Appendix A

Wind Energy Resource Assessment

Klickitat County
Energy Overlay

Environmental Impact Statement

Appendix A – Wind Energy Resources

This section identifies and assesses areas within the Klickitat County Energy Overlay Zone that have the potential for wind energy development. The assessment is based on recently updated wind maps and other available wind data. This section describes the typical process developers would follow to collect wind data to further characterize and evaluate the commercial potential of wind energy at a particular site. This detailed description of the wind resource assessment process provides an understanding of the kinds of data wind energy project developers use to characterize a site for project development.

Tools for Determining Available Wind Resources

The following describes the process typically used by wind developers to evaluate commercial-scale wind energy projects.

The wind energy industry has developed several standard tools and techniques to select candidate areas for development. Generally, the approach follows the steps described in a document written for the National Renewable Energy Laboratory (NREL) in 1997 as a guide to wind energy feasibility and development. The *Wind Resource Assessment Handbook* (NREL 1997) specifically describes the steps for reviewing existing wind data and local topography. The NREL Handbook describes the following steps to collect information for review and analysis:

- Obtain and analyze available wind speed data sets from the surrounding area
- Analyze wind resource maps developed by NREL
- Observe topographic features, vegetation growth characteristics, and tree flagging in the area and identify potential areas for monitoring. Also observe the area from an aircraft to evaluate the deformation of trees and vegetation and other unique topographic relief features
- Conduct interviews with local residents about historical wind and weather patterns
- Study topographic maps to determine local terrain features that are favorable for producing localized high winds
- Use computer modeling and mapping tools to further evaluate the wind resource potential based on the available data.

Using these tools in a progressive manner pinpoints localized areas for additional data collection. Site-specific wind data are required to determine the wind power potential at a specific location. A minimum average annual wind speed of 15 to 17 miles per hour (mph) at 50 meters above ground level is necessary to economically produce energy from commercial-grade wind turbines.

Description of Wind Power Density and Wind Power Classes

The best indicator of the wind resource in any particular area is determined by calculating the wind power density (WPD) based on available wind speed data. To calculate WPD, an annual average of the wind speed data for a specific location is determined. This calculation, which combines the effects of wind speed and air density, is the industry standard that provides the best indication of wind energy potential. The WPD formula is based on the cube of the wind speed. Because the magnitude of an individual wind speed value can increase considerably by cubing it, the WPD is dramatically affected by small changes in wind speed. Therefore, obtaining wind speed data is the first, and most important, step in evaluating an area's feasibility for wind power development.

The air density term of the WPD formula is calculated from temperature and barometric pressure data. This term is affected by long-term climatological influences that vary seasonally, and therefore affect the WPD. However, this factor is not as significant as the cubed wind speed relationship.

Wind Power Class Determination

Annual averaged wind speed data are evaluated by characterizing the wind speed and WPD into wind power classes—the higher the class, the higher the wind energy potential. These classes are based on the annual WPD for a specific location. Class 1 and 2 areas are unsuitable for development because of low mean winds. Class 3 areas are marginal for development. Generally, Class 4 areas or higher are considered favorable for most wind power projects. These sites are suitable for development using turbines mounted with the rotating hub of the turbine located at least 50 meters above the ground (referred to as hub height).

Graphic A-1 shows the wind power class ranges for wind speed measurements at 10 meters above ground and 50 meters above ground. The shaded rows of the table indicate classes that are favorable for development.

Graphic A-1. Wind Power Classification

	10 meters (33 feet)		50 meters (164 feet)	
Wind Power Class	**Wind Power Density (watts/m^2)**	**Wind Speed meters/second (mph)**	**Wind Power Density (watts/m^2)**	**Wind Speed meters/second (mph)**
1	≤ 100	≤ 4.4 (9.8)	≤ 200	≤ 5.6 (12.5)
2	≤ 150	≤ 5.1 (11.5)	≤ 300	≤ 6.4 (14.3)
3	≤ 200	≤ 5.6 (12.5)	≤ 400	≤ 7.0 (15.7)
4	≤ 250	≤ 6.0 (13.4)	≤ 500	≤ 7.5 (16.8)
5	≤ 300	≤ 6.4 (14.3)	≤ 600	≤ 8.0 (17.9)
6	≤ 400	≤ 7.0 (15.7)	≤ 800	≤ 8.8 (19.7)
7	≤ 1000	≤ 9.4 (21.1)	≤ 2000	≤ 11.9 (26.6)

(a) Note: Shaded classes are favorable for wind power development.
m^2 = meter squared.
mph = miles per hour.

