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APPROACHES TO WIND RESOURCE VERIFICATION

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ABSTRACT

Verification of the regional wind energy resource assessments produced by the Pacific Northwest Laboratory addresses the question: Is the magnitude of the resource given in the assessments truly representative of the area of interest? Approaches using qualitative indicators of wind speed (tree deformation, eolian features), old and new data of opportunity not at sites specifically chosen for their exposure to the wind, and data by design from locations specifically selected to be good wind sites are described. Data requirements and evaluation procedures for verifying the resource are discussed.

INTRODUCTION

Wind energy resource assessments have been completed for 12 regions of the United States and its territories. These assessments are based primarily on readily available, summarized, near-surface wind data; upper air data contributed to the assessments in mountainous areas. Annual and seasonal average wind energy flux (wind power class) is given for sites which are well exposed to the wind. Figure 1 shows those areas of the country with a wind resource of ≥ 300 W/m^2 at 50 m. However, in many areas of the country only a small percentage of the stations used in the assessment could be considered to be representative of well-exposed sites.

An estimate of the degree of certainty associated with the resource assessment was made. Assignment of a certainty rating was based on the availability of data in well-exposed locations, the complexity of the terrain, and the expected geographic variability of the resource. Certainty ratings of 1 or 2, shown in Figure 2 for the 48 conterminous states of the United States, indicate that little quantitative data is available in that area, that the complexity of the terrain makes the available data unrepresentative of well-exposed locations, or that the wind resource may vary greatly over small distances. Areas with low resource certainty are candidates for verification.

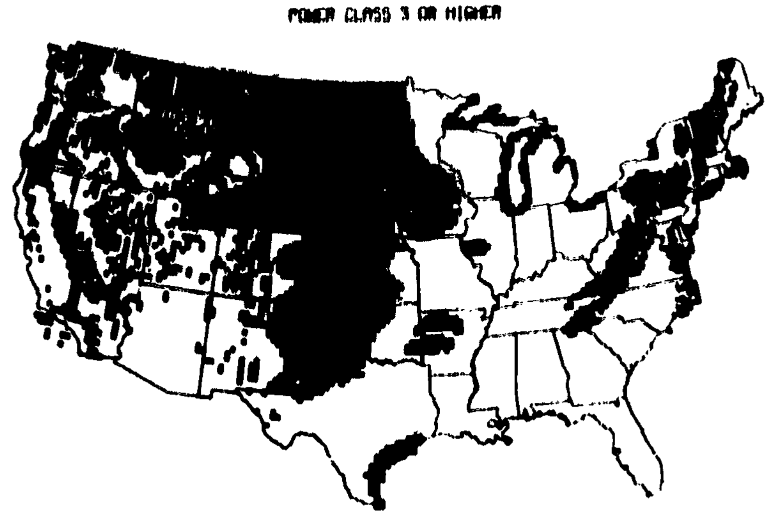


FIGURE 1. AREAS OF THE CONTERMINOUS 48 UNITED STATES WITH A WIND ENERGY FLUX $\geq$300 W/m^2 AT 50 m ABOVE THE GROUND

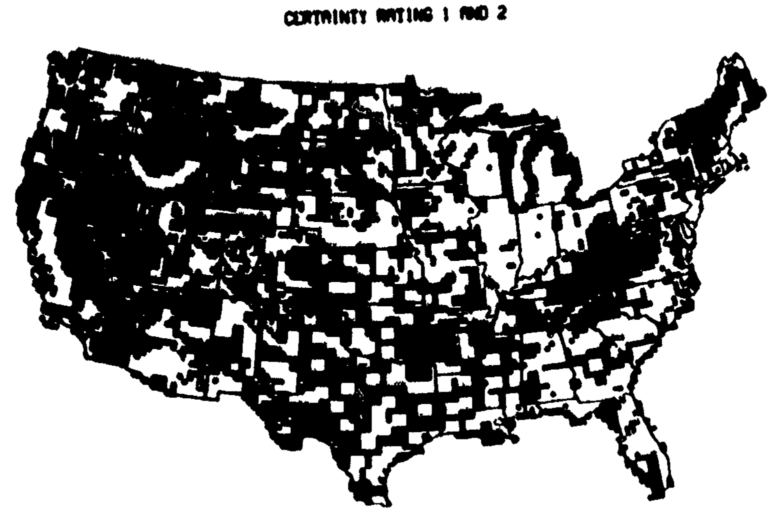


FIGURE 2. AREA OF THE CONTERMINOUS 48 UNITED STATES WITH A LOW OR LOW-INTERMEDIATE (2) RESOURCE CERTAINTY RATING

But, a low certainty rating alone is not a sufficient reason for conducting verification activities. Other factors related to the wind resource will likely enter into a decision on verification. For example, in areas with low wind energy potential (say, less than 300 W/m^2 at 50 m), in areas with low present costs of energy, or in areas with no apparent markets for wind energy, there is likely to be no urgency for verification activity.

