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WIND-POWERED ELECTRICAL SYSTEMS – HIGHWAY REST AREAS, WEIGH STATIONS, AND TEAM SECTION BUILDINGS

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Wind Powered Electrical Systems – Highway Rest Areas and Weigh Stations and Team Section Buildings

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16. Abstract

This project considered the use of wind for providing electrical power at Illinois Department of Transportation (IDOT) highway rest areas, weigh stations, and team section buildings. The goal of the project was to determine the extent to which wind power could offset electricity costs, provide a reasonable return on investment, offset energy use, and provide educational opportunities. The project gathered and analyzed the natural wind resources available at (or near) these facilities. These data were then used in conjunction with various wind turbines that are currently commercially available. The result of this analysis is an approximation to the wind-based electrical energy potential of a given wind turbine at a given site. Thereafter, the monetary value of this electrical energy was computed and put in context of the cost of the wind turbine and associated overhead. In order to assess economic feasibility, the levelized cost of energy was then compared to current electricity rates for Illinois. This analysis showed that indeed there are some combinations of location and wind turbines that may produce electricity at a competitive rate. One of the most important factors in this analysis is the cost of wind turbines, which is generally unknown (but can be approximated) and depends on many factors. To account for this variability, the authors of this report have provided a spreadsheet containing all the data necessary to rapidly calculate the levelized cost of energy. The user of the spreadsheet need only enter some simple information, such as cost of the turbine and interest rates. The spreadsheet should enable procurement agents to rigorously compare the prices and returns for given locations and turbine manufacturers.

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EXECUTIVE SUMMARY

This project considered the use of wind for providing electrical power at Illinois Department of Transportation (IDOT) highway rest areas, weigh stations, and team section buildings. The goal of the project was to determine the extent to which wind power could offset electricity costs, provide a reasonable return on investment, offset energy use, and provide educational opportunities. The project gathered and analyzed the natural wind resources available at (or near) these facilities. These data were then used in conjunction with various wind turbines that are currently commercially available. The result of this analysis is an approximation to the wind-based electrical energy potential of a given wind turbine at a given site. Thereafter, the monetary value of this electrical energy was computed and put in context of the cost of the wind turbine and associated overhead. In order to assess economic feasibility, the levelized cost of energy was then compared to current electricity rates for Illinois. This analysis showed that indeed there are some combinations of location and wind turbines that may produce electricity at a competitive rate. One of the most important factors in this analysis is the cost of wind turbines, which is generally unknown (but can be approximated) and depends on many factors. To account for this variability, the authors of this report have provided a spreadsheet containing all the data necessary to rapidly calculate the levelized cost of energy. The user of the spreadsheet need only enter some simple information, such as cost of the turbine and interest rates. The spreadsheet should enable procurement agents to rigorously compare the prices and returns for given locations and turbine manufacturers.

CONTENTS

CHAPTER 1 INTRODUCTION

It is well known that energy prices are a major issue today. Record high oil and gasoline prices have put considerable strain on our economy. The use of fossil fuels, which produce carbon emissions when burned, has brought environmental preservation to the forefront. One way to counter these problems is to seek alternative forms of energy. In Illinois, where coal and nuclear power dominate, wind power shows considerable potential for electricity generation. Electricity is the most flexible form of energy, since it can be transported long distances with very low loss and can be converted easily to other forms of energy. Demand for electricity can be expected to grow, particularly with the expected development of more electric, and plug-in hybrid vehicles. Wind power has the potential to provide electrical energy that is clean and incrementally free.

The Illinois Department of Transportation (IDOT) has multiple reasons to be potentially interested in wind power. First, it could be used to reduce the price of electricity, or at least as a hedge against future rises in price. Second, the IDOT already has some land resources that may be underutilized. Third, IDOT facilities, such as rest areas, are exposed to many travelers, presenting the opportunity for education and highly visible environmental responsibility.

This project was proposed to determine the feasibility of using wind turbines at IDOT facilities, such as weigh stations, rest areas, and team section buildings. In the course of one year, we gathered data on wind resources and wind turbines. We aggregated that data so that the expected energy yield of a given turbine in a given location could be determined easily. We further provided the framework to analyze the economics of a given turbine in a given location. We provided examples based on estimates of wind turbine costs. These data and analyses together will provide the IDOT with the tools necessary to make informed procurement decisions.

CHAPTER 2 WIND DATA COLLECTION

The first task of this project was the collection of wind data at or near the sites of interest. From these data, we estimated the wind energy resource for these sites in terms of kilowatt-hours (kWh) per year per unit area. This energy represents only the kinetic energy in the wind itself, and not the wind that can be harvested for electricity by the wind turbine. Nonetheless, it is an essential starting point.

We worked with the technical review panel to determine the specific sites of interest. Based on this information, we collected weather data from several sources (US DOE 2008a, US DOE 2008b, American 2008, Weather 2008). The data were downloaded systematically from the various web sites using an available software tool (Zenopolis 2008). Typically, the data files contain average wind speed as measured over small time intervals such as ten minutes. It is important to have such detailed information since the energy yield from a wind turbine depends strongly on the actual time-varying wind profile rather than just the average wind speed alone. Since the sites themselves did not have detailed data, we used data from the closest station available.

The need for these details can most easily be explained in terms of an example. The power in the wind (that is, the rate at which energy is available) is given by the formula

$$P_w = \frac{1}{2}\rho v^3 A \tag{1}$$

Where ρ is the density of air (about $1.225\ \mathrm{kg/m^3}$), v is the velocity in $\mathrm{m/s}$, and A is the cross-sectional are of space (in $\mathrm{m^2}$) under consideration. Normally, A would be the area swept by the blades of a given wind turbine (which may have diameters from a few meters to over forty meters).