Ten meters is the typical measurement height for most wind data collected at airports and for air pollution studies. Northwest Sustainable Energy Economic Development (NW SEED) is a renewable energy organization. Some of the data used in developing the NW SEED map are collected from this height. Fifty meters is the height normally used for analysis of wind power feasibility, because it is the typical minimum hub height for wind turbines.

Ten-meter data commonly are used to screen for potential sites when they are the only available data set. The 1/7th power law algorithm is used to extrapolate the 10-meter data to 50 meters. This algorithm estimates the increase in wind speed with height. This equation takes into account an approximation of wind shear (turbulence). This wind shear factor is highly dependent on the local terrain, the season of the year, day versus night, and wind direction. The wind shear factor has a significant effect on converting 10-meter data to hub height and is used only as a cursory test of suitability. Because this estimating method results in an approximation, an unknown margin of error is introduced. For example, a small error in this estimated wind speed increases significantly as the estimated wind speed value is cubed during the WPD calculation, adding an even larger potential for error in evaluating the potential of the wind resource. For this reason, 50-meter or higher hub-height data are preferred in order to minimize potential errors.

It is important to note that future wind projects likely will use wind turbines with hub heights ranging from 60 to 100 meters above ground. Because extrapolating data from lower heights will add a significant level of uncertainty, new methods of data collection are becoming part of the toolkit for evaluating wind resources. Uncertainty is a fatal flaw for developers, and speculative wind data extrapolated from one height to another may not be acceptable.

Data can be collected at multiple heights using a remote sensing instrument called a Doppler acoustic sodar (*so*und *d*etection *a*nd *r*anging). The sodar is a self-contained, portable system that uses audible pulses of sound aimed vertically into the air. A receiver measures the reflected sound, and a computer processes the received signal based on the physical principle of the Doppler shift, or the change in frequency of a sound as it is affected by wind speed. The sodar collects vertical profiles of wind speed and direction up to a height of approximately 300 meters above ground.

Topographic Effects on Wind

The evaluation of topography is another useful tool for determining the potential wind resource of a particular area. The terrains that are considered most suitable for potential wind energy sites are elevated ridges that are perpendicular (90 degrees) to the prevailing winds. Elevated terrain tends to cause accelerating forces that increase local wind speeds. The ridges intercept the winds and compress and accelerate air as it moves up the ridge slopes, increasing the wind speed at the ridge tops. Therefore, exposed ridges are known to be sources of higher localized winds. Other areas where the wind accelerates are steep divides or valleys that funnel the wind. This “canyon effect” is analogous to blowing air through a straw; the force of air coming through the straw is much greater than merely blowing air out of one’s mouth.

Topographic increases in wind speeds also tend to deform vegetation. Ground vegetation grows in the direction of the prevailing wind. Shrubs and trees exhibit “flagging” (that is, less growth occurs on the upwind side of a tree or shrub). These vegetation characteristics are useful for determining optimal locations for further wind data collection. An experienced wind resource meteorologist can walk or fly over an area to identify specific areas for placing wind monitoring towers.

Analysis of NW SEED Wind Resource Map for Klickitat County

This section summarizes existing information about the wind resource in the Klickitat County Energy Overlay Zone area, based on the NW SEED map and associated data. An analysis of existing data helps identify the locations for field measurement that would provide the most useful additional information to form the basis for a definitive wind resource assessment of the Overlay zone’s wind resources.

Description of the Wind Resource Map

Because the power generated by wind is proportional to the cube of the wind speed, wind turbines must be located in areas with strong, persistent winds. A reliable definition of the wind resource is crucial for wind development. In the past, knowledge of the Pacific Northwest's wind energy resources was based on data collected in various wind resource assessment programs, principally by the Bonneville Power Administration (BPA) and others, as well as the *Wind Energy Resource Atlas: Volume I The Northwest Region* (Elliott and Barchet 1980), which synthesizes data collected from various Pacific Northwest wind measurement programs. Unfortunately, the available data are sparse, and wind energy can vary widely over distances of a few hundred meters. Unlike the Great Plains region, where the wind resource often is located in relatively featureless terrain, promising wind areas in the Pacific Northwest typically are found in complex terrain. This exacerbates the problem of a sparse network of wind measurement sites. A further difficulty is that only five of the wind monitoring sites used for the 1980 *Wind Energy Resource Atlas* and maintained by the BPA—Browning Depot, Montana; Cape Blanco, Oregon; Goodnoe Hills, Washington; Kennewick, Washington; Seven Mile Hill, Oregon—are still in operation and available to the public. Therefore, few high quality reference stations exist for use in assessing long-term climatology.

