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Philippines Wind Energy Resource Atlas Development

Dennis Elliott

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National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

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Philippines Wind Energy Resource Atlas Development

Dennis L. Elliott
National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, CO
USA

Abstract

This paper describes the creation of a comprehensive wind energy resource atlas for the Philippines. The atlas was created to facilitate the rapid identification of good wind resource areas and understanding of the salient wind characteristics. Detailed wind resource maps were generated for the entire country using an advanced wind mapping technique and innovative assessment methods recently developed at the National Renewable Energy Laboratory. The technique uses Geographic Information Systems to produce high-resolution (1 square kilometer) annual average wind resource maps. In addition to the annual average wind resource distribution, the seasonal and diurnal variability and other salient wind characteristics were analyzed. The wind mapping results show many areas of good to excellent wind resource throughout much of the Philippines, particularly in the northern and central regions. The total wind electric potential from areas with good to excellent wind resource is conservatively estimated to be 76,000 megawatts of installed capacity or approximately 195 billion kilowatt hours per year. Even if only a small fraction of this potential can be readily developed, this still represents a substantial wind potential that is much greater than estimated in previous studies. We strongly recommend that wind measurement programs be conducted to validate the resource estimates and to refine the wind maps and assessment methods where necessary.

Introduction

The Philippines wind mapping and assessment project was initiated to define the wind resource availability and to facilitate and accelerate the use of wind energy technologies—both for utility-scale generation and off-grid wind energy applications—in the Philippines. This major project was the first of its kind undertaken for the Philippines. The key to the successful completion of the project was a computerized wind resource mapping technique recently developed at the National Renewable Energy Laboratory (NREL), a U. S. Department of Energy (DOE) laboratory. The technique uses Geographic Information Systems (GIS) software to produce high-resolution (1 square kilometer [km^2]) wind resource maps.

This project evolved through the cooperation and assistance of Winrock International and several Philippine agencies. Upon learning of NREL's advanced wind mapping capability, the Winrock International Philippines Renewable Energy Project Support Office (REPSO) and Preferred Energy, Inc., worked with other interested parties in the Philippines to propose and fund the development of a national Wind Energy Resource Atlas. The Philippine Council for Industry and Energy Research and Development, of the Department of Science and Technology, and the Philippines National Oil Company each provided funding for the study through Winrock International. DOE also provided significant funding for the development of the wind energy resource atlas, and the U.S. Agency for International Development supported the overall coordination and data gathering for the wind atlas development effort. The Philippines National Power Corporation (NPC) supported the project by contributing wind-monitoring data collected at 14 prospective wind energy sites and by providing other technical assistance.

Winrock International and REPSO had the lead responsibility in administering this project and in collaborating with the Philippine organizations and NREL on project activities. NREL had the technical lead for the wind resource analysis and mapping activities. The primary goal was to develop detailed wind resource maps for all regions of the Philippines and to produce a comprehensive wind resource atlas documenting the mapping results.

The document *Wind Energy Resource Atlas of the Philippines* (Elliott et al. 1999) presents the wind resource analysis and mapping results for the Philippines project. The wind resource maps were created at NREL using its recently developed, GIS-based wind resource assessment system. In addition to the Philippines, NREL has applied its new wind mapping system to produce wind resource assessments of the Dominican Republic (Elliott

1999) and Mongolia (Elliott et al. 1998), and specific regions of Chile, China, Indonesia, Mexico, and the United States (Schwartz 1999).

Mapping System and Methodology

NREL has been developing its GIS-based wind resource mapping technique since 1996. This technique replaces the manual analysis techniques employed in previous mapping efforts, such as the *Wind Energy Resource Atlas of the United States* (Elliott et al. 1987). It produces wind maps that reflect a more consistent and detailed analysis of the wind resource distribution throughout a region.

At present, the wind mapping system takes a strictly empirical, analytical approach to determine the level of wind resource as a particular location. It does not use explicit atmospheric boundary layer equations or geostrophic adjustment equations as other wind-flow models do. The mapping system is designed to display regional (rather than local or micrositing) distributions of the wind resource to a spatial resolution of 1 km^2. The detailed maps are intended to facilitate the rapid identification of the most favorable wind resource areas within a region.

