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Tackling Climate Change in the United States: The Potential Contribution from Wind Power

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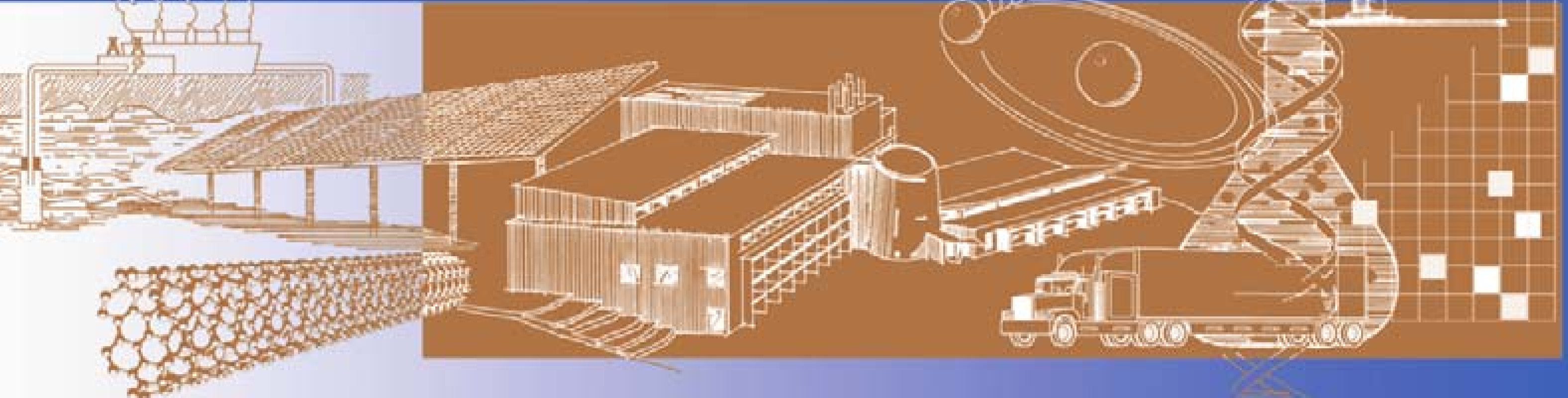

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Tackling Climate Change in the United States: The Potential Contribution from Wind Power

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ABSTRACT

To support the Western Governors' Association's (WGA's) Clean and Diversified Energy Advisory Committee (CDEAC), a Wind Task Force (WTF) was convened to assess the feasibility of achieving 30,000 megawatts (MW) of clean and diversified energy in the West by 2015. The WTF examined the near-term potential of wind energy in the West, using a combination of technical supply curves based on GIS data, and information from recent utility and transmission studies. The study results indicate a very large potential for wind generation in the West. Supplementing the GIS analysis is information extracted from utility integrated resource plans (IRPs) that include wind additions in the near term, along with estimates of wind development that will be induced by state renewable portfolio standards (RPSs). However, these results depend on federal and state policy support and transmission access.

In this paper, we briefly discuss the results of the WTF report and develop expanded wind supply curves for the entire United States. Wind potential was estimated using a GIS database that contains data on average annual wind speed and transmission lines. We also develop estimates of carbon reduction that would result from large-scale deployment of wind and find that 2,000-4,000 million metric tons of carbon could be avoided by 2030.

1. INTRODUCTION

Modern wind turbines have evolved significantly in the past few years. In the United States, the typical modern turbine has a generating capacity exceeding 1 MW and a hub height of 80 meters from the ground. Recent wind power plants may consist of projects owned by several entities and that have aggregate capacity in the hundreds of megawatts. Energy produced by a wind turbine depends on the wind, which is a variable resource over several time scales. This variability is cause for concern among power system operators, who are responsible for maintaining system balance. During the past several years, several comprehensive wind integration studies have been performed that analyze the power system's ability to incorporate wind. The U.S. studies show a modest cost ranging up to about $5/MWh for the ancillary service impact of wind. This is the additional cost that wind imposed in the process of maintaining electrical system balance. Most integration studies involve detailed chronological power system simulations that mimic the overall power system operation with wind. To date, the variability of wind does not appear to be a significant hindrance to its use as an energy resource, although the specific impacts and costs would vary from system to system and would depend on the size of the wind plant relative to the balancing authority.

