Energy Trust of Oregon

Analysis of Small Wind Program Energy Generation

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ABSTRACT
Meter readings from past small wind participants were analyzed to determine the accuracy of pre-installation energy generation estimates. Meter readings were normalized to account for seasonal and annual variation in wind speed. On average, the sites studied generated only 48% of the amount of energy forecasted on their Energy Trust incentive application. This reflects a percent error of 157%.

INTRODUCTION

Energy Trust provides financial incentives to residential and commercial customers installing qualified small wind turbine systems through a trade ally contractor. To qualify, sites must have an estimated annual hub-height wind speed of 10 mph or greater. Annual wind speed estimates from a wind resource map at 30 m or 50 m heights are scaled to hub-height using a power law conversion and a shearing coefficient. From 2008 to current, 31 of these projects have been funded and installed throughout the state. In 2010, an additional financial incentive was added for projects choosing to enroll in the newly created wind monitoring program. Enrollment in this program requires customers to provide Energy Trust with monthly energy production readings and average monthly wind speed measurements. The wind monitoring program was created to assess the accuracy of the wind resource map and shearing coefficient. A survey was conducted recently to obtain meter readings from the small wind program participants not enrolled in the wind monitoring program.

NORMALIZATION METHOD

Meter readings were adjusted to account for variations in wind speed by using National Oceanic and Atmospheric Association (NOAA) weather data from the Portland International Airport (reference site) for the past 10 years. The airport was chosen as the reference site because of the availability of historical data. The wind characteristics of the airport are different than those of the wind turbine sites. Typically, locations for airports are selected to be protected from the wind. Even though the wind speeds at the airport will be lower than those at the turbine sites, it is assume that they are correlated. This means if the wind speed for a given sample period at the airport is less than that of the long term average at the airport then the measurement taken at a correlated sample site during that same period should be proportionally less than the long term speed at the sample site. This relationship is used to adjust the observed energy meter reading, $E_{ob}(P_i)$, for variations in wind speed. $E_{ob}(P_i)$ is multiplied by the ratio of the average wind speed at the reference site over 10 years, $V_R(P_A)$, to the average wind speed at the reference site during the sample period, $V_R(P_i)$. The output of this equation, $E_{ob}(P_A)$, is the expected output from the sample site during the sample period with annual and seasonal variations removed.

$$E_{ob}(P_A) = E_{ob}(P_i)\frac{V_R(P_A)}{V_R(P_i)} \qquad (1)$$

$E_{ob}(P_A)$ is then divided by *t*, the number of days in the sample, to obtain a daily energy output. This daily output is multiplied by 365 to get E_{norm}, the annual output that is adjusted for seasonal and annual changes.

$$E_{norm} = \frac{E_{ob}(P_A)}{t}(365) \qquad (2)$$

GENERATION ANALYSIS

During the recent survey of past small wind program participants, meter readings were obtained from nine projects that have been installed longer than six months. These readings, along with previous meter readings and initial readings from the post-installation inspection, were used to determine the accuracy of pre-installation energy generation estimates. On average, these sites generated 51% of the annual energy output originally estimated on their Energy Trust incentive applications. Table 1 displays the data from these sites. Each sample represents one year. Sites with multiple years of data were separated into multiple samples.

TABLE 1—ENERGY GENERATION FROM SMALL WIND SITES WITHOUT WIND MONITORING

Sample Number	Site	Date	Normalized Annual kWh Production (E_norm)	Estimated on Incentive Form (kWh)	Normalized Annual is __% of Estimated	% Error
1	A	6/28/2011	8812	19782	44.5%	124.5%
2	B	5/31/2011	14270	26100	54.7%	82.9%
3	C	6/22/2011	540	2700	20.0%	400.2%
4	D	6/22/2011	1331	2590	51.4%	94.6%
5	E	9/9/2009	2195	2500	87.8%	13.9%
6	E	9/10/2010	1751	2500	70.1%	42.7%
7	E	8/29/2011	1932	2500	79.9%	25.2%
8	F	8/7/2009	24591	50000	49.2%	103.3%
9	F	8/7/2010	15823	50000	31.6%	216.0%
10	F	6/25/2011	6797	50000	13.6%	635.6%
11	G	6/29/2011	6461	10000	64.6%	54.8%
12	H	6/28/2011	791	2700	29.3%	241.4%
13	I	7/15/2011	1803	2700	66.8%	49.7%
Average			**6700**	**17236**	**51.0%**	**160.4%**

In addition to these nine projects, the seven sites enrolled in the wind monitoring program with over six months of data were included in the analysis. These seven projects generated, on average, 43% of the annual energy production estimated on their Energy Trust incentive application. The energy generation data from these sites is displayed in Table 2.