The meteorological assumption that there are empirical relationships in many parts of the world among the free-air (higher than 100-200 meters above ground) speed, the wind speed over the ocean (where applicable), and the distribution of the wind resource over land areas is the basis of NREL's technique. NREL uses a "top down" method to adjust much of the available wind data. That is to say, NREL takes the free-air wind speed profile for heights up to 3000 meters above the surface and adjusts these data to produce a wind power profile for the lowest few hundred meters above the surface. The prime advantage of this method is that NREL can produce a useful wind resource map without having high quality surface wind data for the study region. Years of work at NREL have found many problems with the available land-based surface wind data collected at meteorological stations around the world. Examples of these problems are described in previous publications (Schwartz and Elliott 1995). Problems include a lack of information about observation procedures and anemometer hardware, height, exposure, and maintenance history. In general, available surface wind data in much of the world are not reliable or abundant enough to use directly as input in the wind mapping system.

NREL's "top down" approach requires a critical analysis of the available climatic data sets in the study area. Graphical and tabular wind characteristic products generated from the raw data need to be cross-referenced to understand the prevalent wind-flow patterns in the study area and salient wind characteristics, including the seasonal and diurnal variability. The ultimate goal of the analysis is to create a conceptual model of the physical mechanism(s) that cause the wind to blow in a particular region. The conceptual model guides the development of the empirical relationships that are the basis of the wind power calculation algorithms and enables meteorological input into the model to be as precise as possible. The accuracy of the final wind map is highly dependent on the precision of the input data. A description of the meteorological data sets, details on the digital elevation data used by the mapping system, and formats of the meteorological input can be found in previous publications (Elliott and Schwartz 1997, 1998; Schwartz and Elliott 1997).

The final meteorological inputs to the mapping system are vertical profiles of wind power density, wind power roses (the percentage of wind power by direction sector), and the ocean wind power density (where appropriate). The GIS model determines any required adjustments to these composite distributions for each 1-km^2 grid cell. The factors that have the greatest influence on the adjustment for a particular grid cell are the topography in the vicinity of the grid cell and a combination of the absolute and relative elevation of the grid cell. The primary output of the mapping system is a color-coded map containing the estimated wind power density, and equivalent wind speed, for each individual grid cell.

Philippines Application

Surface, satellite, and upper-air data were assembled, processed, and analyzed for the Philippines. These data sets included information provided by the Philippine Atmospheric, Geophysical, and Astronomical Services Administration, NPC, data sets from the U.S. National Climatic Data Center, U.S. National Center for Atmospheric Research, and other U.S. sources. The satellite data sets of derived 10-meter (m) wind speeds over ocean areas were extremely useful in this analysis because of the large expanse of ocean surrounding the archipelago and the limited number and value of land-based observations. We applied NREL's mapping system to generate the wind resource estimates throughout the Philippines. To portray the mapping results, the Philippine archipelago was divided into 13 regions (see Figure 1). Each region covered an area approximately 300 km by 300 km. The regional divisions were