In this paper several approaches to conducting resource verification will be discussed. These approaches mainly address the question: Is the magnitude of the wind resource given in the regional wind energy resource assessments truly representative of the area of interest?

Verification activities could also be designed to answer other questions about the resource. For example, is the areal distribution of the wind resource representative of the area of interest? The latter question is much more difficult to answer than the former. A measure of the wind resource at specific sites will suffice to answer the question on magnitude but an extremely large number of measurements would be needed to effectively verify the areal distribution. In fact, numerical modeling may be the only tractable approach to verifying the areal distribution estimates.

APPROACHES

All approaches to verification of resource magnitude rely on the availability of wind data. This data may be qualitative, i.e., the result of the analysis of some indirect indicator of wind speed such as the deformation of trees or quantitative, i.e., the result of a wind measurement program, using data of opportunity or data by design.

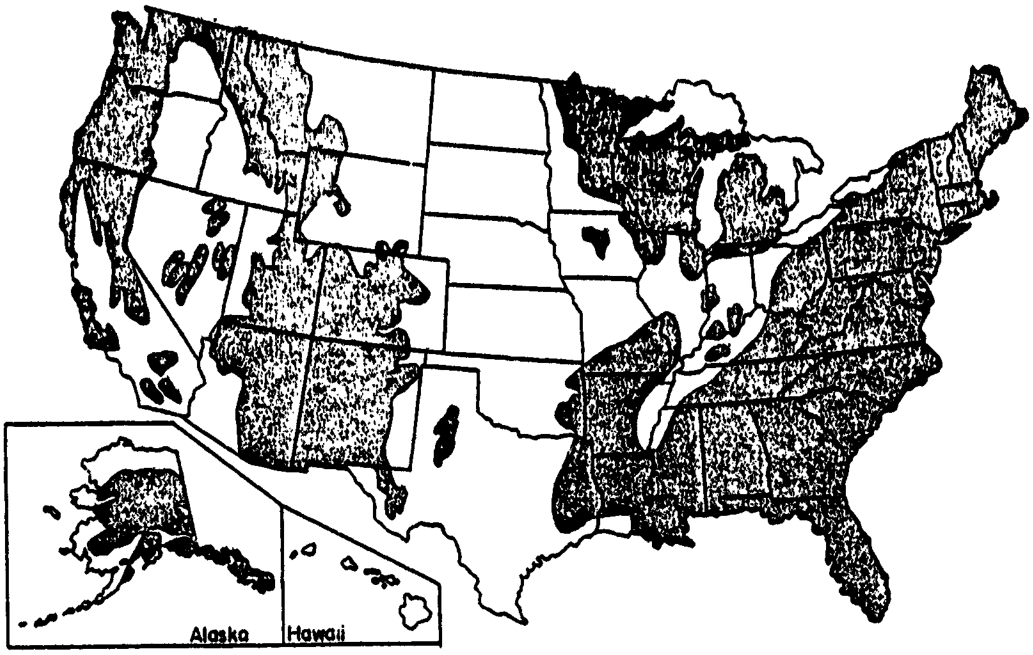
Qualitative

Qualitative approaches to resource verification depend on the presence of indicators of wind speed such as wind deformed vegetation and evidence of wind erosion. Techniques have been developed for estimating mean annual wind speed from wind-induced tree deformation [1,2]. Figure 3 shows the distribution of tree species (pines, hemlock, spruce, Douglas fir, and firs) for which the extent of wind-induced deformation has been calibrated in terms of the annual mean speed. These calibrations have been developed from data obtained mainly in the Pacific Northwest and the Northeast; similar species growing in other areas may not respond to the wind in an identical fashion.

