



Intermittent Renewables in the Next Generation Utility

Presented at PowerGen-RE 2008 conference & Exhibition, February 19-21 2008

*Lena Hansen and Jonah Levine
Rocky Mountain Institute
Boulder, CO*

Abstract

Advances in digital communications and renewable energy technologies are poised to facilitate a transition to a “next generation utility” that fully integrates both supply- and demand-side resources in a way that can enable significantly larger penetrations of intermittent renewable energy technologies than conventionally thought possible.

However, as the penetration of intermittent renewable energy grows, the variability of the resource becomes of increasing concern. This paper evaluates the potential reduction in variability due to the geographical dispersion of wind resources across large geographic areas. Specifically, the analysis uses data from within the Midwest Reliability Organization (MRO), the Southwest Power Pool (SPP), and the Electric Reliability Council of Texas (ERCOT).

This analysis shows that there is a significant advantage to geographically distributing wind resources, even if individual sites do not exhibit large negative covariance. One of the primary advantages is the drastic reduction in time in which there is zero power production. Furthermore, all geographic regions show a reduction in portfolio variability compared to any individual site. The implication of this finding is that choosing locations for wind development in part based on benefits to system reliability can both decrease the cost of and likely increase the total amount of intermittent renewables that can be integrated on to an electric grid.

I. Introduction

The ever-growing energy demands of our 21st century lifestyle are dependent upon a power infrastructure designed for the early 20th century. However, advances in digital communications and renewable energy technologies could facilitate a transition to a “next generation utility” that fully integrates both supply- and demand-side resources in a way that can enable significantly larger penetrations of intermittent renewable energy technologies than conventionally thought possible. Table 1, below, summarizes the components of the next generation utility and the form each might take under traditional, modern conventional wisdom, and next generation utility concepts.

Table 1. Next Generation Utility Concept Building Blocks

	Traditional approach	Conventional wisdom now	Next generation concept
Energy efficiency	Up to the customer	Component-based utility programs	Breakthrough-level system efficiencies
Load response	Emergency curtailment	Price response to limit peak demand	Real-time response to balance system
Plug-in vehicles	R&D only	Lucrative off-peak demand	Vehicle-to-grid storage resource
Renewable generation	Marginal fuel saving, no capacity value	Some capacity value with gas-fired firming	Firming by load-side & other renewables
Distributed (co-) generation	Emergency standby only for reliability	Co-generation OR emergency standby	Tri-generation AND reliability support
Advanced grid intelligence	Unidirectional tree from source to load	Some intelligence to automate loads	Omnidirectional web of sources & loads

A fundamental component of this next generation utility is the large-scale incorporation of intermittent renewable energy resources, including wind and solar. While many U.S. electric utilities are currently looking at the possibilities for incorporating wind power up to 10–20 percent, the next generation utility would require a significantly higher penetration.

However, as the penetration of intermittent renewable energy grows, the variability of the resource becomes of increasing concern. This paper evaluates the potential reduction in variability due to the geographical dispersion of wind resources across a large area. Specifically, the analysis uses data from within the Midwest Reliability Organization (MRO), the Southwest Power Pool (SPP), and the Electric Reliability Council of Texas (ERCOT).

The paper also qualitatively discusses the possible efficiencies associated with more dynamic control of demand-side resources, including increased control over flexible loads and the integration of plug-in hybrid electric vehicles. Taken together, these resources can allow a utility to better manage the variability of intermittent resources.

II. Intermittent Renewables

One of the primary goals of electric utilities is maintaining the reliability of the electric system—the implication being that the reliability of any individual generator is only important in the

larger context of system reliability. This insight also recognizes that all generators, both conventional and intermittent, have some probability of failure. The forced outages of conventional generators result from unplanned mechanical failures, whereas the effective “forced outages” of intermittent generators are due to the risk of “fuel” (i.e., wind) availability. These two factors lead to the conclusion that we must evaluate intermittent renewable generators for their contribution to overall system reliability, rather than the reliability of an individual renewable generator.

Because of the implications for reliability, capacity credit—the amount of capacity that can be counted on to contribute to system reliability—has financial value and can therefore greatly improve the cost-effectiveness of wind power. Conventional wisdom holds that capacity credit is given to an individual site based on the individual site characteristics.¹ This philosophy generally leads to the assumption that wind farms have little or no capacity value because the degree of the resource’s variability is so high at each individual site.²

However, modern financial portfolio theory offers a different way of looking at the world. A financial portfolio consists of a combination of individual stocks.³ Developed by Harry Markowitz in 1952, modern portfolio theory enables the creation of minimum-variance portfolios for a given level of expected return.⁴ This theory is based on diversification—the lower the correlation between the individual assets that make up the portfolio,⁵ the lower the portfolio variance, or risk.

Portfolio theory can be easily applied to energy resources. In this context, a renewable portfolio can comprise a geographically dispersed set of wind farms. This paper seeks to analyze the reliability value, and therefore capacity value, of a set of wind farms dispersed across the U.S. Midwest.

III. Literature Review

Analysis of the benefits of geographical dispersion began in 1979, when Kahn⁶ concluded that reliability increases as a function of geographic dispersion of wind development in California. From the late 1990s to today, the National Renewable Energy Laboratory (NREL) and various co-authors have published considerable material on this topic, concluding that increased spatial diversity decreases intermittent power outputs.^{7,8}

¹ Milligan, M. Modeling Utility-Scale Wind Power Plants Part 2: Capacity Credit. (National Renewable Energy Laboratory 2002). NREL/TP-500-29701.

² Kirby, B., et al. California Renewable Portfolio Standard Renewable Generation Integration Cost Analysis, Phase III: Recommendations for Implementation. (California Energy Commission 2004).

³ Alexander, C. Handbook of Risk Management and Analysis. (John Wiley & Sons 1996).

