Impact Evaluation of Small-Scale Wind, Biopower, and Fuel Cell Programs

for the New Jersey Office of Clean Energy

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Rutgers, The State University of New Jersey
New Brunswick, NJ

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Executive Summary

Cadmus, in partnership with Rutgers University, has completed an evaluation of the New Jersey Office of Clean Energy (NJOCE) wind, biopower, and fuel cell programs. This evaluation combined field inspections, engineering analyses, customer interviews, and other research to determine the status of projects funded under these incentive programs and to estimate, where possible, energy savings for each of these technologies. We also assessed system operations and maintenance (O&M) requirements. In this report, we present our findings and recommendations to the NJOCE to support its planning of future incentive program and state-level efforts to support wind, biopower, and fuel cell technologies.

Key Findings

We made several key findings and offer recommendations for future programming, which we present here by technology—wind power, biopower, and fuel cell.

Wind Energy

NJOCE has supported the installation of 39 customer-sited wind energy projects throughout New Jersey. These projects have generated significantly less electricity than expected, and customers have undergone extensive challenges related to system O&M. On a fleet-wide basis, these NJOCE wind projects generate approximately 68% of the expected electricity, and this number falls to 45% for the majority of projects with nameplate ratings of 50 kW or less. This low result is partly due to the substantial operational issues exhibited by systems funded under the NJOCE programs. Customer interviews revealed that 60% of funded systems experienced at least some notable downtime, characterized by the system being offline or unavailable despite available wind resource and grid conditions. Downtime was caused by a mix of mechanical and electrical issues that varied widely from site to site for events such as alternator failures, worn bearings, brake failures, and, in one case, fire.

In addition to these maintenance issues, the available wind resource data to support pre-installation estimates of electrical output are extremely limited. Public or free data sources are outdated or have insufficient resolution to accurately assess site-specific wind resource conditions. The available fee-based wind resource assessment options are prohibitively expensive compared to the cost of typical small-scale wind energy systems.

Based on these findings, we do not recommend that the NJOCE fund further small-scale wind energy projects at this time. Larger wind projects tend to be more cost-effective and are generally developed based on a more thorough understanding of the available wind resource.

We suggest, instead, that the NJOCE focus its wind-related efforts on supporting the development of projects larger than 100 kW. To the extent that the NJOCE wishes to support distributed wind energy, we strongly recommend that the NJOCE prioritize dissemination of accurate wind resource information and restrict incentives to turbines certified by the Small Wind Certification Council (SWCC).

Biopower

We found that NJOCE's biopower program has been relatively successful. Overall, the NJOCE-funded biopower projects are producing electricity consistent with pre-installation estimates and are proving to be cost-effective for both customers and NJOCE. Customers are satisfied with their systems but offer suggestions to streamline the New Jersey Department of Environmental Protection (DEP) air emissions permitting process. Some customers reported that this process can take years to complete, which has caused significant delays in completing projects and processing NJOCE incentives.

Customers also expressed an interest in using biopower facilities to improve energy resiliency, particularly at wastewater treatment facilities. Before this can be implemented, the NJOCE, New Jersey Resiliency Bank, the utilities, and other stakeholders should collaborate to codify the costs, benefits, and processes for enabling islanding operation of 200 kW to 2 MW biopower facilities.

Fuel Cells

In this evaluation, we studied eight fuel cell projects that were installed under a combination of programs run by the NJOCE and various utilities. All of these fuel cell projects, installed between 2003 and 2010, appear to have been decommissioned by their system owners because of the high costs of operations and unfavorable long-term natural gas contracts.

Though fuel cells may have some applications in combined heat and power (CHP) applications, we do not recommend that the NJOCE initiate a new direct incentive program or any customer-owned fuel cell projects.

Introduction

Evaluation Goals

Cadmus was selected, through a competitive selection process and under contract with Rutgers, the State University of New Jersey, to conduct an evaluation of the New Jersey Office of Clean Energy (NJOCE) wind, biomass, and fuel cell programs. The goals of this study were to:

- Calculate energy (e.g., electricity) savings attributable to each technology
- Determine the operational status of projects receiving an incentive from NJOCE
- Identify key barriers, challenges, and opportunities for future NJOCE incentive programs involving wind, biopower, and fuel cells

To meet these goals, Cadmus used a variety of research approaches including:

- On-site inspections of completed projects
- Phone interviews with NJOCE incentive recipients/system owners
- Written and verbal surveys of wind energy system owners
- Engineering analysis of system downtime and electricity generation results

Programs Included in this Study

The renewable energy programs administered by the NJOCE, and included in this study, are:

- Small Wind Energy Systems
    - Renewable Energy Incentive Program (REIP)[1]
    - Customer Onsite Renewable Energy (CORE) Program[2]
- Sustainable Biopower Energy Systems
    - Renewable Energy Incentive Program (REIP)[3]
    - Customer Onsite Renewable Energy (CORE) Program
- Fuel Cell Energy Systems
    - Customer Onsite Renewable Energy (CORE) Program

In addition to these programs operated by the NJOCE, some of the earlier (pre-2004) projects in our sample were installed under previous utility-run programs. The full records for these past programs were not readily available for this study but included the Customer-Sited Program for some wind and fuel cell projects installed before 2004.

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1 The REIP is ongoing, though not currently providing incentives for small wind energy systems.

2 The CORE Program ended effective December 31, 2008.

3 The REIP offers incentives on a competitive basis for sustainable biopower projects. As of this writing, New Jersey's Clean Energy Program is not accepting further applications for the 2015 program year.

Program Description

Customer Onsite Renewable Energy (CORE) Program

The CORE program ended as of December 31, 2008. The following description is taken from the Market Manager Operations Manual, available on the NJOCE website:[4]

> "The CORE Program offers incentives to customers of the utilities regulated by the [New Jersey Board of Public Utilities] who invest in eligible electricity-producing equipment. CORE incentives make renewable energy investments more cost-effective by offsetting a portion of the initial cost of system installation. As a key component of New Jersey's Clean Energy Program, the CORE Program offers financial incentives for ratepayers to assist in the creation of a thriving renewable energy market in the State.
>
> "The CORE Program is considered one market development tool in the suite of New Jersey's Clean Energy Program initiatives offering financial incentives, educational resources, and information on renewable energy systems, energy efficiency measures, and combined heat and power technologies. These programs are available to all New Jersey ratepayers, including residential customers, businesses, schools, and municipalities served by regulated electric and gas utilities. Applicants requesting funding through the CORE Program must satisfy all of the eligibility requirements contained in the application forms and Technical Worksheets and adhere to all of the processes and procedures contained in this Operations Manual. System applications approved under previous program processes and procedures remain governed by those processes until the projects are completed, expired, or cancelled. Market updates and information on installed capacity, program participation, budgets and project approval queues are available at www.njcleanenergy.com."