TABLE 2—ENERGY GENERATION FROM SMALL WIND SITES WITH WIND MONITORING

Sample Number	Site	Date	Normalized Annual kWh Production (E_norm)	Estimated on Incentive Form (kWh)	Normalized Annual is __% of Estimated	% Error
14	J	7/1/2010	6066	10000	60.7%	64.9%
15	J	9/30/2011	5547	10000	55.5%	80.3%
16	K	5/30/2011	9647	21929	44.0%	127.3%
17	L	6/30/2011	9601	20104	47.8%	109.4%
18	M	9/30/2011	2487	5776	43.1%	132.3%
19	N	9/30/2011	7964	24000	33.2%	201.4%
20	O	6/30/2011	3637	15000	24.2%	312.5%
21	P	6/30/2011	9255	26611	34.8%	187.5%
Average			**6775**	**16678**	**42.9%**	**151.9%**

The average annual wind speeds at these sites were, on average, 65% of the speed estimated on the incentive form. Table 3 contains the wind speed data for each monitored sample site and the Portland Airport reference site during the sample period. The average wind speed at the reference site over the past 10 years, $V_R(P_A)$, was 6.21 mph.

TABLE 3—WIND SPEEDS AT SMALL WIND SITES WITH MONITORING

Sample Number	Site	Average Measured Wind Speed V_ob(Pi) (mph)	Average at Referenc e During Sample V_R(Pi) (mph)	Normalized Wind Speed V_ob(Pa) (mph)	Estimated on Incentive Form (mph)	Normalized Annual is __% of Estimated	% Error
15	J	7.17	5.80	7.67	10.96	70.0%	42.9%
16	K	7.48	6.20	7.49	12.21	61.4%	63.0%
17	L	7.74	6.24	7.70	11.77	65.4%	52.8%
18	M	5.68	5.05	6.99	10.51	66.5%	50.4%
19	N	7.29	5.58	8.11	11.19	72.5%	38.0%
20	O	7.27	5.84	7.73	13.06	59.2%	68.8%
21	P	8.1	6.13	8.21	13.47	60.9%	64.2%
Average		**7.25**	**5.83**	**7.70**	**11.88**	**64.8%**	**54.3%**

The average amount of energy generated in all 21 samples was 48% of the amount of energy estimated on the incentive forms. Several sites have had technical problems which greatly lowered their actual vs. estimated energy generated percentage numbers. Sample 10 had a percent error of 636%, due to the turbine being out of service for most of the year. The same site performed better in the two previous years (samples 8 and 9), but still far below the estimate. Sample 3 had a percent error of 400%. The project owner reported they were unaware of the cause of the low production, but plan to remove the turbine. Sample 12 had reduced output due to a turbine repair that was delayed for six months due to poor weather conditions.

Figure 1 is a graph of estimated production vs normalized annual production. None of the points are above the line of perfect correlation, showing that all sites generated less energy than predicted on their application.