⁴ *Id.*

⁵ *Id.*

⁶ Kahn, E. The Reliability of Distributed Wind Generators. (Energy and Environmental Division, Lawrence Berkeley Laboratory 1979).

⁷ Milligan, M. and Artig, R. Choosing Wind Power Plant Locations and Sizes Based on Electric Reliability Measures Using Multiple-Year Wind Speed Measurements. (National Renewable Energy Laboratory 1999). NREL/CP-500-26724.

⁸ Milligan, M. and Artig, R. Reliability Benefits of Dispersed Wind Resource Development. National Renewable Energy Laboratory 1998). NREL/CP-500-24314.

In 2005, Lena Hansen authored *Can Wind Be a Firm Resource? A North Carolina Case Study*.⁹ This study concluded, “Geographically dispersing wind farms, and considering their output together rather than individually, significantly reduces the variability of the wind system.” The analysis methods used in that study with regards to portfolio optimization have been expanded and reused in this analysis.

Christina Archer and Mark Jacobson at Stanford University have published a series of papers on this topic including: *U.S. Winds and Wind Power at 80 m (2003)*¹⁰; *Evaluation of Global Wind Power (2005)*¹¹ and, *Supplying Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms (2007)*¹².

IV. Methods

Data Collection

Approximately 500 wind data sets were collected from sites around the country (see Figure 1) with the help of the following organizations:

- Plains Organization for Wind Energy Resources (POWER), part of the Energy and Environmental Research Center (EERC), based at the University of North Dakota.¹³
- National Renewable Energy Laboratory (NREL).¹⁴
- Alternative Energy Institute (AEI) based out of West Texas A&M University.¹⁵
- Renewable Energy Research Laboratory (RERL) based at the Center for Energy Efficiency and Renewable Energy (CEERE) at the University of Massachusetts Amherst.¹⁶
- The Oklahoma Wind Power Initiative (OWPI) a collaborative effort between the University of Oklahoma and Oklahoma State University.¹⁷
- Idaho National Laboratory (INL).¹⁸
- Utah Geological survey.¹⁹
- Energy Resources Research Laboratory, based at Oregon State University.²⁰
- Stanford University via Dr’s Mark Jacobson and Cristina Archer.
- Renewable Energy Advancement in Nevada and the Southwest Program sponsored by U.S. Senator Harry Reid and supported by NREL, in cooperation with the Desert Research Institute and the Western Regional Climate Center.²¹

⁹ Hansen, L. Can wind be a firm resource? A North Carolina case study. (Duke Environmental Law and Policy Forum 2005). Vol.15:341.

¹⁰ Archer, C.L., and M.Z. Jacobson. U.S. Winds and Wind Power at 80 m. (Journal of Geophysical Research, 2003). Vol. 108, No. D9, 4289, doi:10.1029/2002JD002076.

¹¹ Archer, C.L., and M.Z. Jacobson. Evaluation of Global Wind Power. (2005).

¹² Archer, C.L., and M.Z. Jacobson. Supplying Baseload Power and Reducing Transmission Requirements by Interconnecting Wind Farms. (Journal of Applied Meteorology and Climate 2007).

¹³ Available online at: www.undeerc.org/programareas/renewableenergy/wind/default.asp

¹⁴ Available online at: www.nrel.gov/wind/

¹⁵ Available online at: www.wtamu.edu/research/aei/

¹⁶ Available online at: www.ceere.org/rerl/index.html

¹⁷ Available online at: www.seic.okstate.edu/owpi/

¹⁸ Available online at: www.inl.gov/wind/idaho/

¹⁹ Available online at: geology.utah.gov/sep/wind/anemometerdata/sitedata.htm#data

²⁰ Available online at: me.oregonstate.edu/ERRL/

Figure 1. Location of data collection sites



Data choice

While nearly 500 distinct data sets were collected, each one spanned a different time period. To accurately assess the possible covariance and therefore benefits of geographically dispersing wind generation, it is imperative that data sets from the same time period be analyzed. Ideally at least three years of consecutive data would be analyzed as that length of time should show variability that may not be seen in any one single year. However, as a first step and to capture the largest geographical area, this analysis uses wind data during a one-year time period. The year chosen for analysis had the most overlapping data sets; in this case, 2004. In addition to having 95 data sets with year 2004 data, data were available for four power pools (ERCOT, SPP, MRO, and WECC), thereby providing a significant geographical spread.

Power Production Model

Wind speed data were converted into power output data by first converting all sub-hourly data to hourly data and adjusting wind speeds to hub-height. Utility-scale wind turbines are generally installed at an 80-meter hub height, plus or minus 20 meters. To increase the validity of this analysis, all attempts were made to collect data sets that were taken at or above 80 meters. For this analysis, all data gathered at lower than 40 meters were discarded, data gathered between 40 meters and 80 meters were scaled up to 80 meters, and all data gathered at or above 80 meters were left at the recorded height. Wind speeds were adjusted for height using the one-seventh-

²¹ Available online at: www.wrcc.dri.edu/nrel/

power rule, as expressed through the equation $(V/V_o) = (H/H_o)^\alpha$, where V = Wind speed at height H , V_o = Wind speed at height H_o , and α = The friction coefficient, which is a function of the terrain over which the wind is blowing.²²

Subsequently, a 2 MW wind turbine (Vestas V80) was chosen to model power production,²³ and the turbine's power curve was adjusted for elevation and air density at each site. This adjustment was made based on recorded elevation and air density derived from temperature data or estimated based on site elevation. Wind power production is determined by the equation:²⁴