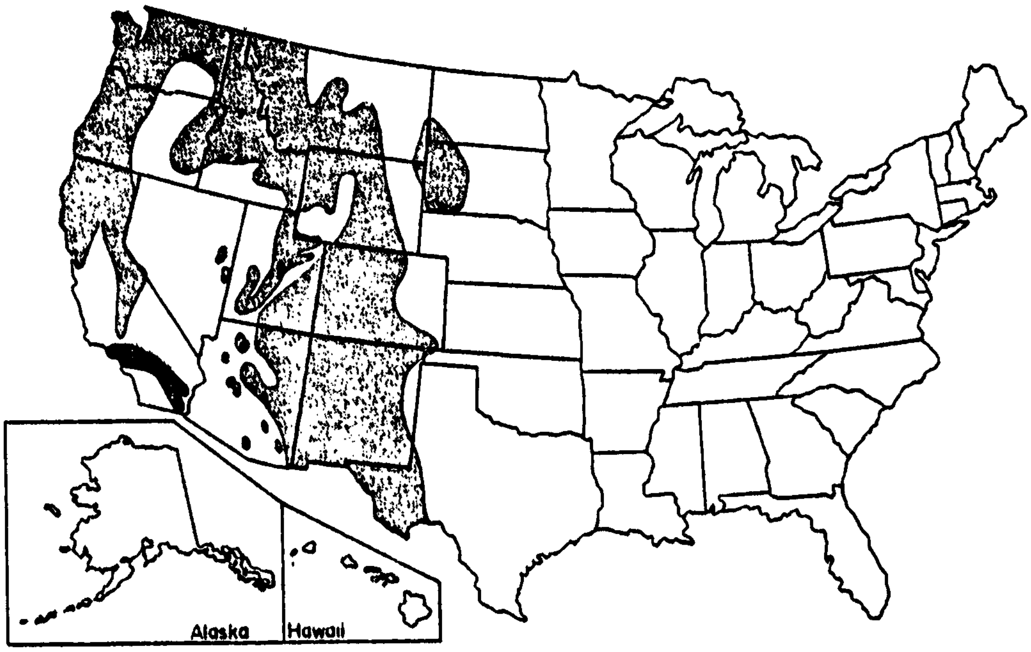
In areas of the country in which wind erosion helps shape the landscape, certain eolian features such as sand dunes, wind scour streaks and playas may be useful indicators of wind energy potential. Figure 4 shows areas of the 48 conterminous United States that may be susceptible to wind erosion [3]. Techniques have been developed for estimating wind speeds from sand dunes and other eolian features [4].

Qualitative approaches to wind resource verification are likely to be labor-intensive and to require personnel with expertise in biology (dendrology) and geology (geomorphology) as well as meteorology. Preliminary studies of satellite imagery and high altitude aerial photography may be needed to identify promising locations for more detailed study. Field observation programs may then be conducted in the promising locations to obtain data on tree deformation or eolian features. Post-field-program analysis will then be needed to convert these data to equivalent wind speeds.

Given the presence of suitable biological or geological indicators, this approach to verification could be carried out in a period of several months over an area of several hundred square miles. Point estimates of wind speed would likely be obtained for many locations



THE DISTRIBUTION OF PINES, HEMLOCK AND SPRUCE IN THE UNITED STATES.



THE DISTRIBUTION OF DOUGLAS-FIR AND PONDEROSA PINE IN THE UNITED STATES.

FIGURE 3. THE RANGE OF SPECIES OF PINE, HEMLOCK, SPRUCE AND DOUGLAS FIR IN THE UNITED STATES [1]