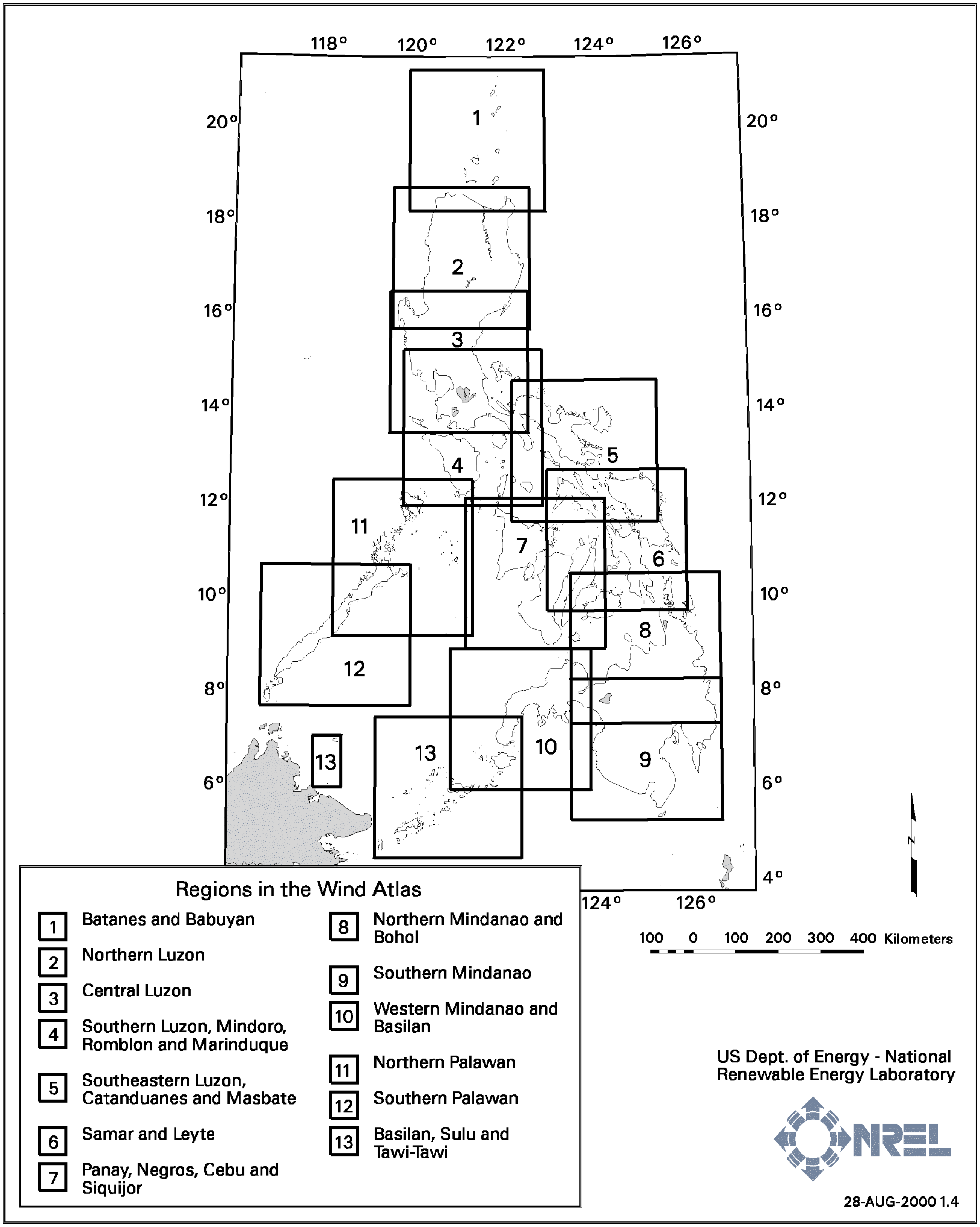


Figure 1. Mapping regions used in the Wind Energy Resource Atlas of the Philippines

determined principally on the geography of the archipelago and the desire to maintain the same map scale for each region.

A combination of wind characteristics helps determine the suitability of the wind energy resource in a particular area. Factors such as the annual and monthly average wind speeds and the seasonal and diurnal wind patterns affect the suitability of an area for development. In general, locations in the Philippines with an annual average wind speed of 6.5 to 7 meters per second (m/s) or greater at turbine hub height are the most suitable for utility grid-connected wind energy systems. Rural power applications are usually viable at lower wind speeds (5 to 6 m/s), and in some cases, at wind speeds as low as 4.5 m/s.

The average wind speed is not the best indicator of the resource. Instead, the level of the wind resource is often defined in terms of the wind-power-density value, expressed in watts per square meter (W/m^2). This value incorporates the combined effects of the wind speed frequency distribution and the dependence of the wind power on air density and the cube of the wind speed. Thus, six wind power classifications, based on ranges of wind-power-density values, were established in each of two categories—one for utility-scale applications, ranging from marginal to excellent, and one for rural power applications, ranging from moderate to excellent. This classification scheme for the Philippines is presented in Table 1.

For the Philippines, we chose the 30-m height above ground as a compromise hub height between large utility-scale wind turbines (which may range between 30 m to 60 m or higher) and small wind turbines (which may range between 15 m and 30 m) for rural power applications. Wind power is calculated only for those grid cells that meet certain exposure and slope requirements. As a result, only the most favorable wind resource areas are highlighted. For example, a grid cell is excluded if there is major blocking of the ambient wind flow by local terrain features. A grid cell must be exposed to at least 70% of the ambient wind flow to be included in the wind power calculations. A grid cell can also be excluded if the slope of the terrain is too steep. To be included, the slope in the grid cell must not exceed 20%. The wind resource values are estimates for low surface roughness (e.g., grassland with no major obstructions, such as trees or buildings).

Wind Mapping Results and Salient Wind Characteristics

The wind resource in the Philippines is strongly dependent on latitude, elevation, and proximity to the coastline. In general, the best wind resource, on an annual average basis, is in the northern and central regions of the country and primarily on hilltops, ridge crests, and coastal locations that have excellent exposure to the prevailing winds.

