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INTRODUCTION

The wind resource characterization team at the National Renewable Energy Laboratory (NREL) is working to improve the characterization of the wind resource in many key regions of the world. This work is especially important because the wind energy market is rapidly being transformed both in the United States and abroad. Wind characterization activities will help optimize wind measurement programs, enhance the development of wind energy, and lead to more opportunities for the domestic wind energy industry.

Personnel who have had extensive experience in wind resource assessment lead the wind resource activity. The current expertise of the group is primarily in meteorology, wind climatology, computer mapping using ARC/INFO Geographic Information System (GIS), software development using FORTRAN, C, and PERL programming, and management of large data bases. The computer equipment used for wind resource assessment activities includes personal computers and advanced UNIX-based operating systems on Sun Workstations.

Major wind resource assessment tasks undertaken by during the past year include:

1. Updates to the comprehensive meteorological and geographic data bases used in resource assessments in the United States and abroad

2. The development and validation of an automated wind resource mapping procedure

3. Support in producing wind forecasting tools useful to utilities involved in wind energy generation

4. Continued support for recently established wind measurement and assessment programs in the United States.

Expert private consultants and subcontractors ably support NREL's wind resource assessment tasks. Areas of support during the past year include wind monitoring station installation, training, and operation; analysis of wind and other meteorological data; wind resource assessment training and presentation; technical assistance in support of utility/industry requests; an inventory of recent U.S. wind measurement data; and surveys of numerical wind flow/prediction models and methods of re-constructing missing meteorological data.

METEOROLOGICAL AND GEOGRAPHIC DATA BASES

The comprehensive global data bases at NREL used for resource assessment activities for regions in the United States and abroad continue to be expanded and updated. These data bases contain the meteorological and geographical information that are the cornerstones for the development of an automated wind resource mapping tool used to produce sophisticated wind resource assessments.

NREL has data from a variety of meteorological and topographical data sets. The principal types of

meteorological data sets include surface data from first-order weather and aviation stations, upper-air data taken by weather balloons, and marine data measured by ships and satellites. A paper by Elliott and Schwartz (1996) describes these meteorological data sets in detail. Digital elevation data are the main type of geographic data sets used in wind resource assessment activities and are especially important in the production of advanced wind mapping tools. During the past year, NREL has obtained, from the United States Geological Survey, digital elevation data sets with 1 km resolution for much of the world. The resolution in these data sets is much finer than what was previously available to NREL and the use of finer resolution grids results in a more accurate wind resource map. The meteorological and geographic data sets have been used in the Mexico wind resource assessment project (Schwartz and Elliott, 1995), and for resource assessments in Indonesia, Chile, and a few other areas.

NREL's wind resource assessments helped optimize new measurement programs in areas shown by the wind maps to have good-to-excellent wind resource potential. Data collected from these new measurement stations are then integrated into the NREL data sets. Wind data from new monitoring stations in Mexico and Indonesia have been useful in refining the distribution of the wind resource in regions where wind energy projects are under consideration or development. Monthly wind power density values measured at several of the new monitoring stations on West Timor, Indonesia, (established and managed by Winrock International) are presented in Figure 1. In general, these data indicate the existence of good-to-excellent wind resources that were predicted by NREL's preliminary wind maps.

