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Wind Resource Analysis

Annual Report

Donald M. Hardy

Solar Energy Research Institute

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Golden, Colorado 80401

A Division of Midwest Research Institute

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Prepared for the
U.S. Department of Energy
Division of Solar Technology
Under Contract EG-77-C-01-4042

PREFACE

This annual status report was performed in compliance with Contract Number EG-77-C-01-4042 for the Division of Solar Technology of the U.S. Department of Energy. The report was prepared by the staff of the Energy Resource Assessment Branch of the Solar Energy Research Institute, a Division of Midwest Research Institute.

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EXECUTIVE SUMMARY

This report describes FY78 results of the Wind Resource Analyses task of the ERAB. Initial steps were taken to acquire modern atmosphere models of near-surface wind flow and primary data sets used in previous studies of national and regional wind resources. Because numerous assumptions are necessary to interpret available data in terms of wind energy potential, conclusions of previous studies differ considerably. These data analyses may be improved by future SERI research. State-of-the-art atmosphere models are a necessary component of the SERI wind resource analyses capacity. However, these methods also need to be tested and verified in diverse applications. The primary data sets and principal features of the models are discussed in the report.

TABLE OF CONTENTS

SECTION 1.0
INTRODUCTION

The purpose of this report is to provide a review of the wind energy task within the Energy Resource Assessment Branch (ERAB) at the Solar Energy Research Institute (SERI). The primary purposes of this task are to evaluate and implement wind energy models, to establish for use at SERI and in industry, appropriate wind energy data, to improve present data interpolation techniques, to translate available data to that required for detailed systems analyses, and to plan field experiments to improve available wind data in selection applications. Activities within the task support other wind research and analysis efforts within SERI and are also used to provide primary wind data and baseline research models to the Solar Energy Information Data Base (SEIDB) at SERI.

The key problem addressed by this task is the need for refined wind energy data to be used in selected case studies that will provide a detailed analysis of wind energy applications evaluated within the overall SERI wind program [1]. As such, this task is an integral part of the wind energy utilization program at SERI. Both the technical and nontechnical aspects of wind energy are treated. The primary objectives of the overall effort are: to improve the wind energy resource data base; to determine the economic and environmental requirements for significant market penetration; to identify appropriate government policies and incentives that will promote such market penetration; to define the requirements of dispersed wind energy systems in small utility and nonutility applications, and to stimulate the development of innovative wind energy conversion devices.

The Wind Resource Analysis task involves data analysis and atmospheric modeling activities and future field measurements which address the specific siting and operational requirements of accelerated wind energy utilization. This activity is strongly concerned with meeting the data needs of a rapidly growing wind energy industry. Accomplishment of tasks within SERI will be achieved by using the results of both the operational divisions of SERI and the results from work contracted to organizations outside SERI in direct support of internal task objectives. A related major activity within SERI is the development of a comprehensive collection of solar energy information in SEIDB. SEIDB will provide a centralized and comprehensive system to furnish technical and nontechnical information to a broad range of users, and will include wind resource data and standardized data analysis models provided by ERAB.

ERAB has several objectives of which the primary purpose is to support and conduct joint studies with internal SERI branches concerning solar and wind energy resource models, data, and data bases. ERAB also serves to aid industry in obtaining and using energy resource models and data bases. It performs basic and applied research to evaluate existing models and data collection procedures, and to develop improved models and data collection methods in solar and wind resource mapping. It provides support to the Department of Energy (DOE) in the area of resource modeling, data, and data bases. It also provides for the technical monitoring, direction, and management of energy resource assessment program within DOE.

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SECTION 2.0
DESCRIPTION OF TASK 3604

The overall approach in the Wind Resource Analysis task for FY78 was to first identify and obtain important wind energy data sets, and second to acquire and evaluate wind field models and wind data analysis methods. Numerous important wind data sets have been created in previous DOE sponsored wind energy studies. These data sets include both continental-scale data and special regional data sets prepared for specific research purposes. Several national assessments of wind energy were recently summarized by the Battelle PNL [2]. Other important continental-scale data sets include the SOLMET data, and the recently produced typical meteorological year (TMY) based on selected SOLMET data. Regional data sets used in previous major studies also include those created at the Georgia Institute of Technology. Progress toward obtaining standard data of these types is discussed later.