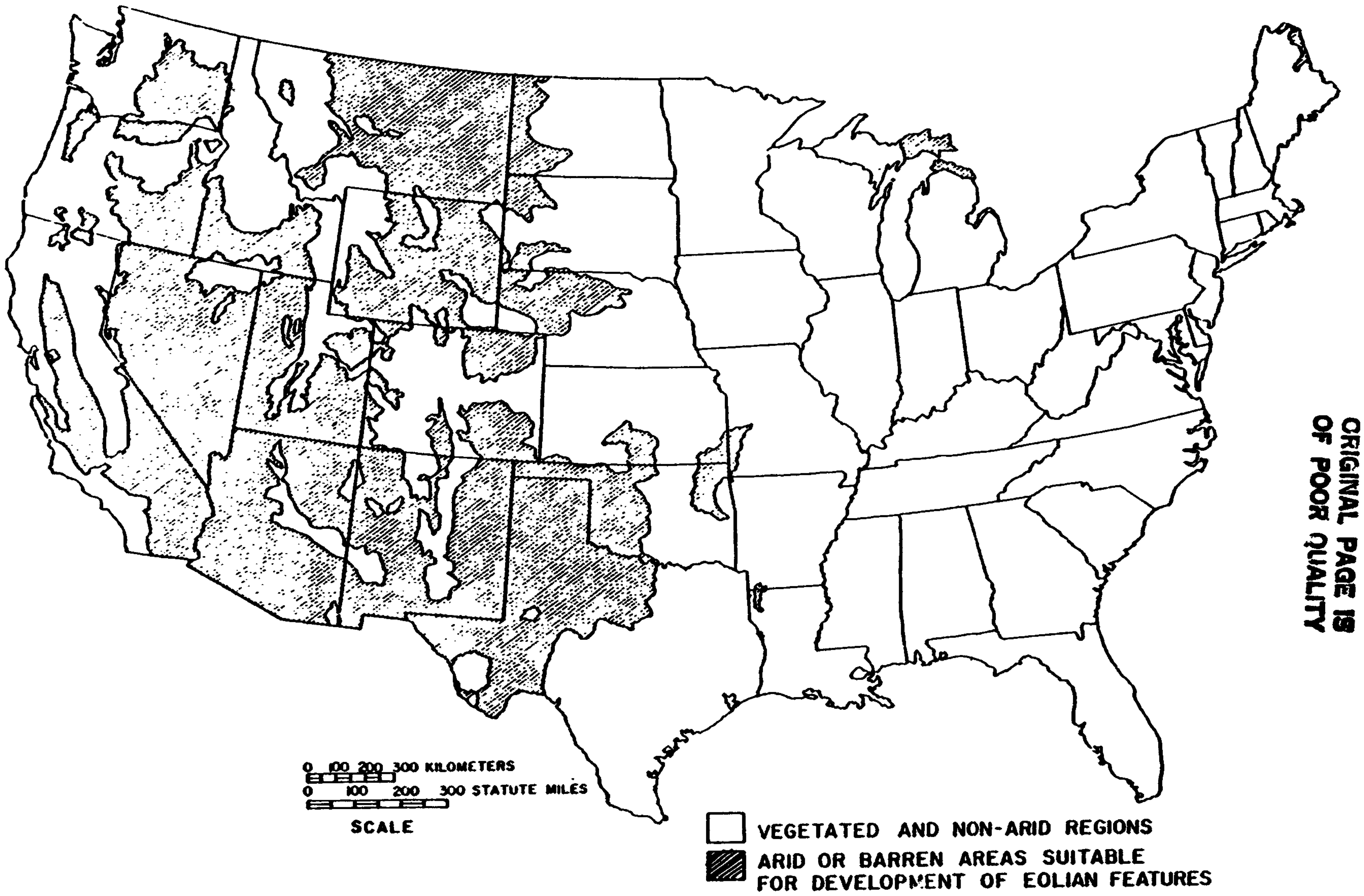


FIGURE 4. BARREN AND ARID AREAS OF THE 48 CONTERMINOUS UNITED STATES [3]

that meet the criterion of good wind exposure. The accuracy of the resulting verification is dependent on the accuracy with which indirect indicators can be converted to wind speeds.

Data of Opportunity

The wind resource assessments available today are based primarily on "data of opportunity", that is, data taken for purposes other than wind energy prospecting or monitoring. As a result the location of such stations is generally quite different from the optimal wind energy site that is well exposed to the wind in an area of low surface roughness and with no nearby obstacles.

At present existing quantitative methods do not reliably convert wind data obtained at a less than optimally situated site to what it would be at the optimal site. The approach taken by PNL is to first become as familiar as possible with the topographic setting and exposure of each station. The weather patterns that affect each location and their influence on the wind resource are thoroughly examined. Then the wind resource at exposed locations is estimated by subjectively extrapolating the available data. In this extrapolation those sites with the best wind exposure are given greatest weight.

In some areas, especially in terrain of large vertical relief, the data of opportunity are supplemented with upper-air wind climatologies. Vertical extrapolation techniques are applied to estimate the free-air wind resource at mountain-top and ridge-crest levels. Estimates of the ridge crest or mountain summit wind resource are guided by both the upper-air extrapolation and available surface data of opportunity.