The pattern of wind generation may not match loads on a seasonal or diurnal basis. Wind is primarily an energy resource, but it can displace other capacity at a relatively small fraction of its rated capacity.

During 2005, approximately 2,500 MW of wind generating capacity was installed in the United States. According to the American Wind Energy Association[1], current U.S. wind capacity stands at 9,149 MW. The task force used a recent analysis[2] to estimate potential wind that would come online by 2015 in response to state RPSs in the West. According to the WTF, new wind capacity induced by these RPSs could range from about 5,600 MW to about 10,200 MW by 2015. Utility IRPs in the West may also result in about 3,600 MW of new wind capacity by 2015. And recent volatility in natural gas prices has had a significant impact on utilities that burn gas to produce power. In some cases, wind energy is the cost-effective choice, further stimulating wind development.

In the United States, a production tax credit (PTC) that reduces the effective cost of wind generation has been in place over the past few years. Unfortunately, the PTC expired in 2004, causing wind development in the United States to nearly cease. When the PTC was renewed, wind development that had been on hold quickly materialized, causing an enormous increase in the demand for turbines. Because of this large swing in turbine demand, manufacturers have had difficulty providing sufficient turbines to the market, and prices have increased. Combined with higher steel prices and unfavorable currency exchange rates, 2005 and 2006 experienced a significant increase in turbine costs. Because of the complex interaction of all the contributing factors to this cost increase, it is not clear whether the current prices represent a temporary condition or whether turbine costs are on an upward trend. The WTF report discusses this issue in more detail.

2. NOMENCLATURE

CDEAC – Clean and Diverse Energy Advisory Committee
GIS – geographical information system
GW – gigawatt
GWh – gigawatt-hour
IRP – integrated resource plan
LCOE – levelized cost of energy
MISO – Midwest Independent System Operators
MTEP – MISO Transmission Expansion Plan
MW – megawatt
NREL – National Renewable Energy Laboratory
NTAC – Northwest Transmission Assessment Committee
PTC – production tax credit
RMATS – Rocky Mountain Area Transmission Study
RPS – renewable portfolio standard
SSG-WI – Seams Steering Group of the Western Interconnection
TWH – terawatt-hour
WECC – Western Electricity Coordinating Council
WGA – Western Governors' Association
WTF – Wind Task Force (of the CDEAC)

3. RESOURCE OVERVIEW

The National Renewable Energy Laboratory (NREL) has assembled a comprehensive GIS system for renewable generation. The GIS dataset for wind is based on a large-scale meteorological simulation that "re-creates" the weather, extracting wind speed information from grid points that cover the area of interest. Mapping processes are not always directly comparable among the states, but NREL has validated maps from approximately 30 states. The wind can exhibit many different patterns that vary over time and space. During the fall and spring seasons, it is common to observe more wind than during other months. Wind patterns also may not match load patterns, limiting wind's capacity contribution to the grid. Wind shear, the difference in wind velocity at different elevations from the ground, is pronounced in many parts of the United States. Because the GIS database contains wind speed at 50 m from the ground, this creates a mismatch with currently available wind turbines with a hub height of 80m. In the next few years it is likely that hub heights will increase further, to 100 m (as is becoming common in Europe) or even higher. This implies that the estimates of the wind resource shown by the map likely understates the wind resource, perhaps significantly, resulting in supply curves that also understate the quantity of wind at various prices.

Figure 1 shows a low-resolution version of the U.S. wind resource map[3]. Many states have higher quality maps, and those were used for this analysis. As can be seen in the map, the upper Great Plains states and the West generally have a significant wind resource, and other areas of the country also have good wind. Although the map shows offshore resources, only onshore was considered in the supply curve analysis because the offshore technology and costs have not matured sufficiently. Alaska and Hawaii were not included in the analysis.

