August 1999 • NREL/CP-500-26723

Conference Paper

Evaluation of Optimal Distribution of Wind Power Facilities in Iowa for 2015

T. Factor
Iowa Wind Energy Institute

M. Milligan
National Renewable Energy Laboratory

Presented at Windpower '99
Burlington, Vermont
June 21-23, 1999

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-98-GO10337

NOTICE

This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

Available to DOE and DOE contractors from:
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831
Prices available by calling 423-576-8401

Available to the public from:
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
703-605-6000 or 800-553-6847
or
DOE Information Bridge
http://www.doe.gov/bridge/home.html

♻ Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

EVALUATION OF OPTIMAL DISTRIBUTION OF WIND POWER FACILITIES IN IOWA FOR 2015

Tom Factor
Iowa Wind Energy Institute
1204 Lakeview Drive
Fairfield, IA 52556
tfactor@lisco.com

Michael Milligan
National Renewable Energy Laboratory
1617 Cole Blvd.
Golden, CO 80401
milligan@nrel.gov

INTRODUCTION

By the end of June 1999, about 250 megawatts of wind generation will have been dedicated in the state of Iowa. This represents the beginning of what is likely to be significant wind capacity development during the next 20 years in the state, as a result of possible public and governmental mandates and consumers' desire for sustainable sources of energy. As the utility industry in the United States moves towards a new structure, renewable energy sources continue to be an important part of new resource development.

In this paper, we consider the predicted trends in load growth in Iowa. After accounting for the retirement of nuclear and older fossil fuel facilities over the next 15 years, we estimate Iowa's potential renewable generating capacity through the year 2015 and anticipate the contribution of wind energy to Iowa's portfolio.

The Iowa Wind Energy Institute (IWEI) has been monitoring the wind resource in Iowa since June 1994 to obtain wind speed averages at 10, 33 and 50 meters above ground at fourteen geographically dispersed potential wind farm sites. Winds in the Midwest are primarily generated by fronts moving through the region. The Northwest Buffalo Ridge area of Iowa typically has wind speed averages of 7—8 m/s. Central Iowa may have typical winds slightly below this mean value. However, as a front passes through the state, there will be times when a wind farm in Central Iowa will produce more energy than one on Buffalo Ridge.

For this analysis, the Iowa Wind Energy Institute provided clean hourly wind speed, direction, and pressure averages measured at 50 meters from several sites. IWEI has also estimated the output of appropriately sized wind farms at the geographically dispersed wind sites based on a detailed wind resource mapping of the area and the average density of turbines in a typical array. The purpose of this study is to find the best way to distribute a given level of wind generating capacity among several sites.

This project uses an electricity production-cost and reliability model and applies the model to hourly electric load and generator data for the state of Iowa to determine the mix of wind generators that provide the highest benefit. We calculate this benefit in terms of reduction in the fuel cost of conventional generators. We also consider system reliability in terms of energy not served (ENS) and loss of load expectations (LOLE). Although they are also important factors, transmission constraints and the economic value of the environmental benefits of wind generators are beyond the scope of this study. Our results are based on a very large number of power production simulations and show that there are several possible ways in which to distribute wind capacity among several sites in Iowa.

IOWA LOADS AND UTILITY DATA

We used publicly available data for all of the investor-owned utilities, cooperatives, and municipals in the state of Iowa. This data includes hourly electric load data and data for each generator in the state. In some cases, it was necessary to combine small generating units, such as combustion turbines or hydro facilities. When this was done, we combined only units that share similar characteristics, such as heat rates, fuel type, and so forth. We also modeled energy inflows and outflows in Iowa. This data was adjusted to reflect recent and projected interchanges as accurately as possible. These exchanges include base economy energy, intermediate economy energy, peaking capacity and energy, and emergency capacity purchases from other utilities in the control region. These purchases are projected to decline at about 1,000 GWh per year from a current level of about 9,000 GWh. We also incorporated projected gas-fired simple-cycle and combined-cycle capacity into the future resource mix.

To project wind energy's contribution to Iowa utilities energy portfolio over the next 15 years, we took several factors into consideration. From an economic perspective, we considered the potential retirement of older and less efficient power plants and nuclear plants. From the side of demand, we looked at the public mandates for renewable energy being considered on the state and federal levels. We also looked at European models of wind's impact on system reliability. And finally we considered the anticipated growth in capacity required over the next 15 years and the implications this would have for adding new generation.