Renewable Energy Incentive Program (REIP)

The following program description is taken from the REIP Program Guidebook:[5]

> "The Renewable Energy Incentive Program offers upfront incentives to customers of utilities regulated by the [Board of Public Utilities] who invest in eligible electricity-producing equipment for use in offsetting on-site electric consumption. REIP incentives improve the financial returns of renewable energy investments by offsetting the cost of system installation and/or providing ongoing benefits in the form of renewable energy credits from the generation of renewable energy. The REIP is considered one market development tool in New Jersey's Clean Energy Program, which offers upfront financial incentives, educational resources, and information on renewable energy systems, energy efficiency measures, and combined heat and power

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[4] New Jersey Office of Clean Energy. *Customer Onside Renewable Energy Program Market Manager Operations Manual*. October 31, 2007. Available online: http://www.njcleanenergy.com/files/file/Renewable_Programs/CORE/2007COREguidebook.pdf

[5] http://www.njcleanenergy.com/files/file/Renewable_Programs/CORE/REIPGuidebookfinal0202mq.pdf

technologies. These programs are available to all New Jersey ratepayers, including residential customers, businesses, schools, and municipalities served by regulated electric and gas utilities. Applicants requesting funding through the REIP must satisfy all of the eligibility requirements contained in the application forms and technical worksheets, and must adhere to all of the processes and procedures contained in this Program Guidebook. System applications approved under previous programs' processes and procedures remain governed by those processes until those projects are completed, expired, or cancelled."

Programs Not Operated by the NJOCE

Some of the older fuel cell and wind projects in this study may have been funded under utility-run programs prior to funding offered by the NJOCE. Descriptions of these programs were not readily available for inclusion in this report.

Funding and Incentive Levels

Table 1 shows the number of NJCEP wind, biopower, and fuel cell installations with their total kW and dollar amount as of October 31, 2014.

Table 1. NJCEP Wind, Biopower, and Fuel Cell Installations for Rebate Programs As of October 31, 2014*

Technology	Wind[6]	Biopower	Fuel Cell	Total
Project Quantity	42[7]	14[8]	8	64
Total kW	9,734	8,505	1,505	14,744
Total Dollar Amount	**$4,432,100**	**$7,359,120**	**$4,707,312**	**$16,498,533**

* New Jersey's Clean Energy Program. "Wind, Biopower, and Fuel Cell Installations Reports." Accessed February 2015. http://www.njcleanenergy.com/renewable-energy/project-activity-reports/installation-summary-by-technology/wind-biopower-and-fuel-cell-installation-reports

[6] This evaluation did not include the 7.5MW ACUA Jersey Wind project

[7] Cadmus received application files for 39 of the 42 funded projects

[8] Cadmus reviewed 17 biopower applications, including 3 projects that are not included in the online data summary

File Review

Cadmus compiled application materials for the 39 program participants in the small wind program, drawing data primarily from NJOCE program records and tracking systems, supplemented by online research (e.g., for missing equipment specifications) where needed. These application materials included turbine technical information, site location, system costs, predicted energy savings, and customer contact information. We compiled the information in a tracking spreadsheet so we could organize surveys and site visits and analyze activities for the evaluation.

System Inspections and Interviews

Cadmus worked with the NJOCE to draft a letter to program participants announcing the evaluation and introducing Cadmus to prepare them for the calls and e-mails asking for their cooperation in phone surveys and to schedule inspections by one of Cadmus' small wind project experts. This step was helpful to avoid raising suspicion because customers knew in advance why Cadmus was calling. It also provided credibility to the evaluation.

Cadmus attempted to contact each customer via phone and e-mail to ask about scheduling on-site inspections of each participating wind project and to collect pertinent data needed for the inspection, including:

- Operational status of the system
- Major downtime or equipment failure issues
- Factors affecting access to the turbine and surrounding terrain
- Availability of generation and weather data
- System startup date

We also asked customers to have their system documentation available for the inspector to review during the site visit.

Although we diligently attempted to schedule inspections with each participant, in our experience evaluations rarely achieve a 100% participation rate in practice. Some customers were upset with their experience with wind and refused to allow a site visit. Some customers did not respond to contact attempts; we made a minimum of three separate contact attempts before declaring the customer nonresponsive.

We were able to schedule site visits at 22 of 39 turbines. These inspections involved:

- Documentation of system operating condition, including known downtime or failures
- Cumulative electricity generation (from meter, inverter, or data acquisition system)
- Verification of program records regarding the equipment installed (e.g., tower height, turbine model)

- Detailed site assessment including height and location of major obstructions to wind flow in each of 16 directions
- Compliance with relevant installation best practices, codes, and standards (e.g., NEC 694, NEC 705, manufacturer instructions, American Wind Energy Association [AWEA] siting guidelines)
- Gathering documentation of system startup date or other items noted during the phone survey

In addition to the technical inspection, each inspector also delivered a prepared in-person survey to gather data on:

- Accuracy of system cost information
- Satisfaction with system installer
- Satisfaction with the NJOCE program
- Satisfaction with small wind system
- Motivation for installing a small wind system
- Existing or planned O&M activities (e.g., maintenance contracts, extended warranties)

Small Wind Performance Analysis

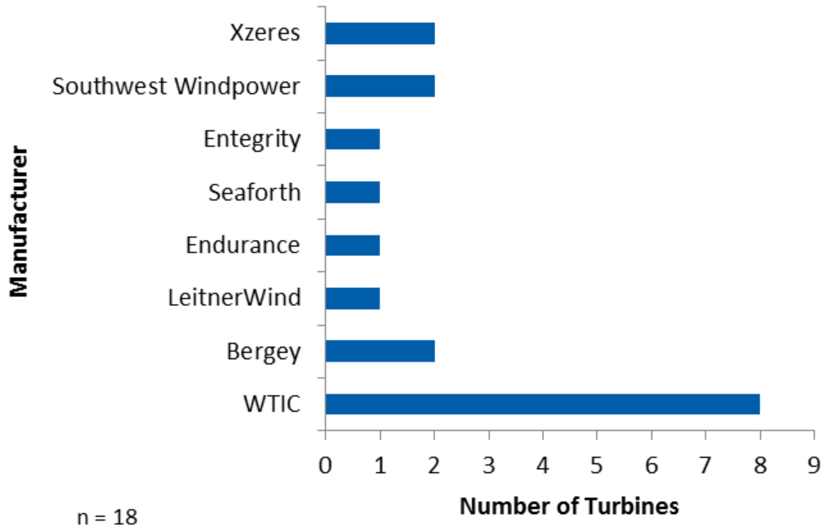
Sample Development

We began the process of calculating the electrical generation of NJOCE-funded wind projects by reviewing the available data to ensure that each system in the sample had reasonable meter readings and pre-installation estimate values. From our initial sample of 22 inspections, with meter readings, we removed:

- 1 off-grid system that was used only for battery charging
- 2 systems whose meter reading appeared to include generation from co-located photovoltaic (PV) systems
- 1 system with no pre-installation estimate available

Following this data-validation process, our sample for calculating energy savings was 18 wind projects. The manufacturers represented in this sample are shown in Figure 1.