The important feature of equation (1) is that it is proportional to the cube of velocity, while the other numbers are constants. This means that if the wind speed doubles, the power in that wind goes up by a factor eight. Therefore, the power (and subsequently, energy) available are very sensitive to wind speed. Power density versus wind speed is shown in Fig. 1.

For example, consider two fictitious sites each with an average wind speed of 5 m/s. At the first site, the wind always blows 5 m/s. At the other site, the wind blows 10 m/s half the time and 0 m/s half the time. At the first site, the power per unit area is always $76.6\ \mathrm{W/m^2}$, so its average power is also $76.6\ \mathrm{W/m^2}$. At the second site, the power per unit is $612.5\ \mathrm{W/m^2}$ half the time and zero the other half of the time. Therefore, the average power is $306.25\ \mathrm{W/m^2}$ at the second site, which is about four times as high as the first site even though they have the same average wind speed. This example shows the importance of detailed, minute-by-minute wind data.

The data gathered is listed in the spreadsheet that accompanies this report (Wiczkowski 2008). An example of a wind speed distribution is given in Fig. 1 below. The average wind speed is about 7 mph, with only a small amount of time spent above 30 mph.

In addition to wind speed, local terrain has a strong effect on performance. The effect of terrain can be accounted for by modification of the ground wind speed. Although it is difficult to accurately gauge the effect of terrain since it is so variable, an acceptable approximation (Master 2004) is available. The velocity, as adjusted for height and terrain, is in (2); v_0 is the velocity measured at a reference height, H_0; H is the height of the wind turbine; and α is a parameter that is used to approximate the effect of terrain.

$$\frac{v}{v_0} = \left(\frac{H}{H_0}\right)^{\alpha}. \tag{2}$$

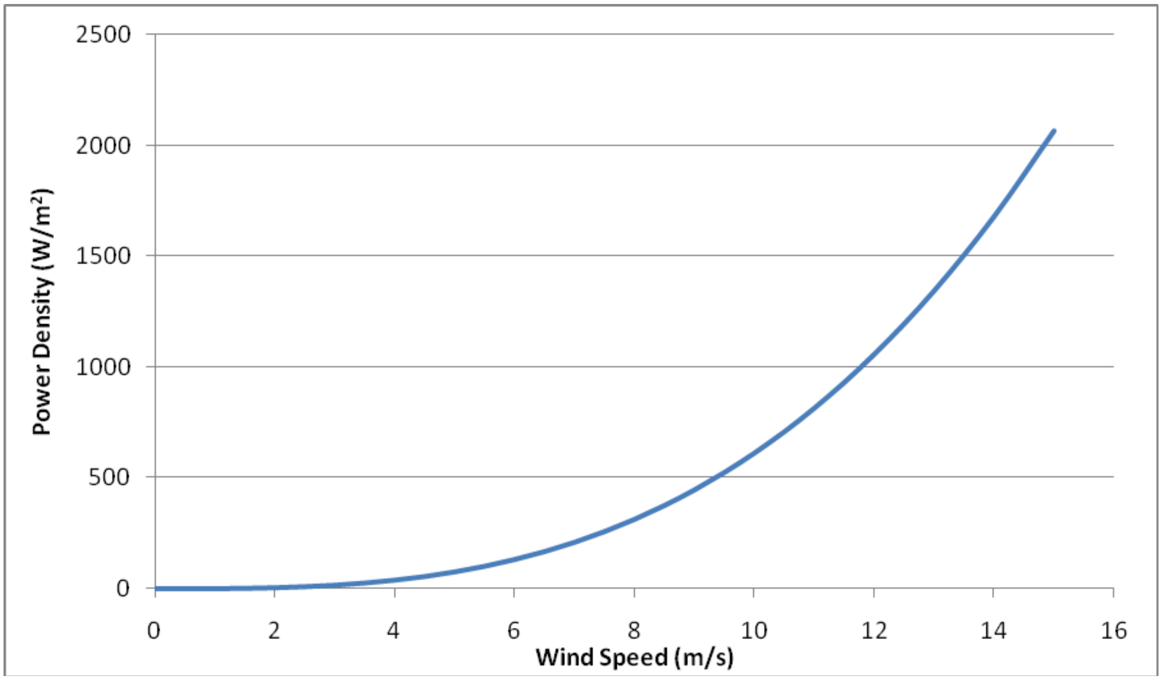

Figure 1. Power density versus windspeed – a cubic relationship.

A table of typical values for α is given by (Masters 2004) and is shown below.

Table 1. Typical Values for a Terrain and Height Velocity Adjustment Factor

Terrain Characteristics	**Friction Coefficient α**
Smooth hard ground, calm water	0.1
Tall grass on level ground	0.15
High crops, hedges and shrubs	0.2
Wooded countryside, many trees	0.25
Small town with trees and shrubs	0.3
Large city with tall buildings	0.4

It is definitely preferable to use measured wind speed performance. However, this is time consuming and costly. The scope of this project is to narrow down the selection of sites and wind turbine choices so that this expense is minimized. For large wind turbine projects, a year or more of field measurements are normally required. For small wind turbines, approximations such as the ones given here should suffice.