Iowa has about 8,900 GWh of energy generated annually by nuclear plants. The U.S. Department of Energy has stated that wind energy may fill the gap created by nuclear plants as their licenses expire or options for waste storage become limited. In Minnesota, the wind energy mandate was part of an agreement to allow the utility to store nuclear wastes.

Iowa currently has 1.8% of its energy portfolio in wind turbines. This is a result of the Alternative Energy Production law enacted in 1983. These new wind farms became operational on June 28, 1999. As they prove themselves reliable and efficient, this will pave the way for greater confidence in wind energy. Already the Iowa Department of Natural Resources is submitting legislation for approval requiring Iowa utilities to deliver 10% of their energy from renewable sources by the year 2015. This mandate is in line with U.S. Department of Energy targets and current presidential administration proposals for a federal renewable portfolio standard especially since Iowa would likely be called upon to deliver wind energy to its neighbors Wisconsin, Illinois, and Missouri, which have much lower resources.

Wind energy is becoming cost competitive with fossil fuel alternatives for new energy production in Iowa. Although wind energy is considered non-dispatchable because it is intermittent, areas outside the U.S. which have reached the ten percent level report no disruption in their ability to meet load requirements. And there is a very favorable public climate towards wind energy. Taking these facts together, we decided to analyze the ten- percent target for renewable energy applications in the next 15 years.

We took the utility projections for energy growth over the next 15 years and calculated the wind capacity in MW that would be required to meet 90% of the 10% mandate for renewable energy. This yields a 1600 MW target. Although wind energy is the most cost-effective renewable technology in Iowa, there may also be significant contributions by biomass, small hydro, and other renewable sources.

IOWA WIND RESOURCE AND WIND MEASUREMENT STATIONS

The state of Iowa has significant wind energy resources, with substantial areas of class 3 winds and above. The northwest corner of the state is adjacent to the Buffalo Ridge area in Minnesota, a location where significant wind power plant development continues to take place.

The Iowa Energy Center provided a grant to the Iowa Wind Energy Institute in 1993 to begin a wind resource assessment of Iowa. This included the installation of twelve 50-meter wind-monitoring stations around the state. The sites were chosen because of their high potential for wind farm development. They are well exposed, with a large developable area, near to transmission lines, and geographically dispersed.

Data was acquired using NRG9300 CellLoggers. The data was compiled into a database followed by quality assurance checks to eliminate bad data from sensor and logger failures, tower wind shadowing, lightning and icing. Missing data were replaced using either a shear correction to other working anemometers on the tower, or correlation to nearby stations or National Climatic Data Center archived data. Cleaning of the data was performed jointly by Tom Factor and consulting meteorologist Ron Nierenberg.

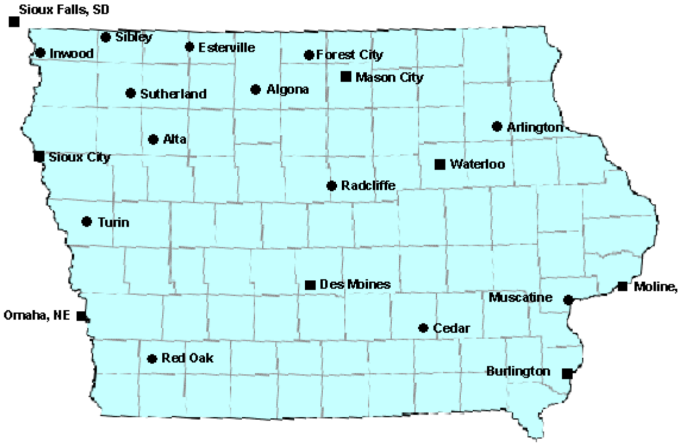

FIGURE 1: WIND MONITORING SITES (CIRCLES REPRESENT IWEI SITES, SQUARES ARE NWS AIRPORT SITES)

Wind data used in the study was for the calendar year 1997. This year was chosen because it was very close to the norm and also so that the wind data would be consistent with the latest Iowa utility load data available at the time of this study. The 1997 hourly wind data were further scaled by comparing the 1997 average to the four-year average measured at the 12 sites. This was done to make the wind data more representative of long-term norms. We also considered the relationship of 1997 to the 20-year norms provided by the National Weather Service.