Figure 1. Manufacturers Represented in Evaluation Sample



In addition to this base sample of 18 sites, we elected to separately consider the performance of any turbines that had not reported substantial downtime. This separate, smaller sample should represent the best case performance of the NJOCE-funded turbines, given the available wind resource and technical limitations of the turbines. To develop this operational subset, we eliminated any systems that were being curtailed due to customer noise concerns (two turbines) or had reported downtime totaling more than 10% of their operational lifetimes. There were 11 turbines in this subset.

Cadmus Estimate of Annual Electricity Savings

Cadmus generated an independent estimate of annual electricity savings. Using Cadmus' Distributed Wind Site Analysis Tool (DSAT),[9] with inputs from the site inspection, we calculated the long-term annual energy savings for each inspected site. DSAT uses wind map data and turbine power curves but also relies on empirical data for wind resource adjustments such as wind shear, wake effect, and effective ground level. We compared the DSAT output to the actual electricity savings and the pre-installation estimates from the incentive applications.

Comparison of wind speeds during operating period to the long-term average

The wind resource at the site is vital to the level of generation possible. When analyzing small-scale wind turbine performance, it is important to isolate factors unrelated to the system or siting, such as overall low wind speeds. Cadmus researched historical wind speed data from publicly available sources, such as airport data, and calculated an adjustment to predicted electricity output that accounts for relative wind conditions during the operational period. This process did not identify the specific site-level wind resource, only the time-based wind resource trends that are likely to impact turbine performance.

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9 Cadmus. "Distributed Wind Site Analysis Tool (DSAT)." Available online: https://dsat.cadmusgroup.com/.

Annualize energy savings

In order to accurately compare actual and predicted energy savings, both values must be referenced to the same wind resource (i.e., we cannot compare actual output during a windy year to a pre-installation estimate based on long-term data that does not match any one particular year). Using the normalized average wind speed from the previous step, we re-calculated the pre-installation prediction and compared that value against the actual output.

Of the sample of 22 reviewed projects, the two subsets are:

- N=18: Subset with valid estimated and actual generation data
- N=11: Subset removing systems with curtailment or >10% downtime

Step 1: Normalize Annual Energy Production (AEP) to Long-Term Weather Data

We normalized the measured annual mean wind speed to the nearest long-term weather station data available. First, we calculated the ratio between the annual mean of the weather station data for the most recent year that matched the measurement period and the long-term (10-year) mean of the weather station data:

Equation 1. Wind Speed Ratio

$$R_{ws} = \frac{U_{LT}}{U}$$

Where:

R_{ws} = The ratio of the weather station annual mean wind speed for the measurement period and the weather station long-term mean wind speed;

U = The weather station annual wind speed for the measurement period (m/s); and

U_{LT} = The long-term (i.e., 10-year) weather station mean wind speed (m/s).

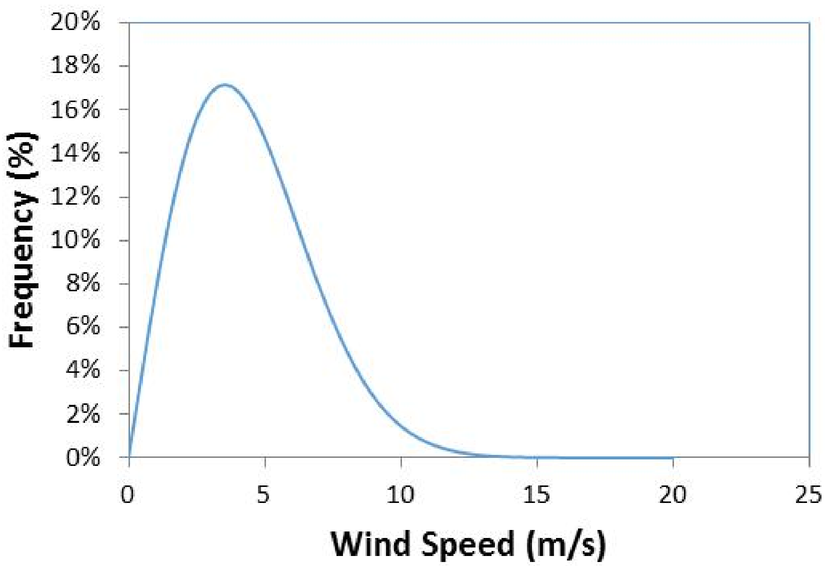
Step 2: Wind CAD Weibull Correction Calculation

We used WindCAD,[10] a Microsoft Excel-based calculator, developed by National Renewable Energy Laboratory (NREL) and Bergey WindPower, to establish a relationship between relative wind speed changes and annual energy production (AEP). WindCAD uses a statistical Weibull distribution to model the frequency at which different wind speeds occur during the year. This model has been widely used throughout the wind energy industry and is generally accepted as an approximation of wind speed distributions in many locations. We have provided an example of a typical Weibull distribution, such as

[10] The WindCAD model can be accessed online. Bergey WindPower. "Technical information." Accessed January 2015: http://bergey.com/technical

we used in this analysis, in Figure 2. We have provided the general form of the Weibull distribution in Equation 2.

Figure 2. Typical Weibull Distribution of Wind Speeds



Equation 2: General Form of the Weibull Distribution

$$P(u) = k\Gamma(1+\frac{1}{k})\left[\frac{u}{U}\Gamma(1+\frac{1}{k})\right]^{k-1} e^{-\left[\frac{u}{U}\Gamma(1+\frac{1}{k})\right]^{k}}$$

Where:

P(u)	=	Probability that the wind will be moving at a wind speed, u
U	=	Mean wind speed
k	=	Shape factor, assumed to be 2
Γ	=	Gamma function

The Weibull wind speed distribution is driven by two assumed factors—mean annual wind speed and the shape factor of the distribution. Empirical data for the northeastern United States shows that a shape factor of 2.0 is reasonable for many areas; therefore, we used the 2.0 value in this analysis.