An example set of measured data is given in Fig. 2. Therein, the numbers of hours at different ranges of wind speed are graphed for the Silver Lake Rest Area. It can be seen that the wind is often not blowing at all, or is at least below 1 mph. It is possible to model wind patterns with probability functions, but with such measured data, there is no need. A considerable amount of project effort was devoted to downloading and organizing wind speed data so that it could be easily used for performance prediction.

When the data from Fig. 2 are converted to power (using (1)), we can view the power in the wind versus the numbers of hours available. The example for Silver Lake is shown in Fig. 3. Notice that in Fig. 2, the velocity profile peaks around 4-5 mph, but in the power profile of Fig. 3, the peak is much higher at around 17 mph. As such, most of the power that can be harvested occurs at higher wind speeds, even though they are comparatively infrequent. This example reinforces the importance of the cubic relationship of velocity and power and that average wind speed is not necessarily an indicator of power availability.

Based on the power data, we can estimate the energy in the wind. The energy is ultimately what we are interested in since it will translate to the electricity savings. Given a histogram type of data availability as in Fig. 3, the energy in the wind is

$$E_w = \sum_i P_i n_i \qquad (3)$$

where i is the i'th data point for a given velocity v_i, P_i is the power (in kW/m^2) for that data point, and n_i is the number of hours spent in a year at that data point. The result of (3) is the number of kWh/year of energy in the wind. By comparing the energy in the wind with the energy output of the wind turbine, we can measure how effectively the wind turbine has harvested the wind energy.

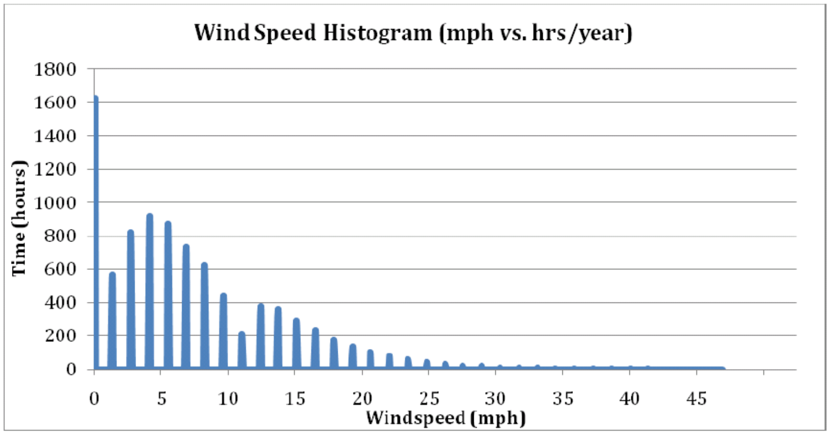

Figure 2. Silver Lake Rest Area wind speed histogram.

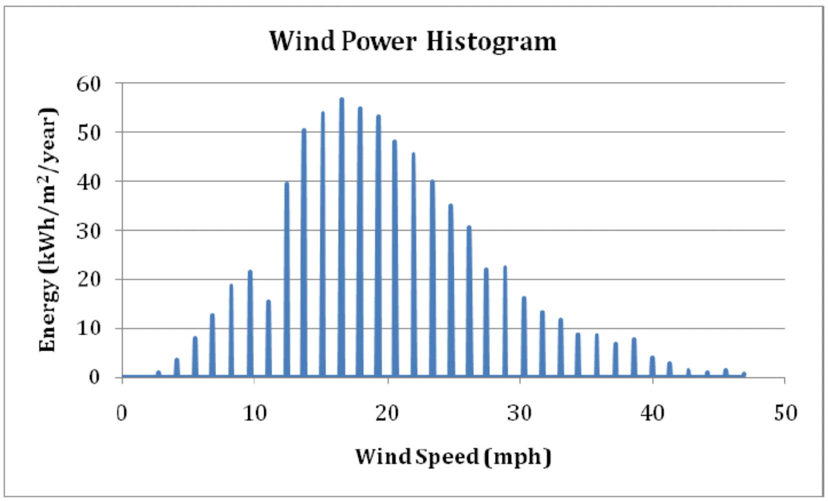

Figure 3. Average wind power, over one year, per square meter versus velocity for the Silver Lake Rest Area.

CHAPTER 3 WIND TURBINES

The power available in the wind is only one aspect in determining the performance of a given wind turbine at a given site. Different wind turbines perform differently with different wind speed characteristics. It is very important to match a turbine to a site to maximize the energy yield.

An example wind turbine (the Bonus 300 kW Mk II) power curve is given in Fig. 4 (Idaho 2008). The low-speed power output is zero or essentially zero. Most wind turbines are designed not to operate at the lowest speeds since there is very little energy available and it would be expensive to build the turbine such that it could produce power at low wind speeds. After this “cut-in” period, the turbine picks up power nearly proportional to the cube of the wind velocity. It would be exactly proportional if it were not for internal power losses in the wind turbine. Eventually, the turbine reaches a speed where the electrical and mechanical stresses prevent further power output and the power versus wind speed is nearly constant. In this constant-power region, many wind turbines actively shed power by turning their blades in order to capture less wind. Finally, at high enough velocities the wind turbine will shut down completely to avoid potential failures. These extremely high winds are powerful, but are so rare that attempting to capture this power is not worth the risk.