The second aspect of the technical approach is to acquire, use, and evaluate modern atmospheric models and procedures for data analysis that have been developed specifically for wind energy. A broad program of study in wind characteristics is led by Battelle PNL [3-5]. Various techniques for interpreting data over three very broad spatial and temporal scales required have been investigated, including the use of sophisticated atmospheric models [6-8], statistical analysis of estimated wind farm performance by region [9], climatic variations at selected measurement stations [10], and advanced methods of data interpolation and extrapolation [11]. These key capabilities developed within the present federal program and additional similar techniques available through the private sector are the cornerstone of the data analysis and interpretation activities in wind energy at SERI.

The specific approach to providing a detailed and improved wind resource analysis in support of applications studies within SERI includes those aspects noted before. The first is to acquire and review technical reports on specific numerical models. This review involves a comparative summary of model resolution, physical assumptions, needed input data, prior validation efforts, and primary advantages and limits in predicting vector wind fields. Relevant codes are obtained and then implemented on the SERI computer system. The primary SERI effort is directed to the technique of Principal Components Analysis. Work in this area includes an extension of the basic method to the treatment of spatial/temporal data interpolation problems. Another aspect of the technical approach is to review DOE and industry definitions of data needs for WTG performance evaluations, determination of vital design factors (e.g., maximum strength), and resource assessment on the continental and local scale. This involves an examination of the national NWS data base and data collection procedures. Activities also include planning field experiments to test modern data collection systems designed specifically to meet wind energy needs. Research activities with data collection systems that directly measure parameters specific to wind energy are used to formulate recommendations for improved national data collection procedures.

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SECTION 3.0
PROGRESS AND STATUS

Initial steps toward the acquisition of primary data sets for wind energy analysis have been completed. The SOLMET meteorological data tapes have been acquired and implemented at SERI. A summary of data collected by Lawrence Livermore Laboratory (LLL) [12] has been acquired, and a comprehensive library of wind-characteristic technical reports has been acquired from Battelle PNL. Work is in progress to acquire the TMY data set created from the SOLMET data files. Contact has been made with the National Climatic Center (NCC) regarding acquisition of the primary data used in previous national wind resource assessment studies. Specialized data sets prepared by the Georgia Institute of Technology for regional wind energy analysis are also under review and procedures to acquire selected data have been initiated. Work is also in progress to plan a suitable data storage and retrieval system to index and use these and other primary data sources in future wind analyses.

In the area of numerical modeling and analysis, detailed reference documents have been obtained for several primary methodologies. Documentation on the site selection methodology developed by Science Applications, Inc. [6] and that of LLL [13] were acquired. Detailed technical reports on wind-field models developed for National Oceanic and Atmospheric Administration (NOAA) [14] and for the USFS have also been acquired. Work is in progress to review these basic modeling techniques to provide a comparative analysis of their advantages and technical limitations. These or other modeling methods will be implemented on a large-scale scientific computer in a standardized form for verification studies and research applications to problems of interest in FY79.

Additional activities within the task included several reports and presentations. These include a journal publication on the application of Principal Components Analysis to wind energy problems [11], a review on the problems of wind energy assessment [16], and an invited presentation on the problems of regional wind energy development [17]. Another publication of importance is a survey paper covering wind energy activities at SERI [1].

Further work within the task includes an effort to plan field experiments and subcontracts to acquire and process wind data from very tall towers. Such data are relevant to local resource assessment problems and potential equipment stresses and hazards in siting the largest wind turbines now planned by DOE. Task personnel also supported the Sun Day presentation for President Carter's visit by selecting and installing wind energy display items for that event. Related activities within the task have provided assistance in the preparation of the Annual Review of Solar Energy (Volume 1) in regard to wind energy technology and future problems. In addition to these activities, several foreign visitors were hosted in support of the International Programs Branch and briefings were presented to them on the Federal Wind Program, wind technology, and wind assessment problems. An additional related activity included an international telecast on the subject of wind energy in support of the Department of State.

3.1 SYNOPSIS OF MODELS

Several atmospheric models are currently under review. Following this review, these and other models will be implemented and applied in resource assessment studies as SERI develops an appropriate scientific computational capability. A brief summary of model features is given below for each presently being examined.

