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Evaluating the Most Promising Sites for Wind Energy Development in Arizona USA

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Introduction

In August 2002, Northern Arizona University (NAU) contracted with TrueWind Solutions to buy a set of high-resolution wind maps. Using the numerical weather model coupled to a wind flow model, TrueWind created annual, seasonal, and monthly maps of average wind power density and speed. Mean annual and seasonal maps and data of wind speed were created on a 200 m grid for altitudes of 30, 50, 70 and 100 meters above the ground, and wind power density at 50 meters. Validation efforts by NREL used data from over 50 measurement stations[i] and demonstrated an uncertainty of approximately 10% of the annual average wind speed and 20% of annual wind power density at over 80% of individual validation sites. Also included is normalized annual and seasonal mean diurnal wind speed on a 2 km grid at 30, 50, 70, and 100 meters, and wind power density at 50 meters. Electronic versions of the maps are posted at NAU's Sustainable Energy Solutions web site (www.cba.nau.edu/ses/) and the data is available by request. The complete set of wind maps and data were delivered to NAU at the end of August 2003.

Figure 1 shows a map of the wind power density (W/m^2) at a 50 m hub height. The map indicates the wind power density via "wind class", tribal reservation boundaries, select cities, major transmission lines, and county boundaries. This map, as with all the Arizona wind maps, was designed for regional wind mapping and not for micrositing. It provides an indication of the magnitude of the wind energy resource and points to favorable wind resource areas.

NREL quantified the potential developable wind areas as summarized in Table 1 (see Reference i). The "Raw" wind resource results from summing the total area of windy lands in each wind class and directly converting it to a wind electric potential through multiplying the land area by 5 MW per km^2 of available windy land. The "Developable" wind capacity is computed by removing various exclusion areas such as National Parks, Fish and Wildlife Service, State and private environmental lands, Wildlife, Wilderness, and Recreation Areas on federal land, U.S. Forest Service and Department of Defense lands, urban areas, airports, wetlands, and water.

Table 1 also shows the expected wind resource at two of the more promising sites in Arizona: Gray Mountain (west of Cameron) and west of Springerville. These resources, modest when compared to other states in the west, represent an important and significant resource in a state with approximately 19,500 MW of summer generating capacity.[ii]

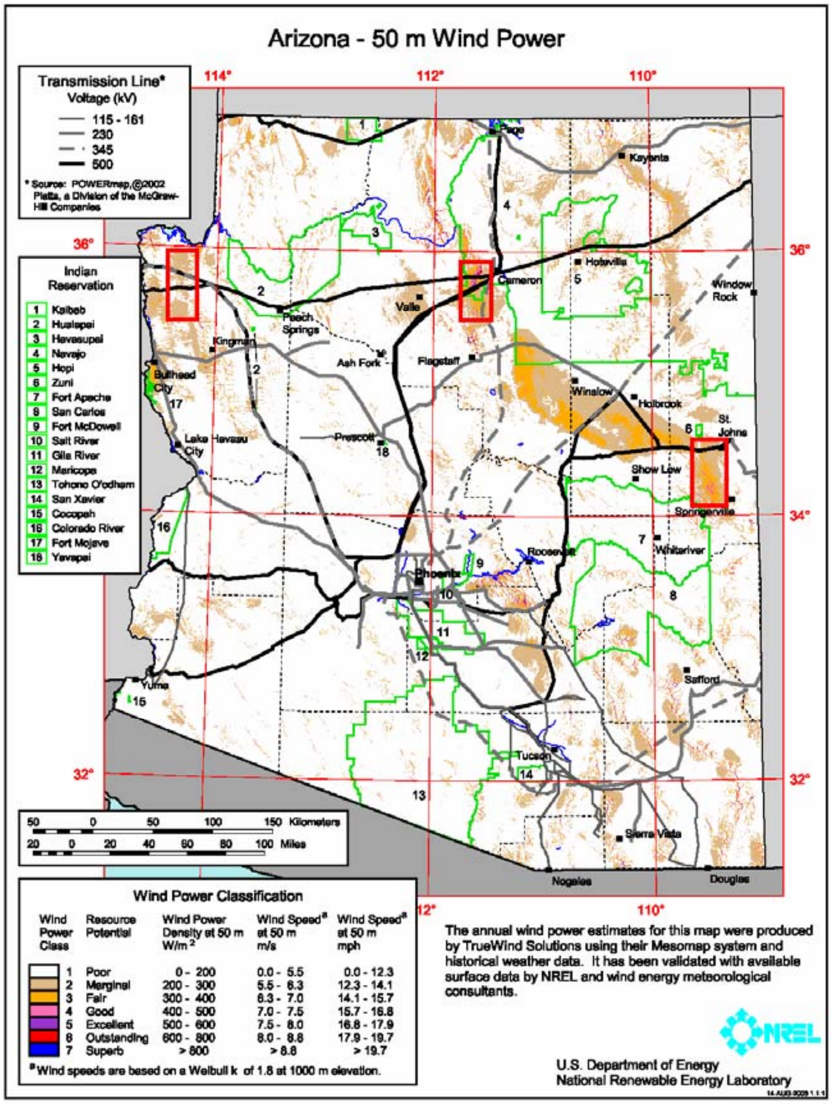

Figure 1 Arizona Wind Map

Table 1 – Wind energy resource potential, both raw and developable, in the state of Arizona.