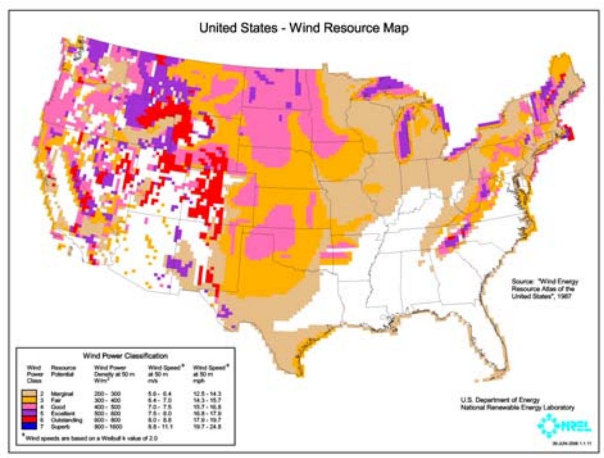

Figure 1. Wind resource map for the United States

4. NEAR-TERM DEVELOPMENT

As part of the CDEAC effort for the WGA, a set of wind supply curves was developed to estimate the potential for wind in the WGA footprint and to analyze the impact of available transmission on supply and cost.[4] In addition to the supply curve development for WGA, many regional and sub-regional transmission plans were used to get a better idea of potential wind development through 2015. Within the WGA footprint, studies have been performed that cover the Western Electricity Coordinating Council (WECC) by Seams Steering Group of the Western Interconnection

(SSG-WI), Rocky Mountain Area Transmission Study (RMATS), and a project underway in the Northwest (Northwest Transmission Assessment Committee, NTAC). For states outside the WECC, the Midwest Independent System Operator (MISO) considered wind development in the MISO Transmission Expansion Plan (MTEP) in 2003[5] and has studied other scenarios in more recent MTEP analyses[6]. Additional work in the West has evaluated new innovative transmission tariffs that provide long-term transmission access on a conditional firm or non-firm basis. The WTF concluded that such transmission tariffs could speed the development of wind and increase the efficiency of the transmission system. Three scenarios for 2015 were developed: (1) assuming little if any transmission tariff development, (2) a mid-range of wind development according to the various transmission studies, and (3) a high-end wind development scenario. Figure 2 illustrates the range of these scenarios, and Figure 3 shows the approximate locations of this wind development in the West.