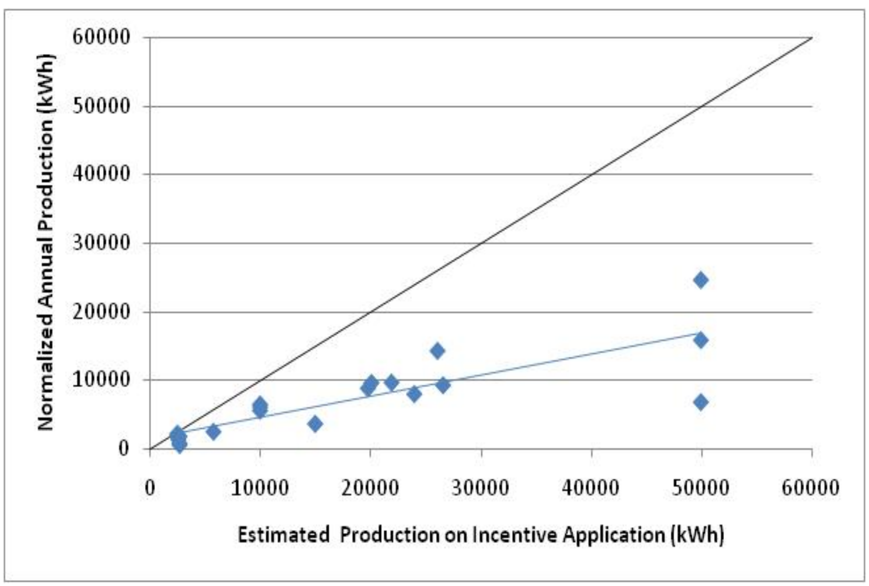

FIGURE 1—ESTIMATED PRODUCTION ON INCENTIVE APPLICATION VS NORMALIZED ANNUAL PRODUCTION. BLACK LINE SHOWS PERFECT CORRELATION, BLUE LINE SHOWS ACTUAL LINE OF BEST FIT.

Figure 2 shows the percent error for each sample. Positive values indicate that the estimated energy generation on the incentive application was higher than the actual amount of energy produced.

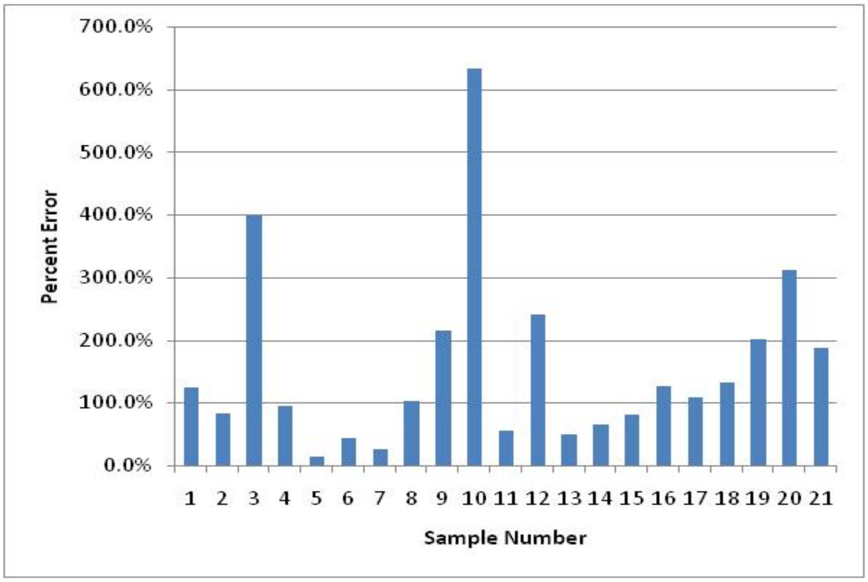

FIGURE 2—PERCENT ERROR FOR EACH SAMPLE

Figure 3 displays the percent error distribution in range categories. The number under each bar on the x-axis represents the maximum of the category, i.e. the bar over 100 shows the number of samples in the 50%–100% error range. It can be seen that the majority of the samples have between 0% and 150% error.