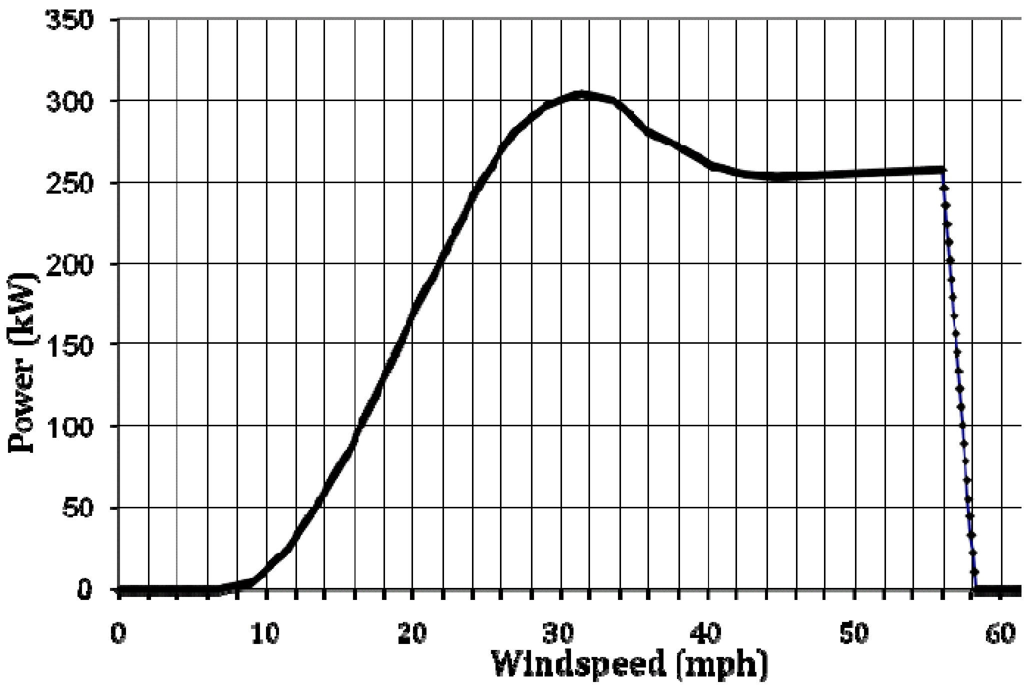

Figure 4. Power output versus velocity for the Bonus 300 kW Mk II (Idaho 2008]).

To determine the energy yield of the turbine, we need to superimpose the velocity histogram with the wind turbine power profile. For example,

$$E_t = \sum_j P_j n_j \tag{4}$$

Where j is the index of the velocity range data point v_j, P_j is the power output (in kW) of the wind turbine at v_j, and n_j is the number of hours per year that the velocity is in the range v_j. The result is the kWh/year that the turbine would produce if a similar pattern of wind were to occur.

We can repeat this process for each site and each available wind turbine to come up with an expected energy yield for each scenario. The energy yield can be divided by the maximum energy of the turbine to determine the capacity factor.

$$CF = \frac{E_t}{P_r \cdot 8760 \text{ hr}} \tag{5}$$

In (5), P_r is the power rating of the wind turbine in kW. Turbines with low CF cannot be expected to be good investments, and likewise, turbines with high CF may be good investments, depending on their prices and maintenance costs. A good CF is considered to be in the 0.3-0.4 range, meaning that the better wind turbines and site conditions harvest about 30%-40% of the maximum energy the turbine could produce in a constant, high-speed wind. Note that the CF depends a lot on the correct matching of a turbine to a site, so a low CF is not necessarily an indicator that the turbine itself is poor.

We gathered data from the major wind turbine manufacturers so that we could evaluate the energy yields of each at various IDOT sites (Idaho 2008). These data were placed in spreadsheets that were used to generate economic data below.

CHAPTER 4 ECONOMIC ANALYSIS

Regardless of energy yields, the most important issue with wind turbines is their return on investment. The simplest way to measure the economic performance of a wind turbine is to calculate the levelized cost of energy (LCOE). The LCOE is an average cost of the energy produced by the energy system (in this case, a wind turbine) calculated over a period of time (usually the lifetime of the turbine).

The cost of the energy must include the initial capital cost of the turbine, the operations and maintenance expenses, the cost of the money (interest rate on loan or lost interest on other investments), inflation, cost growth of grid-based electricity, and lifetime of equipment. Based on this information, we can calculate the LCOE of both grid-based electricity and the electricity provided by the wind turbine (Masters 2004).

In this project, we were forced to make several assumptions in computing these costs. Without the intent to purchase, it is generally impossible to get accurate quotations on wind turbine equipment, installation, and maintenance. The price of the wind turbine alone depends on many factors, including the overall microeconomic environment (current supply and demand for turbines), transportation costs, labor costs, and other aspects that can be negotiated. We must also assume certain interest and inflation rates. We decided to provide the analysis in a spreadsheet that could be easily modified to correct these assumptions if better information becomes available. Table 2 contains a list of the specific assumptions used in this project. A typical page from the LCOE spreadsheet is shown in Fig. 5.

We used $2000/kW as the typical price of wind turbines (Danish 2008) as a starting point for the analysis. It is generally true that larger turbines cost less per kilowatt than smaller turbines. However, at certain sites only small turbines may be feasible. In addition, there has been recently high demand for large wind turbines and major manufacturers such as Vestas and General Electric have been only willing to deal in large orders.