We chose five meters per second (m/s), as this is a typical hub height wind speed for small wind turbine applications throughout New Jersey. This value was used only to establish relative changes in AEP with corresponding changes in wind speed.

Table 1 shows the impacts of relative changes in wind speed on the modeled AEP, along with the resulting Weibull correction used in our analysis of the meter readings data. The non-linear form of the

Weibull distribution produces substantial differences in AEP for large increases or decreases in wind speed, relative to the mean value. For example, an increase in the wind speed of 20% results in more than a 60% gain in AEP.

We used the Weibull correction values in Table 2 to adjust the observed AEP for differences in wind speeds between the turbine's operational period and the typical long-term average wind speed.

Table 2. Impacts of Wind Speed on AEP Based on Weibull Distribution for a 10kW Wind System

Wind Speed (m/s)	Normalized Wind Speed (5m/s base)*	AEP (kWh)	Weibull Correction
4	0.8	7,014	0.51
4.1	0.82	7,574	0.56
4.2	0.84	8,158	0.60
4.3	0.86	8,765	0.64
4.4	0.88	9,396	0.69
4.5	0.9	10,049	0.74
4.6	0.92	10,724	0.79
4.7	0.94	11,421	0.84
4.8	0.96	12,138	0.89
4.9	0.98	12,876	0.94
5	1	13,633	1.00
5.1	1.02	14,407	1.06
5.2	1.04	15,199	1.11
5.3	1.06	16,007	1.17
5.4	1.08	16,830	1.23
5.5	1.1	17,667	1.30
5.6	1.12	18,517	1.36
5.7	1.14	19,377	1.42
5.8	1.16	20,248	1.49
5.9	1.18	21,128	1.55
6	1.2	22,016	1.61

This table is useful for finding the Weibull Correction for each wind speed.

* Wind speed has been normalized using a shape factor of 2.0 and a mean wind speed of 5 m/s for a 10 kW system.

Step 3: Multiply Actual Production by the Weibull Correction

To normalize AEP, we multiplied the actual AEP from each wind project (obtained from customer meter readings) by the Weibull correction for R_{xi} (the ratio of the mean wind speed during the monitoring period for the weather station nearest each site and the long-term mean wind speed), as shown in Equation 3.

Equation 3. Normalizing AEP for Relative Wind Speed and Weibull AEP Impact

$$AEP_{normalized} = AEP_{actual} * WC_{x,i}$$

Where:

$AEP_{normalized,I}$ = Annual energy production for system *i*, normalized to the long-term mean wind speed (kWh/yr)

$AEP_{actual,i}$ = Actual annual energy production for system *i* during monitoring period (kWh/yr)

$WC_{x,i}$ = Weibull Correction for the ratio, R_{xi} , of the annual mean wind speed for the measurement period and long-term mean wind speed for weather station *x* during the monitoring period for system *i*

Step 4: Calculate Individual Realization Rates

We calculated the realization rates for each wind system by dividing the actual production of each by the long-term adjusted AEP estimates found in Step 2. This calculation is shown in Equation 4**.**

Equation 4. Realization Rate for On-Site Wind Project AEP

$$RR_i = \frac{AEP_{normalized,i}}{AEP_{estimated,i}}$$

Where:

RR_i = the realization rate of system *i* for 12-month monitoring period.

$AEP_{normalized,i}$ = the estimated energy production for system *i* (kWh/yr);

Step 5: Calculate Realization Rate of Fleet

Next, we calculated the realization rate for the entire fleet by summing the normalized annual productions for each system and dividing this total by the sum of the annual energy-production estimates:

Equation 5. On-Site Wind Fleetwide Realization Rate

$$RR_{fleet} = \frac{\sum AEP_{normalized,i}}{\sum AEP_{estimated,i}}$$

Where:

RR_{fleet} = the realization rate of the fleet

Assess Wind Resource Data

In order to assess the options for obtaining wind resource data, we reviewed the available wind resource data for siting distributed wind energy projects in New Jersey. Relevant data points needed for accurate site characterization include mean wind speed, wind directional frequency, and Weibull parameters.

Wind Resource Data Used for NJOCE-Funded Projects

Cadmus reviewed the application files to determine the wind resource data used as the basis for the pre-installation estimates. We found that applicants relied on various sources to obtain wind estimates— NASA Surface meteorology and Solar Energy - Available Tables, AWS New Jersey Wind Resource Explorer[11] and 3TIER's First Look. The majority of applications appeared to use 50 meter wind speed values taken from an average of values from the NASA, AWS New Jersey Wind Resource Explorer, and 3TIER FirstLook online data.

Tools Used to Estimate Electricity Generation

Though many of the application files documented the method used to project energy savings, the records were inconsistent and it was not possible, in many cases, to determine how pre-installation estimates were made. From application files with documentation of this calculation process (e.g., a printed results page from online tools), the most common tool used for the NJOCE wind programs was the 7th Wind Performance Calculator. Thirteen of the eighteen sites in our sample used 7th Wind (Table 3), while the remaining five sites used a mix of estimation methods. Wind resource data, as described above, was entered into the calculator, along with basic parameters such as turbine manufacturer, turbine model, tower height, and assumptions for losses due to turbulence.

Table 3: Performance Calculators

Wind Tool	Number of Sites	Average Realization Rate
7th Wind	13	0.33
Other	5	0.41

Review of Currently Available Wind Resource Data Sources

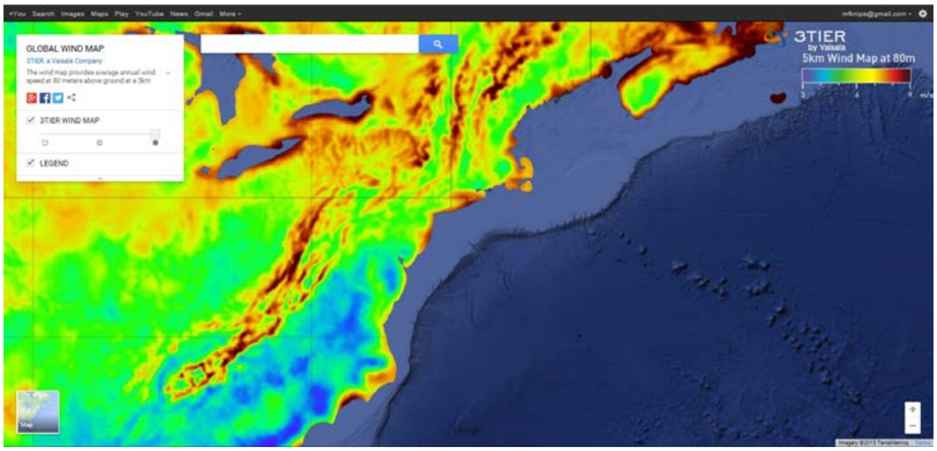
Google 3TIER global wind speed map

3TIER's First Look, which provided free access to average wind speed ranges in a five-kilometer resolution map, is no longer available. 3TIER partnered with Google to provide its global 80-meter wind

[11] AWS New Jersey Wind Resource Explorer. No longer available.

map for free[12]. Figure 3 shows northeastern United States and southeastern Canada. This map presents a graphical color-based overlay of local wind speeds on Google's satellite imagery. This tool gives no numerical data, but the reader can glean a general value by examining the color overlays and legend.