The LLL model [13] has been applied to wind energy studies [7]. This model is a sophisticated objective analysis method that interpolates observed vector wind measurements in the presence of complex terrain. It is used primarily to extrapolate and interpolate wind observations in mountainous areas, where large increases and decreases in speed occur due to terrain. The primary physical assumption is the mass-consistency of nondivergent flow channeled by topography and an assumed inversion profile aloft. The model produces three-dimensional vector wind fields in the layer computational volume.

Typical model resolution is 0.5 km to 5.0 km in the horizontal over domains of approximately 50 km to 100 km on a side. Wind vectors within 2 km of the surface are simulated. Required input data include a definition of the topography, inversion profile, and near-surface horizontal wind measurements. Vertical wind profiles, when available, may be used. Validation of the model has been through applications in air pollution tracer experiments and wind energy siting experiments. Formal validation is planned but not yet reported. The advantages of the model include greater computational efficiency than highly complex boundary layer models, and the use of few input data (characteristic of data availability in many practical circumstances). Limitations include a nonhydrodynamic formulation that excludes simulation of strongly stability-dependent flows or convective effects due to surface heating.

Science Applications, Inc. (SAI) has developed and applied modeling methods in wind energy studies [6]. Two such models were employed. One is an objective analysis (OA) model similar to the LLL model. This OA model is formulated using terrain conformal coordinates to represent terrain variations with greater accuracy than step-function approximations. Terrain conformal mapping is accomplished by transformation of the governing equations. Topographically forced nondivergent wind fields are estimated (in transformed equations) by a numerical method analogous to LLL. The wind field in transformed space is then back-transformed to real space to yield local wind velocities. The OA model can also be used to initialize more complex hydrodynamic model calculations.

Necessary input data include topography and observed horizontal winds. Model resolution is approximately 3 km to 9 km in the horizontal over domains of about 100 km. Variable resolution in the vertical above ground level is used. Advantages of the model include viable vertical resolution and conformal terrain mapping. Limitations include those characteristics of nonhydrodynamic calculations.

One-, two-, and three-dimensional meso-meteorological models were also developed by SAI. These models include the physical effects of radiation (surface heating) and turbulence. Atmospheric density variations and turbulent diffusion of kinetic energy are allowed. Turbulence quantities (e.g., vw) are calculated using assumed closure relations and then used in governing equations for the mean flow.

Necessary regional (or assumed) input data include topography, geostrophic wind, surface roughness length, vertical temperature profile, surface albedo, soil moisture, and radiation flux. Initial validation tests of the two-dimensional model were conducted by comparing model results to wind tunnel studies. Further validation tests are planned by SAI. Advantages of the model include a more detailed representation of atmospheric physics. Limitations include computational time required per simulation and the necessity of providing detailed time dependent input parameters, some of which may not be accurately known.

NOAA has developed a three-dimensional mesoscale model of airflow and cloud formation [14] that has not yet been applied to wind energy analysis. The model was formulated to simulate cold cloud microphysics and wind fields over mountainous terrain. It links dynamical, thermodynamical and microphysical interactions in simulating temperature, moisture, and wind fields. Transformed (sigma) coordinates provide greater vertical resolution near the surface. A constant flux layer with prescribed roughness length is assumed for the lowest 20 m, surface fluxes of sensible and latent heat are included, and subgrid scale turbulent transport is parameterized by eddy exchange coefficients (defined for heat, moisture, and momentum). Horizontal resolution of approximately 10 km is employed and vertical layer depths of about 6 km are treated. Input parameters include specification of thermodynamic variables at all boundaries and wind velocities at flow-through boundaries. Validation studies have used calculations of flow fields and cloud patterns over the island of Hawaii. Advantages of the model include simplified formulation of foundary conditions via terrain following coordinates and inclusion of dynamically important physical processes. Disadvantages include variable vertical resolution over the complete horizontal domain, computational requirements, and uncertainty over boundary values which must be specified.

