). Last modified 25 Feb 2013. "The Climate Data Guide: NASA MERRA." Retrieved from http://climatedataguide.ucar.edu/reanalysis/nasa-merra. Originally posted on September 30, 2011, and last modified February 25, 2013.

[21] Mistaya Engineering, Windographer Wind Assessment Software: http://mistaya.net/windographer/overview.htm

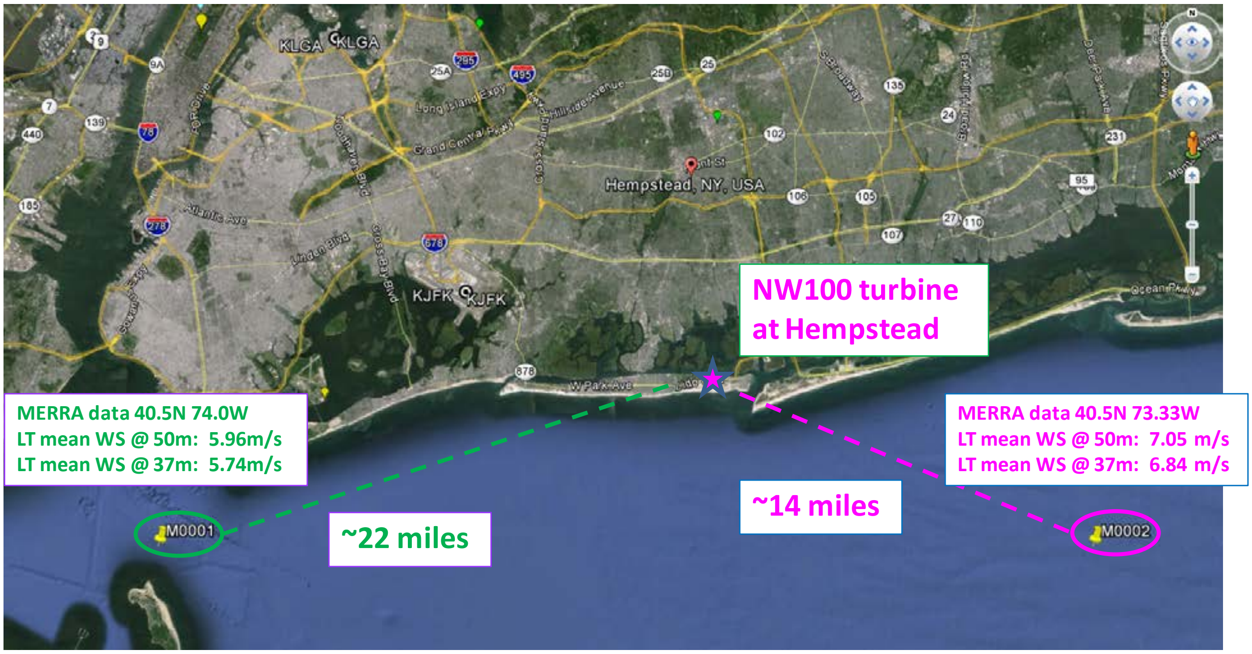

Figure B-8. Map of MERRA data sites and turbine location. ***Image from Google Maps with notes added by NREL***

The photos in Figure B-9 and Figure B-10 show the site from the street and above before and after installation. Table B-3 provides turbine and site details along with the results of the four different site assessment approaches.

Figure B-9. Hempstead, New York, NW100 wind turbine. ***Photo by the Town of Hempstead, NREL 28963***

Figure B-10. Hempstead aerial photo before (left) and after (right) installation . *Left photo by the Town of Hempstead, NREL 32728. Right photo from Google Earth.*

