THE
CADMUS
GROUP, INC.

Progress Report on Small Wind Energy Development Projects Receiving Funds from the Massachusetts Technology Collaborative (MTC)

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Executive Summary

This document outlines the status of MTC funded small (10 kW or less) wind projects. Energy production data is examined by equipment make/model and installer to look for trends in performance. The primary metrics used for comparison in this document are capacity factor and relative production. Relative production is estimated by dividing the actual energy output of the system by the installer's estimate, as provided in the MTC grant application. This gives a sense of both the actual turbine output, normalized to equipment, but also the accuracy of the installers' estimates of energy output. Based on these preliminary data:

- The average capacity factor for 19[1] existing small wind turbines currently installed and reporting to the Production Tracking System (PTS) is 4%. This is less than half of the target capacity factor of 10%.
- Installers, on average, are significantly overestimating annual energy production. On average installers are overestimating energy generation by a factor of 3 to 4
- The most prolific small wind installer, with 6 installations included in this analysis, is Installer 10. These systems are performing with an average capacity factor of 3%.
- The most commonly installed small turbine, using MTC funds, is the Bergey Excel-S, with an average capacity factor of 4%.
- The cause of the overall poor performance of installed small wind energy systems is not known with complete certainty. Known contributing factors include inverter synchronization/standby time, higher than expected site turbulence, and lower than expected average wind speeds.
- Of the 19 systems analyzed, 16 have been inspected by Cadmus. Of these 16, only 6 were found to meet the estimated 10% capacity factor requirement of the SRI program, based on Cadmus' site survey and use of the SWEET modeling tool.

Equipment Performance

There are a wide variety of wind turbine models installed to date using MTC funds. The breakdown of small wind turbines installed, thus far, using MTC funds is given in Figure 1. Only the 19 systems included in the analysis are included in this chart. A full list of systems installed using MTC funds is available in Appendix A.

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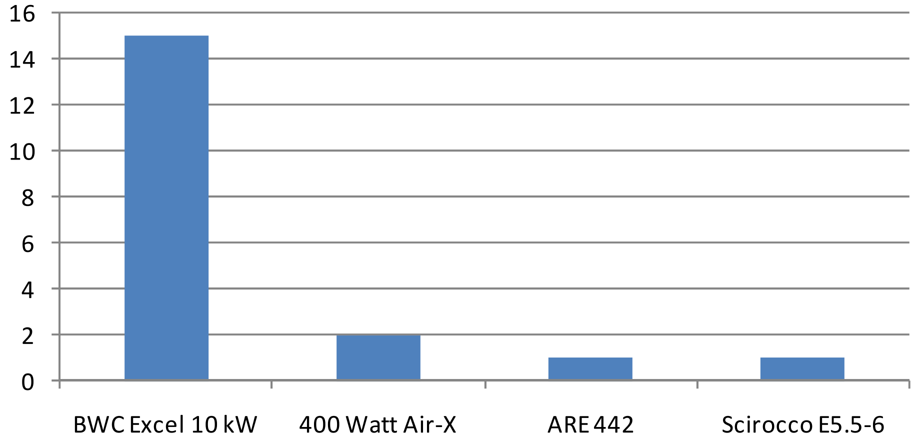
[1] As of this writing, there are 33 small wind systems registered in the PTS. A number of systems had to be excluded for a variety of reasons, as outlined in Appendix A.

Figure 1: Small Wind Equipment Installed Using MTC Funds



Of equipment installed, Bergey Windpower's Excel-S is, by far, the most prevalent model installed, with 15 installations. However, the overall performance of this model was low, with an average capacity factor of just 4% (ranging from 1% to 9%). The best performing turbine model included in this analysis is the ARE 442, a 10 kW turbine, operating with an average capacity factor of 11%. This turbine is installed on Martha's Vineyard, in an extremely windy location, however, so this performance may not indicate a superior turbine - only a superior site. The Eoltec Scirocco, installed in a much more modest wind regime, comes in second, with a capacity factor of 7%. Finally, the worst performing systems currently in operation are two Southwest Air-X turbines. These small battery charging turbines are producing at only an average capacity factor of 1%. The average capacity factor of these, and other turbines, installed to date are shown in Figure 2. Data for the Southwest Skystream may be unrealistically low, at least partly due to a known equipment problem with the Skystream that has effectively stopped production at the Emerson site and may be impacting production at other sites as well. According to Southwest Windpower, a new UL listed replacement part will be available for these systems within the next few weeks and we should see improved output from the Skystreams once those repairs are made.