Table 2. Financial Assumptions Used in This Project

Parameter	**Assume Values**
α	0.2
Electricity Cost	0.10 $/kWh
Dollar Inflation	3.00 %
Electricity Cost Inflation	5.00 %
O&M Cost	2.00 %
Cost/kW Installed	1000-2000 $/kW
Lifetime	20-25 years

Illinois Department of Transportation Wind Power Feasability Study

Site Type	Site	
Rest Area	1 Massac	Import Site Data

Turbine Producer	Model	
Bergey	BWC1	Import Turbine Data

Terrain Characteristics

High crops, hedges and shrubs (Use if type is General Illinois)

Estimated kWh Usage at Site:	143,980	kWh
Estimate kWh Production:	223	kWh
Turbine Rating	1	kW
Total Estimated Cost	$2,000	Dollars
Self Funded Amount	$2,000	Dollars
Loan Amount	$0	Dollars
Annual Interest	6.00%	Percent
Length	1	Years
Payment Periods	12	Months x Years
Monthly Rate	0.50%	Percent
Monthly Payment	$0.00	Dollars
Total Interest Paid	$0.00	Dollars
Operations and Maintenance Cost	2.00%	Percent
Electricity Cost Growth	5.00%	Percent
Inflation	3.00%	Percent
Current Electricity Price	$0.10	Dollars/kWh
Cost Per kW Installed	$2,000.00	Dollars/kW
Lifetime	25	Years
Levelized Cost of Electricity	**$0.1861**	Dollars/kWh
Levelized Cost of Wind Turbine	**$0.4830**	Dollars/kWh
Levelized Annual Cost Savings	($66.29)	Dollars/year

Figure 5. Example output of the LCOE spreadsheet.

In the particular example shown Fig. 5, the site and wind turbine are chosen at the top. The turbine output (per year) is estimated and can be compared to the total electricity usage at the site (this information as provided by IDOT for the rest areas). It was assumed that the turbine was paid for with cash, and the cost of lost investment on that cash was neglected. The dark green areas were filled in with user-defined variables, as discussed above. The LCOE results are shown at the bottom. In this case, the LCOE for the wind turbine was $0.48/kWh, well above the $0.19/kWh for the utility grid. Note that the utility grid LCOE is much higher than today's price of around $0.10/kWh to $0.11/kWh. This is due to the inflation of electricity prices and the averaging of the price over the 25-year lifetime.

Also note that the expected production of the wind turbine is 223 kWh/year, so this LCOE difference ($0.48/kWh - $0.19/kWh) can be applied to the 223 kWh/year of production to get the net benefit per year. In this case, this difference is $66.29 in favor of the utility grid, meaning that $66.29/year would be paid as a premium over conventional electricity.

This analysis can be repeated easily for any other location and wind turbine available.

CHAPTER 5 SELECTED LCOE RESULTS

In this chapter, we summarize some of the findings that can be obtained from the data, the energy analysis, and the financial analysis. In the first experiment, we hold the wind turbine equipment and price constant and vary the site to see which sites look promising for one particular turbine. We used prices of $1000/kW, $1500/kW, and $2000/kW for three separate runs. The Bonus 300 kW Mk II was chosen for this first study. The financial assumptions were as in the previous chapter, except a 20-year lifetime was considered.

The LCOE results for the rest areas are shown in Table 3. The best choices for rest areas would be Willow Creek, Railsplitter, Limestone, and Main Line Station, all having LCOE of around $0.20/kWh using the stated assumptions. These sites would be worthy of more investigation. Note that absent better information, a terrain parameter of $\alpha = 0.2$ was used.

Table 3. Rest Area LCOE Results Based on Bonus 300 kW Mk II Turbine

Rest Area	Levelized Cost ($/kWh) at 1,000 $/kW	Levelized Cost ($/kWh) at 1,500 $/kW	Levelized Cost ($/kWh) at 2,000 $/kW
1 Massac	0.5334	0.8001	1.0668
2 Willow Creek	0.0994	0.1491	0.1988
3 Homestead	1.4767	2.2151	2.9534
4 Coalfield	0.3902	0.5853	0.7804
5 RailSplitter	0.1148	0.1722	0.2296
6 Funks Grove	0.2669	0.4004	0.5338
7 Limestone	0.0878	0.1317	0.1756
8 Trail of Tears	0.3274	0.4911	0.6548
9 Rend Lake	0.5849	0.8774	1.1698
10 Post Oak	0.3193	0.4790	0.6386
11 Green Creek	0.5451	0.8177	1.0902
12 Illini Prairie	1.4526	2.1789	2.9052
13 Main Line Station	0.1113	0.1670	0.2226
14 Prairie View	0.2444	0.3666	0.4888
15 Gateway	0.1705	0.2558	0.3410
16 Goshen Road	0.2914	0.4371	0.5828
17 Skeeter Mountain	3.4223	5.1335	6.8446
18 Silver Lake	0.3902	0.5853	0.7804
19 National Trail	0.5451	0.8177	1.0902
20 Cumberland Road	0.4936	0.7404	0.9872
21 Pride of the Prairie	1.0175	1.5263	2.0350
22 KrisdalaBaka	0.7266	1.0899	1.4532
23 Spoon River	1.6433	2.4650	3.2866
24 Mackinaw Dells	0.5695	0.8543	1.1390
25 Farm Land	0.1309	0.1964	0.2618
26 Salt Kettle	1.0256	1.5384	2.0512
27 Mississippi Rapids	0.1424	0.2136	0.2848
28 Great Sauk Trail	0.5599	0.8399	1.1198
29 Three Rivers	0.5097	0.7646	1.0194
30 Turtle Creek	0.3429	0.5144	0.6858

Likewise, the LCOE results can be obtained for weigh stations as shown in Table 4. The most promising locations were Villa Park, Bolingbrook, Compton, Sheldon, and Williamsville, all in the range of $0.20/kWh to $0.24/kWh for LCOE with a $2000/kW price.