The wind mapping results show many areas of good-to-excellent wind resource for utility-scale applications and excellent wind resource for village power applications, particularly in the northern and central regions of the Philippines. The best wind resources are found in six regions: (1) the Batanes and Babuyan Islands north of Luzon; (2) the northwest tip of Luzon (Ilocos Norte); (3) the higher interior terrain of Luzon, Mindoro, Samar, Leyte, Panay, Negros, Cebu, Palawan, eastern Mindanao, and adjacent islands; (4) well-exposed east-facing coastal locations from northern Luzon southward to Samar; (5) the wind corridors between Luzon and Mindoro (including Lubang Island); and (6) between Mindoro and Panay (including the Semirara Islands and extending to the Cuyo Islands.

Table 1. Wind Power Classification for the Philippines Atlas

Class	Resource Potential Utility	Rural	Wind Power Density (W/m^2) @ 30 m	Wind Speed [(a)] (m/s) @ 30 m
1	Marginal	Moderate	100-200	4.4 – 5.6
2	Moderate	Good	200-300	5.6 – 6.4
3	Good	Excellent	300-400	6.4 – 7.0
4	Excellent	Excellent	400-600	7.0 – 8.0
5	Excellent	Excellent	600-800	8.0 – 8.8
6	Excellent	Excellent	800-1200	8.8 – 10.1

[(a)] Mean wind speed is estimated assuming a Weibull distribution of wind speeds with a shape factor (k) of 2.0 and standard sea-level air density. The actual mean wind speed may differ from these estimated values by as much as 20 percent, depending on the actual wind speed distribution (or Weibull k value) and elevation above sea level.

Figure 2 shows the annual average wind resource map for the northern part of Luzon. In this region, the best wind resource areas are dispersed throughout much of the region and primarily found on exposed hilltops and ridge crests and some of the coastal areas. High-quality wind measurement data useful in validation of the modeled estimates are quite sparse in this region and also throughout the Philippines. However, wind data were available from NPC for several sites where 30-m towers were installed in Ilocos Norte in the northwestern part of northern Luzon and one ridge-crest site in the Mountain Province. Data from these sites verified the existence of the good-to-excellent wind resource predicted by NREL's model. The model confirms the generally low to marginal wind resource in areas where data are available from meteorological stations. Although a few meteorological stations are located in areas of good wind resource, they are mostly located in areas of low wind resource.

In the atlas, all the wind resource maps are in color to facilitate identification of areas and resource values. Also, a political base map and an elevation map, done on the same scale as the wind resource map, are included in the atlas to allow the user to relate the wind resource features to the political and topographic features.

A CD-ROM version of the atlas was also produced, which provides the added feature of allowing the user to zoom-in and enlarge the map features for any selected area. For example, Figure 3 shows an enlargement for the northern portion of Ilocos Norte in the northwestern part of northern Luzon. The 1-km^2 grid cells are easily discernible in this map. Also of interest is the large spatial variability in the wind resource estimates. We believe this degree of spatial detail is most useful in identifying prospective areas for wind measurement and potential wind energy developments. However, the terrain and wind resource can vary significantly within a 1-km^2 area, especially in complex terrain. The wind power estimate for a particular grid cell may not apply to all areas within a grid. Therefore, the maps are not intended for micrositing purposes.

The seasonal variability of the wind resource depends on several factors, including proximity to coastline and exposure to ocean winds, elevation above sea level and surrounding terrain, and geographic location. Throughout much of the Philippines, the highest wind resource at exposed locations with good wind resource occurs from November through February. This period is often referred to as the northeast monsoon season, because the prevailing direction of the strongest winds are typically from northeast. The lowest wind resource generally occurs from April to September, and prevailing winds from the southwest are more frequent during this period (particularly from June to August). However, the northeast winds are substantially stronger than the southwest winds throughout most of the Philippines, so, good exposure to the northeast winds is most important. There are some regional differences in the seasonal variability. For example, in the northern Philippines, the months with the highest wind resource are October through February. In much of the central and southern Philippines, November through March are the months with the highest wind resource. Two areas of the Philippines (the southeastern Mindanao coast and the western coast of Palawan) have a relatively high wind resource from June through September, largely because of stronger southwest winds in these areas.