Figure 2: Average Capacity Factors for Various Small Wind Turbines

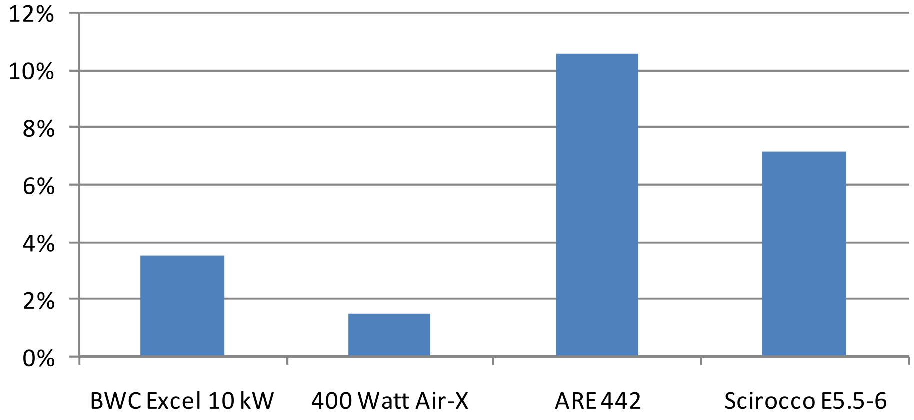
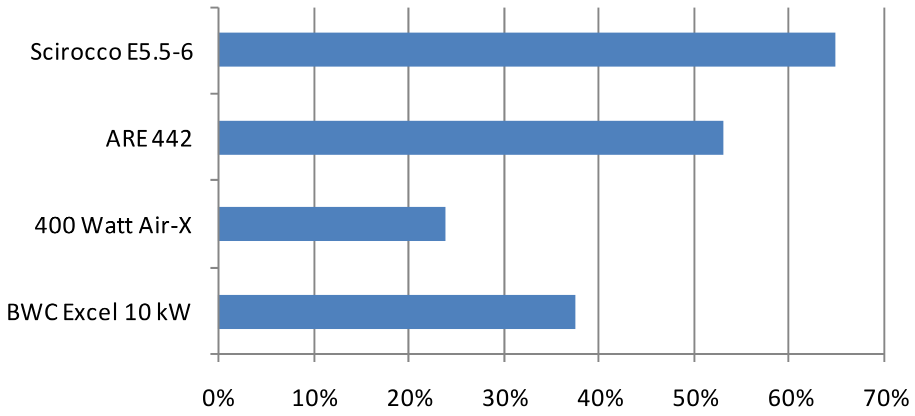


Figure 2 makes no distinction as to the cause of the low energy production and, in many cases, poor site selection, insufficient tower height, or low wind speeds are the driving factors behind lackluster system output. Using the relative production may be a better indicator, based on site surveys conducted by Cadmus.

Figure 3: Relative Production of Small Wind Systems by Turbine Model



The relative production is calculated using the annual[2] energy production of the systems, divided by Cadmus' best estimate of annual energy production. With 12 installations, the relative performance of the Bergey Excel-S remains surprisingly low. At 38% relative production, this indicates that, on average, the Excel is producing only about one third of its predicted energy output. Cadmus' estimate includes roughness and wind shadow impacts from surrounding obstacles, corrected[3] wind speed estimates from the AWS Truewind map, and published power curves. In comparison, estimates completed by installers were less accurate in predicting the output of these small wind systems, with an average relative production of only 27%. Removing one outlying system, installed by a homeowner and performing exceptionally well, reduces this number to only 23%.

Installer Performance

There are currently 10 installers with small wind systems installed and reporting to the PTS. Most of these installers have installed only one or two systems that are currently reporting to the PTS. The most prolific installer statewide is Installer 10, with 6 installations reporting to the PTS, with an average capacity factor of 3%. Interestingly, the best producing system is installed by the system owner, with an average relative production of 81%, as shown in Figure 4. Figure 4 shows, side by side, the accuracy of production estimates completed by the installers, as well as by Cadmus. In Figures 4 and 5, the term "revised" indicates sites where Cadmus has adjusted the wind speed based on available data from RERL. Installer 5 has provided the most accurate energy production estimate, with a single turbine operating on Martha's Vineyard at approximately 58% of their estimated energy output. Other installers typically are typically achieving 20-40% relative production figures, based on the estimates that they provided in the SRI applications.