We ran a large number of power production-cost simulations for this study, using the Elfin model. This modeling process is described in greater detail below. After an initial set of runs was complete, we examined the sites that were selected by the model for significant wind energy development. A wind speed, wind power density, and turbine output map of each 20 x 20 kilometer area surrounding each wind monitoring site selected by the Elfin model was made. We used the WindMap software developed by Michael Brower. The maps used USGS digital elevation models to a 100-m grid cell, surface roughness data, and wind rose data for each ground measurement station. The area was then modeled for relative exposure, elevation, and terrain roughness to create a graphical map of wind speeds and turbine power outputs. This map was used to determine the average wind speed and output for an array size suggested by initial runs of the Elfin model. The maps were used to determine the average wind speed for the size of terrain required to meet the recommendation of the Elfin model at a density of 10 megawatts per square mile. This allowed us to account for declining average wind speed as sites are more fully developed. The wind speed used originally by the model was then adjusted up or down, and the Elfin model was re-run to yield more accurate results. In the case of the Estherville site, which was initially selected by Elfin as the largest generation facility, two monitoring stations a half-mile apart at 50-foot different elevations were used to further refine the modeling of this area.

The adjustments to wind speed we made were as follows: Sibley + 2.3%, Estherville - 2.4%, and Algona -.4%. Alta was not adjusted because nearly 200 MW is already installed at that site. Radcliffe, Sutherland, and Forest City were unchanged because sufficient similar terrain was found in the area to support increased development (pending landowner acceptance and transmission access).

MODELING THE ELECTRICITY SUPPLY SYSTEM WITH ELFIN

We used the Elfin (Milligan, 1996) production-cost and reliability model for this work (Elfin was developed by the Environmental Defense Fund). Although Elfin contains a generation-expansion module, we were unable to use it for this work. Instead, we used an optimization shell developed at NREL that utilizes Elfin to run various scenarios on an iterative basis. The optimization shell collects the results of a large number of individual simulations, which can be used for further analysis.

To calculate hourly wind power output from the 12 wind sites, we used information from the U.S. Department of Energy's (DOE) Wind Technology Characteristics forecast report (DOE, 1997). This information provided us with plausible wind turbine power curves out to 2015. The DOE report projects turbines of 1 MW nameplate capacity on 80-meter towers. The turbines have slight efficiency gains through 2005, and benefit from the wind shear adjustment for the increased tower height from 2005 through 2015. Turbines up to 2 MW of capacity on taller, more flexible towers are already in development. Therefore, we believe this forecast to be too conservative. But it does provide us with a defendable position to project future output of Iowa wind farm sites. The impact of this future technology can be seen in Figure 2, which shows the capacity factor at one of the promising wind sites for the next 15 years. Figure 3 shows the projected capacity factor at all sites using projections for the 2015 technology. All capacity factors are net 15% losses.

Figure 3 can be used to provide us with a glimpse of what will be further described in this paper. There is significant variation in the capacity factor at different sites. For example, Estherville has an annual capacity factor of over 40%, whereas some other sites have capacity factors in the 25—30% range. Milligan and Parsons (1997) presented a study that compared the use of capacity factor with a capacity credit measure that is based on reliability criteria. They found a reasonably good correspondence, but noted that a site with a high capacity factor may not have high capacity credit. In a similar way, we conjecture that most sites with high annual capacity factors will be useful in a large wind power portfolio. However, if a given wind site features a high capacity factor during periods of low load, this wind capacity may not provide high value to the utility. Nevertheless, if we examine Figure 3 we can

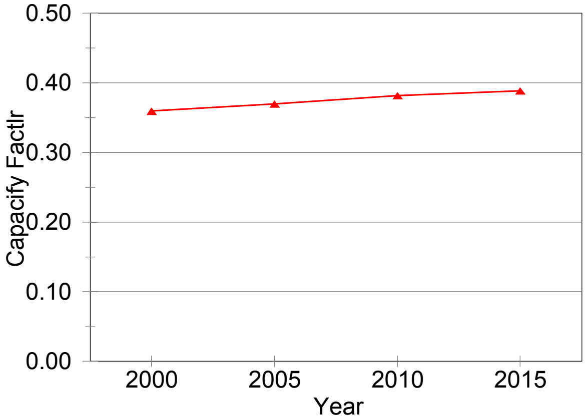

FIGURE 2: PROJECTED INCREASE IN CAPACITY FACTOR. YEARS 2000-2015. SIBLEY, IOWA.