The diurnal (time-of-day) variation of the wind resource is influenced mostly by site elevation and proximity to the ocean. The wind resource at relatively low-elevation inland areas (with respect to surrounding areas) is typically highest during late morning and afternoon and is lowest from late night to early morning. In most coastal areas, where land-sea breeze effects and other land-based influences are prominent, the seasonal and diurnal variations of the wind resource are usually similar to those for inland areas. Coastal points on capes and peninsulas or small islands that are well exposed to the ocean winds usually exhibit only small diurnal variations in the wind resource, as these areas are not significantly influenced by land-sea breeze flows and other types of land-based effects on the wind flow. Exposed ridge crests typically have the highest speeds during the night and early morning hours and lowest during midday. This diurnal characteristic was verified by data from a ridge-crest site in the Mountain Province of northern Luzon, where NPC had installed a wind measurement system.

Wind Electric Potential

The assumptions and methods for converting the wind resource to wind energy potential were based on those in the report *Renewable Energy Technology Characterizations* (DeMeo and Galdo 1997) and are listed at the bottom of Table 2. Each grid cell included in the wind power calculations has an annual average wind power density, in watts per square meter (W/m^2) at a 30-m height. We developed an equation to compute the total net annual energy delivery for grid cells with an annual average wind power density of 300 W/m^2 or greater (good to