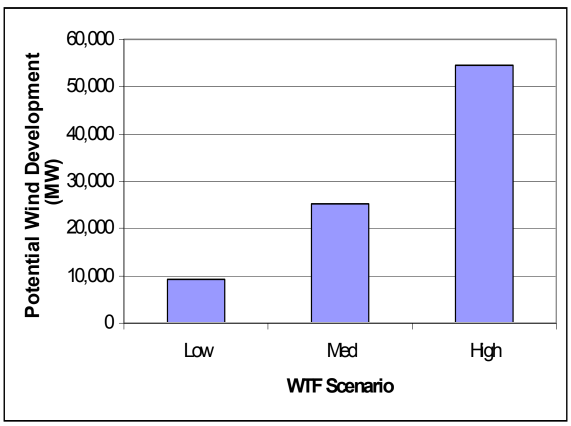

Figure 2. WTF wind development scenarios

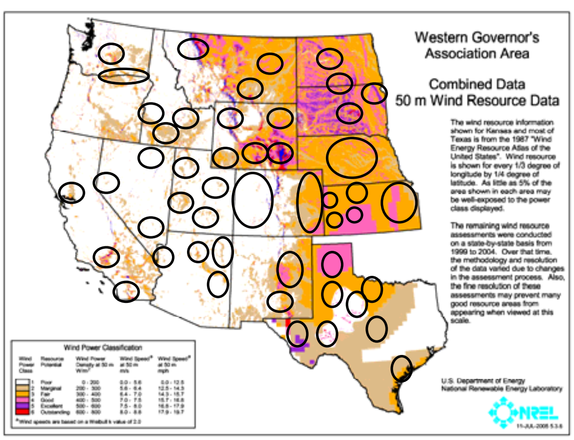

Figure 3. Wind scenario locations for WTF high-development scenario, 2015

5. SUPPLY CURVE DEVELOPMENT

Supply curves were developed based on the GIS data represented in Figure 1. Not all land can be used for wind plant development, even though there may be a viable resource. Exclusions for urban areas, national parks and preserves, wilderness areas, and water were applied to the GIS data. The analysis converts wind speed to potential wind power using modern wind turbine characteristics and an average shear factor to account for the difference between the mapped wind speed and the assumed turbine hub height. An area with a high average wind speed would have a lower energy cost than an area with a low wind speed. It is likely that the mapping database misses some high-quality wind locations, which would result in more supply of wind at a lower cost than what is shown in this paper. Table 1 shows the base data for the supply curve development. Costs do not include the PTC, which would reduce the effective cost of energy.

Table 1: Wind Levelized Cost of Energy and Capacity Factor by Wind Power Class

Wind Power Class	Wind Speed @ 50 m	Capacity Factor	Nominal LCOE
3	6.4-7.0	30.0	.0744
4	7.0-7.5	33.8	.0659
5	7.5-8.0	39.8	.0537
6	8.0-8.8	43.6	.0490
7	8.8-11.1	49.6	.0431

For this analysis, several sets of supply curves were developed for each state and then combined for the entire country. Each supply curve is based on an assumption concerning how much of the existing transmission grid is available to transport wind. The first assumption is that no existing transmission is available, requiring wind to pay to build all of its own transmission. The subsequent cases assume that 10%, 20%, 30%, or 40% of the existing grid is available to transport wind. If the wind generation uses up all the available transmission capacity, new transmission is "built" to the nearest load center(s). Because the GIS database includes transmission locations and line ratings, it was possible to simulate building new transmission to connect the wind plant to the existing grid. For each load center, wind energy as a percent of the total was limited to 20%. Once this limit was reached, additional transmission was built to the next nearby load center at a cost of $1,000/MW-mile.

Figure 4 shows the supply curves for the entire United States. The supply curve on the far left is the case of no available transmission for wind, and the supply curve on the far right is the wind supply assuming 40% of existing transmission is available for wind.

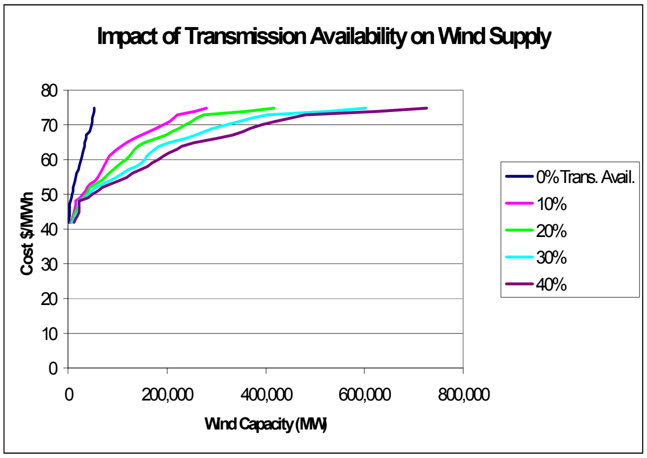

Figure 4. Supply curves with alternative assumptions for the percentage of existing transmission that is available to transport wind to load

Because some of the detail is difficult to discern in the graph, Figure 5 shows an inverted supply curve as discrete points. To further expand the view over the lower wind costs, Figure 6 zooms in further.