Table 4. Weigh Station LCOE Results Based on Bonus 300 kW Mk II Turbine

Weigh Station	Levelized Cost ($/kWh) at 1,000 $/kW	Levelized Cost ($/kWh) at 1,500 $/kW	Levelized Cost ($/kWh) at 2,000 $/kW
1 Rosecrans	0.1476	0.2213	0.2951
2 Harvard	0.1620	0.2431	0.3241
3 Villa Park	0.1062	0.1593	0.2124
4 Carlock EB	1.1099	1.6648	2.2197
5 Richmond	0.1663	0.2494	0.3326
6 Bolingbrook SB	0.1062	0.1593	0.2124
7 East Moline EB	0.3228	0.4841	0.6455
8 Chicago Heights	0.4726	0.7089	0.9452
9 Wadsworth	0.1476	0.2213	0.2951
10 Frankfort WB	1.4817	2.2225	2.9634
11 Compton	0.1115	0.1673	0.2231
12 Moline WB	0.3228	0.4841	0.6455
13 Peotone NB	0.2444	0.3666	0.4887
14 Marion NB	0.3988	0.5981	0.7975
15 Brownstown EB	1.6192	2.4287	3.2383
16 Bolingbrook NB	0.1062	0.1563	0.2124
17 Sheldon	0.1172	0.1758	0.2344
18 Marion SB	0.3988	0.5981	0.7975
19 East Moline WB	0.3228	0.4841	0.6455
20 Pittsfield	0.2354	0.3531	0.4708
21 Marshall WB	0.1948	0.2923	0.3897
22 Moline EB	0.3228	0.4841	0.6455
23 Peotone SB	0.2444	0.3666	0.4887
24 Carlock WB	1.1099	1.6648	2.2197
26 Frankfort EB	1.4817	2.2225	2.9634
28 Crossville	0.1859	0.2789	0.3718
30 Ware	0.2062	0.3094	0.4125
31 Maryville WB	0.1705	0.2557	0.3410
32 Litchfield	0.1279	0.1919	0.2558
34 Williamsville SB	0.1153	0.1729	0.2306
35 O'Fallon EB	0.1705	0.2557	0.3410

As for the numerous team section buildings, we did not have comprehensive data on their locations so a detailed study was not possible. However, we can provide some general results based on wind speed classes (US DOE 2008a). An Illinois wind map from [US DOE 2008a] is given in Fig. 6. It shows that the majority of the state has “marginal” (13.4 mph average speed) or “fair” (15 mph average speed) potential for wind energy. Some of the state is “good” (16.25 mph average) and the rest is “poor” (6.5 mph average).

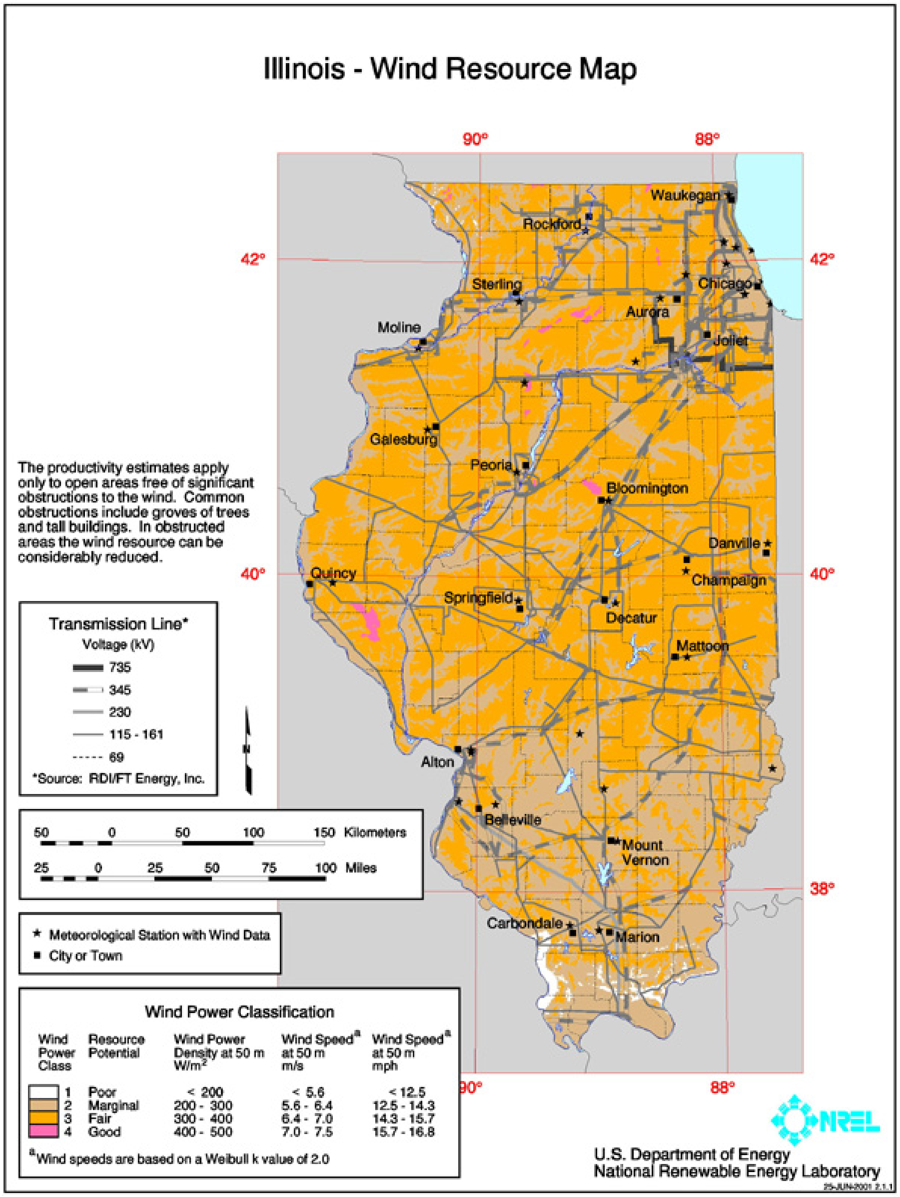

Figure 6. Illinois wind map (US DOE 2008a).