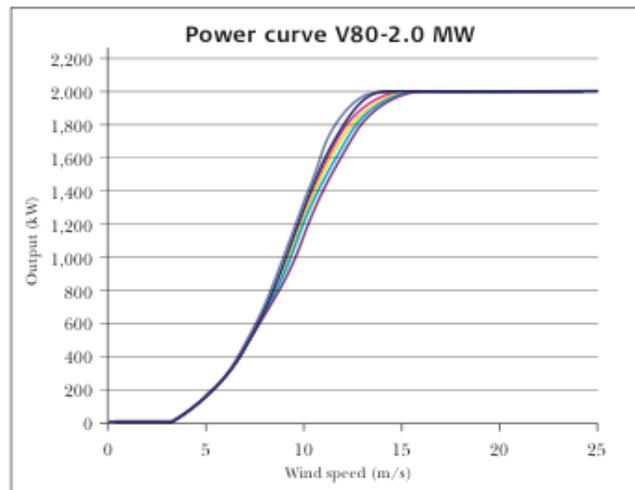
$$P_w = 1/2CP\rho AV^3$$

Where:

- CP = The coefficient of power
- P_w = Power in watts of the wind
- ρ = Air density in kg/m^3
- A = Swept area of the rotor in m^2
- V = Wind speed

Hourly power output was calculated for each data set, based on adjusted power curves as displayed in Figure 2.

Figure 2: Power Curve for a V80 2 MW at 1.22 kg/m^2 Air Density



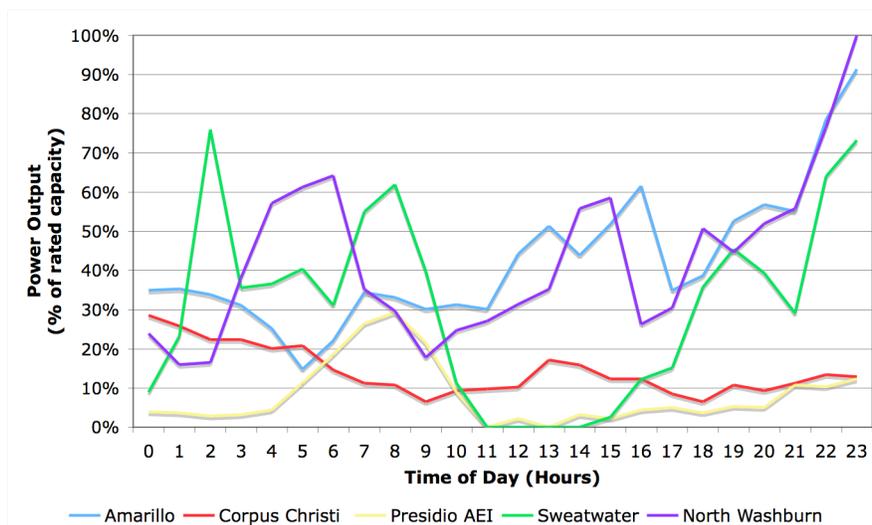
²² Masters, G. Wind Power Systems, (John Wiley and Sons 2004).

²³ Technical specifications are found at: www.vestas.com/vestas/global/en/Products/Wind_turbines/V80_2_0.htm.

²⁴ Masters, G. Wind Power Systems, (John Wiley and Sons 2004).

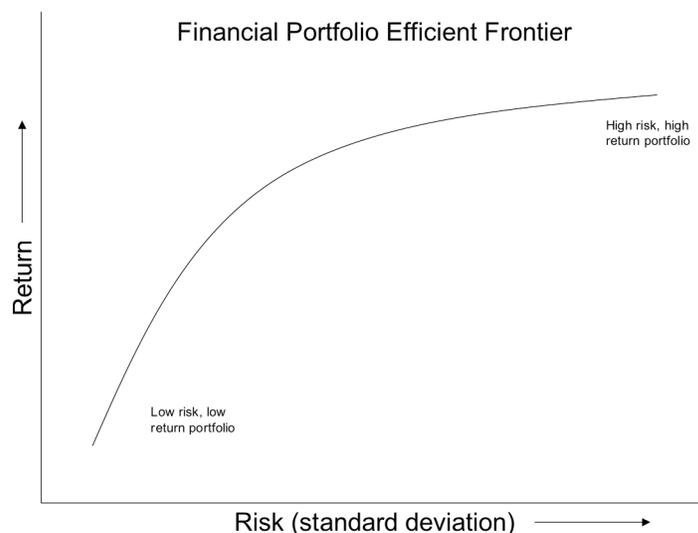
An example of power production during one day for five sites in Texas is shown in Figure 3.

Figure 3. Daily Variation in Power Output (5 sites in Texas, January 1, 2004)



*Optimization*²⁵

The concept behind optimizing the portfolio of individual wind sites is based on financial portfolio theory. In the figure below, the curved line illustrates how expected return and standard deviation change with different combinations of two stocks. This is known as the efficient frontier. Portfolios below the curve are not efficient, because a greater return could be achieved for the same risk. Portfolios above the line are impossible. Portfolios on the line represent the portfolio with the highest return for a given risk level, and involve different quantities of each stock.



²⁵ The following optimization methods are taken from Hansen 2005.

Due to topography and meteorology, winds in different geographic locations are often not correlated while sometimes they are negatively correlated. By blending individual sites together into a portfolio, the overall risk, or variability, of a power portfolio should be reduced.

The first step in determining the benefit of geographical dispersion is to determine whether the sites of interest exhibit any covariance. If two sites have a negative covariance, one site's power output is small when the other site's power output is large, and vice versa. This negative covariance should have the effect of reducing the variability of the combined output of the system as a whole.

Covariance matrices were generated between sites on a state-, power pool-, and system-wide basis, according to the formula:

$$\text{Cov}(x, y) = 1/n * \sum (x_i - \mu_x)(y_i - \mu_y)$$

Where:

x, y = Data series

n= Number of data points

μ = Data point series average

i = Data point

The value of negative covariance in reducing the system variability was determined by running an optimization model that determines the amount of power that should be installed at each site to achieve a collective minimum variability. This optimization model minimizes the portfolio variability by changing the amount of capacity development in each location, subject to:

- The percentage of total development at each site is ≥ 0 and ≤ 1 ;
- The total development of all sites combined = 100 percent of the development; and
- The output of the total development is \geq a minimum specified production number.