The non-profit organization NW SEED identified a need to publicly disseminate high quality wind resource maps to encourage and support wind energy development in the Pacific Northwest. To meet this need, NW SEED initiated a project to map the wind resource characteristics of the northwestern United States, including offshore areas. The resulting map (reproduced in Figure 2-1) provides support for the planning and evaluation of future wind energy development opportunities. NW SEED produced high-resolution maps of the wind resource that use GIS-based data to enable identification and ranking of the most promising potential wind development areas. Overlays include roads, transmission lines, boundaries of wilderness areas, national parks, Indian reservations, and urban areas.

The NW SEED approach used an advanced modeling system called MesoMap™ to produce wind resource maps of the Pacific Northwest. MesoMap can simulate complex meteorological phenomena, such as sea breezes, offshore winds, mountain/valley winds, low-level nighttime jets, temperature inversions, surface roughness effects, flow separations in steep terrain, and channeling through mountain passes, which are important in the Pacific Northwest.

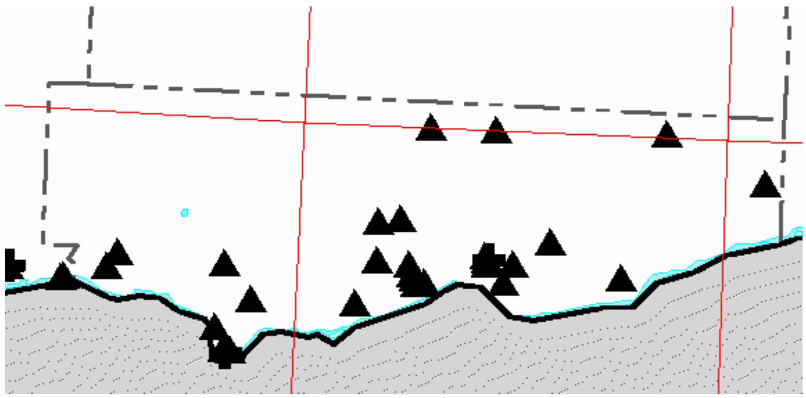
MesoMap also uses the National Weather Service's twice-daily vertical profiles of upper air wind, temperature, and pressure data collected with rawinsonde (weather balloons). The model merges the upper air data with surface meteorological data, providing a consistent long-term, three-dimensional wind resource record. The system has two basic components: 1) a MASS model output, which is a three-dimensional, hydrostatic, primitive equation numerical mesoscale model used by organizations throughout the world for regional-scale weather forecasting, and 2) a wind flow model called WindMap™, which employs three-dimensional weather data, topographic data, and surface roughness information.

The modeling approach involves preparation of a 400-meter grid for the region at multiple heights (10, 30, and 50 meters) with topographic data, weather measurements, and ground cover information. The model calculates a full year of wind speed, wind direction, and WPD. The results are validated against existing data and the model is adjusted and re-run. The final results of the wind model are incorporated with the GIS data to produce interactive maps and databases. The databases include information sufficient to run models such as WA^{s}P, PARK, WindOps, WindFarmer, and other industry-leading software used to microsite wind turbines.

Maps such as those produced by the NW SEED project are being used in 15 states, 5 Canadian provinces, and 11 countries.

Validation of the Wind Resource Map

A team of about 12 expert wind resource meteorologists helped to validate the Pacific Northwest wind resource map. Where possible, non-proprietary data were used to validate the model. Graphic A-2 shows the location of non-proprietary data available in Klickitat County for validation of the model.



Graphic A-2 Non-Proprietary Data Validation Locations in Klickitat County.

Proprietary data were also used, but in a non-specific way; that is, the meteorological experts made general corrections to the preliminary wind maps without compromising the specific proprietary data that were the basis for their corrections. This further added to the number of validation points. In addition, the experts also made subjective suggestions based on experience or observation of qualitative indicators of wind strength, such as wind-deformed trees. Sometimes these subjective or qualitative suggestions resulted in conflicts with the model output results. These discrepancies were resolved by a small team of meteorologists at NREL with extensive experience in developing regional wind resource assessments.