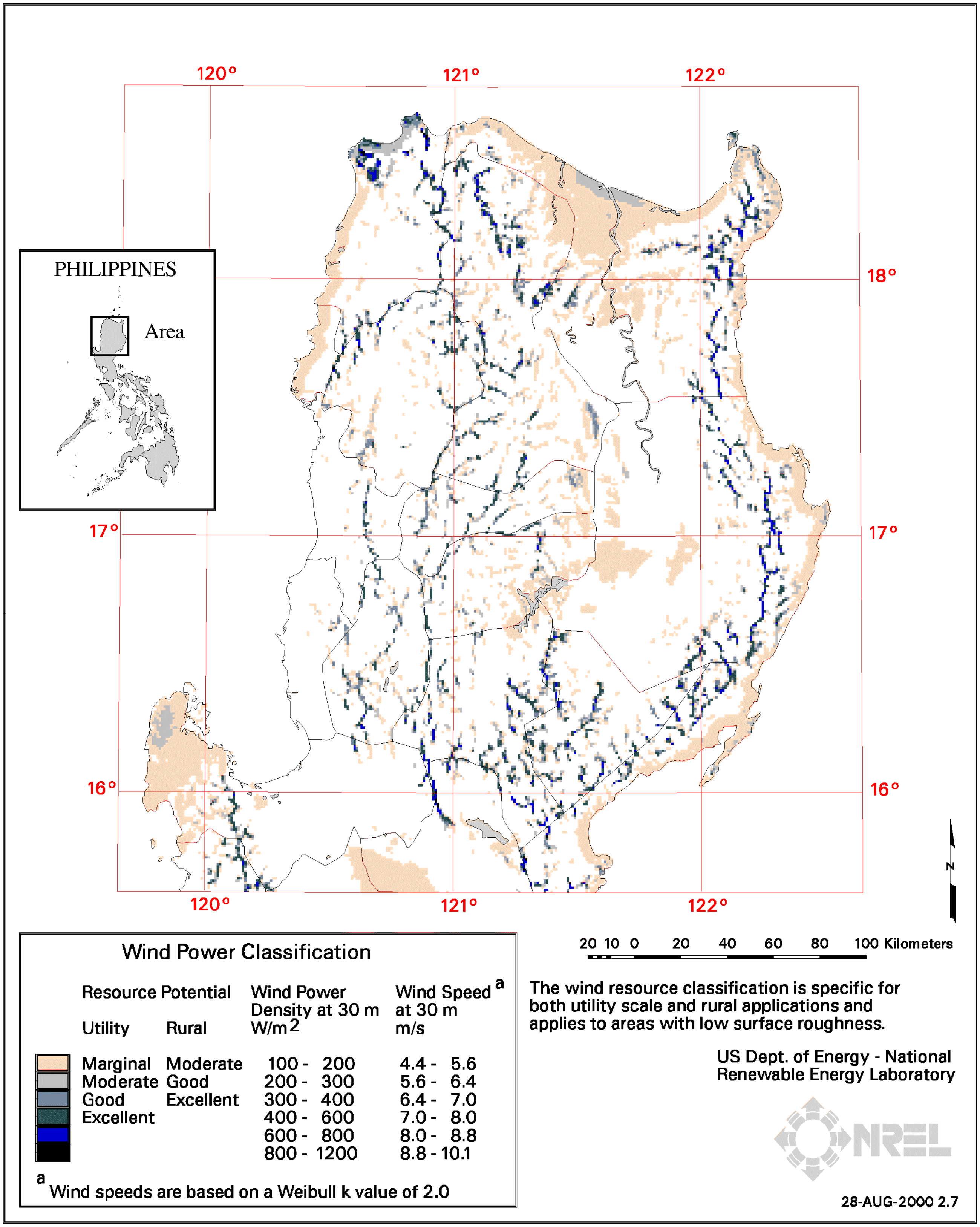


Figure 2. Wind resource map of northern Luzon

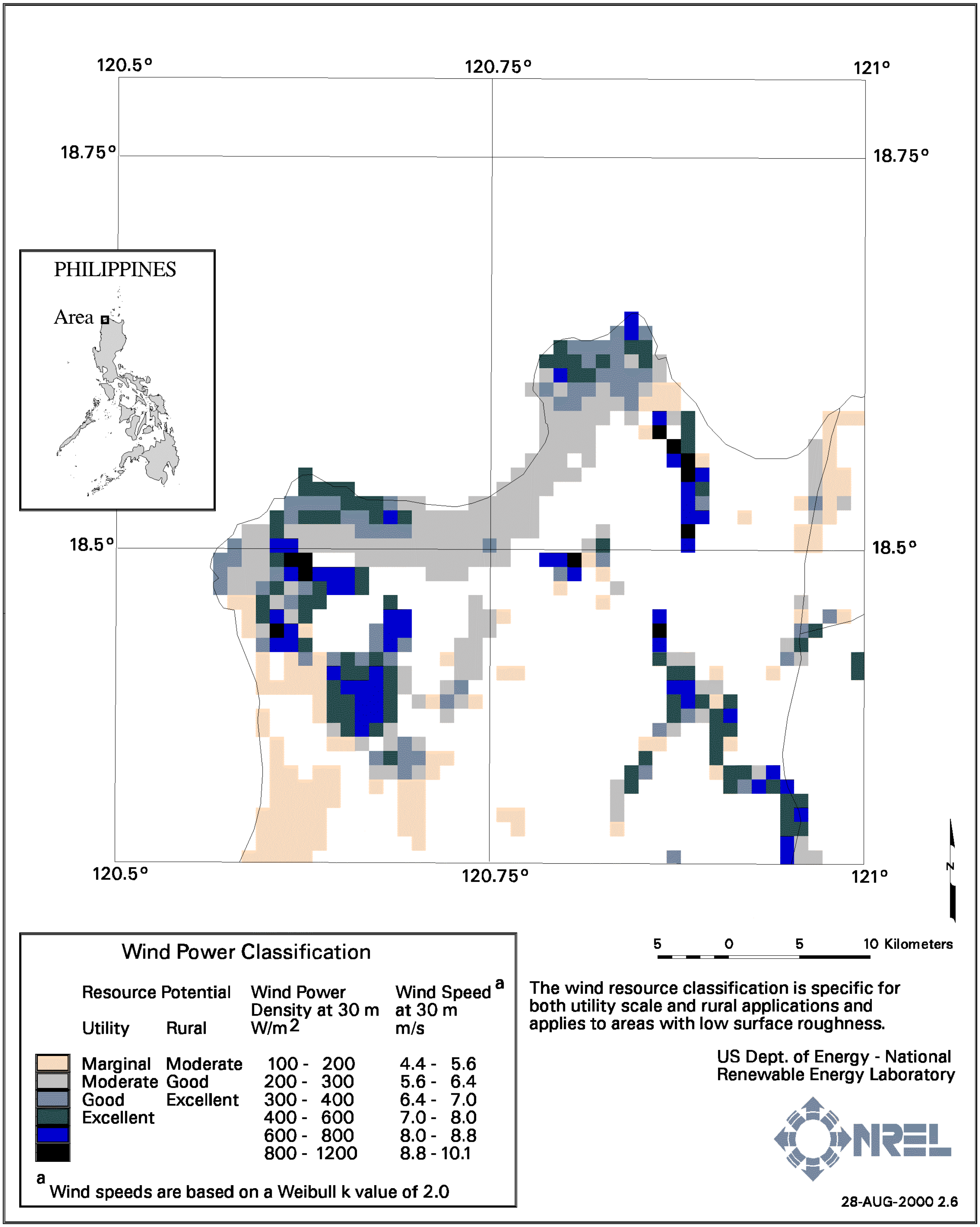


Figure 3. Wind resource map of the northern portion of Ilocos Norte

Table 2. Philippines - Wind Electric Potential

Good-to-Excellent Wind Resource at 30 m (Utility Scale)