V. Results & Discussion

For this analysis, several geographic regions were analyzed, including:

- States
 - Texas,
 - Kansas,
 - Minnesota, and
 - North Dakota.
- Reliability Regions
 - The Midwest Reliability Organization (comprising Minnesota and North Dakota).
- System-wide

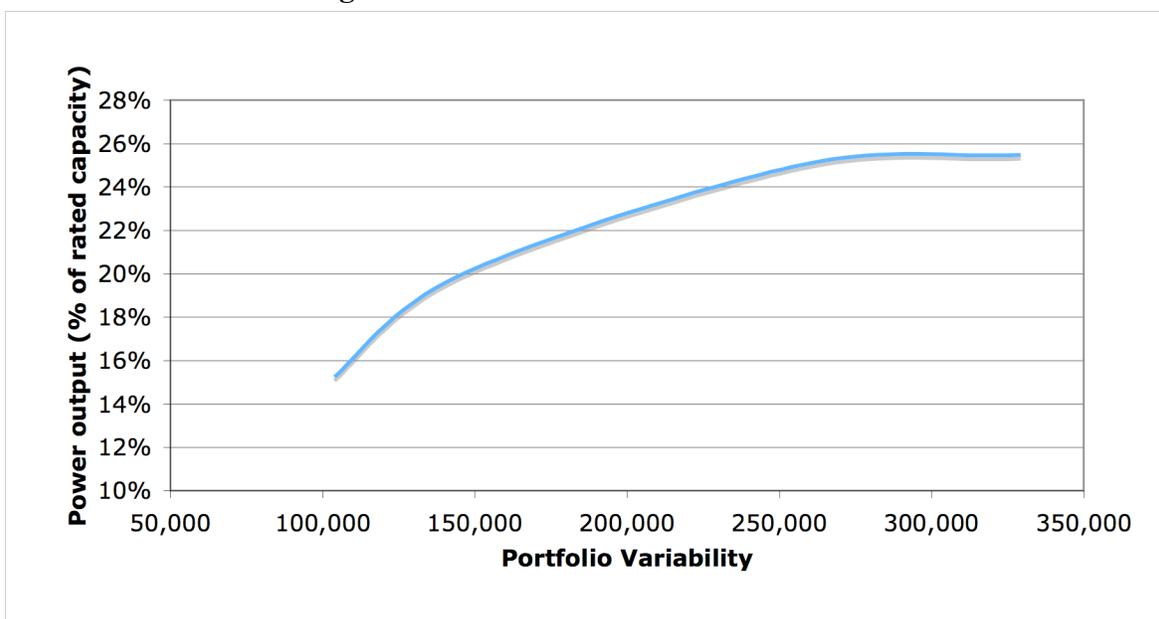
For each of the geographical regions analyzed, reduction in variability was found due to negative covariance between some sites. Not surprisingly, more variability reduction was found over larger geographical areas or where wind regimes vary based on terrain. Results from each region are discussed below.

Texas

Five sites across Texas, each with capacity factors between 10-25 percent, were used to determine the benefit of geographical dispersion across the state. Using these five sites, different portfolios can be created that exhibit the minimum variability for a specified portfolio average power output. That is, if a certain level of power output is required in order to make the investment cost-effective, the system can be optimized to minimize variability while producing the minimum required level of power.

Figure 4 below shows the different portfolios that can be created in Texas, each with an average power output and associated variability. This mean-variance frontier shows that increasing portfolio variability is coupled with an increasing percentage of power output relative to the rated capacity of the system.

Figure 4: Texas Mean-Variance Frontier



In general, this system shows a significant increase in variability per percent increase in output. This pattern indicates that there could be an advantage to selecting a portfolio with a slightly lower power output and corresponding much lower variability. The remainder of this analysis examines the specific portfolio that produces 20 percent of the rated power output on average across 2004. That portfolio included generation in the following proportions:

Table 2. Capacity at each site to produce 20% capacity factor with minimum variability

Texas Site	% of total installed capacity
Amarillo	0%
Corpus Christi	51%
Presidio	0%
Sweetwater	9%
Washburn	40%

Figure 5, below, shows the output of each individual site over the course of a day, as well as the output of the optimized portfolio. As is clearly evident, this optimized portfolio has a lower average power output than some individual sites, but is also much less variable over the course of the day.

Figure 5: Optimized output (5 sites in Texas, January 1, 2004)