In a program of wind resource verification in which data of opportunity are the principal source of quantitative information, extrapolation techniques similar to these will have to be applied. In this case the verification information may be subject to the same uncertainties as the resource assessment being verified. Nevertheless, if the two estimates of the resource magnitude are based on independent data sets and are in agreement, a significant increase in credibility of the resource magnitude will have been achieved.

Where are these data of opportunity to be found? The regional resource assessments made use of data that had been archived by the National Climatic Center, either in time series form in the TD1440 tape series, or as wind summaries [5]. Wind data from other sources such as electric utilities, nuclear power plants and research projects were used in the resource assessments whenever they were already summarized. The Wind Energy Resource Atlases provide the location of stations used in each regional assessment. Additional data of opportunity, not used in the regional assessments, are available from the NCC for many stations for which the data have not been summarized or digitized [6]. Many colleges and universities, electric utilities, consulting meteorologists, state highway departments, state departments of natural resources, other government agencies, etc., have wind data in unsummarized form (e.g., strip charts, magnetic tape, log books) or as summaries not used in the regional assessments which may be suitable for resource verification. Locating, reducing and analyzing these data for resource verification will be a major undertaking.

The data of opportunity so far discussed have been previously taken and archived; they are old data. However, new data of opportunity are now being taken at many sites across the country. Much of these data will have a short life time because the data are being used for real-time monitoring rather than for obtaining a climatological record. Therefore, tapping these sources of data will require that: 1) the organization responsible for collecting this data be made aware of the usefulness of their data for wind energy purposes; 2) an arrangement be made whereby the wind data are in some way retained or made accessible for retrieval by someone else; and 3) the data be collected or retrieved by those doing the resource verification in a timely and routine manner.

A number of federal and state agencies presently make use of the Geostationary Operational Environmental Satellite (GOES) Data Collection System (DCS) to telemeter data from remote sites to the National Earth Satellite Service (NESS) computer in the World Weather Building in Marlow Heights, Maryland [7]. Data received by NESS are archived for at least 24 hours and can be made available to parties other than the original user upon request. Access to the data in the computer can be via dial-up modem or direct line [8]. It is also possible to receive the telemetry signals directly from GOES with an appropriate ground receiving station.

Some of the federal and state users of GOES-DCS [9] are:

U.S. Department of Interior Bureau of Land Management	Mr. Dale Vance Office of Scientific Systems Development (303) 234-4620
U.S. Department of Interior Bureau of Reclamation	Mr. Donald Rottner Office of Atmospheric Resources Management (303) 234-3901
State of California Department of Forestry Department of Water Resources	Mr. Larry A. Mertens Department of General Services (916) 445-2034
State of Washington Department of Natural Resources	Mr. James B. Tucker (206) 753-5350
U.S. Department of Agriculture Forest Service	Mr. John Warren (208) 384-1439

Each of the GOES-DCS users listed above collects wind data along with other parameters and has expressed a willingness to share this data with other interested parties. Because the data sent through the

GOES-DCS may not be in engineering units, it will be necessary to obtain calibration equations or tables from the organization operating the remote telemetry platform.

The use of data of opportunity in resource verification has the advantage that data over long periods of record can be used and that the expense of procuring, installing and operating a wind measurement system are avoided. However, the disadvantage is the lack of control over the location of the station and the quality of the data.

Data by Design

In contrast to data of opportunity, data by design refers to a measurement program specifically designed to meet the needs of resource verification. Such a measurement program should encompass activities such as anemometer site selection and acquisition, measuring system procurement, calibration and installation, data retrieval, and data processing. This approach to resource verification will involve an investment in hardware (the measuring system and processing equipment) as well as labor (siting, calibration, installation, maintenance and data processing).

Site selection is very important to the verification of resource magnitude. Since the assessments give the resource at locations well exposed to the wind, proper verification depends on selecting sites that meet this criterion. Siting guidelines similar to those needed for siting wind turbines [10,11] should be followed for selecting the anemometer sites. Preliminary site identification may be made from an analysis of topographic maps of the area of interest. Field inspection of these sites must follow to further refine the selection.

At this point the access to desirable sites may be an issue. Ownership of or jurisdiction over each site may need to be determined and permission for access to and installation of the anemometer may have to be obtained. Permission for access may be needed even for the field inspection activity.

Some resource verification activities have operated on the principal of data by design at locations of opportunity. Most anemometer loan programs operate in this mode. By a careful screening of applicants to a loan program, sites suitable for resource verification can be located if the loan program is widely advertized.

