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Mexico Wind Resource Assessment Project

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MEXICO WIND RESOURCE ASSESSMENT PROJECT

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ABSTRACT

A preliminary wind energy resource assessment of Mexico that produced wind resource maps for both utility-scale and rural applications was undertaken as part of the Mexico-U.S. Renewable Energy Cooperation Program. This activity has provided valuable information needed to facilitate the commercialization of small wind turbines and windfarms in Mexico and to lay the groundwork for subsequent wind resource activities.

A surface meteorological data set of hourly data in digital form was utilized to prepare a more detailed and accurate wind resource assessment of Mexico than otherwise would have been possible. Software was developed to perform the first ever detailed analysis of the wind characteristics data for over 150 stations in Mexico. The hourly data set was augmented with information from weather balloons (upper-air data), ship wind data from coastal areas, and summarized wind data from sources in Mexico. The various data were carefully evaluated for their usefulness in preparing the wind resource assessment. The preliminary assessment has identified many areas of good-to-excellent wind resource potential and shows that the wind resource in Mexico is considerably greater than shown in previous surveys.

BACKGROUND

In 1992, an interagency agreement between the U.S. Department of Energy (DOE) and the U.S. Agency for International Development (USAID) was established to support renewable energy development and conservation in Mexico. The goal of the DOE/USAID agreement is to support greater use and commercialization of proven renewable energy technologies in practical cost-effective applications including rural electrification, water pumping and other productive uses, and grid-connected bulk power generation. The various activities such as resource assessment, training, and technical assistance supporting these goals are undertaken as part of the Mexico-U.S. Renewable Cooperation Program (PROCER). The Mexican organizations involved in the PROCER activities include private sector companies, selected state governments, and national organizations involved in energy development and distribution.

In discussions between U.S. and Mexican industry and DOE contractors, the development of a preliminary wind resource map for Mexico was deemed a high priority, and a prerequisite to widespread use of wind energy systems. Based on these and other discussions, funding was provided to support mapping of the Mexican wind resources. The goals of this activity are : to develop a preliminary wind energy resource atlas which can support project and program development effort; to provide the level of resource information required to allow for high-confidence investments in decentralized wind energy systems by the private and public sector; and to support windfarm development through identification and initial characterization of areas with good resource potential for windfarms. Existing methodologies used in the wind resource assessment for the United States (Elliott et al. 1987) plus more sophisticated techniques of estimating the wind resource were utilized to identify and infer wind resources in different regions of Mexico. New techniques of displaying and interpreting statistical data using a comprehensive software package were developed and tested to aid in a more accurate assessment of all regions in Mexico.

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ASSESSMENT METHODOLOGY

Various sources of summarized surface wind data and previous wind energy assessments were reviewed and evaluated for use in this wind resource assessment. Useful summarized climatological data for selected stations in Mexico were found in the *World Survey of Climatology* (Bryson and Hare 1974). Valuable historical monthly summaries (for some stations, dating back to the 1920s) of the wind speed were obtained from the Servicio Meteorologico Nacional (SMN), which is the national meteorological service of Mexico. Other Mexican organizations with summarized surface wind data for various locations included the Universidad Nacional Autonoma (UNAM), the Servicios a la Navigacion en el Espacio Aereo Mexicano (SENEAM), which is the federal aviation authority in Mexico, the Instituto de Investigaciones Electricas (IIE), and the Centro de Investigacion en Energeticos y Desarrollo A.C., a company developing wind energy projects in rural areas of Mexico. Preliminary wind energy resource maps and mean wind speed data for Mexico produced by the Organizacion Latinoamerica De Energia (OLADE) and UNAM were also reviewed.

A meteorological data set, DATSAV2 Surface Climatic Database, was the main source of surface data used in this assessment. This data set was obtained from the U.S. National Climatic Data Center. The data is composed of hourly surface weather observations collected and stored from sources such as the Global Telecommunications System. The period of record is primarily 1973 to 1993.