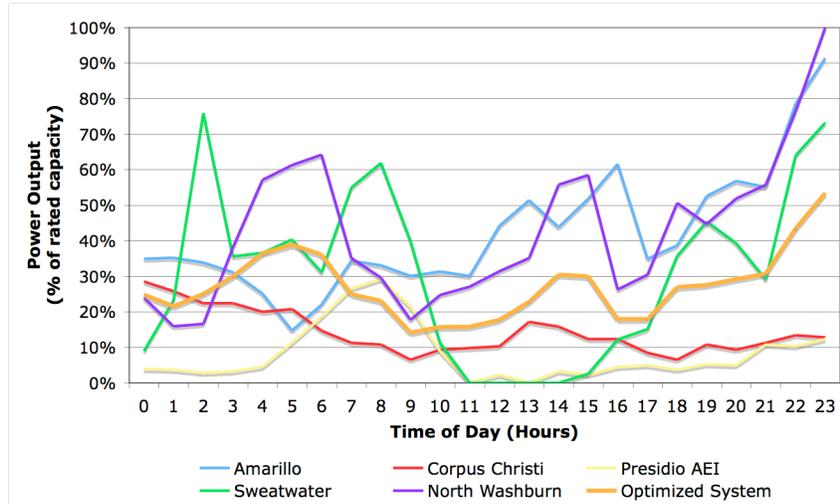
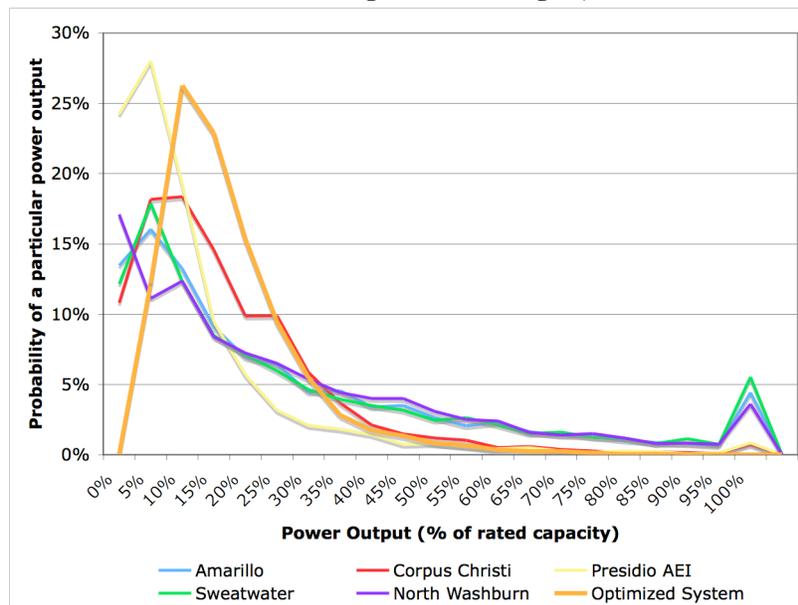


Figure 6 is a histogram of an entire year (2004) of the Texas system's hourly outputs. Of particular interest is that the optimized portfolio, shown in orange, never has zero output. That is, the wind is always blowing at at least one site in the portfolio. Conversely, the wind is also never blowing at maximum speed at all sites at the same time. Together, this pattern indicates a wind regime that is relatively reliable.

Figure 6: Texas 2004 Output Histogram (optimized system specified with 20 percent minimum portfolio output)



The histogram shown above indicates that the optimized portfolio produces more power more frequently than the individual portfolios, while at the same time exhibiting less variability, as seen in the narrow shape of the curve. This data is reproduced in

Table 3 in a cumulative percent showing the reliability of the 2004 data. That is, for this portfolio, there is virtually zero time with zero production. The 0.03 percent probability of zero energy production in the optimized system equates to three hours of zero production per year whereas each of the wind sites individually would have between 40 and 89 days of zero production.

Table 3: System reliability percentage at x percent of capacity

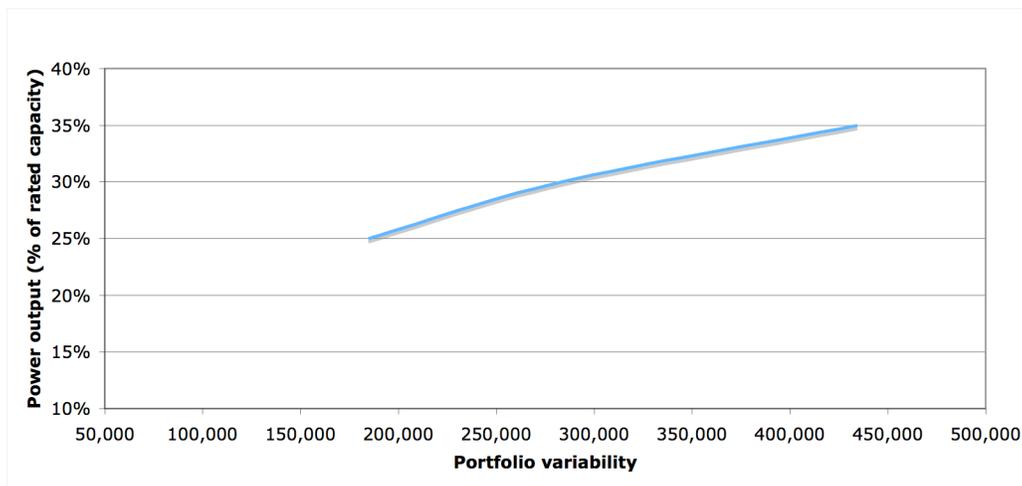
Capacity %	System Reliability %					
	Optimized System	Amarillo	Corpus	Presidio	Sweetwater	Washburn
0%	0.03%	13.46%	10.82%	24.24%	12.14%	17.10%
5%	99.97%	86.54%	89.18%	75.76%	87.86%	82.90%
10%	87.77%	70.51%	71.02%	47.77%	69.98%	71.78%
15%	61.51%	57.30%	52.65%	28.54%	57.64%	59.43%
20%	38.64%	48.20%	38.08%	19.11%	49.17%	51.04%
25%	23.30%	41.29%	28.21%	13.43%	42.08%	43.82%
90%	0.01%	5.84%	0.99%	1.06%	7.40%	5.15%
95%	0.00%	5.04%	0.83%	0.97%	6.27%	4.34%
100%	0.00%	4.41%	0.72%	0.84%	5.53%	3.61%

Based on this data, it can therefore be concluded that there is likely a great advantage in geographically dispersing wind capacity across Texas.