Wind Class*	Entire State of Arizona		West of Cameron		West of Springerville	
	Raw	Developable	Raw	Developable	Raw	Developable
Class 3 +	35430 MW	23290 MW				
Class 4 +	5980 MW	2630 MW	433 MW	433 MW	330 MW	299 MW
Class 5 +	2040 MW	775 MW	210 MW	210 MW	43 MW	37 MW
Class 6 +	790 MW	235 MW	61 MW	61 MW	9 MW	8 MW

* Class 3+ implies class 3 or greater; class 4+ implies class 4 and greater, etc

Analysis of Wind Resource

The TrueWind map data consists of both comma-delimited files and geographic information system (GIS) files. NAU utilized its GIS software to “mine” the data to rank the wind resource at various locations based upon specific attributes. The first step in mining the data was to divide the state into a grid of 4 km squares. Each 4-km “block” of land contains 400 of the 200-meter wind map data cells. Assuming a conservative 5 MW per km^2 of windy land, each block is capable of supporting 80 MW of wind turbine capacity. Dividing the state into these blocks resulted in 18,710 distinct blocks, of which 4,370 contained at least one cell of windy land class 3 or greater. A “decision matrix” was then used to rank the blocks of land with windy land. This matrix lists the most important wind development attributes for each block of land.

The key attributes identified for this study were wind power resource potential, distance to transmission and substations, distance to roads, land use/ownership, county location, and tribal reservation information. In order to assign these attributes to each block of land, the GIS wind map data was combined with overlays of transmission and substation data, roadways, land use/ownership information (e.g., National Forest, Wilderness Area, State Trust Land, private land, etc.), tribal reservation boundaries, county boundaries, and city locations (urban areas).

A "Wind Power Number" (*WPN*) was computed to quantify a given land block's wind power potential. Counting only the cells of windy land within a block (class 3 or better wind resource), the *WPN* was defined as follows:

$$WPN = \frac{\sum_{i=3}^{7}\left(WPD_i \times A_{rotor} \times WL_i \times N\right)}{A_{rotor} \times N} = \sum_{i=3}^{7}\left(WPD_i \times WL_i\right)$$

where

WPD_i = mean wind power density for wind class i (W/m^2)
A_{rotor} = swept area of rotor (m^2)
WL_i = area of windy land in block of wind class i (km^2); computed by multiplying the number of cells within the block with this wind resource by the cell area.
N = number of turbines that can be installed per unit land area ($1/km^2$)
i = wind power class ranging from 3 to 7

For the purpose of this analysis, it was assumed that the number of wind turbines per square kilometer is the same on all blocks of land, and that identical turbines are used (thus A_{rotor} and N cancel in the above equation). The resulting *WPN* physically represents an approximate wind power potential number and has the unit of Watts. Due to the simplifying assumptions, the *WPN* is used only to *compare* the relative potential of blocks of land and not as an indicator of the actual wind power potential. Due to the irregular shape of the state border, many blocks of land along the border have less than 16 km^2 of land area. Thus, it is necessary to normalize the *WPN* to account for varying block area. The *normalized WPN* (denoted *NWPN*) is computed as follows:

$$NWPN = \frac{WPN}{WPN3}$$

where

$WPN3$ = wind power number for a block of land in which ALL cells within the block have a class 3 rating.

$$WPN3 = WPD_3 \times Area_{block}$$

WPD_3 = mean wind power density for a class 3 resource; equal to 350 W/m^2
$Area_{block}$ = area of land within block in km^2

The *NWPN* allows a fair comparison of land blocks of different areas and allows for easy interpretation. If a block has an *NWPN* of 1.0, then the block has on average a class 3 wind resource. Similarly, if a block's *NWPN* is equal to 1.26, 1.57, or 2.0, then on average the block has a class 4, 5, or 6 resource, respectively. Forty blocks within Arizona had an NWPN greater than or equal to 1.0 and were near transmission lines, the top five of which are shown in Table 2.

Table 2 – The top five rated land blocks within Arizona based on the *NWPN*.