Caveats, Benefits, and Recommendations Based on the Wind Resource Maps

While validation of the model was extensive, as can be seen in Graphic A-2, the non-proprietary validation points are clustered in certain areas of Klickitat County. It is reasonable to assume that proprietary validation sites are in the same general areas, because some are located in the general areas that the original 1980 *Wind Resource Atlas* and recent NW SEED maps showed to have potential for better wind resources. Therefore, there is a high confidence level in estimates in the southern part of the county along the Columbia River Gorge. This conclusion was confirmed during a telephone conversation on 17 July 2002 with Dr. Mark Schwartz of NREL, one of the principals to validate the map. Fewer validation points are located in the northern part of the county. Areas such as High Prairie in the west and the plateaus above Alder, Stegman, and Douty Canyons to the east are under-represented with validation points, and thus these estimates have a somewhat lower confidence level. More data are needed to increase the confidence of wind resource predictions in those areas. Dr. Schwartz also stated that the overall resource is well documented by the map, but the confidence level for the estimates about specific local sites is lower because of the conflicts described earlier.

It should be noted that the model might miss small topographic features in extremely complex terrain. This failure to recognize sub-grid-size features can result in underestimates or overestimates of the resource. The model also depends on aerial photograph and map data of local surface roughness (which is affected by vegetation cover) and is only as accurate as the data are current. Unlike landforms, ground cover or roughness changes from year to year and even on a seasonal basis. Error in the specification of surface roughness can result in significant error in resource estimates.

Estimates may be questionable along north-south- and northwest-southeast-oriented ridges on the western border of Klickitat County. The NW SEED map indicates an excellent wind resource in this area. Even though the wind resource is likely to be excellent at well-exposed locations, the terrain is complex and the roughness varies from meadows to heavy tree cover. Additionally, the area's possibility of rime (white) icing could reduce wind plant output by 1 to 3 percent. Rime icing can be expected in the winter at most locations above 2,000 feet in Klickitat County. Typically wind turbines are shut down during ice accumulation conditions.

Despite these caveats, the NW SEED map provides more precision than was available in the past and is a valuable tool for the site identification task. It provides much greater certainty about site-specific wind conditions and project feasibility before developers invest in the necessary, but expensive, wind monitoring equipment that is needed as the final proof of the resource at a specific site. Therefore, the map should be used as the first step in wind resource assessment. An indication of a lack of a good wind resource on the wind map does not mean that the resource is poor, but it does suggest a low probability of a good resource.

Other Public Data Not Used in Map Development

It should be noted that other meteorological data sets may be available. These data sets are used for environmental permitting, specifically for compliance with local, state, and federal air quality regulations. These stations must meet certain EPA requirements with respect to distance from buildings or other structures, paved areas, and trees. These data sets, although usually of several years' duration of wind speed, wind direction, and temperature data, typically are not located in areas that are representative of highly probable locations for proposed wind energy development. Because these sites are selected to meet EPA requirements, they are useful for general feasibility determination, usually to justify further data collection and to correlate with additional data in nearby suitable terrain. At least two such sites are located in the Klickitat County Energy Overlay Zone: 1) a 10-meter-tall meteorological station operated by the Columbia Aluminum Plant near Goldendale, Washington; and 2) a 10-meter-tall meteorological station operated at Klickitat County's Roosevelt Landfill. These data sets may be useful in determining the viability of certain nearby areas for potential wind resource development.

Assessing Prospective Areas for Development

After determining the potential viability of a site for commercial wind energy development, the next step is to develop a field data collection program. The general requirements as described in the NREL Handbook and more recent standard approaches that have evolved since the NREL Handbook was published in 1997 are discussed below.

Monitoring Requirements

The following describes the general requirements for wind resource monitoring. This section does not describe all the necessary details of a monitoring program, but provides an overview of the major components of such a program. The NREL Handbook and an experienced monitoring contractor are valuable resources for developing a complete monitoring program.

Optimally, meteorological data from towers as close to hub height as feasible are installed to collect data for a minimum of 12 months. To provide accurate measurements, instruments must be mounted on towers that are hinged at the base to tilt down for access to instruments.

Monitoring Parameters

Wind speed, wind direction, and air temperature measurements are required for useful wind resource assessment. Typically, each parameter is scanned every 1 to 2 seconds, and the data points are averaged by a data logger mounted on the tower. Data normally are collected at 10-minute average intervals. Historically, hourly averaged data have been used, but with the increased capabilities of wind models and computers, the 10-minute averaged data provide additional precision. The data logger calculates and stores the standard deviation of both wind speed and wind direction. Calculations of maximum and minimum wind speeds and temperature are also often recorded.