Kansas

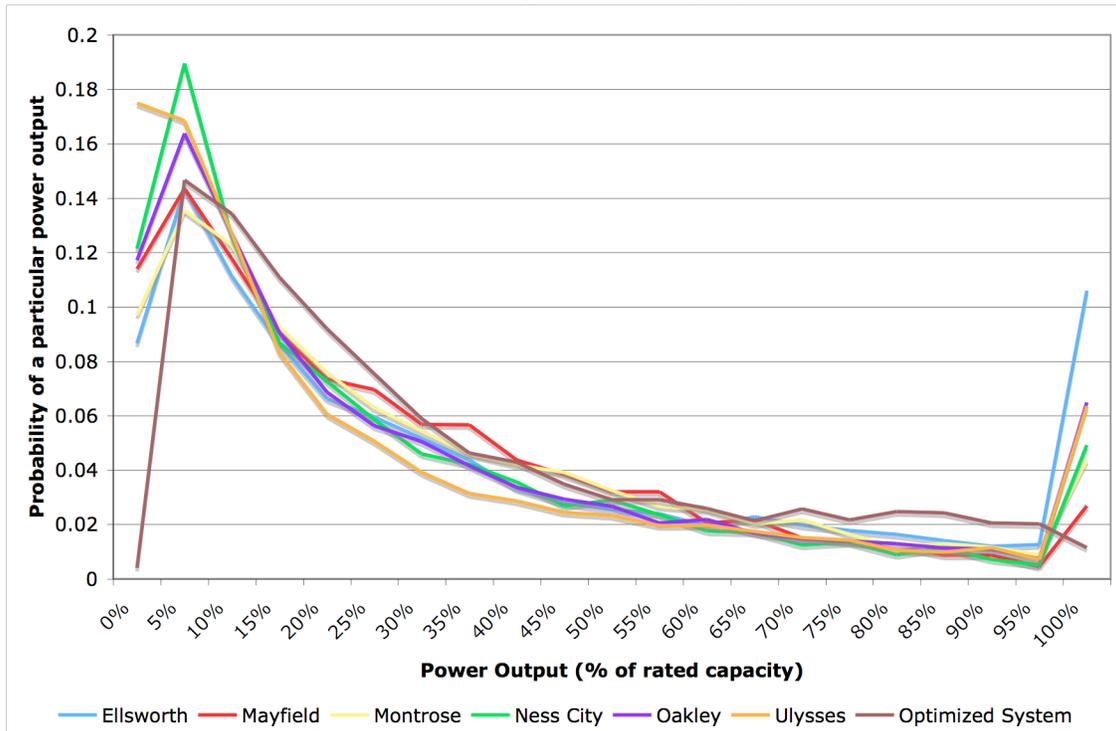
The mean-variance frontier comprising different portfolios of seven wind sites in Kansas shows a large increase in variability compared to the increase in portfolio capacity factor.

Figure 7: Kansas Mean-Variance Frontier



Due to the relative uniformity of topography in Kansas, winds in the state tend to exhibit positive covariation, and also have relatively high speeds. This is evident in that the capacity factors for the sites in Kansas range from 25-35 percent, as compared to 10-25 percent in Texas. Figure 8 is a histogram of an entire year (2004) of the Kansas system's hourly outputs.

Figure 8: Kansas 2004 Output Histogram (optimized system specified with 25 percent minimum portfolio output)

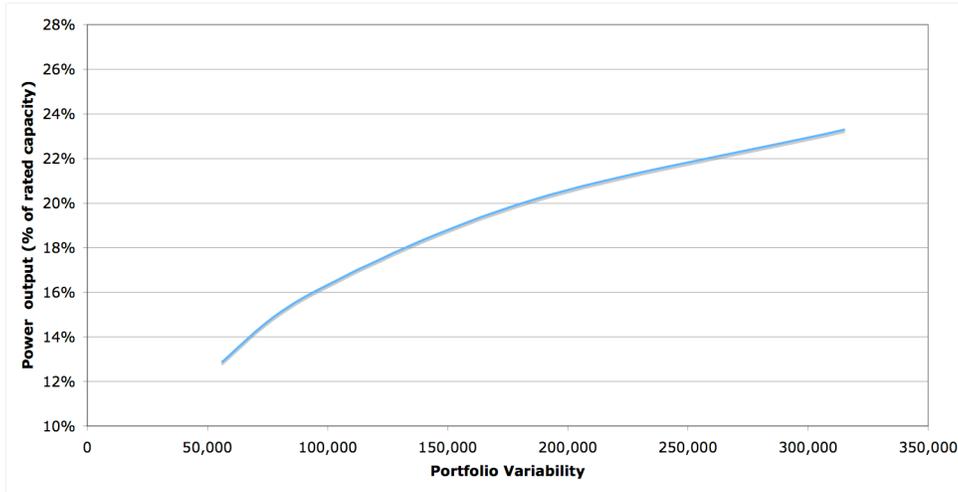


The Kansas system has a high power output potential along with a high degree of variability. Because the winds are quite correlated, the optimized system shown in the graph above does not show a dramatic improvement in variability compared to the individual sites. However, there is significantly less time during which zero power is produced, compared to the individual sites. Furthermore, because the wind speeds are generally high, it is likely that combining these Kansas sites into a larger geographic portfolio could prove beneficial.