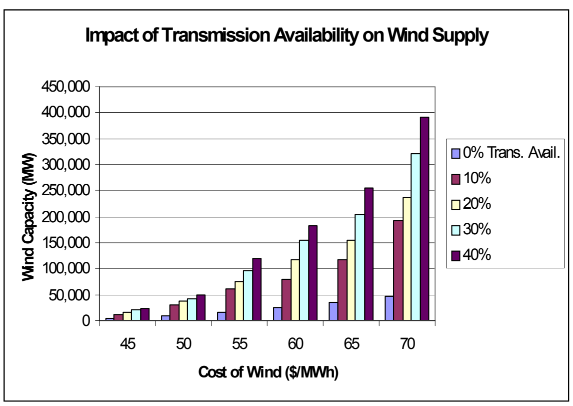

Figure 5. Impact of transmission on wind supply

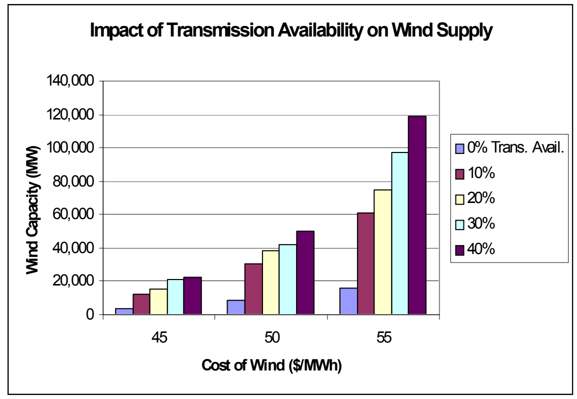

Figure 6. Zoom of Figure 5 at lower wind cost of energy

6. MARKET SIMULATIONS

The U.S. Department of Energy Wind Program has developed a set of cost goals for technology development. For wind Class 6, the levelized cost of energy targets from 2010 to 2050 are shown in Figure 7. The cost of wind energy in lower wind speed locations is also expected to improve, and the Wind Program is developing low wind speed technology that is expected to allow the use of less energetic sites that are closer to transmission and load centers. Because the supply curves shown above are based on current technology and wind speed at 50 meters, these supply curves underestimate the potential for wind.

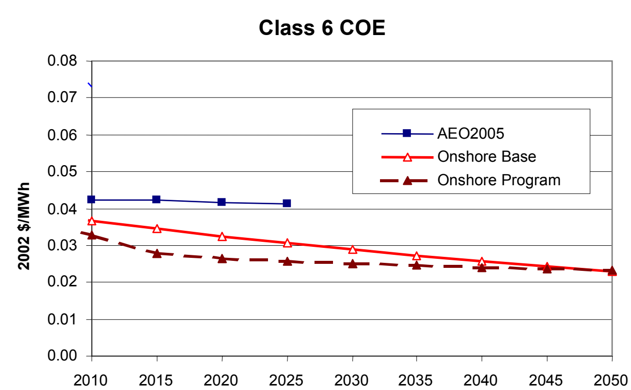

Figure 7. Projected wind energy cost decline from 2010 to 2050 for Class 6 wind sites

A high-penetration market simulation was developed based on the Wind Deployment System model, currently under development at NREL.[7] [8] This model represents the U.S. power grid by control area (balancing authority), uses projected wind costs shown in Figure 7, and GIS representations of wind and transmission. The model contains generation from all generation technologies along with price forecasts, and competes resources based on cost to determine the least-cost national generation portfolio that will successfully meet demand and energy requirements. A key assumption used for this scenario is that the PTC is renewed until 2010, followed by a smooth phase-out until 2030. The results of the simulation are shown in Figure 8.

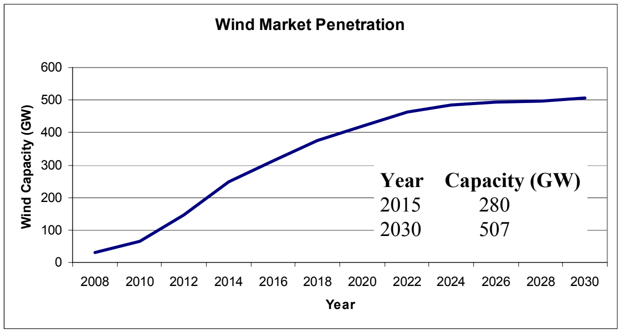

Figure 8. Results of wind market simulation

To assess the carbon reduction potential, the wind capacity from the market simulation was converted to annual energy. Because different regions of the country have significant differences in generation fuel mixes, quantifying the carbon reduction potential from wind is not straightforward. Under the assumption that wind displaces only coal, we used the rate of 260 metric tons of carbon per GWh to estimate offset carbon.