Wind speed is the most important measurement parameter. A 3-cup anemometer is the typical instrument. Several manufacturers offer low-cost, highly accurate, and resilient anemometers that have been used in wind resource monitoring for years. An instrument with a distance constant of less than 5 meters generally is preferred. Collecting speed data at multiple heights is preferred to aid in simulating turbine performance caused by wind shears (changes in speed with height). The multiple height data also provide a valuable backup if a sensor at one height fails. The typical recommended scenario is to measure wind speed at three heights on a tower. For a 50-meter tower, measurements at 10, 25, and 50 meters are normal. For a 60-meter tower, measurements are at 10, 30, and 60 meters.

Ten-meter data are the standard height for wind measurements. In areas that contain obstructions or vegetation, particularly within forest canopies, the lowest wind sensor is placed at a height that minimizes effects of surface roughness or obstructions.

The 25- to 30-meter height is approximately the lowest level that turbine blades reach in their down position. Turbine performance can be estimated better with these data.

The 50- to 60-meter height data represent wind turbine hub height. Turbine performance models require data at hub height.

If turbines with hub heights exceeding 60 meters are proposed, the cost to erect and instrument a taller tower is significant. A sodar provides an alternative for data collection in these cases.

For accurate wind speed data it is important to minimize the effect of the tower on the instruments. Following industry standard recommended practices in the NREL Handbook and *Wind Speed Measurement and the Use of Cup Anemometry* (Hunter 1999) ensures quality data.

Wind direction data are collected at the same heights as wind speed data. A wind vane is recommended. Several manufacturers offer inexpensive, accurate, and versatile instruments.

Wind direction data measure wind shears based on wind changes caused by shifts in the direction with height. This is another valuable data set for turbine performance, because changes in wind direction with height can generate torque on turbine blades, thus affecting turbine output. Proper orientation of the sensor to true north is of crucial importance for direction. Optimal layout of the wind plant depends on good wind direction information.

Air temperature data are needed to determine the air density term in calculating wind power density and turbine performance. This measurement may be made at 2 to 3 meters above ground. Measuring at this height minimizes the effects of surface heating during daylight hours. It also enables the site to visually inspect the temperature sensor during a visit to the site.

Additional data parameters—barometric pressure, vertical wind speed, and precipitation—are recommended, but not mandatory. The rationale for each is provided below.

Barometric pressure is used with temperature to calculate WPD. Barometric pressure data from a nearby National Weather Service or other 24-hour monitoring station can typically be used. However, because pressure varies with elevation, each case must be evaluated individually to determine whether a suitable source of pressure data is available. If not readily available or deemed representative by a meteorologist, it should be measured on at least one tower within a monitoring program.

Vertical wind speed often is measured when turbines are located near a bluff or a significant non-horizontal component to the wind is expected. Vertical winds present two serious problems: 1) a significant vertical component results in the wind speeds measured by cup anemometers to be in error (often high) and the output of the turbine to be lower than expected because the turbine uses wind normal to the blades; and 2) the higher the vertical wind component, the greater the stresses on wind turbine blades.

Precipitation often is measured at wind plants because dirty blades are a significant factor affecting turbine performance. For stall-regulated turbines, dirty blades can reduce turbine performance by 15 to 20 percent. Even for pitch-regulated or combi-strall machines, some losses as a result of dirty blades are expected. After a rainstorm, wind plant performance generally increases as a result of blade wash. The duration and intensity of rainfall affects the amount of improvement in performance.

Other optional parameters may be useful on a case-by-case basis, such as solar radiation or vertical temperature data. Both of these parameters provide data about the vertical mixing and turbulence in the near-surface winds, which may affect turbine selection, design, and performance.

Recent Advances in Measurements

Advances in wind measurement data collection continue to provide better data collection efficiency, precision, and accuracy. These advances are the result of higher-speed computers, increased storage capacity of data loggers, and the advent of Web-based communications. Equipment is readily available for downloading data from tower data loggers by telephone or via satellite directly to a Web site, or even e-mailed to the data manager. This provides increased opportunity to review data and minimize lost data as a result of malfunctioning equipment. It also reduces the need to send a person to each site to download data on a routine basis.

Another recent advance is a 60-meter-tall tilt-down tower. Until recently, 40- or 50-meter-tall tilt-down towers were the tallest available. The taller tilt-down tower affords data collection at higher hub heights.