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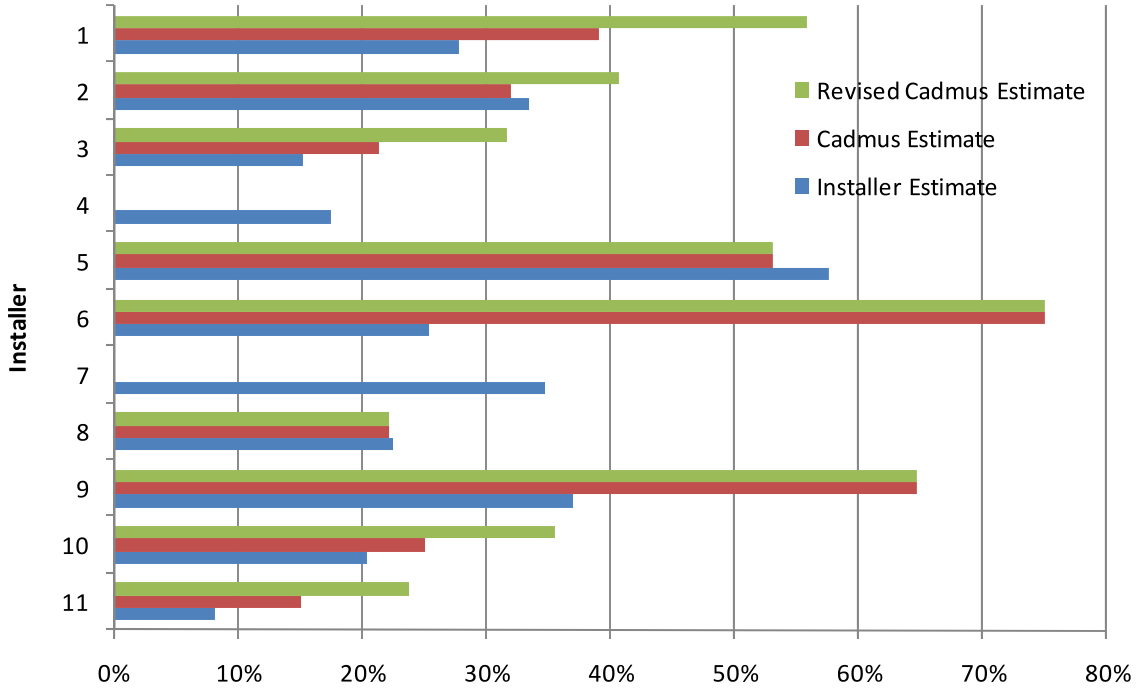
[2] Some systems do not yet have one full year of logged energy production. In these cases, we have applied seasonal weighting factors to extrapolate annual energy production values. This method is typically accurate to within 10% when compared with data from systems which have more than 1 year in service.

[3] For several regions, particularly Cape Cod and the South Coast, the Truewind map appeared to deviate from data collected in recent meteorological studies. For sites in these general areas, an adjustment factor was applied to the Truewind wind speed. This correction factor was determined based on the average difference between measured and wind map wind speeds for one or more sites in each region. See page 5 for discussion of this preliminary adjustment method.

Figure 4: Estimated Energy Production by Installer, Relative to Actual Production of Installed Systems



Causes of Poor Performance

The underlying cause(s) of this poor performance are not presently known with great certainty, however there are several clear contributing factors. Based on our experience inspecting systems, the installers almost universally overestimate annual energy production. Often this overestimation is quite significant. For the sites inspected by Cadmus, an independent energy production estimate is generated based on site conditions and system configuration. However this estimate, while generally more comprehensive than the original estimate by the installer, does not provide a sole explanation of the lower than expected energy output. Figure 5 provides an illustration of relative production for a number of sites inspected by Cadmus over the past several months. In almost all cases, Cadmus' estimate, using the SWEET model, are closer to the observed energy output than the installers' estimates but overall relative production remains at less than 50%. Figure 5 also shows revised estimates based on corrected wind speeds, as discussed below.

This result suggests that site conditions such as terrain roughness and tree cover, as modeled by SWEET, are not the primary driver of the lower than expected energy production. The SWEET model does, we believe, a good job of accounting for tree cover and site roughness but relies on key inputs such as annual average wind speed and the manufacturer's power curve to produce annual energy output estimates. Potential causes of poor production include:

- Accuracy/variability of annual average wind speed
- Accuracy of manufacturer power curve
- Inverter efficiency, standby settings, and power draw
- Greater than expected losses due to site conditions (turbulence/wind shear)
- Other system losses (e.g. wiring/voltage drop, wind speed/direction changes)