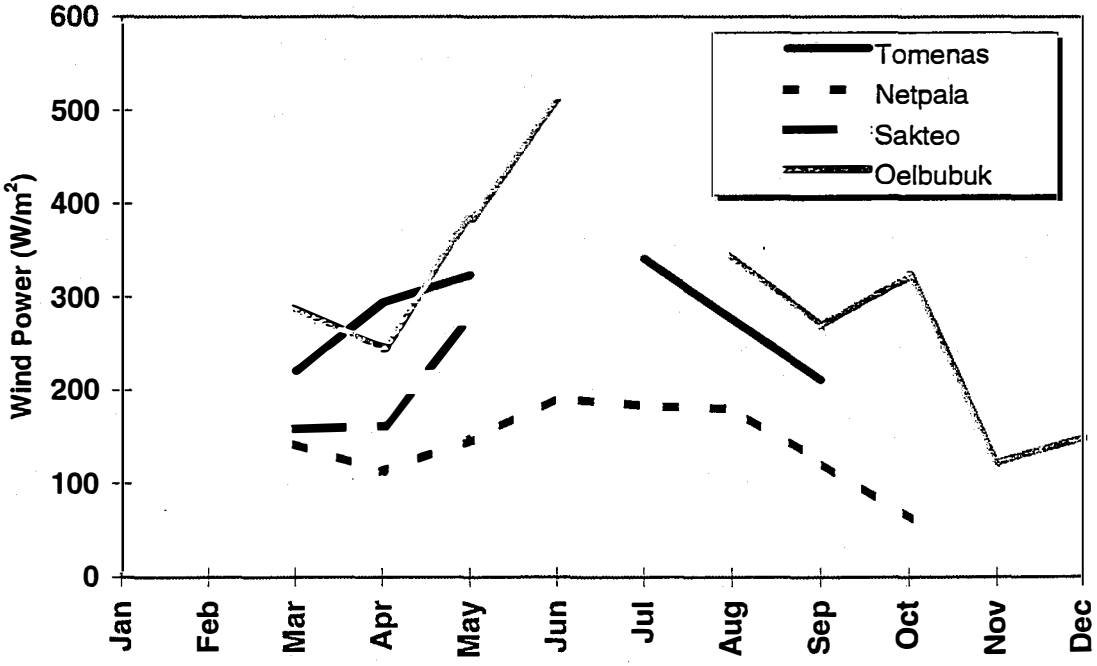

FIGURE 1: 1996 MONTHLY WIND POWER DENSITY VALUES OF 4 STATIONS IN WEST TIMOR, INDONESIA. THESE STATIONS WERE ESTABLISHED AS PART OF A DOE/USAID WIND RESOURCE ASSESSMENT PROJECT.

DEVELOPMENT AND VALIDATION OF WIND MAPPING TOOLS

The creation of automated progressive wind mapping tools is a key component in the production of sophisticated wind resource maps. The computer mapping system developed by NREL uses an analytic approach and portrays a regional distribution of the wind resource. The computerized mapping technique

greatly reduces the effort needed to create a wind map as compared to the old-style manual analysis, especially in areas of complex terrain. Computer mapping also analyzes the distribution of the wind resource in a consistent manner throughout the region of interest. The initial step in producing an automated wind resource map is to define the meteorological inputs used by the mapping system. These inputs are defined by the use of advanced analysis techniques based on information from the updated NREL data sets. A key task in deriving these inputs is the formation of a conceptual model that explains what causes the wind to blow in a certain region. The scale of the meteorological factors that cause the wind flow can vary from several hundred kilometers (storm-scale) to only a few kilometers when local circulations (e.g., sea-land breeze, mountain-valley circulation) predominate. A variety of meteorological data sources assimilated at NREL facilitates the process of conceptualizing wind patterns in most regions of the world. The diversity of the wind data sources also enables poor quality or suspect data from one data set to be checked and screened against data from other sources. The meteorological inputs derived from the advanced analysis techniques are then combined with digital elevation models and GIS software to produce wind maps showing the most favorable wind resource areas. Recent advances to the computer mapping tool developed by NREL (Elliott and Schwartz, 1996) include an algorithm to account for diminution of the wind resource caused by large-scale blocking (e.g., in the vicinity of an island with complex terrain) and a modification to the section that calculates the effect of terrain on the wind resource.

Validation tests are being designed and conducted on the wind resource mapping tool. These tests are using wind energy measurement data from the United States and other areas as a check that will help determine the effect of varying the input parameters and algorithms on map output and accuracy. Some of the factors being tested include upper-air data input, digital elevation grid data, and varying the algorithms that calculate the effect of the terrain on the distribution of the wind resource. The results of these tests will be used to modify existing software and to create, when necessary, new software to increase the accuracy of the mapping system.

WIND MAPPING PRODUCTS

An example of NREL's computer generated wind resource maps is shown in Figure 2, a resource map of the island of Sumba, located in southeastern Indonesia. This map was developed as part of a wind resource assessment project funded by DOE and USAID and administered by Winrock International. This island is characterized by moderately complex terrain and is in a band of moderate-to-strong easterly winds that predominate from April through October. The meteorological inputs for this map were aided by analysis of satellite derived ocean wind speeds, an upper-air climatic atlas data set, and weather balloon stations at Waingapu on Sumba and at Kupang on West Timor.

NREL has also produced computer wind resource maps for areas of Region 9 and Region 10 in south-central Chile in support of a DOE/EPA renewable energy development project. The process of producing computerized wind resource maps of Chile was more difficult than Sumba. The regions have more complex terrain (coastal range and Andes mountains) and a complex wind climatology. Several new algorithms were introduced into the mapping tool and modifications were made to existing ones to account for these factors. The Chile maps are being be used to identify and target possible wind energy project sites for wind measurements.