Finally, the advent of Doppler acoustic sodar has provided the ability to collect data at even greater heights. As turbines get larger and hub heights increase to taller than 60 meters, the sodar becomes a more cost-effective alternative to a lattice tower. Towers taller than 61 meters require approval by the Federal Aviation Administration (FAA) because they can obstruct aircraft navigation. The towers must be lighted and/or painted, and the FAA approval process is time-consuming.

The sodar collects wind speed and direction data at 10-meter height increments up to approximately 300 meters. The maximum height the sodar reaches varies from site to site. The data are valuable for determining the wind effects on turbine blades at hub height and at the top and bottom of the blades. Historically, this wealth of data has not been available because the cost to install a fixed tower of this height with instruments at this many levels is not economically feasible. Therefore, the sodar data are useful in determining wind shear and stress on the turbine blades, an effective means to evaluate various turbines and select those that best fit the particulars of each location.

Micro Site Selection (Micrositing)

Each measurement site must be selected based on topography and the optimum location where the highest consistent wind speeds are presumed to occur. This crucial step requires an experienced professional with a thorough knowledge of terrain effects on wind. Sites are selected by walking the project area and reviewing topographic maps for areas with favorable terrain characteristics, such as plateaus and crests of hills. A flyover of a proposed area allows more territory to be covered than can be accomplished on the ground. It also provides another frame of reference for terrain influence and vegetation deformations resulting from localized increased winds.

Additional information about site selection is included in the NREL Handbook. Careful attention to the site selection process is important in order to collect data most representative of the area and minimize anomalies that could affect the accuracy of model results and turbine performance studies.

Installation, Operation, Maintenance

Because stations typically are located in remote areas that are often difficult to access, visiting each site routinely can be costly and time consuming. Therefore, the stations should be designed so data can be downloaded easily. As mentioned previously, data loggers are now available that send data via modem or satellite link directly to a personal computer or Web site. This allows the data manager to receive and review data daily and minimizes down time if an instrument failure is detected. It also allows labor in the field to be minimized and optimized to yield the highest percent of data collection during a 12-month monitoring period.

Each site should be evaluated to determine whether icing of the wind sensors may occur. This is particularly likely in elevated terrain during winter months in Klickitat County. Anemometers and wind vanes equipped with heaters are available; however, they require significantly more electric power to operate, which is important to include in the design specifications for a monitoring program, particularly for sites with elevations higher than 2,000 feet. An alternative to heated sensors is duplicate sensors at multiple heights on each tower. This can reduce data loss during icing conditions.

Instruments should be inspected and tested before field deployment. The manufacturer's recommendations for testing, installation, operation, and maintenance should be followed. A qualified person should visit the monitoring sites on a routine, scheduled basis. This person should be identified before the stations are installed, participate in installation, and be properly trained in operation and maintenance.

Data Management

Normally a monitoring plan is written to detail the site operator's responsibilities and to describe the quality assurance activities to be conducted throughout the monitoring program. The NREL Handbook is a valuable tool for describing the details of a monitoring plan. Among the most important issues to be addressed in a monitoring plan are the procedures for managing the data from a monitoring program.

Data Collection

Data must be collected by a data logger at each site. The data then are stored and retrieved routinely either by a site operator or by remote means.

Data Validation

The data must be thoroughly reviewed by an experienced meteorologist or similarly trained individual to determine validity. Data should be validated routinely to minimize the loss of data as a result of instrument malfunctions. Data validation at the outset of a monitoring program also may show that additional parameters should be measured or alterations or modifications are necessary to fully evaluate the wind resource.

Data Reporting

Information about wind speed frequency distributions, wind power density, wind roses, energy roses, shear, turbulence intensity for wind speed and direction, peak hourly speed and peak gust, temperature, temperature extremes, and percent data capture customarily are reported. Additional information may be reported on a case-by-case basis.

Wind Resource Assessment Modeling

As the cost of wind power development increases, project developers and investors are seeking additional proof that a particular location is economically feasible. Recent advances in computer modeling tools can assist in these predictions.

Several wind energy resource assessment modeling products are on the market to determine the viability of a location for wind power development. Some are built on proprietary wind flow models, and others use publicly available models for the actual meteorological assessment and/or forecast.

Resource assessment modeling is a two-step process using mesoscale modeling followed by micro-siting analysis of specific potential wind farm development locations. In addition, the models may contain additional add-on packages that can offer other outputs, such as energy prediction or forecasting, array losses, noise calculations, electrical losses, visualization, and data export and reporting.