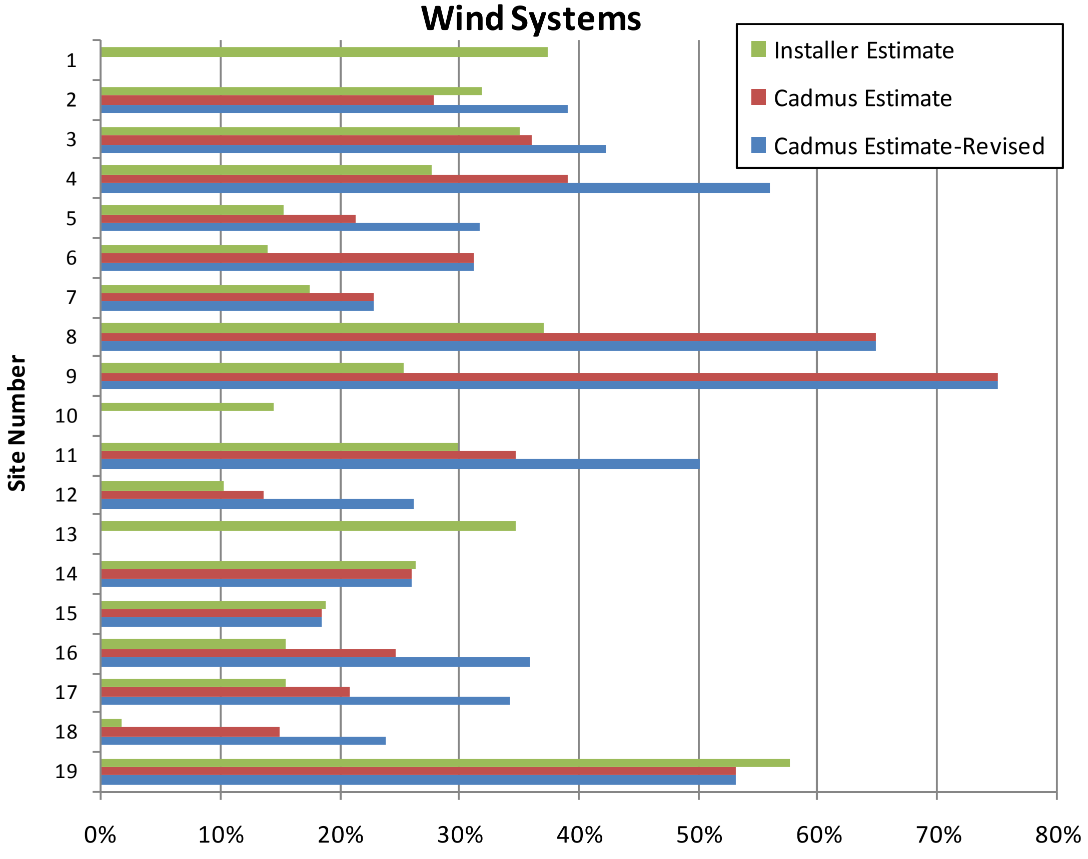
These issues are discussed further below.

Individual System Performance

Figure 5, below, displays the relative production of the 19 small wind systems included in the analysis. Overall, it is clear that installer estimates tend to be significantly less than estimates completed by Cadmus at post-installation site inspections. There may be several contributing factors to this, including a lack of installer education, inclusion of early systems (many of these are first or second time installations for each installer), and systems installed under less strenuous MTC program requirements.

From the data in Figure 5, it can be difficult to draw general conclusions. One general observation that can be made is that estimates tend to be less accurate for systems with shorter towers and/or dense vegetation. For example sites 18, 5, 6, 7, and 12 all have less than the AWEA recommended clearance between hub height and surrounding obstacles. By comparison, systems such as sites 3, 2, 4, 8, 9, 11, and 19 all have hub heights greater than 30 ft above surrounding obstacles. Even at these sites, however, predictions are typically overestimating actual production by as much as 60%. Including an additional margin to account for turbulence intensity can improve these estimates (and will be added to future versions of SWEET), reducing the overestimation to 30-40% for most sites. Discussion with both NYSERDA and Wisconsin Focus on Energy indicate that overestimation is common for small wind systems, particularly those installed in complex terrain, such as is typical in Massachusetts, New York, and Wisconsin.

Figure 5: Energy Output Relative to Predicted for Small Wind Systems



Wind Speed

Of the above, average wind speed has significant potential error (due to siting concerns, wind map inaccuracies, etc.), as well as a large compounding effect on energy output. A small error in the wind speed estimate can result in a very significant impact on energy production. Due to the economic constraints of small wind projects, it is almost never feasible to collect actual wind speed measurements, leaving the various wind maps as the sole means of estimating the available resource.

Fortunately, Massachusetts is blessed with a fairly rigorous set of measured wind speed data, due to the ongoing efforts of the Renewable Energy Research Lab and the MTC Community Wind Collaborative. A preliminary survey of the available wind speed data, based on RERL's measurements, can be compared with the AWS Truewind map to generate a very coarse understanding of how accurate the wind maps might be for various regions of Massachusetts. A preliminary assessment is given in Table 1, for a handful of selected sites.