In addition to these models that are capable of analyzing wind fields in mountainous areas, other data analysis methods are being implemented to initialize complex models or to interpret data over relatively smooth terrain. An important problem of wind energy is the extrapolation and interpolation of data from sparse measurement sites to other locations where wind turbines may be located. The statistical method of principal components analysis (PCA) is well suited to the problems of identifying fundamental wind patterns, the variations of such patterns, and the interpolation/extrapolation of data. This method can be used to treat vector wind data as well as scalar wind speeds. Computational analysis codes to employ such methods are being implemented for use in the problems identified above.

3.2 SUMMARY OF DATA SETS

A tremendous quantity of meteorological data relevant to wind energy already exists. However, these data are in many different formats, come from widely varying sources, and represent different content and quality. In general, most of the available data were not obtained with wind energy analysis in mind, and may be difficult to use in precise assessments of the wind resource [2]. Nevertheless, major data sets have been built from current archives for important previous studies of wind energy. As a first step in the wind resource assessment activities at SERI, relevant major data sets used in prior studies will be obtained. Such data may be improved substantially by removing known errors (e.g., correcting for anemometer height variations and density changes with elevation). Acquisition by SERI will make these data available for other internal analysis tasks and ultimate inclusion in the SEIDB. A description of meteorological data currently being evaluated for transfer to SERI is given below.

Long-term records of solar and wind data for 26 locations across the United States were recently organized by Sandia Laboratories into a TMY data set. Data covering 23 years were used to select "typical months" at each location. Months chosen from various years were then combined into a "typical year." Weighting factors were used with parameters (temperature, dew point, wind velocity, radiation) in defining typical months. The primary data used were based on 26 SOLMET stations, giving hourly values for the parameters. These data have been ordered.

In selecting typical months, the four measurements of dry-bulb temperature, dew-point temperature, wind velocity, and solar radiation at each station were used to establish thirteen indices: daily total solar radiation and daily maximum, mean, minimum, and range for dry-bulb and dew-point temperature and wind velocity.

For each of the twelve calendar months, the selection of the year that was "closest" to the composite of all 23 years was made by comparing the cumulative distribution function (CDF) for each year with the CDF for the long-term composite. For each index, the F-S statistics were used as a measure of this comparison agreement. A weighted sum of the 13 F-S statistics was calculated and this sum was used to select five years with the smallest values for candidates as the TMM. The TMY was generated primarily for solar applications. Consequently, the weighting factors were selected as follows:

Solar Radiation	Wind Velocity		Dew Point			Dry Bulb		
	Max	Mean	Max	Min	Mean	Max	Min	Mean
12/24	2/24	2/24	1/24	1/24	1/24	1/24	1/24	1/24

The final selection of the TMM from the five candidate months was a two-step process. First, the F-S statistics and the deviations of the monthly mean and median from the long-term mean and median were compared. The second step involved looking at the persistence in the mean daily dry-bulb temperature and daily total solar radiation.

Several national assessments of wind potential [2] are based on an extensive collection of wind data on file with NCC. Primary data for these assessments are 760 weather stations across the United States. Wind speed summaries, giving percent frequency of occurrence by speed class, are available. More detailed information on wind variations and directions are not specified for all of these stations, but all of the data are based on multi-year records.

Because these records have been the basis for major mission analysis studies by DOE, they will be acquired as a reference set for use at SERI.

More detailed wind records were assembled at Sandia for carefully selected stations within the United States. Fifteen locations judged to be representative of local climatic conditions were identified. At each site hourly observations of speed, direction, temperature, and other parameters were compiled from NCC records. Each site chosen also had a ten-year period of record on file. As these data are useful in examining climatic trends, they are now being considered for acquisition.

Several other extensive data sets of simultaneous observations covering multiyear periods were also compiled by the Georgia Institute of Technology. Most data were three-hour measurements covering five to ten years of record in the various regions of the United States. NCC records were screened to provide the largest number of stations with useful simultaneous observations. A total of 80 sites across the United States were selected and used in statistical analyses. Data for 25 stations in the central United States, a region of high-wind energy potential, have been ordered by SERI, and other regional data may be obtained later.

The basis for several additional meteorological data products available from NCC is the hourly surface observations made at some 300 stations in the National Weather Service Network. These observations are made according to uniform procedures and recorded on so-called "WBAN" Forms. At present, the information on these forms is transferred onto computer compatible storage media for processing by NCC and the Environment Data Service Division of NOAA. Typically, the three-hour data are digitized and available for individual stations for time periods dating back to 1948. On request, NCC will provide either the complete hourly observations or what was termed "short" hourly observations (which include wind data) for any first class reporting station in the network. These data are available on a station/year basis.