Figure 3. Google 3Tier Global Wind Speed Map



3Tier Wind Prospecting Tools

3TIER prospecting tools are available by subscription at an annual cost of $5,000.[13] The tool can access wind speed data for 20-, 50-, and 80-meter hub heights. It also offers global access to five-kilometer resolution wind data with graphs of the wind rose, monthly diurnal data, and wind distribution at a chosen site. The user can produce wind resource data in a one-page PDF, as shown in Figure 4.

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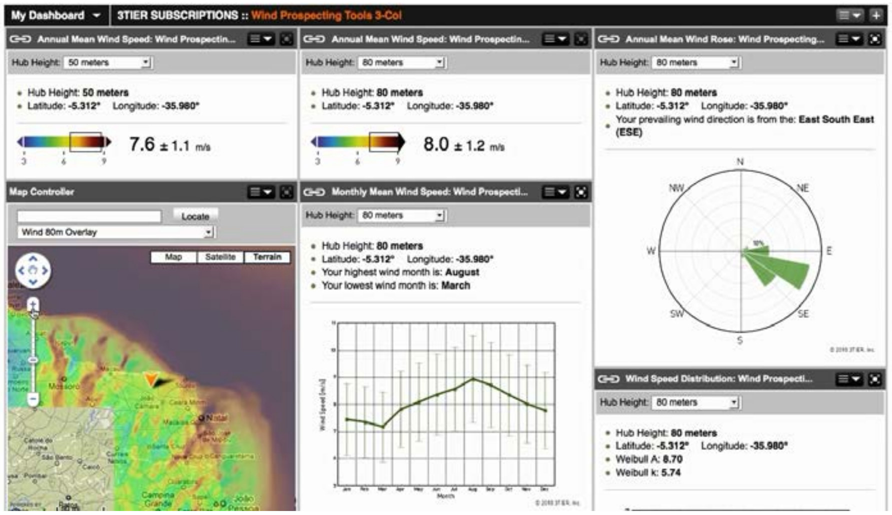
[12] Google Global Wind Map. Available online: https://www.google.com/maps/d/viewer?mid=zJuaSgXp_WLc.kTBytKPmNODY&hl=en

[13] 3TIER prospecting tools. Available Online: http://www.3tier.com/en/package_detail/wind-time-series-and-prospecting-tools/

Figure 4. 3TIER Wind Prospecting Tools

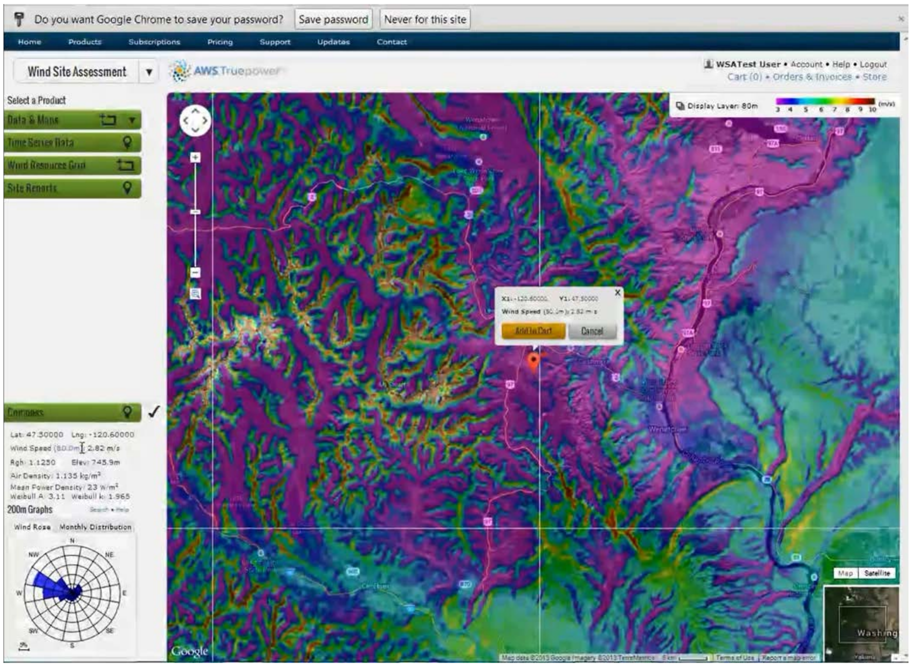


AWS Truepower Wind Dashboard

New Jersey Wind Resource Explorer, from AWS Truepower, also provided free average wind speeds for projects seeking an incentive from the programs included in this study[14] but, like 3TIER, AWS Truepower no longer offers free access to its dashboard. Currently AWS Truepower offers a day pass for $150, which entitles the user to the same features that are available through an annual subscription. These features include these wind site-assessment tools—200-meter resolution wind map, "Access to Compass" with its 10- to 100-meter wind speed selection, graphs of a wind rose of directional data, monthly diurnal data, and wind distribution. Figure 5 shows the AWS Truepower dashboard.

[14] AWS Truepower. "Wind Site Assessment." Available online: https://dashboards.awstruepower.com/.

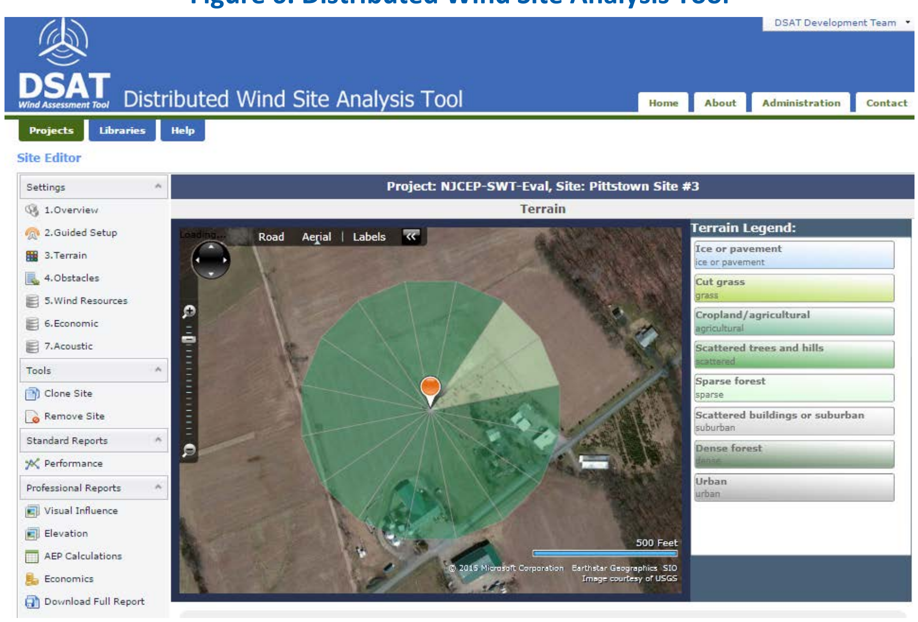
Figure 5. AWS Truepower Dashboard



Distributed Wind Site Analysis Tool (DSAT)