WIND FORECASTING

Wind forecasting has been the subject of interest in the wind energy community for a significant number of years. Due to the recent availability of new data sets, advances in computing power, and advances in numerical weather prediction models, the development of automated wind forecasting tools of value to wind energy operators is now more probable. The initial wind forecasting tools developed as a result of this project will most likely be derived from wind speed forecasts since speed forecasts are produced by computer weather

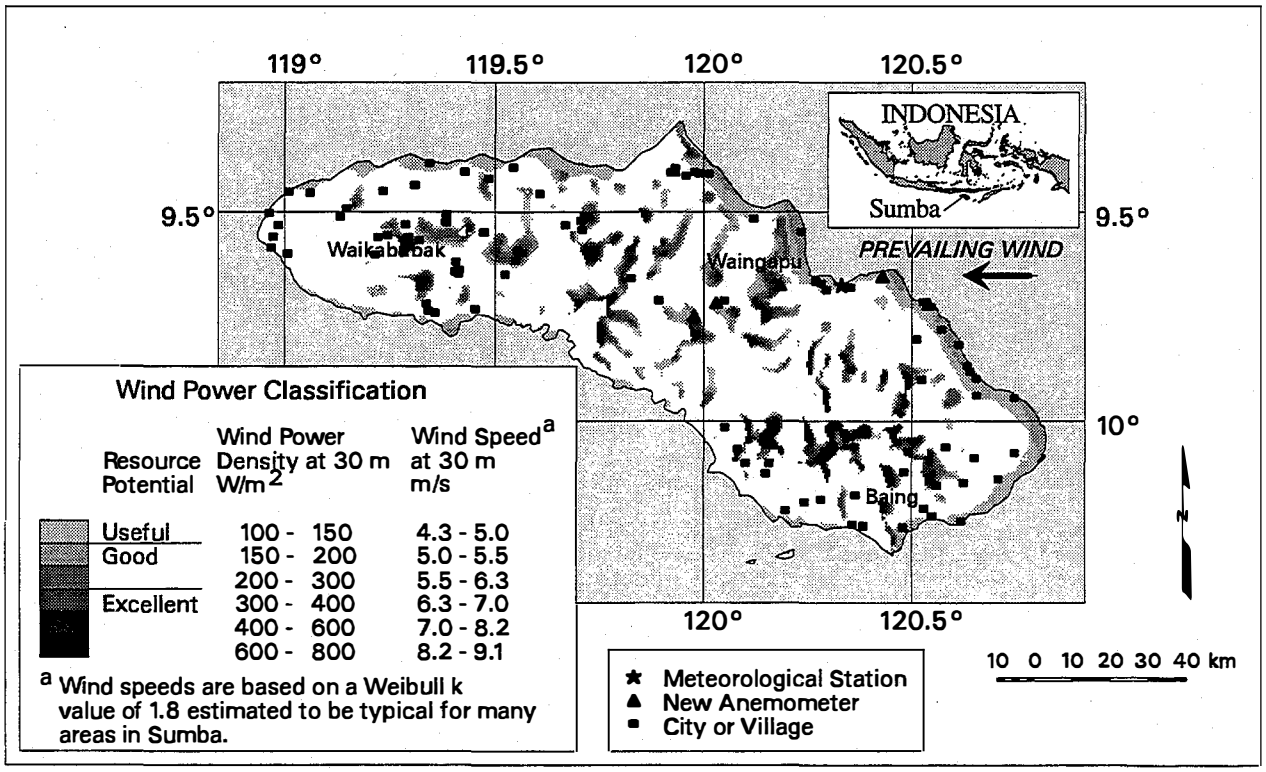

FIGURE 2: COMPUTERIZED WIND RESOURCE MAP OF SUMBA, INDONESIA

prediction models. This enables wind speed forecasts to be directly evaluated as to their suitability to wind energy applications. Research on wind power generation forecasts will follow evaluations of wind speed forecasts. Recent activities undertaken by NREL for the wind forecasting task include evaluating the accuracy of the wind forecasts produced by a routinely run numerical weather prediction model and beginning a dialogue with utilities to get their views on the most useful types of wind forecasting tools.

The Rapid Update Cycle (RUC) is an advanced numerical weather prediction model used to generate weather forecasts for the United States. The model was developed at the National Oceanic and Atmospheric Administration's Forecast Systems Laboratory (FSL) in Boulder, Colorado. This model was chosen by NREL to be evaluated for wind forecasting accuracy in part because its predictions of wind speed and direction have higher temporal and spacial resolution compared to other numerical weather prediction models. NREL and FSL are partners in the evaluation activity. FSL is currently archiving model predictions and writing software in support of this activity.