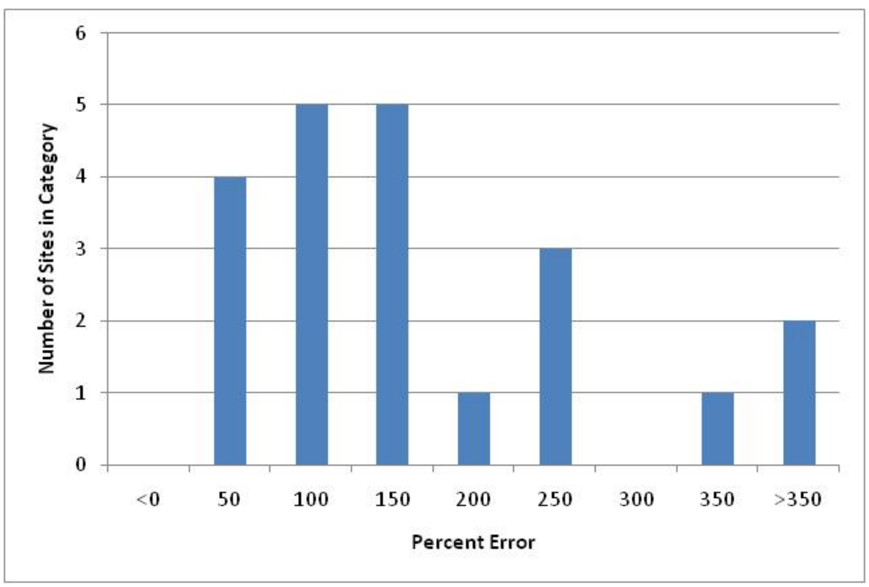

FIGURE 3—PERCENT ERROR DISTRIBUTION

In Figure 4, the distribution of the percent of estimated energy actually generated is displayed in categories. Each category represents a range of 20% with the maximum of the range listed under each bar.

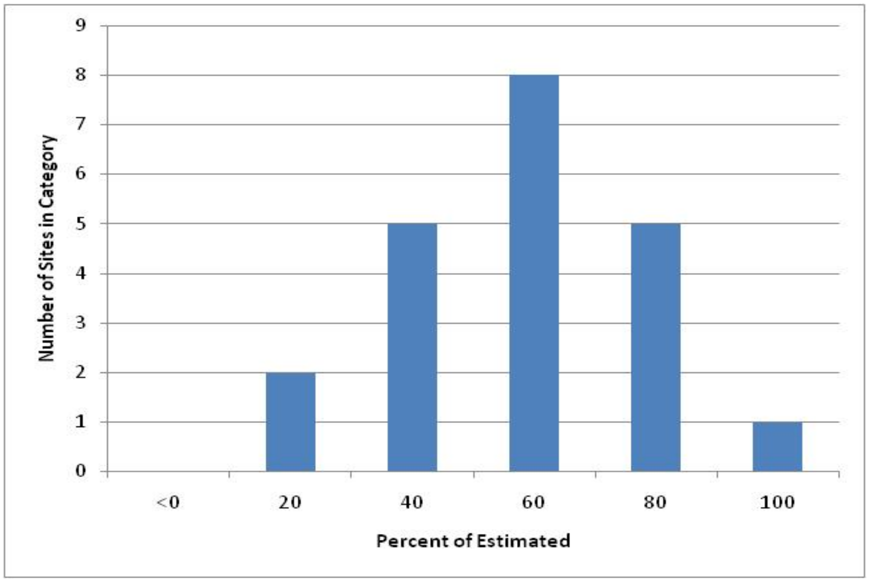

FIGURE 4—DISTRUBUTION OF PERCENT OF ESTIMATED GENARATION ACTUALLY PRODUCED

CUSTOMER SURVEY RESPONSES

Customers were sent a survey via email requesting: a current reading from their net energy meter; any previously recorded readings they had available; and feedback about their level of satisfaction with the installed system. Customers who were not responsive to emails were surveyed over the phone or by conventional mail. Customer responses to the survey were mixed. Some customers were satisfied even though their production values were lower than expected. However, the majority of customers were disappointed with the lower-than-expected production of their systems.

DISCUSSION

Although the sample size is not large enough to be conclusive, it appears that lower-than-estimated wind speeds are a major contributor to the lower-than-estimated annual production numbers. For sites enrolled in the wind monitoring program, the average of the estimated wind speeds on the incentive applications is 11.9 mph. The average measured wind speed at these sites for the recorded period is 7.7 mph. This is a very large discrepancy; the actual average wind speed at these sites is on average only 65% of the estimated speed. This difference is amplified in the energy generation because of the cubic relationship of wind speed to power available in the wind.

$$P = \frac{1}{2}\rho A V^3 \qquad (3)$$

Where P is available power, ρ is air density, A is the swept area, and V is the wind speed. This amplification of error explains how the 54% error in wind speed estimation can result in a 152% error in the energy generated from those sites. Note that Equation 3 is for the power available in the wind and that the actual power generated, while related to Equation 3, is dependent on the power curve of each individual turbine.