Cadmus designed DSAT in collaboration with Encraft and NREL. DSAT is a powerful online tool for predicting the performance of distributed wind energy projects using 2003 wind speed data. DSAT's free license allows a user to model wind resource and electricity savings for up to 3 sites. An example of the tool's output is shown in Figure 6.

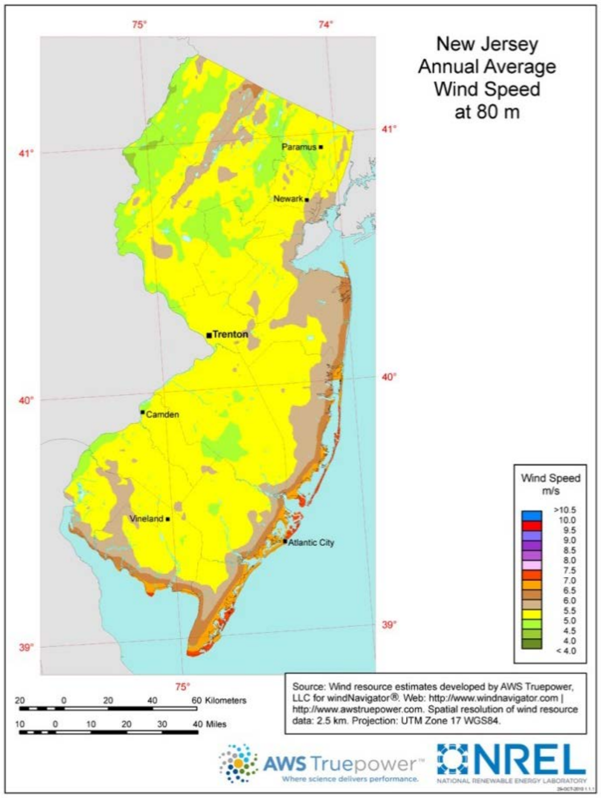
Figure 6. Distributed Wind Site Analysis Tool



Wind Exchange Wind Map

The U.S. Department of Energy's Wind Program and NREL published an 80-meter-height wind resource map for New Jersey (Figure 7). This map—along with other 30-meter, 50-meter, and offshore wind maps—is available on the WINDExchange website.[15]

Figure 7. WINDExchange Map for New Jersey



NASA Meteorological Data

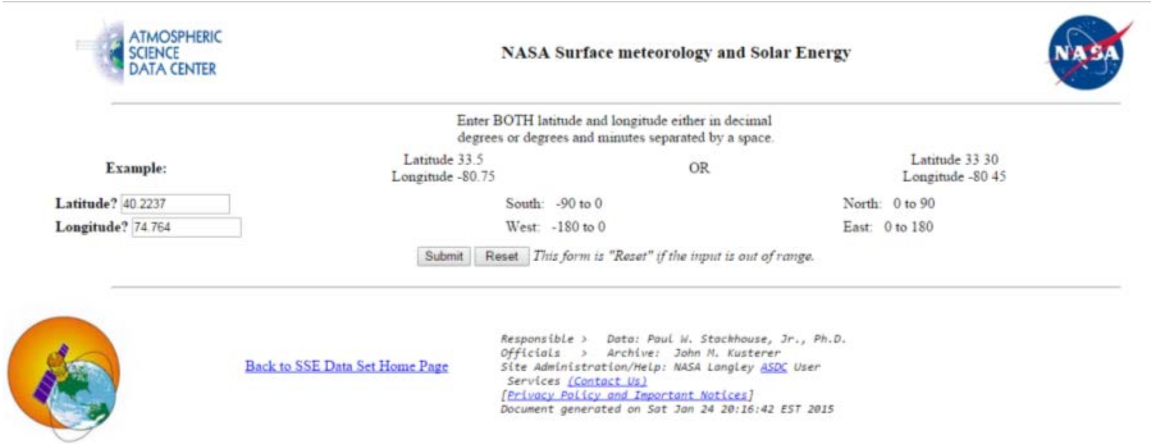
The Atmospheric Science Data Center (ASDC) at NASA Langley Research Center has a website that applicants used to obtain wind speed data.[16] The Surface Meteorology and Solar Energy page provides tables of meteorological data for a user's chosen latitude and longitude coordinates, as shown in Figure

[15] U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy (EERE). "WINDExchange." Available online: http://energy.gov/eere/wind/windexchange.

[16] NASA. Atmospheric Science Data Center. "NASA Surface Meteorology and Solar Energy – Location." Available online: https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi.

8. The resolution of the NASA wind resource data is 1 degree grid cells, which is far lower resolution than that provided in the other tools assessed in this portion of the study.

Figure 8. NASA Surface Meteorology and Solar Energy website



We have summarized our findings for each of these wind resource data sources in Table 4.

Table 4. Wind Resource Assessment Maps and Tools

	Google Global Wind Map 3TIER	NASA Satellite Data	DOE WINDExchange Map	Distributed Site Assessment Tool (DSAT)	3TIER Wind Prospecting Tools	AWS Truepower
Cost	Free	Free	Free	Free	$5,000 annual subscription	$6,000 annual subscription Or $150 one-day pass
Hub Heights Available	80 m	50 m, 100 m, 150 m	80 m (90 m offshore)	30m 50m,70m, 100m	20m, 50m, 80m	10m-100m
Resolution	5 km	1 degree latitude by 1 degree longitude[17]	2.5 km	200m	5km	200m
Annual Average Wind Speed	Approximate	X	Approximate	X	X	X
Monthly Average Wind Speed		X		X	X	X
Diurnal Wind Speed					X	X
Wind Rose		Tabular		Tabular	X	X
Wind Distribution					X	X
Weibull Values				X	X	X
Format	Online Visual Overlay	Online tabulated data	PDF	Online Interface	Online Dashboard	Online Dashboard

[17] This corresponds to a resolution of approximately 111.1km in latitude and 85.8km in longitude

Results

The key results from Cadmus' evaluation of the sample population of 18 small-scale wind projects and subset of 11 projects are presented in Table 5. Overall, for the evaluation sample, the NJOCE-funded wind systems are generating 64% of their pre-installation estimated output, normalized for wind speed. If we consider only the operational subset, the 11 systems with minimal downtime reported performed slightly better, with a realization rate of 67%. This suggests that although reliability and expense was a major concern to customers, it may not have been a driving force for the lower-than-expected generation across the fleet of funded projects.