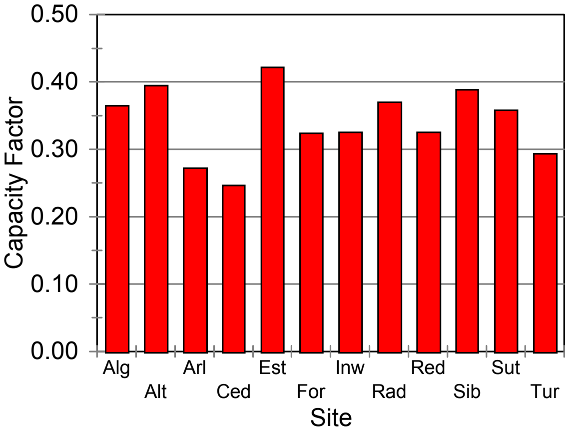

FIGURE 3: PROJECTED CAPACITY FACTOR IN 2015.

conjecture that Arlington, Cedar, and Turin may not make the grade. It is not clear whether Forest City, Inwood, and Red Oak would be chosen in an optimization that is based on finding the best (largest reduction in conventional generation cost) mix of wind sites. We provided the model with hypothetical hourly wind power output from all of the sites, and let the optimization process drop any sites that couldn't contribute in a significant way to the optimal mix of wind resources.

POTENTIAL BENEFITS OF GEOGRAPHICALLY DISPERSE WIND POWER PLANTS

Before describing the optimization process, it is useful to look at the potential for smoothing hourly power output that can be provided by multiple wind farm locations. Figure 4 shows the range of hourly changes in power output from hypothetical 25-MW wind farms at each of the 12 sites in July 1997. For example, at Algona the maximum increase in power output from one hour to the next hour is 17 MW, which is the same as the maximum decrease (positive differences imply increasing power output, and negative differences imply decreasing power output). The tick marks between the maximum and minimum represent the mean plus/minus one standard deviation. So for Algona, these values correspond to about 2.9 and –2.9. The last column of the graph shows the effect of aggregation on hourly swings in wind power output. This last column is based on the assumption that the 25-MW wind farm is now based on equally sized smaller wind plants whose total capacity is 25 MW. There is a clear advantage in distributing the capacity at all sites, as indicated in the graph. From the combined sites, the maximum and minimum power swings are about 7 MW, smaller than any individual site. However, it is unclear as to whether we should equally weight the capacity at all sites or even include all sites in an optimum mix. That is what the optimization process is all about.

OPTIMIZATION WITH ELFIN

Our main optimization is based on the combination of sites that result in highest value to the combined utility system in the state of Iowa. Based on 2015, our target year, we ran a large number of simulations to determine the best mix. We also applied the optimization to choosing the combination of sites that would provide the highest overall level of reliability to the system. Our results were reasonably stable across the three optimization targets: one based on benefit measured in dollars, the other two based on expected energy not served (ENS) and loss of load expectation (LOLE), respectively.

The first set of simulations were performed on all 3 optimization targets using a method based on fuzzy set theory, which is described in Milligan and Artig (1998). A second set of simulations were done using

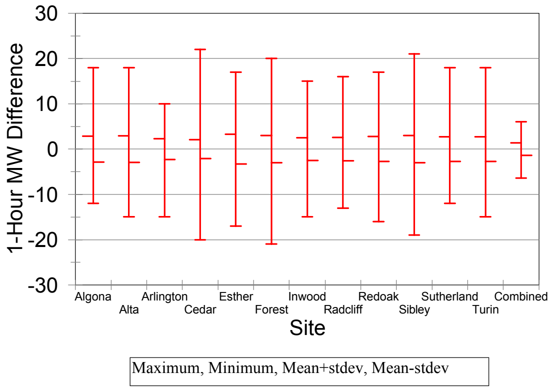

FIGURE 4: HOUR-TO-HOUR DIFFERNECE IN WIND POWER OUTPUT, JULY, 1997.

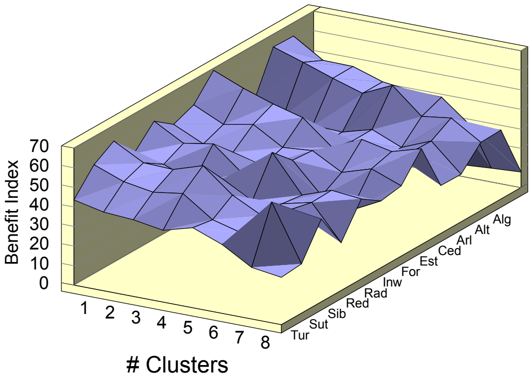

FIGURE 5: MARGINAL BENEFITS OF INCREASING WIND PENETRATION

a static marginal benefit approach, also described in Milligan and Artig, but with a secondary probe to determine the optimal solution. The methods can be conveniently described with reference to Figure 5.