Location	Anem. Height (m)	RERL Wind Speed (m/s)	AWST Wind Speed (m/s)	Wind Map Correction
Western Mass				
Savoy	50	5.84	5.7	**1.02**
Cape Cod				
Barnstable	30	4.87	5.9	0.83
Falmouth	30	4.98	5.9	0.84
Average				**0.83**
South Coast				
Dartmouth	50	4.8	5.6	0.86
Mattapoisett	50	5.74	6.4	0.90
Scituate	30	4.99	5.7	0.88
Average				**0.89**
North Shore				
Lynn	30	5.53	5.6	**0.99**

From this table, it appears that the wind map may be overestimating wind speeds by 10-20% in the region around the south coast and Cape Cod. This is an important area for small wind project development and, to date, most of the small wind systems installed have been installed in these areas. For other areas of the state, the wind map appears to be consistent with RERL measurements. Unfortunately, even incorporating these adjustment factors into the energy production estimates does not fully account for the poor performance of most systems, as shown in Figure 5.

In addition to potential inaccuracies in the wind speeds estimated by the wind map, which are essentially long-term estimates, there is the possibility that 2007-2008 wind speeds have been lower than long term averages. If this were the case, the poor performance of these small wind systems might be only a temporary phenomenon caused by an unusually calm year and might be expected to improve in future years. To address this, Cadmus has examined long-term wind speed averages for Boston and Falmouth. These two sites have robust sets of long term data, which was compared against measurements taken in 2007. The results of this comparison are given in Figures 6 and 7, respectively.

Figure 6: 2007 Wind Year Comparison with Long Term Average: Falmouth, MA

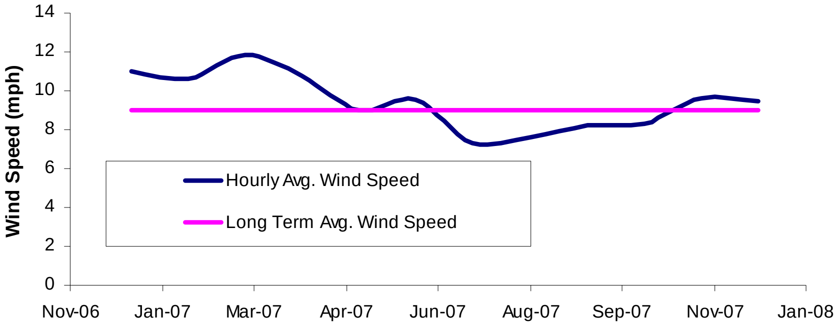
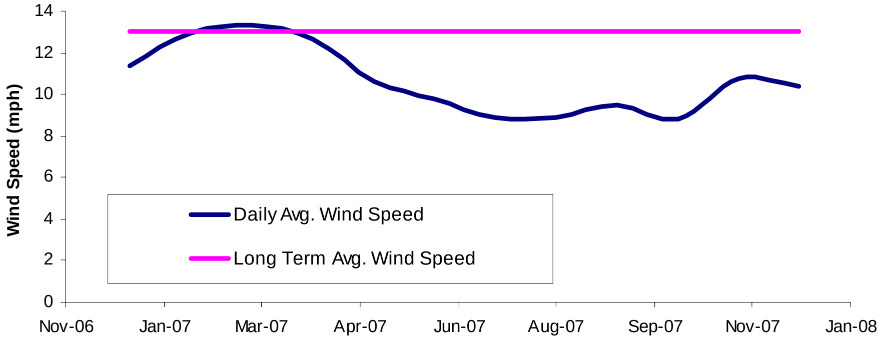


Figure 7: 2007 Wind Year Comparison with Long Term Average: Boston, MA



Unfortunately, examination of wind speed data at these two locations does not provide the needed evidence to suggest that 2007 wind speeds, as seen by the various small wind turbines installed in Massachusetts, were consistently lower than long term averages. In fact, the 2007 wind speeds seen in Falmouth, were actually slightly higher than the long term average. With many of the currently installed small wind systems installed in the Falmouth area, we cannot, from the data presently available, make any generalizations regarding macro scale wind speed impacts on small wind turbine output. Examination of additional station data might shed additional light on this situation but, at this point, the low production of many of the MA small wind systems does not appear to be due to a low wind speed year in 2007.

Accuracy of Manufacturer Reported Power Curves

The SWEET tool, along with every other known estimating method associated with small wind turbines, relies upon manufacturer reported power curves. Unfortunately, the development of these power curves is not as closely regulated as the development of power curves for larger turbines. Standardized test methods are beginning to become available from AWEA and IEC but these standards continue to focus on larger turbines. This leaves small wind turbine manufacturers with a significant amount of latitude in determining their power curves and little has been done to certify these power curves through third party testing. Invariably, these curves should be viewed as marketing pieces, more than stringent engineering test results. At present there is no readily available way to ascertain the accuracy of these curves without further field testing under conditions typical to the northeastern US. Even testing completed, to date, by NREL to verify power curves has focused entirely on very laminar wind flow regimes which may not accurately predict a turbine’s power curves under more turbulent conditions.