Recommendations

Use other methods to determine or adjust wind speeds

It is clear from the findings in this report and in the *Evaluation and Adjustment of Wind Resource Map Estimates for the Pacific Northwest* by Phil Barbour that using the current Energy Trust wind resource map as the sole method of determining wind speeds for a site is highly inaccurate and has a tendency to overestimate wind speeds. This results in overestimation of energy production and, ultimately, unsatisfied customers.

Steps already taken

Energy Trust has implemented rigorous site characterization standards that should help to reduce the wind resource map errors. Since April 2011, sites have been required to de-rate the effective hub—height wind speed based on surrounding macro and micro terrain conditions and localized obstructions. Prior to April 2011, a shear exponent of 0.14 was uniformly used to adjust wind speeds from reference height to hub height. This value is now determined based on the characteristics of the site vegetation and is usually between 0.2 – 0.4. Displacement height from dense obstructions and elevation variations is taken into consideration. A turbulence intensity adjustment is also made to the final generation estimate, based on the proximity and magnitude of on-site obstructions.

These factors should improve the accuracy of hub height wind speed estimations and energy generation estimations. Since these requirements were implemented recently, sites affected by these changes do not have enough data to be included in this report.

Conditional Error Adjustment

Barbour presents a conditional error adjustment method in his report as a possible solution to the inaccuracies of the wind resource map. In this method, hub height wind speeds are reduced by an error factor that is determined by the characteristics of the site. Results from the sample sites in Barbour's report look promising and greatly reduce the error in the wind resource map estimates. However, a possible problem with this solution is that it is somewhat subjective. If this method is used by someone with less knowledge of meteorology than Barbour (who holds a masters degree in atmospheric sciences) the results may not be as accurate.

Micro-Siting

Another possible solution would be to use software or a service that does small wind micro-siting using fluid dynamic modeling. This method would serve the same purpose as the conditional adjustment method by making adjustments to the wind map speed using information about the site, but it is less subjective and more analytical. An advantage of micro-siting over other methods is the ability to determine the best location for the turbine at a proposed site based on the fluid dynamic model of the local terrain and obstructions. There is much less guesswork involved in how a change to tower placement or height will affect the wind speed.

On Site Wind Measurement

The most accurate solution would be to install an anemometer at the exact location of the future turbine to record a year of wind speed data. It is possible to do a site analysis based on as little as four months of data, but six months to a year is recommended. Due to the year-to-year variability of wind resource, even a year of data may not provide a good representation of the long term wind characteristics at a site. Average annual wind speeds can vary up to 25% at a given site from year to year (Gipe, 2004). Since it is not practical to record 10 years of data, the same method used in the normalization section can be used to create a long term average wind speed for a site based on comparing short term measured data to long term data from a reference site.

Although this method will likely produce the most accurate energy production estimates because it is based on actual on-site measurements, there are several disadvantages as well. This method costs more and is more time consuming than others. The equipment requires careful installation and calibration by experienced professionals, and the collected data must be analyzed before it can be used. Missing data, due to equipment malfunction and data storage and collection problems, is a common problem. Also, the measured data is only for one specific location. Therefore, the turbine sitting must be known prior to testing. For the most accurate estimates of energy generation, measurements should be done at the proposed hub height of the turbine. If the anemometer is located lower than the proposed hub height, a power law conversion must be done which requires an accurate estimate of the shear exponent.

COMMUNICATION

Another important factor is to communicate to customers the inaccuracies in whichever wind speed estimation method is being used. The purchase and installation of a small wind turbine is a big investment. Prior to investing in a system, customers should understand that the wind speed used is only an estimate and that, in addition to potentially large annual variations in wind speed, there is always a possibility that the estimate is inaccurate.

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