*Windpower Resource Screening for The Western U.S. Region**

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ABSTRACT

This article describes a comprehensive screening study performed in 2007 to identify wind energy resources in the 14-state Western Electric Coordinating Council (WECC). WECC comprises the entire Western Interconnection. With a footprint of 1.8 million square miles within the U.S., two Canadian provinces, and Baja Norte, Mexico, WECC offers significant but widely dispersed potential for farming wind resources. The methodology described in this article is novel but tested in application.

Using resource maps of greatest wind potential, electric generation is incrementally increased to reach a regional 25% penetration target. This approach allows overloaded transmission corridors to be identified that will require investment to reliably ship power to the areas of greatest demand growth. In this study, resolution is based on 1 km cells. Explicit consideration is given to reserve transmission capacity to estimate WECC's ability to move power from remote sites. Wind resource assumptions are based on National Renewable Energy Laboratory (NREL) wind maps, Class 3 or higher (mean annual wind speeds = 6.9 m/s at 80 m). The wind resource is converted on the basis of generating clusters of 77-meter diameter, 1.5-MWe turbines with a capacity factor of 48%. Limits are placed on distance to load centers to avoid transmission congestion and to implicitly acknowledge an economic breakeven towards lower speeds and closer distance.

OVERVIEW OF SITING ANALYSIS

This analysis of WECC's grid attempted to determine if large increases in renewable energy, namely wind turbines, could be accom-

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plished, without sacrificing electric reliability and while yielding manageable transmission costs. The goal of this task is to analyze transmission bottlenecks, currently known and likely to arise, which exist in the WECC system through 2025 and determine where improvements are required, as well as determining the investments needed to implement them. There have been many proposals identifying needed investment in the Nation's transmission corridors to assure that the electric grid is safe, reliable, resilient, and operated efficiently and economically. Investments have been proposed based on 1) cost/benefit analyses and 2) stability, reliability, and resiliency of the resulting grid. The approach taken in this study is primarily based on (1), although factors related to (2) are significant and for the most part, unresolved.

The first scenario is the baseline case where the growth of electric power demand follows WECC's current projections through the year 2025. WECC currently projects only 10 years; however, a linear extrapolation was assumed from the WECC plan for the remaining years. The second scenario assumes that 25% of WECC's required energy production is supplied by wind turbines. Because the grid would be required to also transmit power generated from large centralized power stations, it is likely that the location of this additional generation will be in areas of maximum wind potential but potentially low transmission capacity. In this scenario, bottlenecks to shipping the power from these areas of maximum potential to areas of increased demand are identified.

SCENARIO 1—WECC BASELINE

The grid model contained more than 17,000 nodes and links, and identified the key power import points to the electric grid. Because these import points represent intentionally low capacity transmission points to promote grid stability, it has been suggested that interties would be an initial step in strengthening the grid's ability to transmit power. However, for this study interties are held constant, and all new capacity is assumed to be new generation (including wind). Figure 1 shows the 2025 baseline case for WECC.

Displayed in Figure 1 and highlighted (wide darker areas) are lines loaded over 150 percent for Scenario 1 or "business as usual." Additional investment is required in the transmission grid area around Tucson and Phoenix, Northern New Mexico, and Eastern Idaho to relieve overloads.

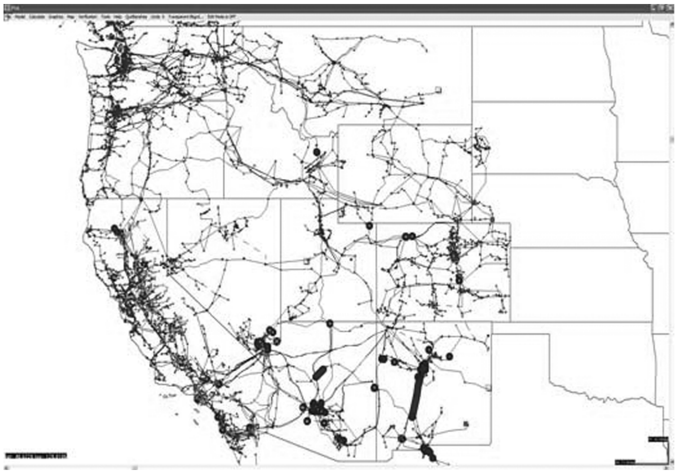

Figure 1. 2025 WECC Baseline.

By 2025, the baseline case develops additional overloads extending along the north-south New Mexico corridor, west of Denver and in the Pacific Northwest west of Spokane.