Meteorological parameters such as wind direction, wind speed, temperature, sea-level pressure, and altimeter setting were extracted from the hourly observations and used to create statistical summaries of wind characteristics. Stations in Mexico operated by the SMN transmitted synoptic observations every 6 hours, four times a day. Stations located at airports are operated by SENEAM and transmit hourly standard airways observations during the hours that the airport is in operation.

Overall, DATSAV2 surface wind data for 186 locations (Figure 1) were evaluated in the wind resource assessment of Mexico. Of these stations, 86 were located at airports, and the rest were largely at city locations. Information on anemometer location, height, and station history was not available. The anemometer heights at these stations were assumed to be close to 10 m, the standard anemometer height of the World Meteorological Organization.

Upper-air wind data can be useful in estimating the wind resource at low levels just above the surface and in estimating vertical profiles of the wind speed aloft for extrapolation of the wind energy resource to elevated terrain features. A 10-year period (1982 to 1991) of the National Center for Atmospheric Research archive of the National Meteorological Center upper-air observational data was obtained and used in the assessment. This data set contains daily processed radiosonde data from stations throughout the world at 00, 06, 12, and 18z (Greenwich Mean Time). Wind information is available for the surface level, the mandatory pressure levels (1000 mb, 850 mb, 700 mb, 500 mb), the significant pressure levels as determined by the vertical profile of temperature and moisture (different for each upper-air observation), and specified geopotential heights above the surface (different for each upper-air observation). Data from 16 upper-air stations in Mexico and in the United States near the Mexico border were used in this analysis. Most of the stations launched radiosondes twice a day, with two of the stations launching radiosondes only once a day.

Marine wind data, which are largely based on observations by ships, can be used to estimate the wind resource for offshore areas. Through extrapolation of these data, the wind resource can be estimated at coastal and inland sites that are well exposed to the prevailing direction of the ocean winds. Summaries of marine data were obtained from the U.S. National Climatic Center for 1° latitude by 1° longitude quadrangles. The summaries include monthly means and standard deviations of wind speed, pressure, temperature, wind directional frequency and speed, and other meteorological observations. Maps of the

marine wind data were generated for areas in the vicinity of Mexico, and were generally useful in the preparation of the wind resource maps.

A comprehensive data processing package was written to convert the wind data in the DATSAV2 data set to statistical summaries of the wind characteristics at each station in a graphical form. The primary statistical summaries of surface data used in the assessment include the interannual variability of the wind speed and power, the average wind speed and power on an annual and monthly basis, the frequency distribution of the wind speed, the mean wind speed by direction, and the diurnal variability of wind speed and power. Other statistical plots for a given station used in the analysis included the number of observations on an annual, monthly, and hourly basis, and station and sea-level pressure by month.

QUALITY OF SURFACE DATA

A visual inspection of the surface plots from the DATSAV2 data set enabled quick screening of various characteristics of the wind measured at stations in a particular area. The visual inspection of the data also revealed trends or peculiarities or both in the observation data at many stations that called into question the quality of the data. After the initial inspection, the wind characteristics at stations with evidence of wind resource useful for at least rural power applications (mean wind speed >3.5 m/s or mean power density >60 W/m^2) were analyzed in more detail.

The data from Mexicali Airport (760053) (Figure 2) provides an excellent example of a trend in the surface wind data. A steady downward trend in wind speed and power density on an annual basis exists from 1973 to 1991. The number of observations is fairly consistent throughout the period. This trend in the data could lead to quite different conclusions about the wind resource at Mexicali depending on the period of record used in the analysis. An analysis of the wind resource at Mexicali using the data from 1990 to 1991 would lead to the conclusion that the average wind speed was about 1.5 m/s and wind power density about 25 W/m^2. In contrast, using the data from 1974 to 1975, the conclusion would be that Mexicali had a mean wind speed of 5 m/s and a power density of 170 W/m^2, almost seven times the 1990 to 1991 power density. A steady downward trend of wind speed at a station frequently indicates either a site becoming less exposed to the prevailing wind because of increased vegetation or other obstructions around the site, or a degradation in the anemometer used at that site. Because the percentage of calm (wind speed reported as 0 m/s) conditions increases as the average wind speed decreases, it is likely that the anemometer at this station is degrading with time. A better representation of the wind resource at Mexicali can be gathered from the period during the 1970s rather than the most recent data.