The output produced from the software packages can differ significantly, so experience with them is a necessity. When used correctly, these models become a valuable tool for a qualified wind resource assessment meteorologist to refine and quantify the proposed area for development.

Energy Output Estimates

An energy output forecast is required for wind project developers to obtain financing for a wind project. A discussion of the necessary elements follows. By anticipating these needs, informed wind energy siting and planning decisions can be made to expedite project deployment.

A crucial need for an energy output estimate is the average wind speed frequency distribution for the life of the project. This requires the data described above and a way to project wind speeds measured for 1 to 2 years out to 15 to 30 years. Klickitat County is fortunate because a high-quality, long-term database is available at the Goodnoe Hills site in the Columbia Hills near Goldendale, Washington. This site has been in operation continuously since 1980. Other long-term sites in the vicinity are the Seven Mile Hill site (since 1978) east of The Dalles, Oregon, and the Jump-Off Joe site (since 1978) south of Kennewick, Washington.

Data measured at a prospective wind plant need to be correlated to a longer-term record to determine the interannual variation of the projected plant output. The cost of financing a wind project is determined by expected risk. The better the uncertainties in the energy output estimates are understood, the lower the risk.

An energy output estimate for a wind plant consists (at a minimum) of the following:

- Description and maps of the site
- Characteristics of the turbine and wind plant (turbine dimensions, plant layout, power curve, and control system)
- Description of the turbine characteristics (dimensions, power curve, and control system)
- Description of the long-term reference site and interannual wind speed variations
- Description of site data, locations, calibration, data collection, and quality assurance program
- Temporal variations of the wind (seasonal, diurnal, and turbulence intensity)
- Spatial variations of wind over the project area, including wind speed and energy ratios of measurement sites and spatial variations in wind direction
- Discussion of wind shear and its impact on selection of turbine hub height
- Estimate of 50-year return speed for peak gusts
- Annual mean temperature and extremes

- Air density adjustment for the site and site-corrected power curve
- Type, amount, and frequency of icing
- Seasonal precipitation patterns
- Wind turbine array efficiency
- Wind turbine expected availability
- Electrical losses
- High wind hysteresis losses (losses near the turbine cut-out speed)
- Expected icing and dirty blade losses
- Frequency of forced shutdowns by the utility
- Discussion of the uncertainties of all measurements and estimates
- Energy output estimate
- Discussion of the uncertainty of the energy output estimate.

Turbine Performance Studies

International standards have been developed for wind turbine generators (WTGs) to ensure that a WTG performs to the power curve provided by the manufacturer. A power curve is a table of expected power outputs in kW for speeds in the operating range of the turbine. Power curves are developed from field measurements using an anemometer placed at hub height on a mast reasonably close to the WTG. The turbine does not always produce the exact kilowatt output in the power curve for a given wind speed for a variety of reasons. A typical power curve shows a cluster of points around a given wind speed. Turbulence, yaw error, density, and other factors can contribute to this spread. Even the wind speed measurement is subject to error. A 3 percent error in the wind speed measurement (a typical error for wind measuring equipment) can result in up to a 9 percent error in power output because the energy content varies with the cube of wind speed.

To provide the best possible power curves, several international test stations have been established that use standardized techniques for establishing the wind turbine power curve for each turbine type. Type approval for a specific WTG is generally a necessary criterion for obtaining project financing. However, a certified power curve is not sufficient. The certified power curve is valid for sea level air density (1.225 kilograms per cubic meter [kg/m^3]) and 10 percent turbulence intensity. The test facilities are located in flat terrain, and the upwind anemometer reading has little or no distortion because of topography or roughness and thus represents the real wind speed experienced by the rotor blades. These are not the conditions a wind turbine typically encounters in a normal, non-ideal situation. The turbine may not be running at standard air pressure and temperature, and consequently it is necessary to make corrections for changes in the density of air. Air density is a function of temperature and pressure and generally decreases by about 2 percent for every 300-meter increase in elevation.

A typical wind project site introduces other possible factors that result in a deviation from the certified power curve. A wind development site in Klickitat County is likely to be on gently rolling hills or a ridge crest. The ambient turbulence level may be significantly greater than 10 percent, and a vertical component may be present, which generally results in less output for given wind speed than predicted by the power curve. For this reason, every wind project should have a site-specific wind turbine power performance test. The procedures for a performance test are specified in International Electrotechnical Commission (IEC) Standard 61400-12.