Table 5 shows estimated LCOE based on these categories and the financial assumptions used above. The wind profiles are estimated from Rayleigh statistics (Master 2004) and the wind turbine is assumed to be the same Bonus 300 kW Mk II. From this table, we see that first, the LCOE data are much better overall than was calculated based on more specific data. The discrepancy can be traced to the assumption of Rayleigh winds, which are an idealization of wind profiles. More accurate results can be estimated from choosing the rest areas and weigh stations that are nearest the team section building of interest. However, the numbers in Table 5 do give us an indication of priority, that is, we should focus mainly on “fair” and “good” sites.

Table 5. LCOE Based on Rayleigh Statistics for Illinois Wind Categories

General Illinois	Levelized Cost ($/kWh) at 1,000 $/kW	Levelized Cost ($/kWh) at 1,500 $/kW	Levelized Cost ($/kWh) at 2,000 $/kW
1 Poor (6.5 mph average)*	3.2204	4.8306	6.4408
2 Marginal (13.4 mph average)*	0.0943	0.1415	0.1887
3 Fair (15 mph average)*	0.0676	0.1014	0.1351
4 Good (16.25 mph average)*	0.0546	.0818	0.1091

CHAPTER 6 SELECTION OF WIND TURBINES

For the sites with the most wind potential, it is important to pick the right turbine for both energy harvest and site considerations. It is well known that larger projects are generally more economical in terms of upfront costs. However, in terms of LCOE this only follows if large wind turbines are well matched to the wind resource available.

Fig. 7 shows a sample comparison of two wind turbines: the Bonus 300 kW Mk II (300 kW) and the Bergey BWC 1 (1 kW). We can see that the larger wind turbine has lower capacity factor at every site. Therefore, even if the larger turbine has a lower $/kW installation cost, its LCOE may be significantly lower if its energy yield is not strong. In general, large wind turbines (from 100 kW and up) are designed only to be used in the most favorable wind conditions. They are used primarily to generate a return on investment, so there is typically no availability of satisfactory large turbines for the more moderate wind conditions over most of Illinois. Furthermore, the site issues associated with large turbines are more complicated and can be prohibitively expensive. For example, a typical rest stop or weigh station will not have a sufficient electrical service to handle a full 300 kW of back fed electric power, in the case of the 300-kW turbine. In addition, turbines require relatively tall towers (preferably at least 50 ft – 100 ft) and also have many safety considerations that impact the location of the turbine. Even a small turbine can require as much as one acre of land to have the appropriate clearances. A large turbine will almost certainly require a three-phase power connection.

Small wind turbines (less than 100 kW), on the other hand, are generally better matched to moderate wind conditions such as those found over most of Illinois. This means that their CF will be higher and that the site construction will be considerably easier. The available electric service is also important. A single 10-kW turbine can produce as much as