DEVELOPMENT OF WIND RESOURCE MAPS

Surface wind data that was most representative of the wind resource at a particular station was used as a first step in producing the analyses of the Mexican wind resource. A time series review of wind data showed that a set of wind data from a long period of record (20 years, for example) was not necessarily representative of the station's wind resource. Inspections of the time series of wind data showed a significant trend, such as that at Mexicali, affected a number of stations. The wind characteristics from the affected stations were calculated from periods of record considered to be most representative of the wind resource at each particular station. The interannual plots were screened for number of observations, trends in wind speed and power density, abnormally windy or calm periods, and any sudden increases and decreases in wind speed and power. In general, representative periods of record from these stations were between 3 and 7 years in length. The information from representative periods gave a good overview of the wind resource at a station.

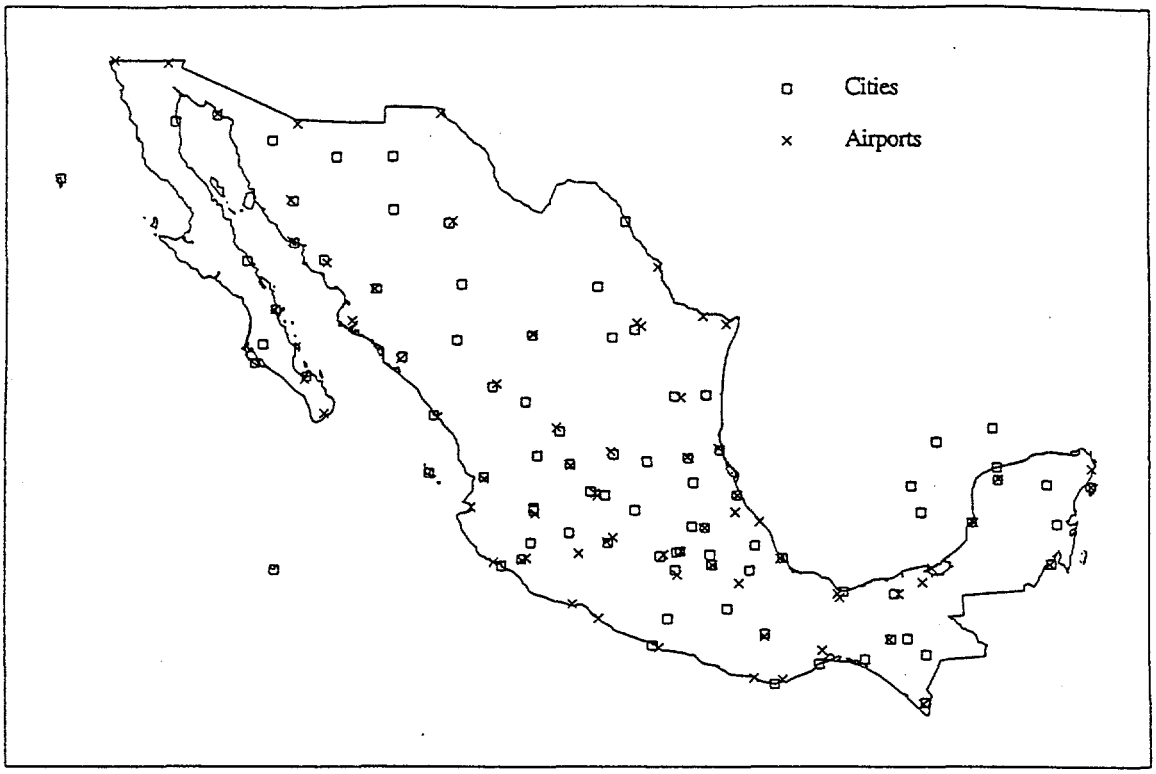
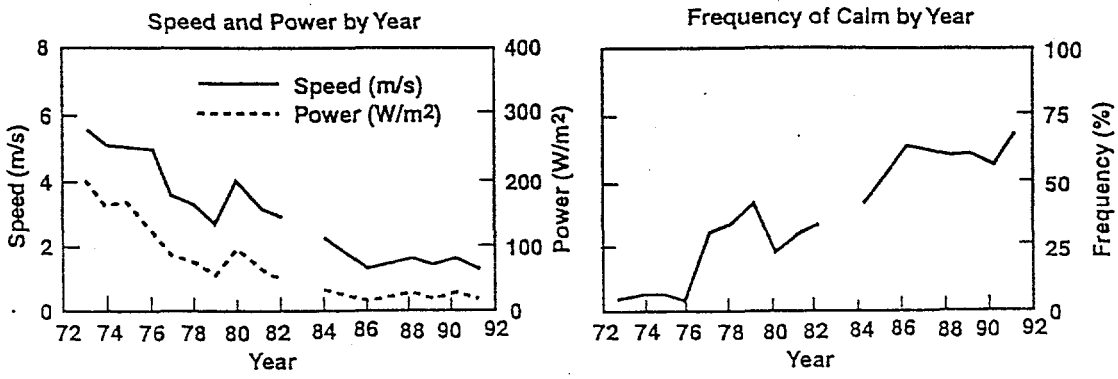