NREL, with help from its support subcontractor for wind resource assessment (AWS Scientific, Inc.), is engaged in a fact-finding initiative, targeted at the operators of utility systems, on the potential use of wind forecasts by utilities for predicting wind plant generation output. Interviews are being conducted with operators and other utility staff from several Utility Wind Interest Group (UWIG) member utilities to obtain their feedback about the use and types of wind forecasts that would fit their needs plus some background information about the utility's operating system. The findings from this series of interviews will serve as a basis of a possible wind forecasting development program tailored to utility interests.

UNITED STATES MEASUREMENT AND ASSESSMENT PROGRAMS

NREL continues to help oversee the three recently initiated DOE cost-shared programs that include wind measurement and resource assessment activities in the United States: 1) the Utility Wind Resource Assessment Program (U*WRAP), 2) the Sustainable Technology Energy Partnerships (STEP), and 3) the Cooperative Networks for Renewable Resource Measurements (CONFRRM). The goal of these programs is to accelerate multiregional U.S. market penetration of wind systems and to move the United States towards leading the world in the development and use of advanced wind turbine technology. The programs are designed to form partnerships with diverse types of organizations including state and tribal energy offices, private and public utilities, universities, research institutions, the financial community, and private consulting firms that wish to help accelerate the commercial development of wind energy.

U*WRAP, administered by UWIG, is a program designed to technically and financially support private and public utilities conducting wind resource assessments. This program will increase the quantity of wind data available to utilities and enlarge the qualified workforce that can conduct a skilled resource assessment program. The results from the U*WRAP program will give utilities the means to assess their wind resources and wind electric potential, identify candidate development areas, target the most compatible wind turbine designs, and assess the economics of wind-based generation. Six utilities are participating in U*WRAP; a total of 34 wind measurement stations have been established. The time frame for the U*WRAP measurements is two years, so most of the monitoring will be completed in 1997 and 1998. The data collected by the utilities under this program will be proprietary for up to 5 years after the start of the measurements because the utilities are cost-sharing one-half of the cost of U*WRAP. After 5 years the data will be made available to the public.

STEP seeks to meet the needs of states, industry, and localities in accelerating the commercialization of renewable energy technologies. One of the areas of interest of the STEP program is wind resource assessment. The STEP program actively supports the establishment of new measurement stations in areas being considered for wind power generation and analysis of existing wind data using GIS techniques leading to detailed areal resource characterization. The states of Colorado, Iowa, Minnesota, Nebraska, New Mexico, and Wisconsin are participating in this area of STEP.

CONFRRM is designed to improve the assessment of solar and wind energy resources in the United States. This program supports the establishment of long-term wind measurement benchmark stations at locations with high wind energy potential. The benchmark stations are located at sites that are representative of areas where wind technology applications appear feasible. There are no restrictions on the type of organizations that are responsible for the operation and maintenance of the benchmark stations. The data collected from the stations will be in the public domain and will be made available through NREL's Renewable Resource Data Center. Twelve wind measurement stations are currently in operation.

Figure 3 shows the distribution of the twelve states that presently have projects under these three programs. The states are concentrated in the Great Plains and Rocky Mountains, the regions with the highest overall wind resource potential in the United States, but other sections of the country, such as the Northeast and the Great Lakes, with a promising wind resource are also represented. Projects in additional states are likely to be funded in the near future. The three cost-shared programs should significantly increase detailed wind resource assessments and accelerate the commercialization of wind energy in the United States.

NREL provides technical assistance to wind resource assessment programs run by non-federal agencies such as state and tribal offices and utilities. The assistance, based on past NREL experience, can include reviewing the station siting approach and procedures, offering historical perspectives on wind resource assessment activity in a region, and offering advice on enhancing wind measurement programs. An example of this type of assistance was the help NREL provided through its support subcontractor to the Tennessee Valley Authority