A well-known result from neoclassical microeconomics is that inputs to a productive process can be chosen up to the point at which the ratio of marginal costs to marginal products are equal (see Milligan and Artig, 1998). If the inputs are independent, then we can simply trace out a curve such as the one in the figure, and find such a point that is consistent with our capacity constraint. In our case, we want to choose a total of 1,600 MW of wind capacity that provides the highest benefit (measured as reduction in conventional fuel cost and variable operations and maintenance cost) to the system. In conventional economic theory, the marginal benefit curves are downward sloping throughout. As can be seen in the figure, however, the slope of each site's marginal benefit curve is generally, but not uniformly, downward sloping. Why? Because as the penetration level of wind capacity increases, eventually the commitment of a conventional generating unit can be avoided, resulting in a lumpy drop in system costs. This occurs at the Turin site as we move from three to four clusters of 100 MW. This greatly complicates the problem of determining an optimum solution. In fact, according to our calculations, an exhaustive search of all possible solutions would take 2—3 years running on a fast PC.

We ran our fuzzy algorithm using minimum cluster sizes of 100 MW at each site. For our final and preferred optimizations, we cut the cluster size to 50 MW. The fuzzy algorithm works as follows: For each site, calculate the benefit contribution of a single cluster. At that site or group of sites that are best, simulate the building of 1 cluster at that (those) site (sites). Given the new capacity just built by the algorithm, repeat the process. At the second step, we are in effect calculating a new surface like the one n the figure. However, the new surface takes into account the newly built capacity. The process continues until we have reached the 1,600 MW target. This process yields a set of possible solutions, which are combined into the preferred solution. We repeated this process for both of the reliability targets so that we could see if there were any significant differences in an optimization based on benefits and optimizations based on reliability.

RESULTS

The results of the fuzzy process appear in Figures 6 and 7. Sites that do not appear in the figure were dropped by the algorithm. We see some differences between the various optimization targets. For example, the benefit target yields a recommendation of almost 300 MW at Algona, whereas the ENS and LOLE targets recommend just over 200 MW. Why the differences? Although we provided Elfin with estimates of the value of unserved energy, this estimate (as all such estimates) are very difficult to

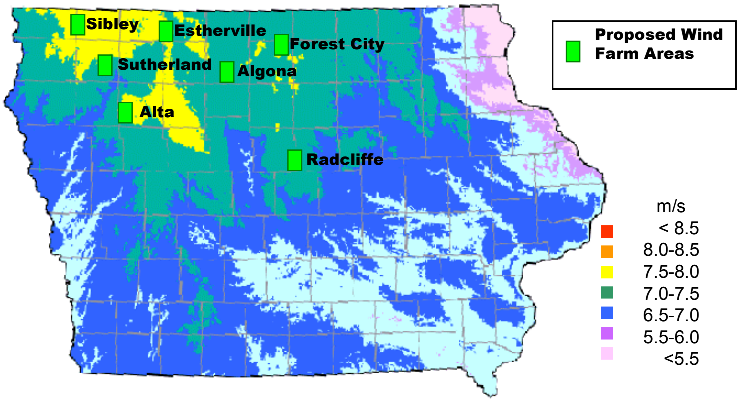

FIGURE 6: LOCATION OF SITES CHOSEN BY OPTIMIZATION PROCESS

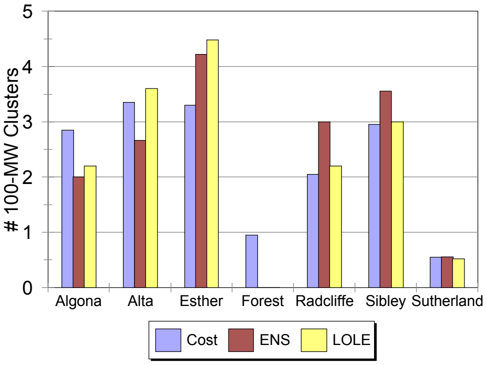

FIGURE 7: COMBINED RESULTS FROM FUZZY LOGIC MODELING

precisely determine. Most of the difference is because of our inability to precisely measure the value of reliability. Other differences arise because of Elfin's inability to perform chronological unit commitment on conventional generating units. This means that there is some inaccuracy surrounding both the reliability measures, and the cost and benefit measures. It is unclear how these inaccuracies will affect the relative recommendations, but the impact is likely seen in our results.