FIGURE 1: LOCATIONS IN MEXICO WITH SURFACE WIND DATA IN DATSAV2 DATA SET.



Period	Wind Speed (m/s)	Power (W/m2)	Calm (%)
1973-75	5.2	170	7
1986-91	1.5	20	62

FIGURE 2: YEARLY AVERAGE WIND SPEED AND FREQUENCY OF CALM CONDITIONS AT MEXICALI AIRPORT FOR THE PERIOD 1973-1991.

After the representative annual wind speeds and power densities for each station were plotted on a map, in-depth analysis of the statistical summaries enabled the most exposed stations to be identified. The wind speed and power densities at the exposed stations were considered typical for other areas of similar terrain in the various regions of Mexico.

Upper-air data was then used to confirm and adjust the surface wind resource pattern. An example of a graph of upper-air data is presented in Figure 3. The early morning (0600 Local Time) vertical wind speed profile at Merida shows relatively high wind speeds (7-10 m/s) only a few hundred meters above the surface throughout the year. Daytime heating will mix this high speed air down to the surface most of the year. These data confirmed the good wind resource (for rural power applications) analyzed at Merida Airport taken from its representative period and indicated that exposed areas on the Yucatan peninsula would also have good wind resources.

The wind power estimates apply to areas well exposed to the wind, free of local obstructions. These terrain features include open plains, uplands, and hilltops. The wind resource maps, while identifying general areas of good wind resource, do not depict the variability caused by local terrain features. These terrain features can cause the wind to vary considerably over short distances, especially in areas of coastal, hilly, and mountainous terrain. This assessment also does not discuss land with good resources that may not be available for wind energy development because of land-use restrictions or environmental exclusion, such as national parks and natural areas.

ANNUAL AVERAGE WIND RESOURCE MAP - UTILITY SCALE APPLICATIONS

The wind power classes 3-5 shown on the map of the wind resource (Figure 4) are based on those used in the *Wind Energy Resource Atlas of the United States* (1987). The range of average wind speeds at 50 m in each power class is large because of the varying wind speed distributions found throughout the different regions of Mexico. The most mountainous areas of Mexico were not assigned power class estimates at this time.

The highest wind resource areas are located in the southern part of the Isthmus of Tehuantepec, and in the central highlands in the vicinity of Zacatecas. Other areas estimated to have sufficient wind potential for grid-connected bulk power applications include parts of the Gulf of Mexico from Tampico to the Bahia of Campeche, the east coast of the Yucatan peninsula, and parts of the Baja peninsula. The northern Yucatan coast, and the northern Gulf Of Mexico plain (north of Tampico) may be suitable for grid-connected development in the near future with further improvements in wind turbine technology.