Block No.	*NWPN*	Distance to Nearest Power Line (meters)	Land Ownership: Private	State Trust	Navajo Indian Reservation	Indian Allotments
3851	1.44	2926	10.8%	0.0%	87.4%	1.8%
3979	1.25	1481	7.0%	0.0%	93.0%	0.0%
4108	1.20	4893	2.0%	0.0%	98.0%	0.0%
3722	1.20	6917	21.0%	0.0%	79.0%	0.0%
9556	1.15	475	1.0%	99.0%	0.0%	0.0%

Cost of Energy Analysis

Cost of Energy (COE) was determined for three blocks of windy land: west of Cameron (class 5 resource), west of Springerville (class 4 resource), and northwest of Kingman (class 3 resource). Figure 1 illustrates via red rectangles the general vicinity of these three sites. The tool employed to compute an estimate of the cost of energy at these sites was the NREL wind energy finance calculator http://analysis.nrel.gov/windfinance. There are 28 inputs to the model including general project parameters such as rated capacity, capacity factor, lifetime, and specific parameters related to capital costs, financing, operating expenses, taxes, and more. Identical inputs were used for the analysis at each site with the exception of the capacity factor (CF). A summary of some of the key assumptions is shown in Table 3.

Table 3 – Summary of key inputs to NREL Wind Energy Finance Calculator.

75 MW project	15-year financing	No PTC or REPI
2005 start date	Level mortgage	3% inflation rate
\$925/kW total capital costs	80% debt percentage	Target IRR 15.22%
\$20/kW/yr total operating costs	6.8% interest on debt	Discount rate 5.5%

The CF is defined as the ratio of the estimated annual energy output of a wind farm to its output if all turbines were running at full rated capacity for the entire year. In order to determine the CF at each site, the wind map data was utilized along with a GE Wind Energy 1.5s turbine power curve to estimate the energy output. The GE turbine was assumed to have a 77 m rotor, and the power curve for an elevation of 6,120 ft was employed (air density of 1.02 kg/m^3). Weibull parameters from the wind map data at a 70 m hub height were used to determine the distribution of wind speeds at each location throughout the year. This distribution was then transformed into an estimated annual energy output by using the GE power curve, and finally an annual capacity factor was computed. The CF at each location was reduced by 10% to account for array losses, soiling, availability, etc. A summary of the relevant parameters for each location, including the COE, is shown in Table 4. The levilised COE figures shown range from 4.21 to 5.04 cents per kWh (in 2005 dollars), as the wind class varies from 5 to 3, respectively. These values are consistent with those published recently by the California Energy Commission in their Renewable Resources Development Report[iii]. Note that the COE goes up by about 0.5 cents per kWh for each decrease in the wind class. It is also worth noting that these figures will likely decrease by as much as 0.5 cents per kWh over the next few years as turbine technology improves and the installed costs decrease. Furthermore, accounting for tax incentives could reduce the cost per kWh by as much as 1.5 cents per kWh.

Table 4 – Capacity factor and cost of energy results at three sites in Arizona.

Location	Real Levelized COE (cents/kWh)	Wind Power Class	Capacity Factor No Losses at 70 m	Capacity Factor 10 % reduction due to losses at 70 m	% Time Turbine is Producing Power	Weibull Parameters c (m/s)	Weibull Parameters k
West of Cameron	4.21	5	37.1%	33.4%	80.5%	8.55	1.721
West of Springerville	4.67	4	33.4%	30.1%	77.7%	7.99	1.672
Northwest of Kingman	5.04	3	31.0%	27.9%	78.0%	7.67	1.777

The cost of energy results reported here are "bus bar" costs, and do not include transmission costs or ancillary services. Transmission costs are project specific and can be significant. Ancillary service costs (i.e., regulation, load following, unit commitment) can also affect COE. For some specific projects, these costs have been shown to range from \$0.005 to \$0.55 per kWh, depending largely on the relative capacity of the wind farm to the transmission control area load.[iv]

Conclusions

The new high-resolution wind map for the state of Arizona has shown the state to have a substantial wind energy resource. The *developable* wind energy potential is 23,290 MW of class 3 or higher, 2,630 MW of class 4 or higher, and 775 MW of class 5 or higher winds. Using data from the high-resolution wind map, a GIS model was employed to create a database that can be easily sorted and organized to rank the most promising locations in the state for wind energy development. Using wind map data to compute the levelized cost of energy in 2005 dollars at three sites within the state revealed estimates ranging from 4.21 to 5.04 cents per kWh, as the wind class varies from 5 to 3, without considering any tax incentives.

References

[i] Schwartz, M., "Arizona Wind Resources," National Renewable Energy Laboratory, presentation to the Arizona Wind Working Group, Flagstaff, Arizona, August 6, 2003.

[ii] Energy Information Administration, "State Electricity Profiles 2002," DOE/EIA-0348(01)/2, Office of Coal, Nuclear, Electric and Alternate Fuels, U.S. Department of Energy, Washington, DC, January 2004.

[iii] California Energy Commission, "Renewable Resources Development Report," 500-03-080F, November 2003.

[iv] Parsons, B., Milligan, M., Zavadil, B., Brooks, D., Kirby B., Dragoon, K., and Caldwell, J., "Grid Impacts of Wind Power: A Summary of Recent Studies in the United States," NREL/CP-500-34318, June 2003.