The good news is that the recommendations from the fuzzy procedure are quite consistent. Algona should be developed in the 200-300 MW range, Alta around 300 MW, etc. There is some merit to developing Forest City based economic benefit, but not on reliability merit. This does not mean that Forest City does not contribute to overall reliability; it means that other sites would be better. We also see that five sites have been dropped from the optimal mix. Arlington, Cedar, Inwood, Red Oak, and Turin all had the lowest capacity factors of the twelve sites. Forest City and Inwood are close, and Forest City has just under 100 MW recommended from the economic optimization, but none from the reliability optimization. The conclusion from this set of runs is that (a) five sites can be dropped, (b) there is good correlation between economic and reliability benefits, and (c) we have an initial mix of sites. We now turn to the second method and our final results.

Method 2 is a two-stage process. The first stage is to run the Elfin model for each wind site, calculating that site's contribution to economic benefits assuming no other wind sites are developed. The sites are then ranked according to their marginal benefit, and the top 1,600 MW are chosen. This gives us a solution that satisfies the original surface in Figure 5. Given the large number of peaks and valleys, however, we want to do some further simulations. The second stage is to probe the initial solution, adding and subtracting wind clusters in the neighborhood of the original solution. Each of these cases is then evaluated to determine which is the best. It is important to note that, although we do not have a guarantee of a globally optimum solution, we are confident that our solution is "near" the best one and is consistent with the demonstrable conditions required for an optimum that we can apply from microeconomics.

Figure 8 shows the optimal mix of wind resources based on method 2. These results are not identical to the method 1 results, but are consistent. The recommended capacity at Algona is a little less than method 1, but Alta and Radcliffe are nearly the same. We see a reduction in capacity at Estherville, which is offset by more capacity at Sibley and Sutherland. The recommended capacity at Forest City is a little less, and in both cases is quite small.

Some readers might be somewhat distressed that we have more than a single answer to our problem. However, we think that this is a feature of our analysis, and a source of flexibility in choosing among an

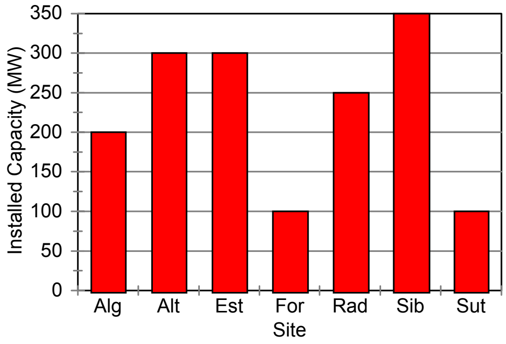

FIGURE 8: OPTIMAL SOLUTION FOR THE YEAR 2015, 50 MW CLUSTERS

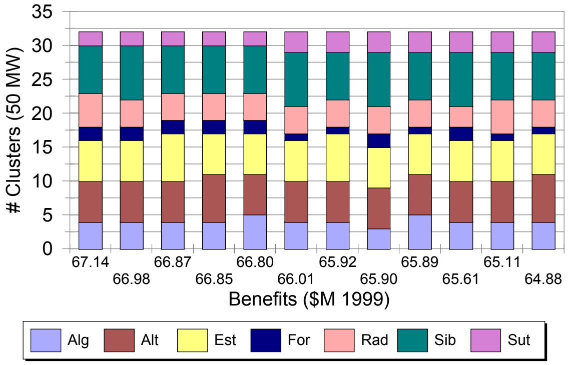

FIGURE 9: TOP 12 SOLUTIONS, 50 MW CLUSTERS

extremely large number of possible configurations. Figure 9 shows several of the potential optimal mixes that were calculated by the probe in method 2. Although we were intending to select the top 10 cases, there was an extremely slight difference between the 10th—12th cases. The benefits of each mix are shown on the x-axis. Each of the stacked bars shows a near-optimal mix of sites. The bar on the far left corresponds to the data shown in Figure 8. The remaining bars show alternative site mixes. The benefits from alternative configurations can be easily compared, and it is apparent that the differences in benefits are quite small. We can conclude that (a) there may not be a single best mix, (b) several alternative mixes might be nearly as good, and (c) alternative solutions, as proposed by Elfin, can be evaluated with respect to other constraints, such as transmission bottlenecks, voltage support requirements, VAR support, and other local considerations. What may be most important, in the final analysis, is to develop good wind sites in tandem with each other, so as to provide the smoothing effects, economic, and reliability benefits to the generation mix.