ANNUAL AVERAGE WIND RESOURCE MAP - RURAL POWER APPLICATIONS

A new wind power class scale was devised for the map of rural power applications. The reason for the new classification is that the level of the wind resource needed to make wind energy economical for rural applications is significantly less than that required for utility-scale applications. As can be seen on the rural power applications map (Figure 5), there are four wind power classes based on the wind power density and wind speed at 30 m. Areas with power classes 3 and 4 are the best areas for rural power applications. As with the utility-scale map the most mountainous areas were not assigned a power class at this time.

Areas suitable for rural power applications are more widespread than those suitable for utility-scale applications and include (in addition to areas mentioned in the previous section): the rest of the Yucatan peninsula, the northeastern states (Tamaulipas and Neuvo Leon), much of the northern and central plateau region, much of the northwestern region (parts of Sonora and the Baja peninsula), parts of the southeastern

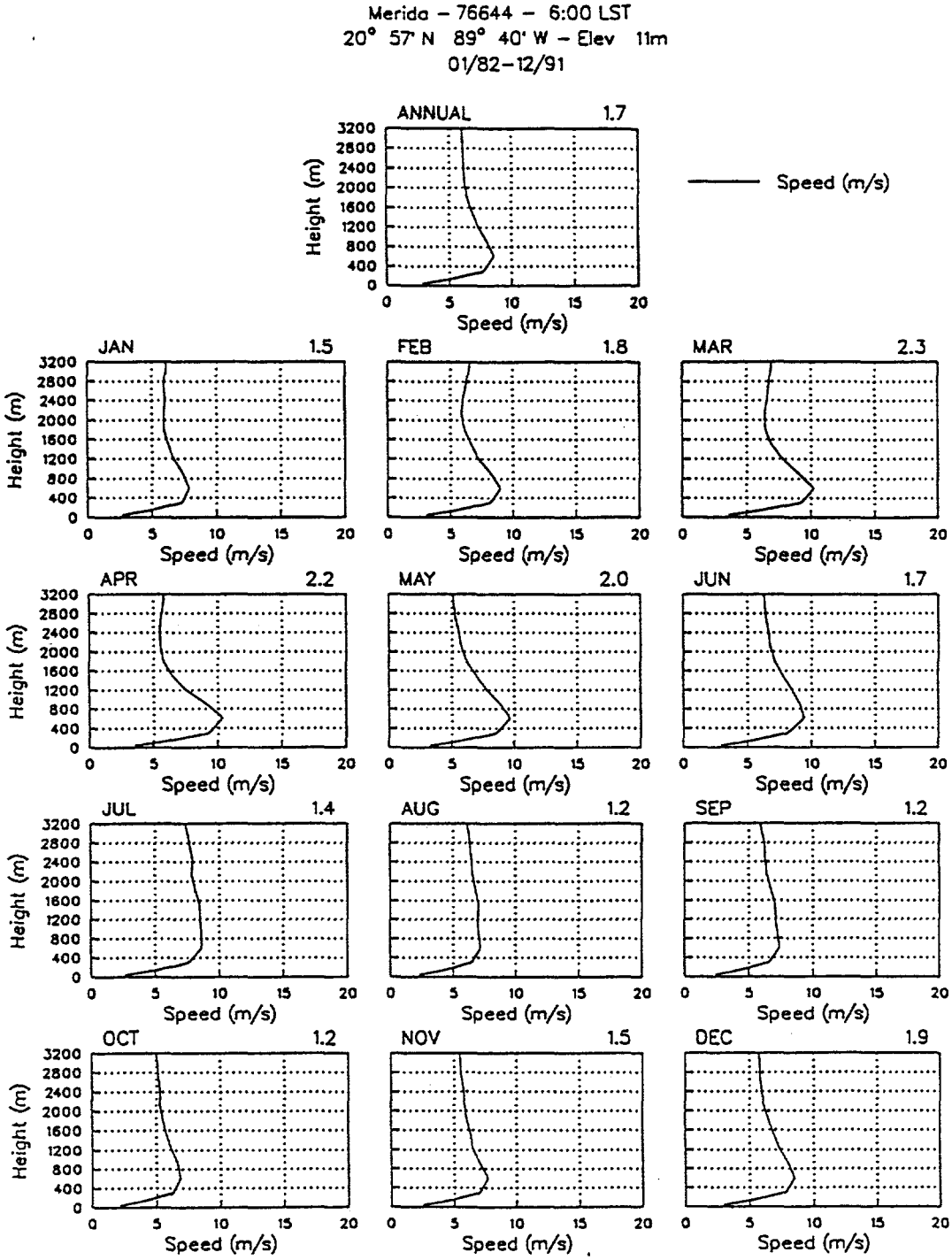


FIGURE 3: VERTICAL PROFILE OF AVERAGE WIND SPEED BY HEIGHT AT 0600 LOCAL STANDARD TIME (LST) AT MERIDA FOR THE PERIOD 1982-1991. THE NUMBER ON THE TOP-RIGHT OF EACH GRAPH IS AVERAGE SURFACE WIND SPEED AT 0600 LST .

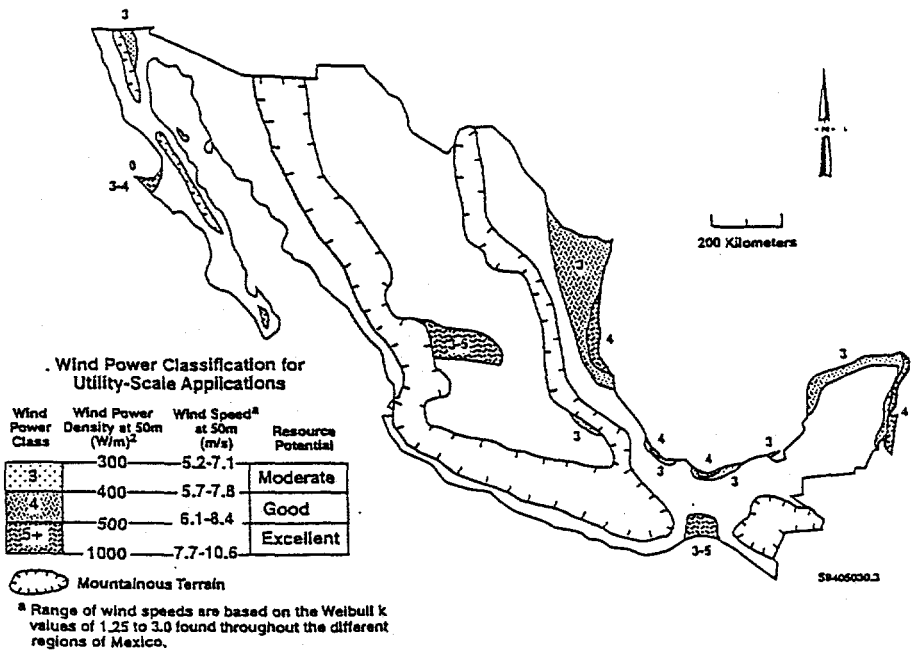


FIGURE 4: ANNUAL AVERAGE WIND RESOURCE MAP OF MEXICO FOR UTILITY-SCALE APPLICATIONS.