Table 5. Summary of Full and Operational Sample Realization Rates

Number of Systems in Sample	Total Capacity of Sample (kW)	Sample Installer AEP (kWh/yr)	Actual Sample AEP (kWh/yr)	Normalized AEP (kWh/yr)	Sample Realization Rate
18	1,854	3,677,542	1,986,359	2,340,092	0.64
11	1,664	3,336,484	1,900,100	2,249,832	0.67

Since we only were given measured wind speed data from one of these funded projects, we did not have adequate fleet-wide data from which we could accurately measure turbine performance relative to on-site wind speed. We ran the realization rate calculations previously described in several iterations to try to identify trends in system performance, relative to expectations, by installer, manufacturer, general terrain, general wind resource, and other factors. By examining these results, we identified the factors that may be having a global impact on the performance of NJOCE-funded wind projects.

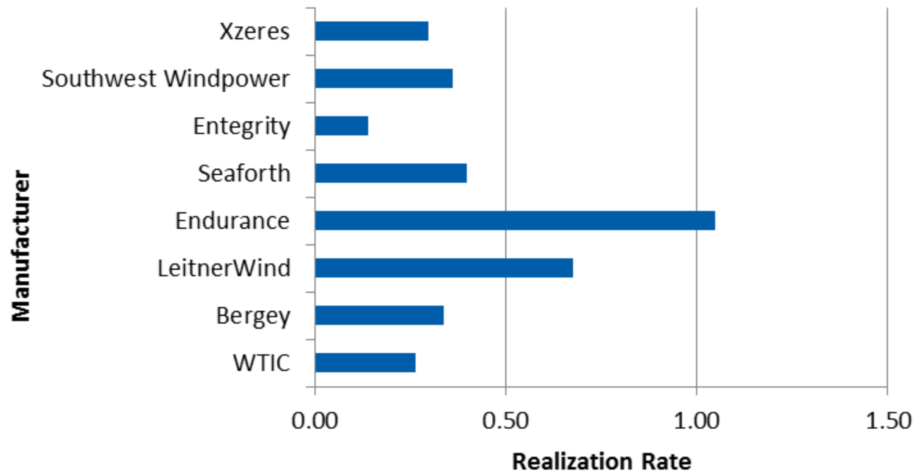
The results given in Figure 2 are mostly for small (i.e., 50 kW and less nameplate capacity) turbines but are heavily driven by the inclusion of a single 1.5 MW turbine. This system was supported by an incentive from the NJOCE, and therefore should be included; however, the technological differences between small and large wind turbines are substantial. By removing this single large system from the sample, we reduced the overall realization rate for the NJOCE-funded small wind turbines to 45%, which means the NJOCE-funded 50 kW and smaller wind systems are generating less than half of their expected annual electricity output.

We show the realization rates from the full sample, by manufacturer, in Figure 9. Although the majority of turbine manufacturers have realization rates below 50%, it is important to bear two key points in mind:

- These sample sizes, per manufacturer, are small and some are based on a single data point.
- Many other factors play a large role in the realization rate calculation, most notably the available wind resource at the site.

Given this, we do not recommend that Figure 9 be used to broadly define "good" or "bad" manufacturers; we provide this information only to establish general trends in the installed fleet. Of the manufacturers shown, however, it should be noted that the performance of the single Endurance turbine in the sample most closely matched the pre-installation estimates. The largest turbine, made by Leitnerwind, at 1.5 MW capacity, achieved a realization rate of 68%, which heavily influenced the rest of the sample, as explained above. The remaining manufacturers—Xzeres, Southwest, Entegrity, Seaforth, Bergey, and WTIC—all have nameplate capacities of 2.4 kW to 50 kW.

Figure 9. Full Sample Realization Rates by Manufacturer

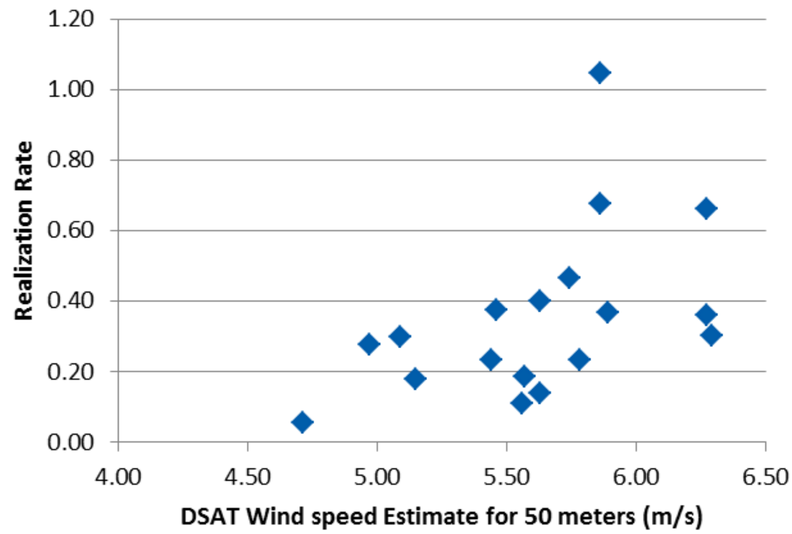


As explained above, the wind resource is a key driver for the performance of wind energy projects. For any given site, for a wind turbine to generate electricity depends on the overall wind resource, which is a function of large-scale meteorological and geographic characteristics and local (micro) siting conditions such as trees, buildings, and local terrain features.

To assess if any of these factors caused a notable trend in the realization rate at the NJOCE projects, we used the base NREL wind maps at the 50-meter anemometer height to gauge overall wind speed at each site. We then plotted the realization rate against each site's 50-meter wind speed to determine any correlation between the accuracy of pre-installation estimates and the overall wind speed at each site.

As shown in Figure 10, there is a general increase in realization rate with overall wind speed, but it is not statistically significant. It is important to note, however, that the 50-meter wind speeds we used here may not be consistent with the wind speeds used by the project applicants and installers. In our review of the available records, we found considerable variability in the source and treatment of wind resource data during the period the program provided incentives.