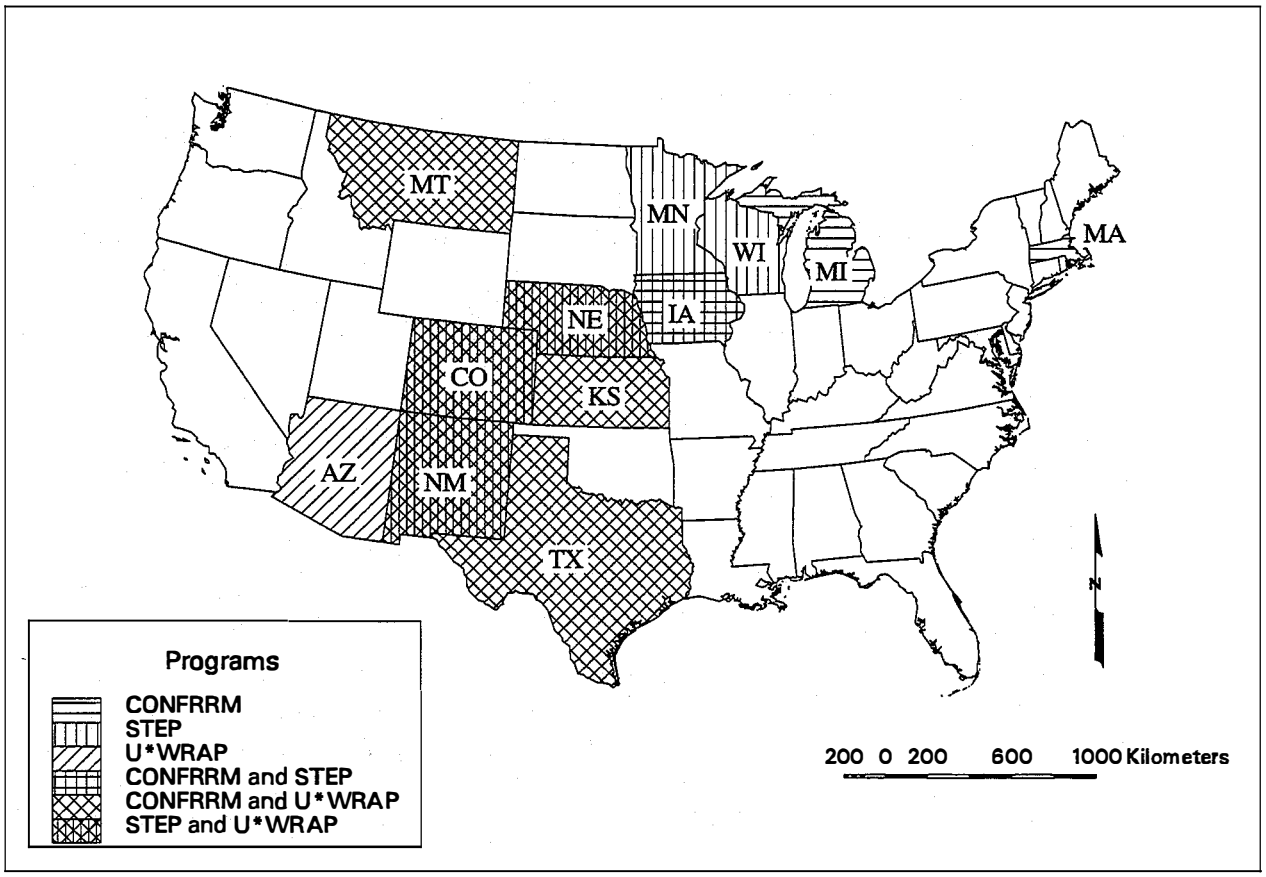

FIGURE 3: STATES HAVING PROJECTS UNDER DOE WIND MEASUREMENT PROGRAMS

in reviewing its methodology for choosing a wind monitoring site and aiding in the installation of that site in southern Kentucky. NREL has also recently published the *Wind Resource Assessment Handbook (1997).* This handbook is suitable for any organization or individual desiring to conduct a structured wind measurement program. The information contained in the handbook was the basis for the NREL sponsored short-course "Conducting a Wind Resource Measurement Program", presented at the Windpower '96 and Windpower '97 conferences.

CONCLUSION

The wind resource assessment program at NREL is involved in a wide variety of activities with the purpose of accelerating the deployment of wind energy. Chief among the activities are developing and validating an automated wind mapping tool and using this tool to produce advanced and sophisticated wind resource maps. Other significant NREL activities include wind forecasting research, identifying and updating comprehensive databases used for wind resource assessment, and providing support to utilities and the wind energy industry in their resource assessment programs.

NREL will continue to expand the capabilities of the automated wind mapping technique in order to produce reliable wind maps of regions with quite complex terrain and/or wind flow. NREL also anticipates engaging in cooperative activities with utilities, industry, state agencies, universities, and private organizations to improve the wind characterization in the United States. The activities of the NREL wind resource assessment group will continue to be a key component in efforts to provide market opportunities for the domestic wind energy industry.

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