A power performance test starts with a measurement of the winds at hub height at a future WTG location and 2 to 2.5 diameters upwind. This is called the site calibration. The met tower at the turbine location is removed when the turbine is installed. The site-corrected wind speeds measured upwind of the turbine are collected along with turbine power output for a period sufficient to establish a statistically significant database for a range of wind speeds, directions, and site conditions. The IEC standard prescribes analysis procedures, calculation of power curve uncertainty, and site annual energy output.

Energy Forecasting

Need and Benefits

Wind has become an increasingly important energy source for the Pacific Northwest. According to the Department of Energy (Western Market and Infrastructure Assessment, Factors Affecting Electric Availability and Prices, Docket No. AD02-20-000, Presentation for Commission Meeting July 17, 2002, Item No. A-3), through 2010, growth estimates for population and retail electric sales are projected to be highest in the regions bordering California. As wind energy production entering the grid increases, it is becoming necessary to reliably predict the output of these new power plants. Wind power plants present new challenges for utility dispatchers and schedulers because of the variable nature of the wind as a fuel. The result is that utilities receiving energy from wind plants are increasingly requiring forecasts of output from the wind plant operators.

Forecasting Challenges and Techniques

The time period of interest for utility forecasts varies from hourly output for dispatching and scheduling, to 1 to 2 days for spot market purchases and sales. Another benefit of a forecasting capability is that wind plant operators can better schedule maintenance work and anticipate severe wind events.

Forecasting wind turbine output is difficult because wind varies widely in space and time. The power curve of a wind turbine adds new complexity to the challenge of forecasting plant output, because when winds are from 0 to 4 meters per second the turbine produces no energy;; from 4 to about 15 meters per second, the output increases with increasing wind speed; from 15 to 25 meters per second, the output is invariable; and beyond 25 meters per second, the turbine shuts down and produces no power. Adding even more complexity is uncertainty regarding the turbine's response to the wind and interaction between wind turbines as a result of aerodynamic wakes. Wind forecasting, which is already tricky, becomes even more difficult.

Despite its variability, wind does exhibit some dependence from hour to hour and from location to location. This is sometimes called a "trend" for temporal dependence and "pattern" for spatial dependence. Wind forecasters have found that when forecasting less than 6 hours ahead, three approaches work best: persistence, statistical, and neural networks. For forecasting the next hour, it is difficult to beat persistence, which is essentially forecasting based on what has just happened. Beyond 1 hour better results can be obtained by a statistical approach that uses multiple regression models and trend analysis, or better yet, neural networks that use pattern recognition. These forecasts use meteorological data collected at/or near the wind plant. Both approaches (statistical and neural) improve as more data are collected; this is particularly true of the neural approach. Persistence is easy to employ and requires no skill, but it is subject to significant error for forecasts beyond an hour.

Long-range forecasts (beyond 6 hours), needed for sales and scheduling, require forecasts from regional weather models like those used by the National Weather Service, but with much higher resolution. The National Weather Service uses a 40-kilometer grid cell size; however, wind forecast models are run at a much higher resolution, such as 4 kilometers. Higher resolution results in a more accurate wind prediction because the model can incorporate more local topography, which is a critical determinant of local wind speed and direction.

Forecasting Needs for Specific Sites

Good forecasts require good weather data, particularly wind data. A network of sentry stations upwind of potential wind plants that can be accessed "real time" is important for accurate forecasts of wind plant output, and building a database of information can help the forecast gain skill. It is also important that wind and power output data from the constructed plant be checked for quality assurance to ensure that the forecast models rapidly gain accuracy.

Conclusions

The findings about wind energy potential described earlier in this section identify only general areas on the NW SEED wind map coverage of Klickitat County that merit additional evaluation. Before wind project developers invest in new wind projects, meteorological monitoring stations must be installed within the proposed project area to better characterize the local winds.

Data from SEED True Wind Solutions MesoMap wind energy maps were used to evaluate areas of potential wind energy for the EIS. The maps estimate wind power, which is a function of wind speed and time. The MesoMap system simulates the wind speed and direction over the region on a 400-meter grid at multiple heights (e.g., 40, 60 and 80 meters) above ground level. The results of the simulations are collected and processed into wind roses, speed frequency distributions, and color-coded maps of mean wind speed.

Figure 2-1 shows the SEED wind energy potential within the County. A criterion of 250 or greater watts per square meter wind power density (Class 4 or higher) was used to identify areas of potential wind development. The areas that meet this criterion are included in the geographic area consideration because the resources are readily available.