Wind Resource Utility Scale	Wind Power W/m^2	Wind Speed m/s*	Total Area km^2	Total Cap Installed MW	Total Power GWh/yr
Good	300 – 400	6.4 – 7.0	5,541	38,400	85,400
Excellent	400 – 600	7.0 – 8.0	4,304	29,800	82,400
Excellent	600 – 800	8.0 – 8.8	1,112	7,700	25,100
Excellent	800 – 1200	8.8 – 10.1	98	700	2,300
Total			11,055	76,600	195,200

Moderate-to-Excellent Wind Resource at 30 m (Utility Scale)

Wind Resource Utility Scale	Wind Power W/m^2	Wind Speed m/s*	Total Area km^2	Total Capacity Installed MW	Total Power GWh/yr
Moderate	200 – 300	5.6 – 6.4	14,002	97,000	165,800
Good	300 – 400	6.4 – 7.0	5,541	38,400	85,400
Excellent	400 – 600	7.0 – 8.0	4,304	29,800	82,400
Excellent	600 – 800	8.0 – 8.8	1,112	7,700	25,100
Excellent	800 – 1200	8.8 – 10.1	98	700	2,300
Total			25,057	173,600	361,000

* Wind speeds are based on a Weibull k value of 2.0

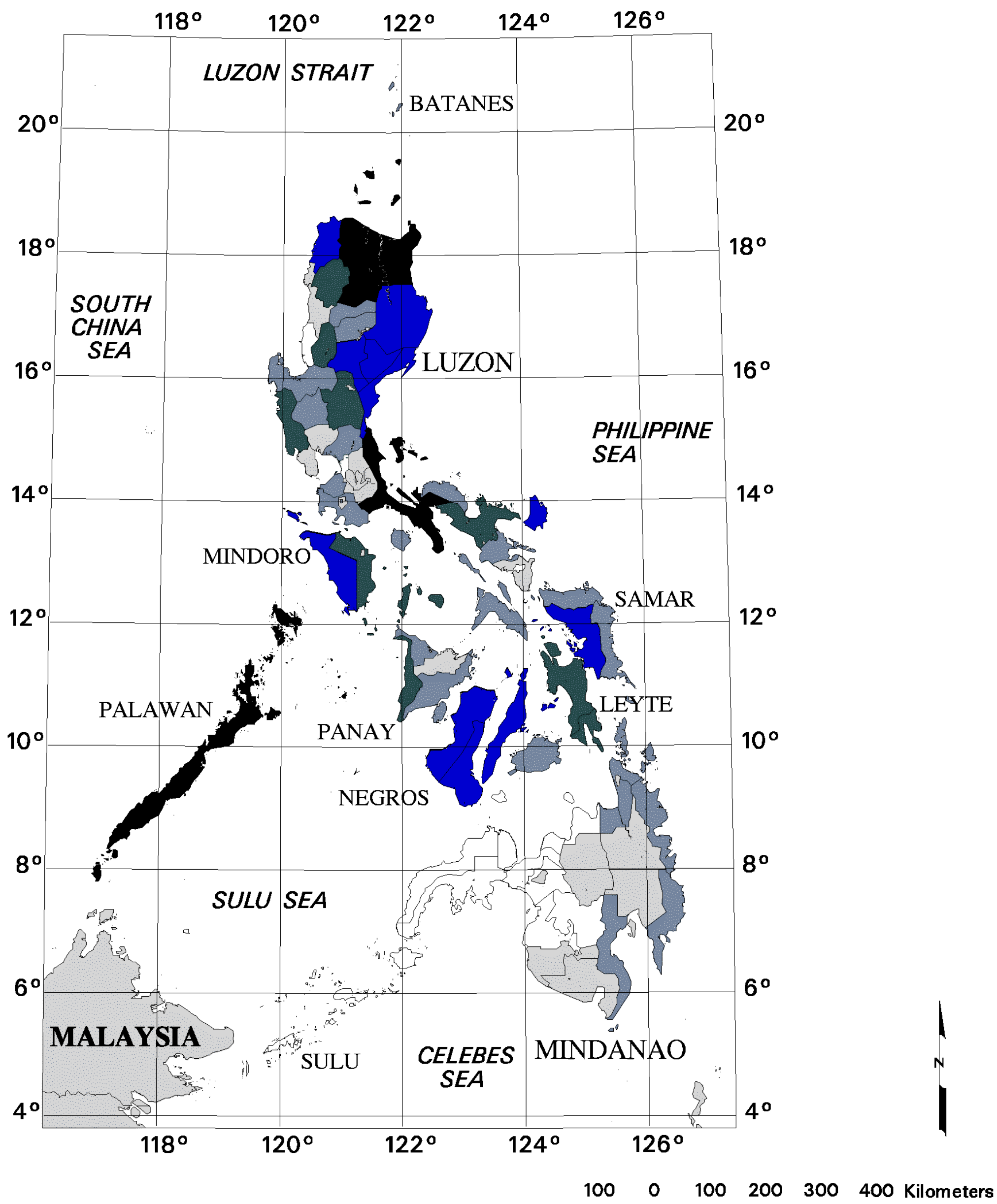
Assumptions

Turbine Size – 500 kW
Hub Height – 40 m
Rotor Diameter – 38 m
Turbine Spacing – 10D by 5D
Capacity/km^2 – 6.9 MW

excellent resource levels) or 200 W/m^2 or greater (moderate to excellent resource levels). If the wind power density was less than these resource levels, the net energy potential was set equal to zero because these grid cells have insufficient wind potential for the economic development of large, utility-scale wind energy. Although the areas with lower wind resource (100-200 W/m^2) are not economic for large wind and thus have been discounted, these areas have the potential for isolated use of small wind for rural electrification projects. Table 2 shows the results for both the good to excellent and moderate to excellent wind resource scenarios, including the portion of windy land and potential wind capacity in each wind power class. About 11,000 km^2 of windy land area with good-to-excellent wind resource potential is estimated to exist in the Philippines. These windy land areas represent about 3% of the total land area (299,000 km^2) of the Philippines. Using conservative assumptions of about 7 MW per km^2 of installed capacity, these windy areas could support about 76,000 MW of potential installed capacity, delivering approximately 195 billion kWh per year. Considering only these areas of good to excellent wind resource, there are 47 provinces out of 73 with at least 500 MW of wind potential and 25 provinces with at least 1000 MW of wind potential (Figure 4). If we consider additional areas that have a moderate wind resource