Figure 9 shows the relationship between wind energy generation and carbon reduction using two carbon displacement rates: 260 metric tons per GWh and 130 metric tons per GWh. This latter rate may be more reflective of fuel displacement that includes fuels other than just coal, although a more rigorous analysis is required to obtain a more accurate estimate of carbon reduction.

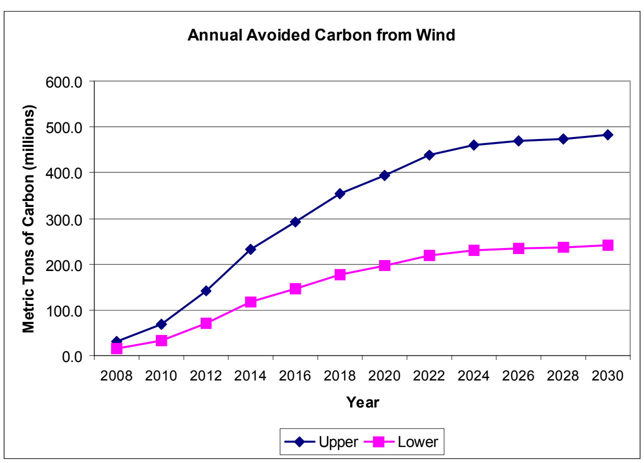

Figure 9. Annual avoided carbon calculated on coal-only displacement (260 metric tons/GWh) and at 130 metric tons/GWh

Cumulative carbon offset is represented in Figure 10 for the two carbon offset rates discussed above.

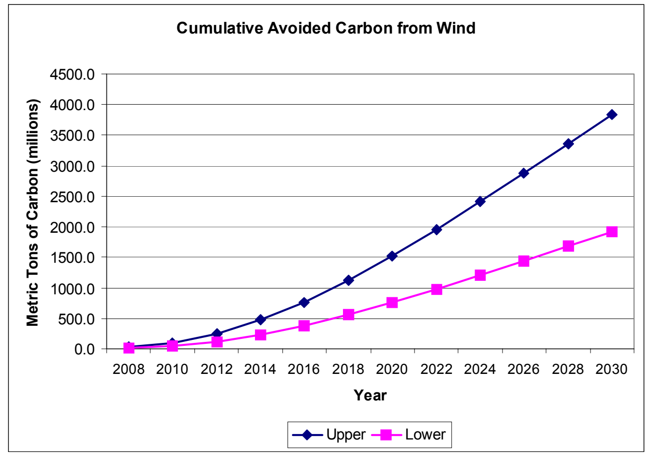

Figure 10. Range of cumulative carbon reduction estimates through 2030

7. CONCLUSIONS

- The potential for wind to supply a significant quantity of energy in the United States is enormous.
- This study is parametric and shows the importance of transmission availability on wind supply; however, detailed transmission studies with appropriate data sets are required to more fully assess this issue for specific deployment options.
- The availability of transmission capacity helps large-scale deployment by reducing the cost of delivered wind energy.
- Since wind transmission does not require firm transmission rights, alternative transmission tariffs can make more effective transmission available for wind delivery.
- Aside from the supply curves, there is additional empirical evidence of a potential large-scale expansion of wind. This evidence comes from utility IRPs, state RPS requirements, and large-scale transmission studies in the West and the Midwest.
- Continuing declines in the cost of wind generation will increase wind development. The recent cost increases may be temporary but may also signal an upward trend in wind turbine prices.
- GIS data used for this supply curve analysis may significantly underestimate the supply of wind in the West.
- Carbon reduction potential of wind is significant but will depend on the specific fuel mix displaced by wind.

8. ACKNOWLEDGMENTS

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The Wind Task Force report of the CDEAC can be found at http://www.westgov.org/wga/initiatives/cdeac/Wind-full.pdf

Information on the WinDS model can be found online at http://www.nrel.gov/analysis/winds

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