CONCLUSIONS

Planning a large system of geographically dispersed wind energy systems is a complicated exercise. There is an extremely large number of ways in which 1,600 MW of capacity can be distributed among the 12 sites we studied in Iowa. At each site, additional development may come at the expense of lower energy yields from the site because the best locations tend to be built up first. There is also the question of interannual variability, and how that might affect the potential mix among sites.

Our analysis has demonstrated that it is advantageous to distribute wind capacity in Iowa at several sites. We have shown that there are abundant sites on exposed crop land with wind speeds in excess of 7.2 m/s, access to transmission lines, low population density, and with low environmental impact that are viable for wind energy development. The study further concludes that the geographic distribution provides the greatest benefit when it is kept within the 7.2 m/s and above wind regions rather than simply the widest geographic distribution occupied by lower wind areas. We ran well over 1,000 different simulations in attempt to find the best wind-resource mix. Based on initial simulation results, we modified the site average wind speed based on site-specific information to account for the expected changes in energy yield that are caused by extensive development. Although we can't guarantee that our solution is a global optimum, there is reason to believe that the solution is nearly optimum, consistent with standard microeconomic optimization. Furthermore, we have identified several attractive alternative mixes of sites and capacity levels. We believe that our approach is useful so that several options can be further explored and refined in the context of other goals or constraints that are related either to the electrical system or to other social or institutional issues.

We think that the wind sites and capacity levels chosen by our analysis will be consistent with actual development in Iowa. This is because wind energy sites are most likely to be chosen based on economics and transmission access. Limited transmission capacity in any one area naturally leads developers to locate new areas for wind development. But the first choice will always be the highest-benefit wind site that does not infringe upon higher population densities or environmentally sensitive areas, such as wetlands. These two natural constraints will likely lead wind energy developers to a similar mix of wind resource sites as those indicated in this study and, as this study concludes, will lead to a combination of wind sites that maximizes the economic and reliability contribution of the wind power plants.

ACKNOWLEDGMENTS

This work was supported by the U. S. Department of Energy under contract DE-AC36-98-GO10337. This report was further made possible by the high quality wind data provided through the Iowa Energy Center's support of Iowa's wind resource assessment program and utility data provided by Thomas Wind.

REFERENCES

Milligan, M,; Artig, R. (1998). "Optimal Site Selection and Sizing of Distributed Utility-Scale Wind Power Plants." *International Association for Energy Economics Annual International Conference; May 13-16, 1998; Quebec, Canada*. NREL/TP-500-24312. Cleveland, OH: International Association for Energy Economics.

Milligan, M. (1996). *Alternative Wind Power Modeling Methods Using Chronological and Load Duration Curve Production cost Models.* NREL/TP-441-8171. Golden, Colorado. National Renewable Energy Laboratory.

Milligan, M.; Parsons, B. (1997). "A Comparison and Case Study of Capacity Credit Algorithms for Intermittent Generators." Presented at Solar '97, Washington DC, April 27-30, 1997. NREL/CP-440-22591. Boulder, Colorado: American Solar Energy Society.

United States Department of Energy, (1997). Draft: Advanced Horizontal Axis Wind Turbines in Windfarms, available at www.eren.doe.gov/power/pdfs/turbines.pdf. Supporting data from Joe Cohen, Princeton Economic Research.

APPENDIX

TABLE 1. UTILITY LOADS FORECASTS THROUGH YEAR 2015

Source: Data from EIA-411 1998 report.