Inverter/Equipment Losses

In addition to uncertainty around the manufacturers' power curve data, there is considerable uncertainty around the additional losses associated with wind turbine balance of system (BOS) components. Each inverter/controller includes both standby and active efficiency losses. Typically, inverters are 90-95% efficient, with standby power consumptions generally less than 10 Watts. There can also be additional losses (typically less than 5%) due to voltage drop over long wire runs. These parameters can be relatively easy to quantify, as published data is available from agencies such as the California Energy Commission (CEC) on inverter efficiency/standby losses. What can be more difficult to quantify are losses associated with inverter standby times coinciding with periods of high winds. While initially counterintuitive, in fact, some small wind turbines include controls that put the inverter into standby or monitoring mode when turbine output falls below a certain level. If the wind at a site is particularly gusty, a turbine can go through repeated on/off cycles. In these situations, an inverter may shut down as the wind speed decreases but, depending on its factory set response time, the inverter may remain in standby mode through one or more subsequent gusts. Not only is average wind speed important but it is also important to have wind speeds that remain steadily above cut-in wind speed for the turbine. Winds that vary between 0 and 8 m/s may mathematically average to 4 m/s over the year but will not produce the same energy output as a site with steady 4 m/s winds. Overall, AC energy production should be derated by approximately 10-15% to account for inverter efficiency and standby losses. The losses due to directional variability will require further study to quantify.

Additional Site Losses

In addition to the site losses discussed previously, such as obstacle height, there can be additional effects attributable to site conditions. For example, in cases where obstacles approach turbine hub height too closely, the turbulent effects can cause more than reduced or inconsistent wind speeds but can also cause the apparent direction of local wind to shift erratically. As this wind shifts, most small wind turbines yaw to bring the rotor into line with the wind. As the turbine yaws, its power output is significantly diminished. Therefore, a site where the wind direction shifts considerably, a small turbine might spend a significant portion of the time yawing, rather than producing useable electricity. Typical values for turbulence intensities range from 0.15, for a relatively smooth/open site, to 0.3 or slightly higher for rough/complex terrain or lower tower heights. This value is typically applied as a derate factor to annual energy output.

Though the site assessment attempts to be comprehensive, there can also be macro-siting considerations that affect local wind speeds. Geographic features, such as bodies of water and sloping terrain can impact local wind speeds and be difficult to quantify. Ideally, these sorts of features are included in wind speeds estimated on the various wind maps but, in reality, there will be some uncertainty, particularly in complex terrain.

Other Losses and Considerations

In order to better understand this issue, we have researched wind turbine field performance studies completed elsewhere. Results appear mixed, with no clear guidance given on causes for low performance. For example, as part of the NY/NJ Distributed Wind Power Field Verification Project, 4 Bergey Excel turbines were installed and monitored over a 2 year period. During this time, the turbines showed capacity factors ranging from 3.1% to 13.1%. The sites with lower production appeared to have more buildings/trees near the tower base but the reports did not include a discussion of turbulence effects.

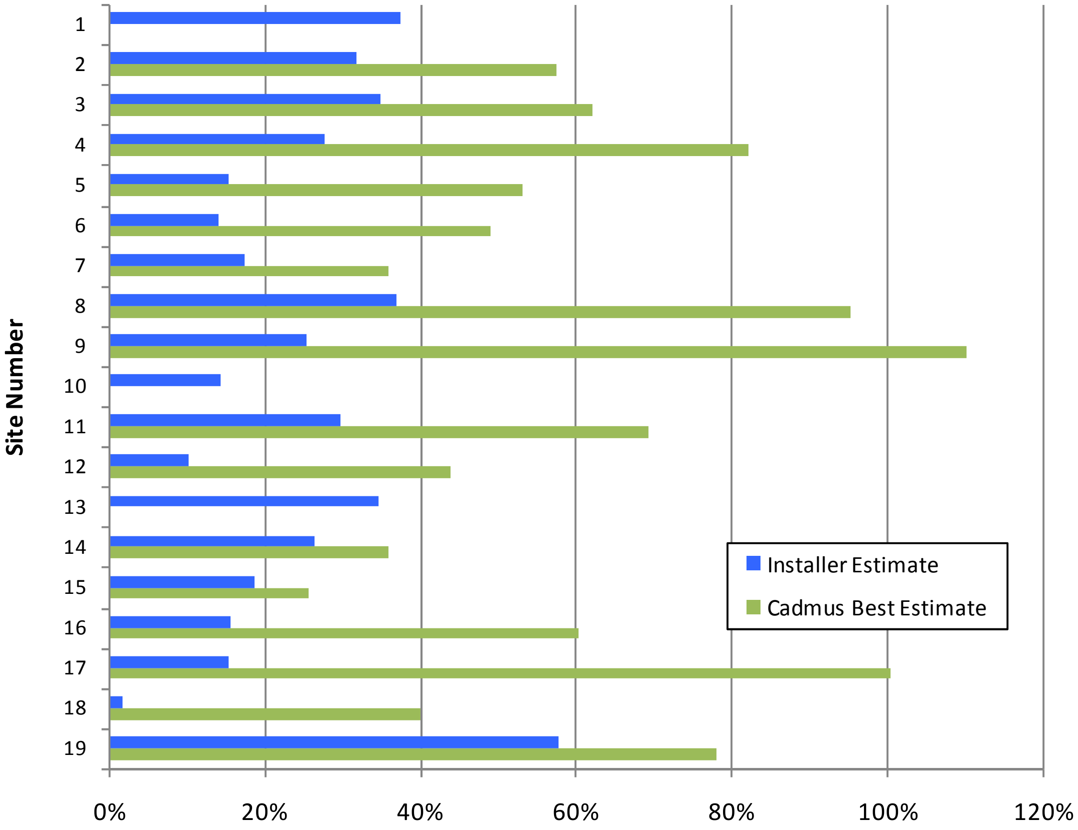
Another field study, conducted by NREL in the Pacific Northwest, on 4 installed Bergey Excel turbines shows similarly varied results. In general, all 4 turbines underperformed by 20-50% and this underperformance was not explainable due to the difference between measured and estimated wind speed.