Minnesota

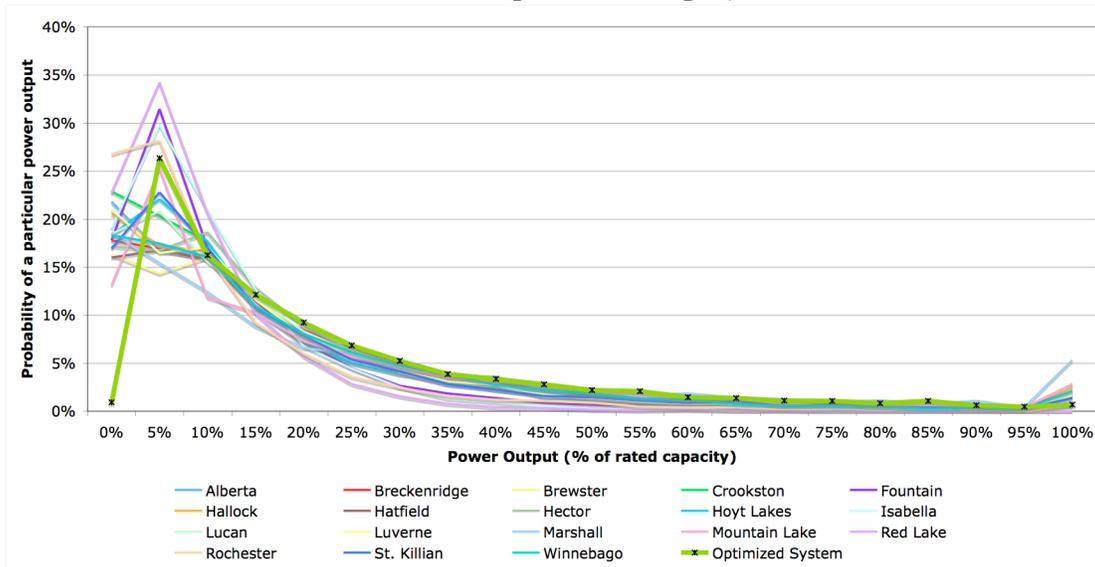
Figure 9 shows the mean-variance frontier for portfolios of 17 sites in Minnesota. Power output increases quickly with little increase in variability until approximately 15 percent of installed capacity. Therefore, the optimized portfolio at that point is presented.

Figure 9: Minnesota Mean-Variance Frontier



With a minimum portfolio output of 15 percent of rated capacity, the Minnesota system is has following histogram of power production.

Figure 10: Minnesota 2004 Output Histogram (optimized system specified with 15 percent minimum portfolio output)



Like Kansas, the primary benefit of geographically dispersing wind across these sites seems to be in reducing time in which there is zero power output. In comparison to the Texas system, the Minnesota system has many more sites available for development. Regardless of this possible advantage, the Texas system produces a higher power output with comparable variability. This result is a function of having greater diversity, and therefore more negative covariance, in the Texas wind regime. Nevertheless, when optimized, the Minnesota wind system becomes less variable and is a strong resource.

North Dakota

The mean-variance frontier for the North Dakota wind system is shown below. Because of the 5 percent increase in capacity factor with virtually no increase in variability, the remainder of this analysis is based on a portfolio with a 25 percent capacity factor. North Dakota has high wind speeds, although that production is also consistent with a high degree of variability.

Figure 11: North Dakota Mean-Variance Frontier

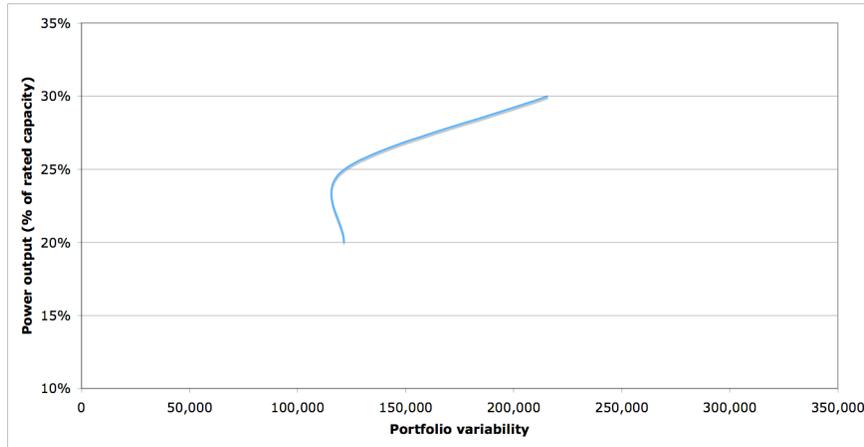


Figure 12: North Dakota 2004 Output Histogram (optimized system specified with 25 percent minimum portfolio output)

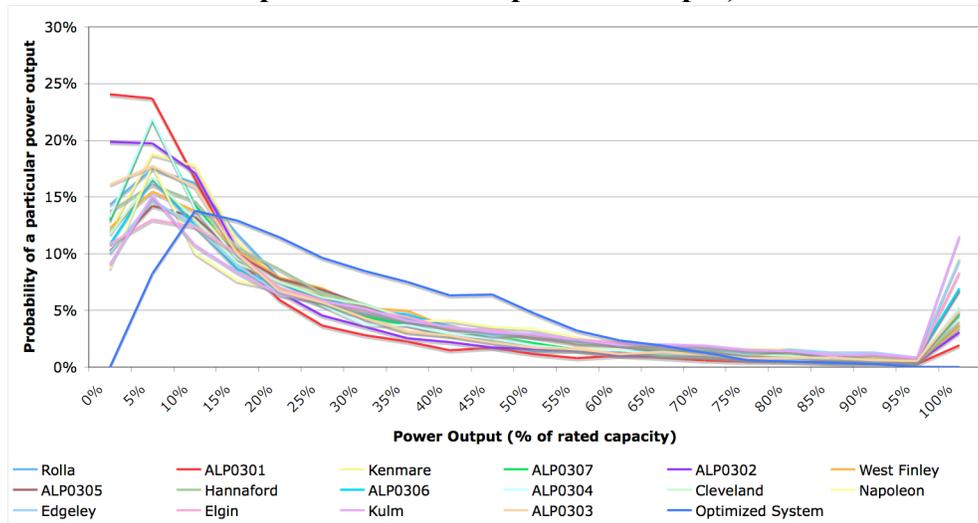


Figure 12 displays the power output of the North Dakota wind system. The optimized portfolio shows little time in which there is zero power production, and more time in which there is higher power production than individual sites.

Midwest Reliability Organization (MRO)

Beyond the reliability benefits of wind geographically dispersed across a state, it is worth analyzing larger geographical areas. As an example, the Midwest Reliability Organization

(MRO) is considered as a geographic region. MRO comprises North Dakota and Minnesota, and since MRO is a recognized reliability region, it is reasonable to assume that power could be integrated across that area.