SCENARIO 2—25% ENERGY PRODUCTION FROM WIND

WECC system demand is projected to grow at an annual rate of approximately 2% through 2025. In comparison, non-wind generation capacity grows at only 0.8%, while wind generation capacity grows at 22%. Table 1 summarizes the projected conditions for each study interval.

Table 1. WEEC Capacity and Demand (Scenario 2)

	Capacity (MWe)		*Demand (MWe)*
Year	Non-wind	Wind	Total System
2005	143,180	1,125	123,643
2015	145,507	50,223	156,499
2025	170,512	60,128	184,203

To simplify this analysis, only existing wind farm sites in each WECC sub region served as the location for expansion, given that sufficient wind resources exist to support the assumed expansion. Table 2 shown below summarizes top-level allocation of renewable energy production by WECC sub region and year.

Table 2. Summary of Wind Capacity and Required Siting Area

Subregion	*Year*	*Total GWh*	*Wind GWh*	*MWe*	*Area (km²)*
CAMX	2015	325,239,000	81,309,750	19,337	2,417
CAMX	2025	378,645,206	94,661,302	22,513	2,814
AZNM	2015	167,121,000	41,780,250	9,936	1,242
AZNM	2025	207,709,980	51,927,495	12,350	1,544
NWPP	2015	279,328,000	69,832,000	16,608	2,076
NWPP	2025	334,185,289	83,546,322	19,869	2,484
RMPA	2015	73,025,000	18,256,250	4,342	543
RMPA	2025	90,760,714	22,690,179	5,396	675
			Total 2015	50,223	62,779
			Total 2025	60,128	75,160

The column titled "MWe" tabulates the installed wind capacity. Installed capacity is calculated from the value shown under "Wind," assuming a firm capacity credit of only 10%, i.e., for every 1 Megawatt (MWe) of capacity needed, 10 MWe of nameplate capacity must be installed. A firm capacity credit is required because wind energy depends upon a highly variable wind vector. The highly conservative 10:1 de-rating of nameplate capacity was assumed to assure sufficient generation capacity would be reliably available. Other solutions to optimize total investment would be to reduce the contingent capacity and, for example, install more natural gas turbines---or combined-cycle natural-gas plants, which are more efficient, or to beneficially use the excess wind capacity.

Wind resource assumptions are based on NREL wind maps, Class 3 or higher (mean annual wind speeds = 6.9 m/s at 80 m). The wind resource is converted on the basis of wind farm clusters of 77-m diameter, 1.5-MWe turbines with a capacity factor of 48%. The rightmost column values can be calculated given this density of generators, "Area km^2." The latter quantity estimates the total area targeted for wind farm development. In 2025, the total area required is estimated to be 75,160 km^2 or approximately 20,000 mi^2. Note that demand growth in WECC requires most of this investment to be made prior to 2020. In addition current industry projections suggest costs of nearly $1 million per MWe for large-scale wind development [1]. The total capacity shown in Table 2 therefore represents an investment of 600 Billion dollars, assuming 1:10 de-rating. There is obviously an enormous economic incentive to reduce overbuilding of capacity by suppressing the effects of wind variability on turbine output.

Figure 2 highlights the areas in WECC with maximum wind potential, a significant concentration occurs within New Mexico, Colorado, Wyoming and Montana. Notably, fewer potential sites exist in southern California, and the Pacific Northwest south into northern California. Figure 3 shows the 2025 case for WECC with 25% wind energy production.

As shown in this case, the transmission bottlenecks are concentrated in the areas of the maximum wind fields because placement of generation in these areas is a significant shift in required transmission.

Wind generation has unfortunately presented problems to utilities in terms of power surges caused by gusting wind and the remoteness of good wind sites. The result has often been lost energy capture or off-normal grid conditions. Many utility systems cannot adapt to large penetrations of such resources because utility networks function most effectively under conditions of uni-directional power flow. An adaptation is clearly needed, which can allow old and new utility resources to operate harmoniously. For example, it may be possible to utilize features of adaptive networks, which are compatible with current methods of grid control. Through these models, a utility gains

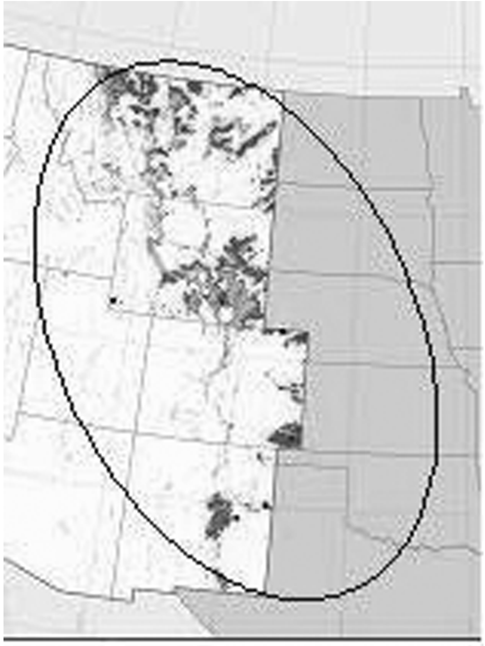

Figure 2. Western U.S. Wind Areas.