These results all suggest contributing factors beyond simple wind speed. In particular, turbulence may be a more significant impact than was previously thought. Wind turbines operate most efficiently when dealing with laminar (smooth flowing) winds and are able to extract more energy from this type of wind than from more erratic, or turbulent, winds, even if the measured wind speeds are the same. Much of the field data collected in these, and other, studies is based on measurement with a single anemometer and, therefore, cannot be used to estimate wind shear and turbulence impacts on energy production but it is likely that these factors contributed to the observed underperformance.

Putting it Together

Combining the losses discussed above, leads to a closer estimate of actual annual energy output for small wind systems. While more specific/accurate numbers should be developed, most sites assessed using the SWEET tool should be further derated by a factor ranging from 0.6 to 0.77 to account for turbulence intensity and inverter efficiency/standby. Applying these factors to the systems, produces relative production numbers much more in line with historical production, as sown in Figure 8. Examination of this graph shows that many systems are now producing within close to 20% of these newly predicted values. Even with these factors included, this estimate continues to overpredict annual energy output for many systems, however, indicating that further study is needed to characterize the myriad factors that can impact the energy output of a small wind energy system.

Figure 8: Best Estimate for Small Wind System Relative Production



Recommendations

Small wind energy is popular at present and, despite little success to date, may yet present a renewable energy option competitive with other small scale renewable energy/distributed generation technologies. The key to unlocking this potential will be to obtain a better understanding of the available wind resource, technology capabilities, and improving estimation methods. To this end, Cadmus recommends the following as we proceed into a new small wind energy program at MTC.

Conduct Small Wind Energy Performance Verification Study

This study, already in its planning/setup phase, will provide key information on both the wind resource and the real-world performance of the Bergey Excel-S and related equipment. Though it will take more than 12 months to get definitive data from this study, preliminary findings could become available beginning in late summer/early autumn. Alternative versions of the proposed study are also an interesting option. For example collecting a smaller subset of data (e.g. wind speed and direction) at a larger number of sites could help to refine our estimating methods for future small wind projects fairly quickly. In particular, a better understanding of turbulence intensity at the lower hub heights common to small wind turbines will be critical to accurately estimating energy production.

Adopt Small Wind as a Research Program

In order to better understand the workings of small wind in non-optimal settings, MTC may elect to pursue a one year research focused program to support small wind installations. This program would seek to adopt innovative measures to assess small wind potential in MA, including:

- Improved collaboration and data sharing with sister agencies. Cadmus already has existing relationships with Mick Sagrillo (Wisconsin Focus on Energy) and NYSERDA that could potentially lead to valuable data/experience sharing. To date, MTC has collected more detailed production data than either of these agencies. However, Wisconsin includes wind speed and power data logging on all funded systems. With 44 systems currently installed, these data could be a valuable source of information that could apply to Massachusetts systems.
- Provide incentives to cover installation of DAS to monitor turbine performance and wind speed data on new and/or existing systems. This interval (e.g.1 5 minute) data could be dumped to the PTS for analysis for relatively low cost. A basic DAS to monitor wind speed and AC power output of the turbine can be purchased for approximately $1,000.

Improve Resolution of Wind Speed Data

There are significant data available that could be used to verify the wind speeds predicted by the AWS Truewind maps. Additional monitoring data from RERL, anemometry installed on existing small wind towers, and weather stations should be examined, particularly near Cape Cod and the south coast region, to improve our understanding of the actual wind speeds available in those areas. In addition, the AWS Truewind maps should be compared against other wind maps (e.g. DOE Wind Atlas), with an eye towards more conservative estimates at low anemometer heights.