A description of the parameters recorded on the WBAN sheets, which are pertinent to wind energy, is given below. Space is provided for hourly observations, special observations at intervals required for aviation safety, and a daily summary of selected parameters. The following parameters are included in the hourly observations:

- wind speed,
- wind direction,
- temperature,
- dew point,
- visibility (and cause of restrictions),
- cloud cover (at four levels), and
- precipitation.

At the end of each day, reports are made as to the following:

- peak wind gust (including speed, direction, time of occurrence),
- max/min temperature, and
- total sunshine and percent possible.

Routine processing of these data at NCC is done for the "WBAN Summary of the Day" (Deck 345, available in magnetic tape TDF-30).

Wind extremes can be assessed from the following parameters,

- peak gust (speed, direction, time of occurrence),
- fastest observed one-minute wind speed and direction, and
- wind speed and direction of fastest mile.

Additionally, indications of other potentially hazardous site-dependent conditions are presented (i.e., days with thunder, hail, sleet, snow, glaze, and dust storms).

Another product available from NCC is the Local Climatological Data (LCD). This is a special summary of the WBAN station data providing a daily summary of important meteorological parameters for each month. This collection of information would also be useful in wind energy assessments. A daily breakdown is given for temperature (max., min., avg.), degree days, weather types (fog, hail, snow, etc.), precipitation, average station pressure, resultant wind direction and speed, average wind speed and direction, minutes and percent possible sunshine, and sky cover estimates. Additionally, three-hour observations are presented for wind, sky cover, ceiling, visibility, weather, temperature, and relative humidity.

Digitized observations of the surface meteorology at 24 stations covering the years 1952 to 1975 are available from NCC in the SOLMET format. This collection also has its origins in the NWS observing network and is intended to satisfy the need for a consistent national data base of wind and solar radiation information. However, it is limited to those stations which had some of the better insolation measurements over the years and a selection of only 27 locations was made by NOAA to form the network. Two important changes were made in the data before placing them into the SOLMET format. First, the three-hour wind observations were interpolated to give hourly estimates at each station. Second, the insolation data were "rehabilitated" using theoretical radiative transfer models because of solar radiation sensor degradation and other factors which would have placed considerable doubt in the validity of the radiation data. The final result of this process was a continuous and as representative a data set as possible for these selected NOAA stations.

Finally, several other fixed duration and special wind data sets have been identified. Experiments designed for the study of air pollution monitoring also include wind data of sufficient spatal and temporal resolution to be useful. Programs such as Metromex, RAPS, and the International Fiscal Year Great Lakes (IFYGL) may provide meaningful additional data sets.

Acquisition of particular data sets assembled for previous wind assessment research is important because of the recognized limitations of many archived records. Anemometers are frequently changed in location and height over several decades of record. Such changes lead to substantial uncertainties in available wind power. Selection of "representative" observations for a region is a time-consuming process. Collection from the archives of a consistent set of measurements that are simultaneous also requires considerable effort. The approach taken in this task is to make the fullest possible use of prior effort by DOE projects to assemble important reference data sets for wind analysis. Special needs beyond those that can be met with such records will require a comparably large effort by atmospheric scientists at SERI in succeeding years to organize more extensive data of particular interest.

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SECTION 4.0
FUTURE ACTIVITIES

The extensive use of data in this task during FY79 points up the need for consideration of a Data Base Management System (DBMS). The utilization of a DBMS may be appropriate in this endeavor since the data are obtained from different sources in different formats and will be used by various computer programs and models. The cost and complexity of DBMS for scientific and engineering data reveals the true scope of this problem. As other branches will have analogous needs, and effort to define SERI-wide requirements for a DBMS may be appropriate.

The experience of two related efforts in handling meteorological data should be considered. The first experience of note is that of the National Center for Atmospheric Research (NCAR) which maintains a vast amount of atmospheric data. NCAR has been unable to find a DBMS which will satisfactorily maintain their atmospheric data files. The main reason for this is the wide diversity of data formats and recording formats. Subsuming all these formats into compatible formats for a DBMS has remained an impractical task. The method which NCAR uses today is a well documented multi-formated tape archival system. Each of the different tape formats is very well documented and each tape is cataloged according to its particular format.