Table B-3. Case Study #3 Turbine System Details

HEMPSTEAD	
Location	Hempstead, New York (Figure B-9)
Date Installed	December 2011
Project Goal	Town of Hempstead installed the turbine to provide power to Long Beach Island's only hydrogen-fueling station
Turbine Information	
Model	Northwind 100
Capacity	100 kilowatts (kW)
Tower Height	37-meters (m), or 121-ft, monopole tower
Site Characteristics/ Surrounding Terrain/Obstacles	Long Beach Island is about 15 kilometers (km) in the east-west direction, and 1 km north-south. The elevation range is 1–3 m. The turbine is located in the eastern portion just north of Lido Beach and west of Point Lookout. Reynold’s Channel is to the north and is ~200 m wide as it winds through a series of islands in the northwest-through-northeast arc. The densely packed residential neighborhood of Point Lookout is to the east-through-southeast arc. There is a mix of open grassy fields, small stands of trees (8–15 m), parking lots, and 1 to 2 story buildings in the south-through-west arc. There is a 1.5-story building about 80 m to the southwest of the turbine. The turbine site had a number of trees removed in preparation for the wind turbine, photovoltaic system, and hydrogen-fueling station. There is clear fetch across the water of the Hudson Shelf Valley to the southeast-through-southwest of the island. Winds from the west-through-north blow across the island.
Elevation	~2 m
Latitude/Longitude	40.59307N /73.58834W
Performance Estimates	
Wind Resource (m/s) and Energy Estimates (kWh/yr)	**Wind Project Installer Performance[22] Estimates** Mean wind speed at 37 m: 5.13 meters per second (m/s) Assumed net losses: 8% Weibull k: 2.0 Weibull a: 5.79 m/s Annual energy production: 134 megawatt-hours per year (MWh/yr) Rotor diameter: 21 m

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[22] Project Installer Estimates: Aegis, Alteris Renewables, Annual Energy Calculation and NW100 Power Curve.

HEMPSTEAD	
	Manufacturer Performance[23] Estimates: Mean wind speed at 37 m: 6.14 m/s Wind shear factor: 0.22 Assumed net losses: 7% Weibull k: 2.391 Weibull a: 6.921 m/s Annual energy production: 209 MWh/yr Rotor diameter: not stated **NYSERDA Small Wind Explorer[24] Performance Estimates** Mean wind speed at 37 m: 6.22 m/s Wind shear factor: 0.22 Assumed net losses: 20% Annual energy production range (Two generator 50-kW wind turbines: 168–216 MWh/yr Rotor diameter: not stated **MERRA Data with Windographer Performance Estimates Using Two Nearby Sites** Average mean wind speed at 37 m: 6.26 m/s Wind shear factor: 0.121 Assumed net losses: 8% Weibull k: 2.3 Weibull a: 7.07 m/s Annual energy production: 235 MWh/yr Rotor diameter: 21 m Annual energy production: 267 MWh/yr Rotor diameter: 24 m
Operational Issues	Operators of the Hempstead site indicated that there was a car accident that caused the turbine to be shut down from August 9 to August 14, 2012, (5 days), and a post-Hurricane-Sandy inspection caused a precautionary safety shutdown from January 12, 2012, to March 4, 2012 (52 days). Expected annual energy production was adjusted accordingly for those 57 days.
Measurement Issues	Measurements taken at the turbine have consisted of very inconsistent time intervals and random gaps. As a result, it is not statistically possible to use these data for verification of the mean wind speed for any meaningful interval. Consequently, the wind speed cannot be correlated to monthly or annual energy production. Cumulative kilowatt-hours produced are recorded in the manufacturer's data set. Despite the inconsistent intervals, the cumulative tracking generally appears to be working, though some monthly totals do not appear to align with MERRA wind speed data during that month.
Actual Energy Production	**Wind Project Installer Actual Energy Production Report** For a 6-month period (March 27, 2012 to September 27, 2012), the Town of Hempstead reported energy production of 142 MWh. This appears to be the cumulative energy produced since the turbine began operating, not since March 27, 2012. Using the Northern Power Systems spreadsheet, the correct amount appears to be 99 MWh/6 mo. **Per Manufacturer Data, Energy Production** for March 27, 2012 to March 26, 2013 Note: Turbine off-line for 57 days during this time; 186 MWh/yr