Improve the SWEET Model/Estimating Methods

There are several improvements that could be added to SWEET to improve accuracy. Examples include:

- Adding inverter efficiency/standby draw data
- Add a turbulence intensity factor
- Making effective ground level calculations more conservative
- Adding a safety margin to account for various system losses (e.g.15%), particularly for systems with battery backup
- Adding an additional output page with educational message, showing output at an optimal site, output with a taller tower, etc. as an educational tool to promote better siting/system design

Adjust Program Structure to Minimize Risk of Underperformance

On currently installed systems, rebate dollars paid by MTC have not generated the expected benefits. While this may change as installers gain more experience with small wind systems and other issues are resolved, for the time being there is a risk that MTC may heavily fund systems that do not produce sufficient clean energy to justify the subsidy. To minimize this risk, we suggest the following changes when implementing the new small wind program:

- Pre-approval review of all sites/systems prior to committing funds (as done by Wisconsin, NY, and others). This review should include a site survey and energy production analysis for the site.
- Continued inspections of systems but with only selected structural inspections, as flagged during post installation inspection, to reduce program costs. Proven installers would face less frequent post installation inspections. Conducting pre approval screening would reduce the cost of post installation inspections somewhat.
- Strictly enforce capacity factor and AWEA siting guidelines from existing SRI program on future applications.
- Establish additional criteria, such as minimum wind speed (e.g. 5 m/s at 30m) to help filter out systems likely to underperform. If these systems perform well, future applications may gradually become less stringent
- Hold one, or more, quality installation training sessions/meetings for installers with a focus on energy production estimates.

Conclusions

Though the overall performance of the small wind systems installed in Massachusetts is lackluster thus far, the technology appears to be viable but highly subject to variables which are difficult to quantify (e.g. turbulence, wind speed, etc.). As the SRI program, with regard to wind energy, has matured, installers have been, and continue to be, educated in good site selection and installation practice. While work remains to be done, many installers are now more carefully assessing site conditions and providing better quality installations. However, in order to realize cost effectiveness on par with, or better than, PV systems, more action will be needed to educate installers and to weed out systems that will not meet performance expectations. For example, of the 16 systems inspected by Cadmus and included in this analysis, 10 would have been eliminated by Cadmus' site survey. Following MTC's existing siting and capacity factor requirements can go a long way towards eliminating the worst performing systems. Strengthening those requirements will only help to insure that only the better sites receive funding. The current underperformance of small wind remains unexplained and more data is needed to accurately assess the long term costs/benefits of including small wind energy in the MTC clean energy portfolio.

Small Wind Systems Registered in the PTS as of 2/14/2008

System Name	Analysis Notes
A & P Chardon	WindTechCo system, no longer operational
Against the Grain	Not included-data not clear given turbine change
Ashlane Farms	Included, no changes needed
B. Fearing	Due to equipment issues related to Skystream, not included in analysis
Beaulieu	Included, no changes needed
Briarknoll Energy Trust	Included, production data manually entered based on Q/A audit completed by Cadmus on 4/4/2008
C & P McVay	Included, no changes needed
C Croteau	Included, no changes needed
Cape Cod Reg Tech HS - WIND	Not included-data not clear given turbine change
Carlton School	Not included-turbine not interconnected to school electric grid
Centerville Elementary School	Based on long history of poor performance, removed due to lack of relevance to currently installed systems
Cider Hill Farm - wind	Included, no changes needed
Cider Hill Farm-Fern St	Not included, less than 3 months production data
Covanta	Included, no changes needed
D Mason	Included, Jan production entered manually
D Silvia	Included, no changes needed
D Vachon	Included, no changes needed
Falmouth Academy	Included, no changes needed
G Cook	Included, no changes needed
G&K Harcourt	Wind turbine changed, data not included in analysis
Kendrick Poultry Farm	Included, no changes needed
Fraser	Included, no changes needed
MVRHS	Included, production entered manually from 6/2007-2/2008
N. Bekemeier	WindTechCo system, no longer operational
P. Mitchell	System having firmware problems-SWWP working on repair, not included in aggregate analysis
R. W. Emerson	System having firmware problems-SWWP working on repair, not included in aggregate analysis
Rochester Golf Club	Significant inverter downtime due to improper surge protection, included in data set because issues were not caused by manufacturer defect and reflect real site conditions
S. & B. Garde	WindTechCo system, no longer operational
S. Mahoney-Battles	Included, no changes needed
Sylvan Nurseries-WIND	WindtechCo system, data includes PV array and is not included in analysis
Sylvan Nursery Inc Wind	Included, no changes needed (cost data not used)
W. Maloney	System not operating correctly yet, unknown equipment issues-not included in analysis
Wyndfield Studios	Originally a WindTechCo project, completed by another installer