potential, the estimated total windy land area increases to about 25,000 km^2, or 8% of the total land area of the Philippines. These windy areas could support more than 170,000 MW of installed capacity, delivering approximately 360 billion kWh per year. There are 51 provinces out of 73 with at least 1000 MW of wind potential and 64 provinces with at least 500 MW of wind potential. However, to assess the wind electric potential more accurately, additional studies considering factors such as the existing transmission grid and accessibility are required.

Conclusions and Recommendations

The wind resource maps and other wind resource characteristic information in the Philippines wind atlas will be useful in identifying prospective areas



Philippines Total - 76,600 MW

Wind Electric Potential
Megawatts

- < 100
- 100 - 500
- 500 - 1,000
- 1,000 - 2,000
- 2,000 - 3,000
- 3,000 - 5,200

The following assumptions were used in calculating the total potential wind electric capacity installed:

Minimum wind power - 300 W/m2
Turbine size - 500 kW
Hub height - 40 m
Rotor diameter - 38 m
5D Side-to-side spacing - 190 m
10D Front-to-back spacing - 380 m
Swept area - 1134 m2
Turbines/km2 - 13.9
Capacity/km2 - 6.9 MW

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Figure 4. Wind electric potential from areas with good to excellent wind resource (utility scale).

for wind-energy applications. However, very limited data of sufficient quality were available to validate the wind resource estimates. Therefore, we strongly recommended that wind measurement programs be conducted to validate the resource estimates and to refine the wind maps and assessment methods where necessary. An expanded wind measurement activity is underway by NPC, in collaboration with NREL, to collect wind data and monitor the wind resource in areas where wind energy projects are being considered. The Philippines wind atlas has been valuable in identifying these areas, and 14 new sites have been identified where wind measurement systems were recently installed. We hope that this activity and many others that benefit from the Philippines atlas maps and information will lead to many successful wind energy projects in the Philippines. We also hope that other countries will pursue the development of these types of wind resource maps and atlases to facilitate the development of wind energy projects in their countries.

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