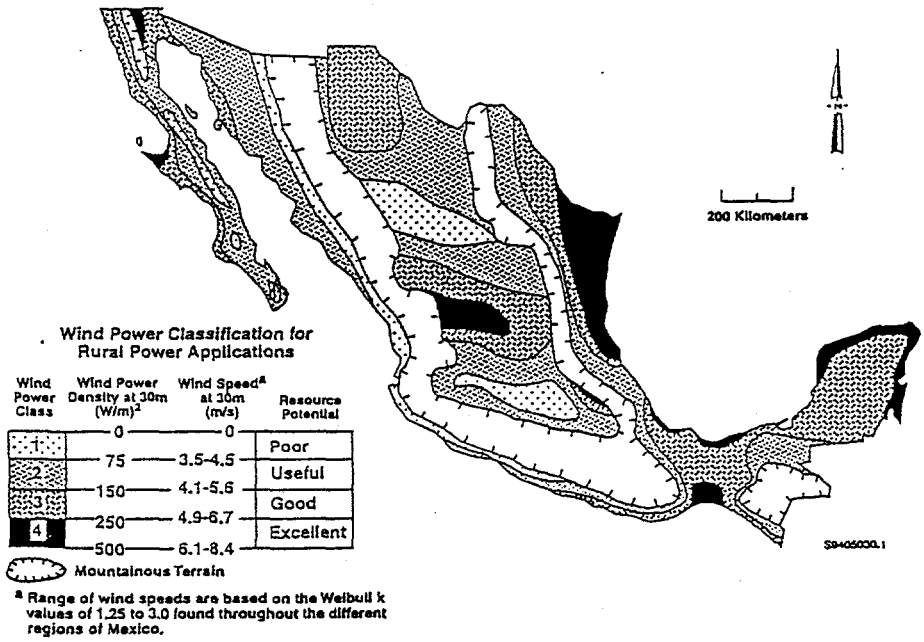


FIGURE 5: ANNUAL AVERAGE WIND RESOURCE MAP OF MEXICO FOR RURAL POWER APPLICATIONS.

highlands (state of Hidalgo), and the southern Pacific coast. Other local areas of good wind resource may exist that have not been identified in this preliminary assessment.

COMPARISON OF 1983 OLADE ANALYSIS WITH 1995 NREL ANALYSIS

Figure 6 compares the values of wind power density at 10 m for selected areas in Mexico directly from the OLADE Atlas (1983) or SMN stations and the 1995 NREL analysis. There are significant differences in overall quantity of the wind resource in Mexico. The OLADE Atlas indicates very low resource throughout Mexico with all stations having less than 50 W/m^2 except for Zacatecas. The NREL 1995 analysis estimated that exposed areas in these regions of Mexico have at least close to 100 W/m^2, with some stations over 200 W/m^2.

The values from the OLADE Atlas are from city locations where the anemometers probably are poorly exposed to the prevailing winds. In contrast, the wind resource maps recently produced by NREL were based on data from a much greater number of stations including airport locations, and incorporated analyses of the quality of wind data, surface flow pattern over Mexico, and terrain effects in the final product.

FUTURE PLANS

There are a number of activities planned to update this preliminary resource assessment. These include a detailed analysis of the surface pressure over Mexico to facilitate the prediction of windy areas in complex terrain, integration of data from 600 new meteorological stations installed by the Comision Nacional del Agua, and development of computerized mapping with Geographical Information Systems.

CONCLUSION

A preliminary wind resource assessment of Mexico using a surface meteorological data set has identified many areas of good-to-excellent wind resource potential. The wind resource in Mexico is considerably greater than shown in previous surveys that have been widely used over the last decade as the primary source of information on the wind resource in Mexico. Areas suitable for rural power applications are widespread throughout Mexico. In addition, local areas of good wind resource may exist in regions of complex terrain that have not been identified in this preliminary assessment.

		Wind Power Density (W/m^2)	
		OLADE Atlas (1983)	NREL Analysis (1995)
Yucatan Peninsula	Merida	22	165
	Campeche	23	120
	Chetumal	28	205
Northern Gulf Plain	Tampico	8	205
	Cuidad Victoria	32	170
	Matamoros	32	165
Central Highlands	Durango	8	140
	San Luis Potosi	35	155
	Zacatecas	94	270
Northwest	Chihuahua	27	120
	Hermosillo	3	80
	La Paz	10	85

FIGURE 6: COMPARISON OF CALCULATED AVERAGE WIND POWER DENSITY BETWEEN 1983 OLADE ATLAS AND 1995 NREL ANALYSIS FOR SPECIFIC LOCATIONS IN MEXICO.

ACKNOWLEDGEMENTS

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