The mean-variance frontier for the MRO system is shown in the figure below; the remainder of this analysis looks at the portfolio with a 15 percent capacity factor, although the portfolio with a 20 percent capacity factor could also prove useful at reducing variability.

Figure 13: Midwest Reliability Organization Mean-Variance Frontier

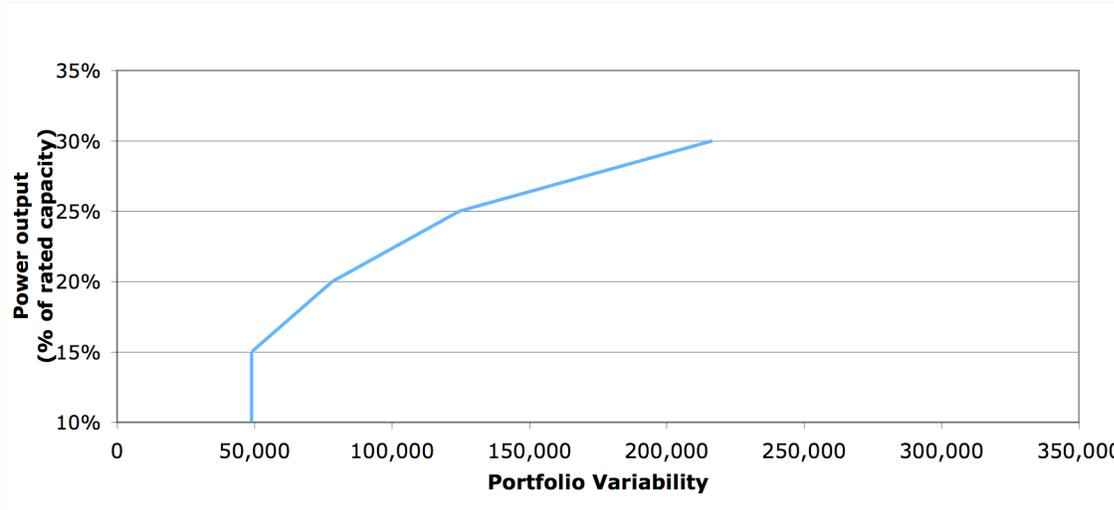


Figure 14: MRO 2004 Output Histogram (optimized system specified with 15 percent minimum portfolio output)

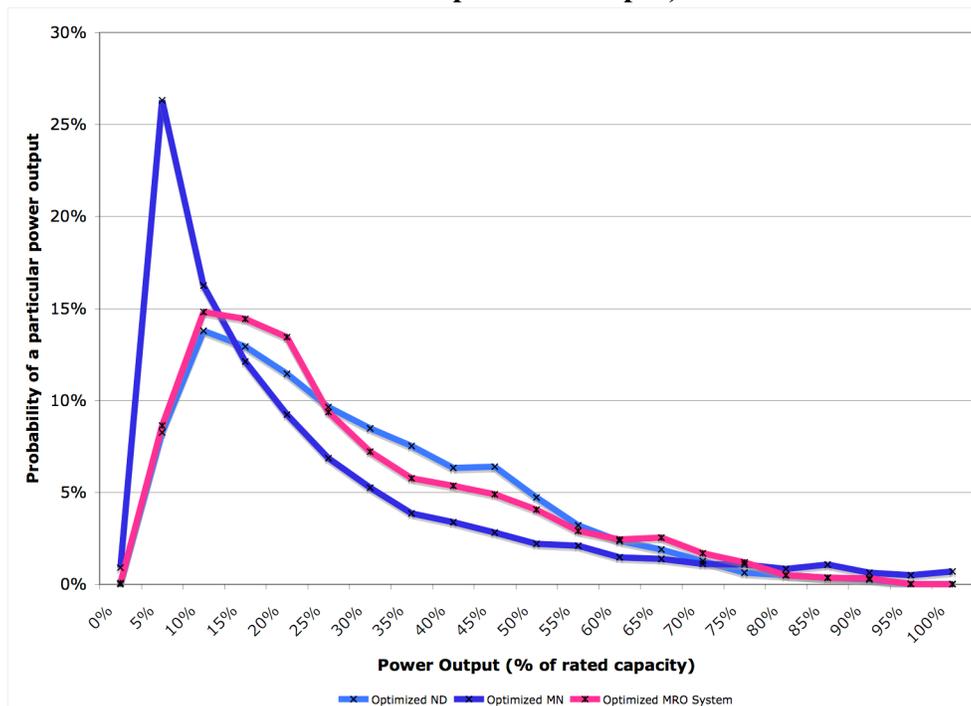


Figure 14 displays the power output of the MRO wind system, compared to the previously discussed optimized portfolios for North Dakota and Minnesota. When optimized, 5 percent of the wind capacity is available at all times. Moreover, significant reductions are seen in time spent at zero power production as well as at full capacity potentially facilitating easier integration of wind power.

VI. Conclusions and Next Steps

This analysis shows that there is a significant advantage to geographically distributing wind resources, even if individual sites do not exhibit large negative covariance. One of the primary advantages is the drastic reduction in time in which there is zero power production. Furthermore, all geographic regions show a reduction in portfolio variability compared to any individual site. The implication of this finding is that choosing locations for wind development in part based on benefits to system reliability can both decrease the cost of and likely increase the total amount of intermittent renewables that can be integrated on to an electric grid.

It is also likely that further reliability benefits will be found by analyzing an even larger geographic region than has been included here. For example, creating a portfolio comprising the entire middle corridor of the U.S.—from Texas through the Dakotas—could take advantage of the fast winds in the Dakotas and the varying wind regimes in Texas. Additionally, creating a portfolio of wind and other renewable resources such as solar, energy storage, demand response, and end-use efficiency could further increase reliability benefits.

Expanding the geographic region under consideration, integrating other energy resources, and enhancing the optimization model are all on-going as part of the development of the next generation utility concept.