	IES/ CIPCO		Interstate Power		Mid-American/ Corn Belt Power		Total			Target of Renew-able Energy	Target of Renew-able Energy	Estimated No. of 750kW Turbines Needed	Estimated MW nameplate wind @ 90% of mandate
Year	Peak MW	Annual GWH	Peak MW	Annual GWH	Peak MW	Annual GWH	Peak MW	Annual GWH	Growth Rate	Pct of Resources	Annual GWH	@35% Cap. Fac.	Nameplate MW
1998	2222	13673	993	5895	3902	19702	7117	39270					
1999	2225	14014	1007	6038	3960	20210	7192	40262	2.53%	1.8%	753	327	**246**
2000	2260	14308	1022	6160	4016	20539	7298	41007	1.85%				
2001	2313	14758	1042	6286	4071	20817	7426	41861	2.08%				
2002	2363	15243	1060	6411	4151	21168	7574	42822	2.30%				
2003	2411	15604	1085	6574	4234	21669	7730	43847	2.39%				
2004	2459	15967	1100	6692	4321	22086	7880	44745	2.05%				
2005	2508	16335	1116	6807	4409	22505	8033	45647	2.02%	5.0%	2282	992	**670**
2006	2557	16702	1131	6924	4513	22898	8201	46524	1.92%				
2007	2603	17069	1155	7078	4617	23296	8375	47443	1.98%				
2008	2653	17398	1177	7215	4706	23746	8537	48359	1.93%	7.5%	3627	1577	**1064**
2009	2704	17734	1200	7354	4797	24204	8697	49268	1.88%				
2010	2757	18076	1223	7496	4890	24671	8856	50169	1.83%				
2011	2810	18425	1247	7640	4984	25147	9014	51062	1.78%				
2012	2864	18781	1271	7788	5080	25633	9170	51946	1.73%				
2013	2919	19143	1295	7938	5178	26127	9324	52818	1.68%				
2014	2976	19513	1320	8091	5278	26631	9476	53679	1.63%				
2015	3033	19890	1346	8248	5380	27145	9626	54528	1.58%	10.0%	5453	2371	**1600**

Note: Interstate Power includes some load in Minnesota and Illinois (up to 40-50%). MidAmerican includes some load in Illinois (perhaps 5%). The total load and energy shown in the figures above is assumed to represent the total Iowa load. We assume that the Municipal, Rural Electric Cooperative, and Western Area Power Association loads not represented here are about equal to the Minnesota and Illinois loads included.

TABLE 2: WIND MONITORING STATION WIND SPEEDS AND ADJUSTMENTS

Site	1997 quality assured 50-m m/s average	Adjustment factor to 1995-1998 norm	Adjustment factor to 20-year NWS norm	Average shear	Terrain adjustment factor
Radcliffe	7.4	1.036	1.060	0.14	1.000
Turin	6.6	1.004	1.005	0.19	1.000
Algona	7.4	1.025	1.061	0.16	0.996
Cedar	6.1	1.008	1.056	0.13	1.000
Inwood	7.0	0.991	1.036	0.14	1.000
Sutherland	7.3	1.007	1.025	0.18	1.000
Alta	7.7	1.012	1.009	0.13	1.000
Sibley	7.6	1.001	1.029	0.16	1.023
Estherville	8.0	0.980	1.013	0.12	0.976
Forest City	7.0	0.991	1.025	0.13	1.000
Arlington	6.3	0.970	1.009	0.15	1.000
Red Oak	7.0	1.022	1.024	0.21	1.000

TABLE 3. WIND MONITORING SITE DESCRIPTIONS

Site Number	Elevation (meters)	Location	Description	Terrain	Longitude (W)	Latitude (N)
11	366	Radcliffe	50-meter tilt-up tower	open crop land	93.44	42.30
22	403	S of Turin	100-meter comm tower	forested ridge above Missouri River basin	95.91	41.97
33	366	SW of Algona	50-meter tilt-up tower	open crop land	94.14	43.04
100	256	West of Cedar	50-meter tilt-up tower	open crop land	92.57	41.19
200	442	S of Inwood	50-meter tilt-up tower	rolling crop land	96.47	43.25
300	464	N of Sutherland	50-meter tilt-up tower	open crop land	95.52	43.00
400	473	N of Alta	50-meter tilt-up tower	high crop land on ridge	95.34	42.84
500	490	E of Sibley	100-meter comm tower	high crop land with drainage and trees to West	95.68	43.40
600	472	S of Estherville	50-meter tilt-up tower	rolling crop land	94.86	43.27
700	385	N of Forest City	100-m comm tower	rolling crop land	93.63	43.28
800	366	N of Arlington	100-meter comm tower	rolling crop land, 10-m level shadowed by terrain	91.61	42.77
900	385	W of Red Oak	100-m comm tower	rolling crop land	95.17	41.00