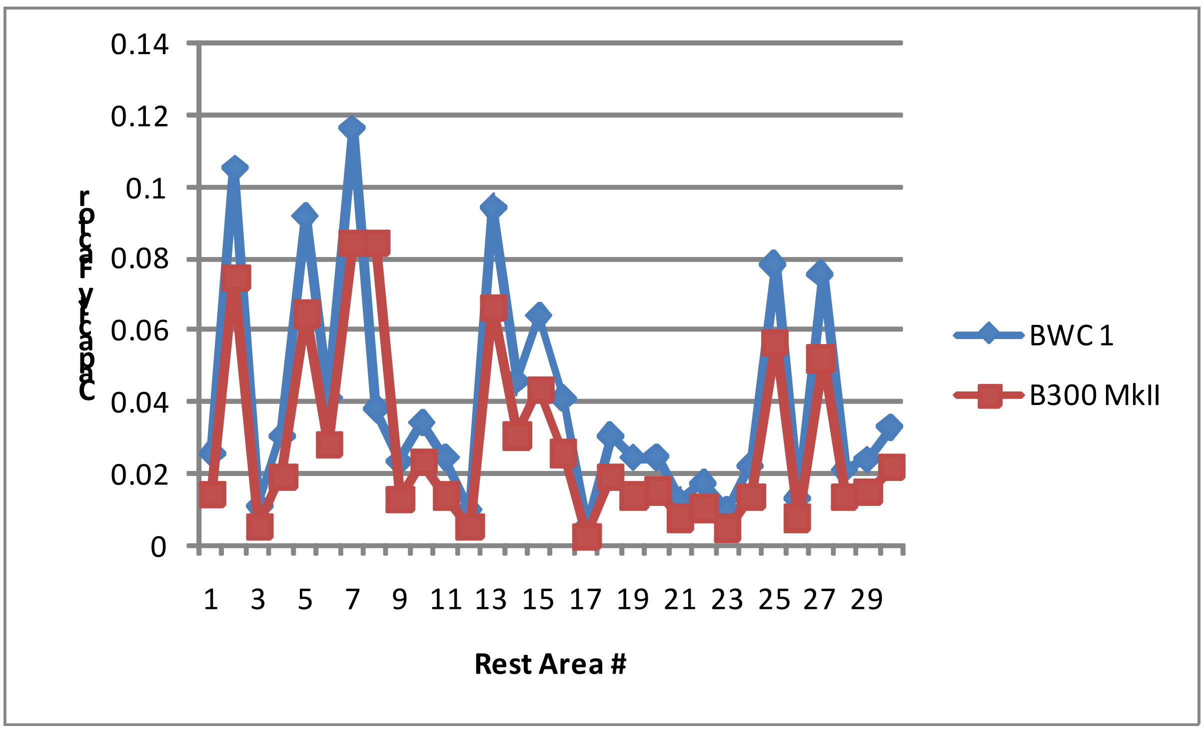

Figure 7. Comparison of capacity factor (CF) for the Bonus 300 kW Mk II and Bergey BWC 1 wind turbines for all rest areas (1-30).

45 A into the service panel. While this current negates the load current seen by the main breaker, it can increase the current on the bus bars inside the service panel. Therefore, site construction will need to consider the National Electric Code (NEC) and whether or not an electrical service upgrade is needed. The cost of this upgrade would need to be factored into the upfront cost of the wind turbine and would adversely affect LCOE. However, if the project is small, it is not likely an upgrade will be needed. As a rule of thumb, the current rating (amps) of the equipment can be as much as 20% of the service panel rating. Therefore, a 10-kW turbine would require a 200-A to 250-A electrical service, which is quite reasonable as this is the range of a typical household.

CHAPTER 7 SUMMARY AND CONCLUSIONS

This report considered the feasibility of using wind turbines at IDOT facilities. It used systematic methods to obtain detailed wind data from which the energy performance of commercial wind turbines could be predicted. The authors provided a spreadsheet loaded with the rest stop and weigh station data so that these specific sites could be considered quickly and overall choices can be narrowed down.

The LCOE and capacity factor of wind turbines were used to evaluate each site, based on a 20-year life. The LCOE of the utility grid was about $0.18/kWh, based on an average electricity price of $0.11/kWh (according to the Energy Information Administration). If a turbine cost of $1500/kW could be achieved, then we can make our recommendations based on comparison of the LCOE of the turbine to the LCOE of the utility grid. If the LCOE of the turbine was less than that of the grid (or within one or two cents), then the site was counted as favorable. Sites with slightly higher LCOE were considered marginal and worth further consideration based on more nebulous factors such as educational value, public relations, carbon emission reduction, etc.

The best rest areas for wind production were 2, 5, 7, and 13. Rest areas 14, 15, and 27 would be worth further consideration. The other rest areas seem to have a very high cost premium and are not recommended. Weigh stations 3, 6, 11, 16, 17, and 34 were considered favorable. Weigh stations 1, 2, 5, 9, 13, 20, 21, 23, 28, 30, 31, 32, and 35 were considered marginal. The other weigh stations were not recommended.

The LCOE results were based on the assumption that the state would bear the entire upfront cost. While this is the true measure of wind turbine feasibility, programs exist, such as the Illinois Clean Energy Community Foundation or others (DSIRE 2008), that could potentially subsidize some of the cost. A significant cost reduction due to subsidy could make the feasible areas very attractive and the marginal areas feasible. However, these results were also based on the assumption of price of around $1500/kW. Therefore, the results could change significantly based on actual price quotes, site surveys, and negotiation, which were all beyond the scope of this report.

In addition to the selection of favorable sites, this report addresses the choice of wind turbines. It was concluded that small wind turbines would have two advantages in terms of LCOE. First, they are better matched to the fair-to-good wind conditions in Illinois and therefore have a higher capacity factor than larger turbines. Second, they can more readily interface to a standard, single-phase electrical panel without need for a service upgrade. Third, they are relatively small and site construction would be more straightforward. The Bergey brand wind turbines had the best capacity factor of the small wind turbines.

The disadvantage is that simply because these turbines are smaller, comparatively little electricity would be generated, even if the return on investment is better. For example, at the Limestone rest area, a Bergey BWC10 would generate about 6,700 kWh of energy, but according to bills provided by IDOT, the site used about 383,000 kWh of electricity in one year. Since Limestone was one of the more favorable sites, it appears that small wind turbines are not feasible for zeroing the electric bill. Unfortunately, the larger wind turbines (at least 500 kW or larger), which could be chosen to zero the electric bill, will not have the same return on investment. Generally speaking, large wind turbines become economical in large, wind-farm arrangements with ideal site selection.

The final recommendation is that the favorable sites (listed above) be reviewed for possible consideration of one or more small wind turbines. This review would include a site survey to assess the terrain (trees, shrubs, crops, etc.), available space, and available electric service. Next, the IDOT would need to obtain all-inclusive quotes on the wind turbines, preferably based on an order of multiple wind turbines to do all sites at once. The exact quotes would then be used with the LCOE spreadsheet provided with this report to reassess the LCOE. It is also recommended that the IDOT request an LCOE analysis from the wind turbine companies to confirm the calculations before proceeding with an order.

The decisions should also consider the educational and public outreach value of the proposed projects (Eggink 2007). Every day, many travelers would pass by and view the rest stops and weigh stations. This could reinforce the importance of renewable energy and instill a perception of Illinois as a leader in renewable energy. While these factors are difficult to quantify, many companies (e.g. Google and Wal-Mart) already have public relations campaigns associated with their “green” efforts.

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