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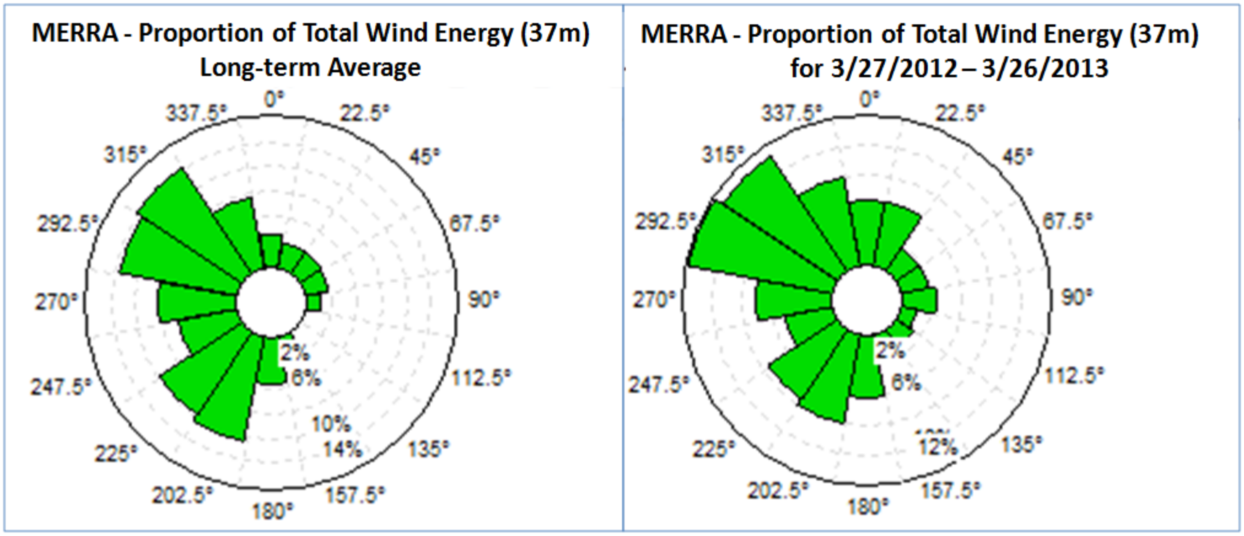
[23] Manufacturer Preliminary Annual Energy Production Estimate.

[24] Small Wind Explorer, NYSERDA. http://nyswe.awstruepower.com/

HEMPSTEAD	
	MERRA Estimated Energy Production Using Averaged Hourly Mean Wind Speed for 24-m Rotor: Mean annual energy production estimate: 267 MWh/yr Mean annual energy production estimate for March 27, 2012 to March 26, 2013: 237 MWh/yr Mean annual energy production estimate for March 27, 2012 to March 26, 2013, with an adjustment for Hurricane Sandy and the car accident: 189 MWh/yr **MERRA Estimated Energy Production Using Averaged Hourly Mean Wind Speed for 21-m Rotor:** Mean annual energy production estimate: 235 MWh/yr Mean annual energy production estimate for March 27, 2012 to March 26, 2013: 210 MWh/yr Mean annual energy production estimate for March 27, 2012 to March 26, 2013, with an adjustment for Hurricane Sandy and the car accident: 165 MWh/yr
Maintenance Issues	Nearly 2 months of production lost to Hurricane Sandy safety precautions and grid issues
Current Operating Status	Turbine is currently operating

The wind rose on the left in Figure B-11 shows the long-term average wind direction distribution. The wind rose on the right shows that for the year in question, more energetic winds came over the land to the west and north and less from the southwest than in more typical years.


MERRA - Proportion of Total Wind Energy (37m) Long-term Average

MERRA - Proportion of Total Wind Energy (37m) for 3/27/2012 – 3/26/2013

Figure B-11. (Left) total wind energy rose using long-term data from two nearby MERRA sites. (Right) total wind energy rose using data from two nearby MERRA sites for the period March 27, 2012 to March 26, 2013.

MERRA Data Sources

There is a relatively new climate data capability available from the National Aeronautics and Space Administration (NASA) called MERRA.[25] MERRA is a climate analysis data set generated by NASA's Global Modeling and Assimilation Office using the Goddard Earth Observing System atmospheric model and data assimilation system.

The aspect that makes the MERRA data particularly useful is that it can be adjusted "after-the-fact" to reflect the actual atmospheric conditions, not merely the predicted ones. MERRA data from two locations are used for this analysis. Spatially, these locations are separated north-south by 0.5 degrees, which equates to roughly 55.6 km (34.5 mi), east-west by 0.67 degrees, which equates to roughly 52.5 km (32.6 mi). The MERRA data set locations can be seen by the yellow push pins shown in Figure B-8.