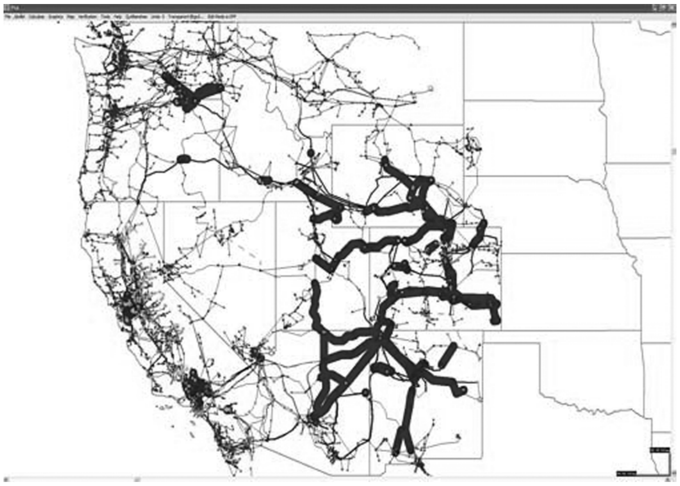

Figure 3. 2025 WECC with 25% Wind Energy.

the ability to adapt to changing conditions of resource availability at lower voltages (subs transmission and distribution) and allow such energy to be used in an optimal fashion with little waste.

SUMMARY OF ECONOMIC IMPACTS

The purpose of this analysis is to estimate investment in the grid required by the two analyzed scenarios. Table 3 below table shows estimated line and transformer expenditures incurred by the two scenarios for 2025.

Table 3. Summary of Scenario 1 and 2 Grid Investments

		Cost in Millions ($2005)		
Year	Scenario	Lines	Transformers	Total
2025	1	209.0	122.7	331.7
2025	2	5,902.0	66.2	5,968.6
—	2-1	5,693.0	-56.5	5,636.9

Costs shown in Table 3 are based on the previously reported estimates of required transmission line and transformer replacements and multiplied by cost estimates for new capacity. Estimates for transmission lines are taken from the U.S. Department of Energy, Energy Information Agency report *Upgrading Transmission Capacity for Wholesale Electric Power Trade* (Table FE2)[2]. Estimates for transformers are taken from the U.S. Department of Energy, Office of Electric Transmission and Distribution report *Technology Briefs—Overview of Advanced Electric Delivery Technologies* [3]. Cost estimates were adjusted to 2006 prices using the producer price index for industrial electric power, fuels and related products and power published by the U.S. Bureau of Labor Statistics.

Transmission investment costs per unit of installed capacity average approximately $95,000 per MWe, based on Tables 2 and 3. That is, a wind farm cluster of 100 turbines (rated at 1.5 MWe each) would require transmission capacity upgrades costing nearly $15 million. Note that the 10:1 capacity assumption stated earlier equates to rated output of only 15 MWe despite the nameplate installation of 150 MWe. Utility planning standards are likely to require higher transmission capacity investments than suggested by the lower rating, because the risk of overloading high voltage circuits is dependent on wind variability. Additionally most of the favorable wind sites are located far from larger load centers in WECC, causing upgrades over longer paths.

SUMMARY

The total capacity shown in Table 2 represents an investment of 600 billion dollars, assuming 1:10 de-rating. There is obviously an enormous economic incentive to reduce overbuilding of capacity by suppressing the effects of wind variability on turbine output. By comparison, the cost of increasing transmission grid capacity at bottleneck points is 5.6 billion dollars over the baseline, assuming installation of over 60,000 MWe of (firm) wind power capacity. It is likely that WECC's grid will be less stable as a result of expanding these lines. Additional investments are highly sensitive to the details of the selected mitigation strategy and to the public tolerance of grid instability. Although the analysis above suggests a methodology to evaluate the consequences of these mitigation strategies, proposal of specific strategies was not considered in this study.

References

[1]http://www.awea.org/faq/cost.html
[2]http://www.eia.doe.gov/cneaf/pubs_html/feat_trans_capacity/table2.html
[3]http://www.energetics.com/pdfs/electric_power/techbriefs.pdf

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