The experience of NCC may also prove enlightening to the research data base efforts of SERI. The NCC is the first institution to study the feasibility of a large-scale DBMS for atmospheric data files. The NCC maintains the NOAA national tape archival system, and has been mandated to establish a DBMS to contain over 2500 tapes which collectively represent some three tera bits of data. NCC has concluded that it is not possible for one format to contain all the data, and propose instead four major data bases which would satisfy about 85% of all users' requests.

It appears that the NCAR approach might best serve the SERI wind data needs for the time being. An interactive tape management system could be written to allow the user to scan a directory of SERI atmospheric data tapes, to select an appropriate tape, to receive online documentation of the tape format and content, to mount the tape, and to place subsets of the data in memory.

Pertaining to the establishment of requirements for a future large-scale DBMS specifically concerning the Wind Resource Analysis task, several milestones can be isolated. First, a description of future data files is necessary. A fairly exhaustive effort would be needed to outline the various kinds of data elements to be processed and the structure of these data groups. Second, an analysis should be carried out to define the types of questions the DBMS may be responsible for handling. Third, an understanding of the usage characteristics must be obtained (e.g., number of users, how much data, response time desired, and computer hardware needed).

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SECTION 5.0
REFERENCES

1. Hardy, Donald M., "Wind Energy Activities at the Solar Energy Research Institute," Solar Energy Research Institute, August 1978, SERI/TP-36-051.

2. Elliott, "Synthesis of National Wind Energy Assessments," Report BNWL-2220 WIND-5, July 1977.

3. Federal Wind Energy Program (FY77 Summary Report), Division of Solar Technology, January 1978, Report DOE/ET-0023/1.

4. Elderkin and Ramsdell, "Annual Report of the Wind Characteristics Program Element," Battelle PNL, July 1977.

5. Ramsdell, "Technical Overview of the Wind Characteristics Program Element," Proceedings of the Third Biennial Conference on WECS, September 1977.

6. Traci, R. M., et al., "Development of a Wind Energy Site Selection Methodology," June 1977, Science Applications, Inc., Prepared for the Department of Energy, under Contract No. EY-76-C-06-2440.

7. Hardy, Donald M., "Numerical and Measurement Methods of Wind Energy Assessment," Proceedings of the Third Biennial Conference on WECS, September 1977.

8. Garstang, "Coastal Zone Wind Energy," Proceedings of the Third Biennial Conference on WECS, September 1977.

9. Justas, "Wind Energy Statistics for Large WECS Arrays," Proceedings of the Third Biennial Conference on WECS, September 1977.

10. Reed, "Meterological Studies for Wind Power: A Progress Report," Proceedings of the Third Biennial Conference WECS, September 1977.

11. Hardy, et al., "Principal Components Analysis of Vector Wind Measurements," Journal of Applied Meteorology, August 1978.

12. Shinn, Joseph H., et al., "Oahu Surface Wind Network, Summary of Data," Lawrence Livermore Laboratory, April 1978, Report No. UCID-17798.

13. Sherman, Christine A., "A Mass-Consistent Model for Wind Fields Over Complex Terrain," Journal of Applied Meterology, Vol. 17 (312-319), 1978.

14. Nickerson, Everett C. and Elemer L. Magzinar, "A Three-Dimensional Simulation of Winds and Non-Precipitating Orographic Clouds Over Hawaii," National Oceanic and Atmospheric Administration, September 1976, NOAA Technical Report ERL 377-APCL 39.

15. Ryan, Bill C., "A Mathematical Model for Diagnosis and Prediction of Surface Wind in Mountainous Terrain," Journal of Applied Meteorology, Vol. 16, No. 6 (571-584).

16. Hardy, Donald M., "Wind Energy Assessment," Proceedings of the Miami International Conference on Alternative Energy Sources, December 1977.

17. Hardy, Donald M., "Regional Wind Energy Development," Report SERI/TP-36-051, Presented at the Solar '78 Northwest Conference, July 1978, Portland, Oregon.

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