Fifteen years of hourly data at 10 and 50 m were downloaded for both of these sites. Collectively, these sites provide insight into the long-term wind trends in the local region and allow for a determination of how well the wind data measured during the period of interest at Hempstead compares with the long-term wind trends reflected in the MERRA data. The power law was used vertically to extrapolate a synthetic data set for each site at 37 m. The average of these two data sets was 6.26 m/s, which compared reasonably well to the manufacturer's estimate of 6.14 m/s and NYSERDA's Small Wind Explorer's estimate of 6.22 m/s. Figure B-12 shows a comparison between the long term wind speed data and the 2012 through 2013 data. Figure B-13 shows the energy production expected based on the 2012-2013 wind speed distribution and the actual energy production during that time period.

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[25] Cullather, Richard & National Center for Atmospheric Research Staff (Eds). "The Climate Data Guide: NASA MERRA." Retrieved from http://climatedataguide.ucar.edu/reanalysis/nasa-merra. Originally posted on September 30, 2011, and last modified February 25, 2013.

Wind Speed Estimates

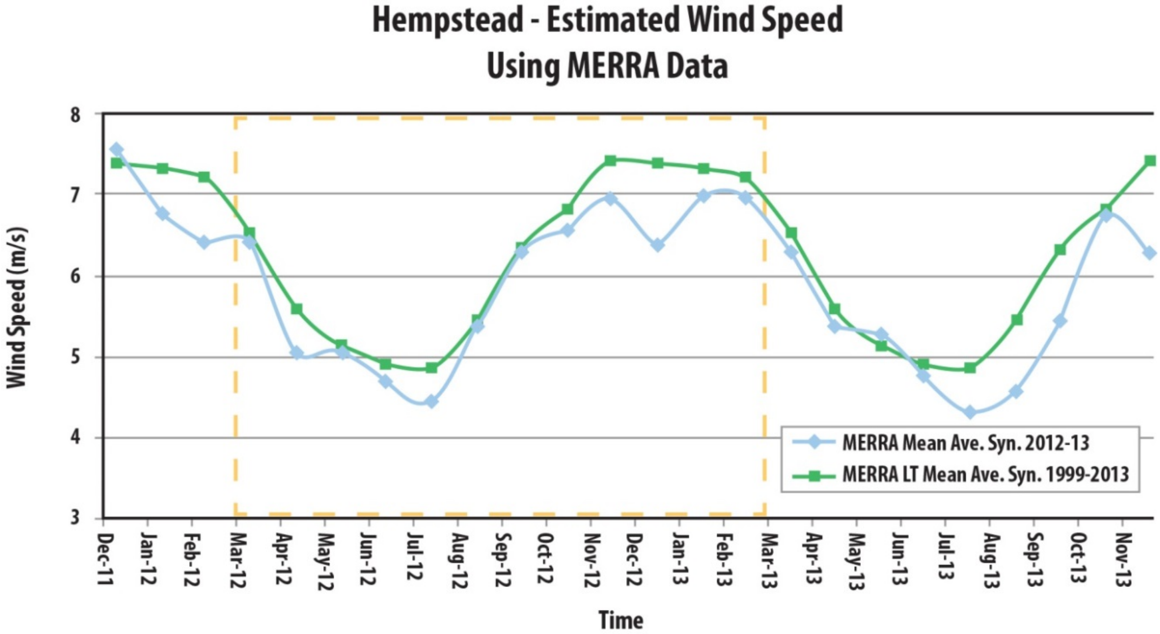

Figure B-12. The synthesized mean monthly averaged wind speed from two nearby MERRA sites at 37 m for the period 1999–2013 (green) and for the period since the NW100 was installed (2012–2013, in blue); the dashed overlay is the 12-month period used for the wind analysis summary