Towers in microwave communication networks also present sites of opportunity for resource verification. Very often the towers are located on ridge crests or hilltops, which may be representative of sites well exposed to the wind. Microwave communications towers offer another advantage in that it may be possible to use the communication system to telemeter the wind data to a central facility for archiving and processing.

The selection of a wind measuring system will depend on the end-use of the wind data. For verification of the magnitude of the wind resource, the minimum that must be measured is the wind speed. However, if it is desirable to have a more complete understanding of the nature of the resource at the verification point, wind direction should also be measured.

Wind-run anemometry over long time periods will provide a measure of the mean wind speed, but not the wind energy flux. As the frequency of reading the wind run increases, the detail about the wind resource will improve. Measurement strategies that provide frequent (more than one per day), uniformly spaced samples of wind speed are desirable [10]. However, other measurement strategies employing intermittent or random sampling may also be applicable [12,13].

Wind measuring systems chosen for resource verification need to be highly reliable and durable. High sensitivity to low wind speeds or to rapid wind fluctuations is not needed for this task. Onsite data storage should, as a minimum provide speed (and direction, if included) frequency of occurrence information. However, if the labor for analysis is available, strip chart recordings of speed (and direction) will suffice. Wind sensors should be positioned no less than 10 m (33 feet) above the ground and even higher in locations surrounded by tall vegetation. Other references to wind measuring systems and measurement strategies may be found in the sources listed in the Solar Energy Research Institute's Wind Energy Information Directory [14].

In any extensive measuring program an effort to ensure the quality of the data is essential to success. Procedures for routine calibration of equipment prior to installation and at regular periods thereafter provide for user confidence in the data. This opportunity for quality control is not available when using data of opportunity.

VERIFICATION

Data processing needs for resource verification are modest. The quantity to be calculated and compared to the resource assessment is the wind energy flux (WEF), also called the wind power density:

$$\mathrm{WEF} = \frac{1}{2} \rho V^3$$

where ρ = air density in kg/m^3
V = wind speed in m/s

so that the WEF is in W/m^2. To compute the average WEF over a long period of time requires calculating the mean of the cube of the wind speed, $\overline{V^3}$, and estimating the mean air density. The mean air density $(\overline{\rho})$ can be estimated from climatic information and the station elevation. $\overline{V^3}$ can be calculated from different types of data:

$$\overline{V^3} = \frac{1}{N} \sum_{i=1}^{N} V_i^{\,3} = \sum_{j=1}^{C} f_j \, V_j^{\,3}$$

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where V_i = the i^{th} wind speed obtained from a time series record (e.g., strip chart) that contains N readings, or

V_j = the midpoint of the j^{th} wind speed bin in a speed frequency distribution for which

f_j = the frequency of occurrence of wind speeds in the j^{th} bin.

Now the mean wind energy flux is

$$\overline{WEF} = \frac{1}{2} \bar{\rho} \, \overline{V^3}$$

If, however, only mean wind speed is available, such as that obtained from a wind run anemometer (wind odometer) then an assumption about the distribution of speeds about the mean speed must be made to arrive at $\overline{V^3}$. A study of 140 stations, showed that the wind speed distribution can be adequately described for most locations with a Weibull distribution [15]. From the information presented in [15], $\overline{V^3}$ can be approximated from $\bar{V}$.

A final adjustment to the mean wind energy flux may be needed to scale the measured (calculated) value to the same reference height (10 or 50 m) used in the wind resource assessments. Standard practice in the resource assessments was to scale the wind energy flux to 10 or 50 m using a 3/7 power law (equivalent to 1/7 law for speed):

$$\overline{WEF_R} = \overline{WEF_Z} \left(\frac{Z}{Z_R}\right)^{3/7}$$

where $\overline{WEF_Z}$ = the mean wind energy flux at the anemometer,

Z = the height of the anemometer above ground in meters and

Z_R = is the reference height of 10 or 50 m.

If the mean wind energy flux so calculated falls within the range of the wind power class given for that location in the resource assessment atlas, the resource has been verified. Departure of the measured value by more than one power class from the assessment could mean

a) that the assessment is incorrect, or

b) that the verification site is really not representative of the typical well exposed site for that terrain type. This situation may be the case if the verification value is less than the assessment.

c) that the period on which the verification is based is not representative of the long term climatological mean for that location. This may be especially applicable to verification's based on data obtained over a period of one year or less.

The author would be pleased to hear about any resource verification activities in progress and, of course, the results of the verification.

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