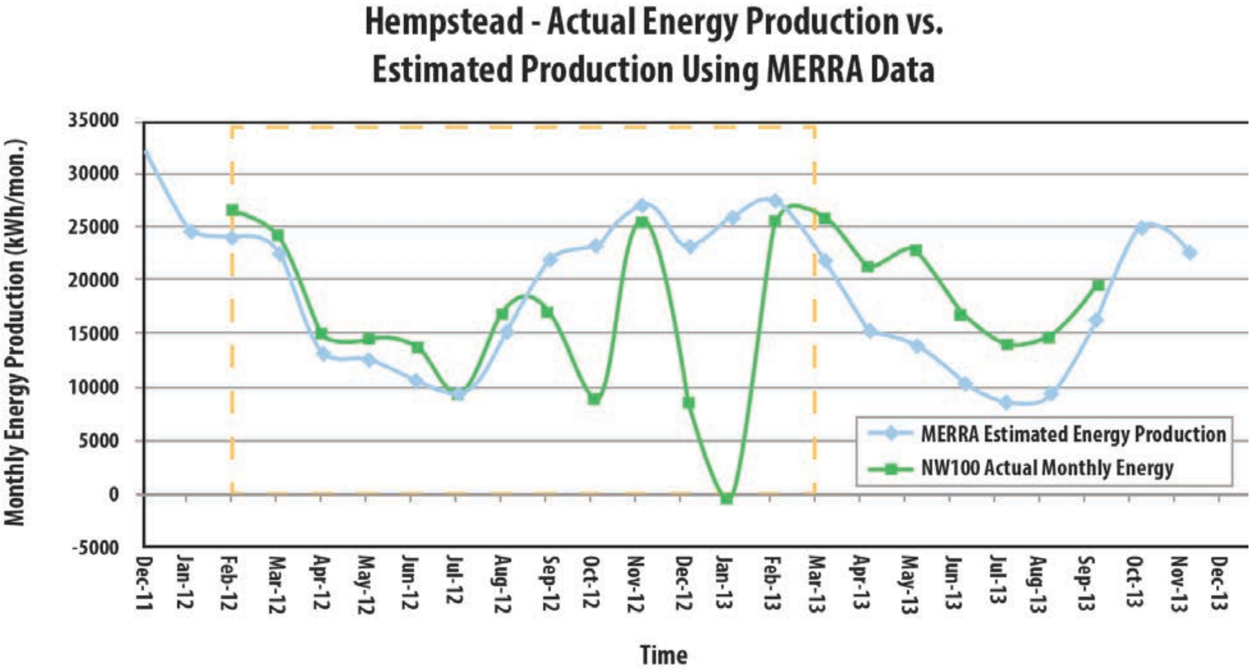

Figure B-13. The actual monthly energy production of the NW100 at Hempstead and the estimated monthly energy production for the same time frame using synthesized hourly averaged wind speed from two nearby MERRA sites at 37 m; the dashed overlay is the 12-month period used for the wind analysis summary

Lessons Learned

Purchasing data from a reputable wind assessment company can be an effective way to obtain data. Free online data from automated surface observing system weather stations (http://www.nws.noaa.gov/asos/), MERRA, NREL (http://www.nrel.gov/gis/data_wind.html), and others can also be effective. In the absence of on-site data, using multiple sources of existing wind data is a good way to cross-reference any data set, though the wider the variation between the data sets, the lower the confidence in the resultant energy predictions.

As seen in the Hempstead case study, the findings of four resource assessments using different methodologies resulted in four different annual energy production estimates. The variation proved to be significant, especially when trying to verify turbine performance in a given wind year.

Concerns

The Hempstead turbine manufacturer provided an estimate of the wind resource and annual energy production for one their turbines, but neglected to specify which turbine (21- or 24-m rotor diameter) the prediction was for, thereby reducing the confidence in the performance verification calculations. The estimate provided was challenging to verify in that the performance most closely aligned with the estimated performance of a NW100 with a 24-m rotor diameter. The only report that included a rotor dimension cited a 21-m rotor, thus there is uncertainty of the rotor diameter for the subject turbine.

The original wind speed estimate that was conducted by the eventual project installers reported the lowest estimated average speed for the site of 5.13 m/s.[26] The low input led to an estimate that was significantly less than the installation's actual production. As a result, inaccurate inputs can distort a project's potential (positively or negatively).

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[26] Project installer annual energy calculation.