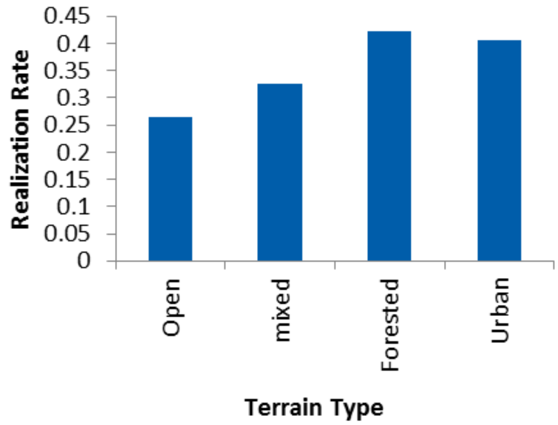
Figure 10. Comparison of Realization Rate to Overall Site Wind Speed



We also classified each site's general terrain and topography into broad categories to determine the effect of local obstructions on the relatively low realization rates. As shown in Figure 11, the lowest realization rates actually occurred for turbines in open terrain. The installer of one of the two sites that were in open terrain made an error in the estimate of production for this turbine. The application file shows that the wind speed input into the calculator used was high and therefore the estimate was high resulting in a very low realization rate. Normally open terrain is preferred for a wind turbine site and would not result in lowered performance.

Taken together, these results suggest that the overall wind resource was probably lower than expected, especially at sites where wind speeds are below turbine cut-in speeds for a subtantial portion of the year. The higher realization rates for more complex terrain types—forested and urban—suggest that the applicants made some effort to adjust the estimates for local terrain and obstructions but may have been overly optimistic about the starting wind speed assumptions. Unfortunately, because we found a widely variable quality and completeness of the estimates in the incentive applications (which was repeated anectotally in interviews), we could not identify the basis of the wind resource and estimation tool the applicants used for many of the projects in the sample.

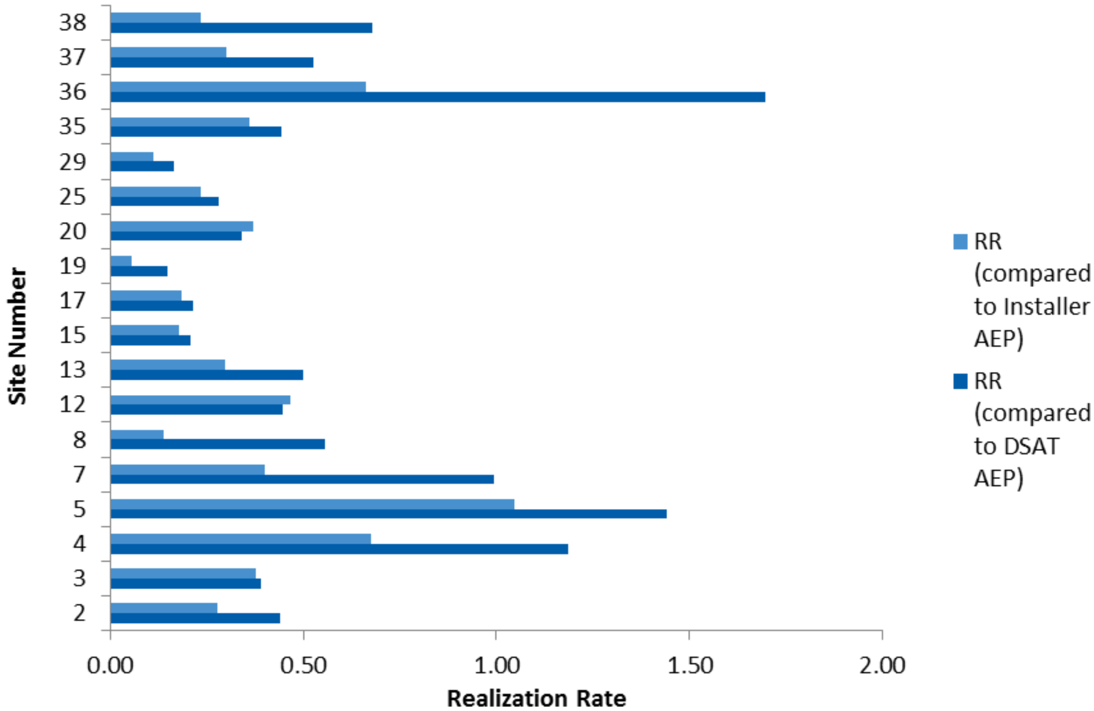
Figure 11. Realization Rates for Wind Turbines in Different Terrain Types



In order to normalize the data for site assessment technique, wind resource basis, and estimation tool consistency, we used DSAT to generate an independent estimate of long-term electricity generation for each of the 18 sites in the sample (Figure 12). After applying our own site visit and modeling techniques, we calculated a realization rate of 111%. We noted that DSAT slightly under-predicted overall system performance, which suggests that it would have been possible to more accurately predict energy savings for this fleet of NJOCE projects if the applicants had used a consistent site assessment and analysis process.[18]

18 Note that DSAT was released in early 2011 but that the underlying wind resource maps were available beginning in 2003.

Figure 12. Realization Rate (DSAT and Installer Estimates) For Sample



Analyze Turbine Failures

The small wind turbines in the analysis sample experienced significant operational downtime-both in terms of lost days of operation and in terms of the number of customers impacted. Of the 20 projects we received completed surveys for[19], 10 customers (50%) reported at least some downtime and the average was over 6 months of lost generation for each project reporting downtime. For this report, we define downtime as the length of time (in days, unless otherwise noted) that the system was not able to operate due to a mechanical, structural, electrical, or grid-related malfunction. Downtime can also be expressed as availability, which is the fraction of the system's operating life during which it has been able to operate compared to its total operational life. Neither downtime nor availability is related to the wind resource at the site; these are only indicators of whether a system, given the necessary weather and other factors, could operate.

We sorted the possible failure modes into four categories:

- **Mechanical:** Mechanical failures relate to the moving/mechanical portions of the system, such as tails, blades, rotors, and gearboxes.

[19] Customer survey results are discussed in more detail in the following section of this report

- **Electrical:** Electrical issues relate to the electronics and/or wiring of the turbine, generally beginning with the generator wire run and ending at the point of interconnection. Examples include inverter failures and faulty wiring.
- **Grid:** Grid-related downtime indicates periods when the system was otherwise operational but could not run due to utility power outages or other issues on the utility side of the customer point of interconnection.
- **Structural:** Structural downtime relates to issues in the turbine's tower and/or foundation.

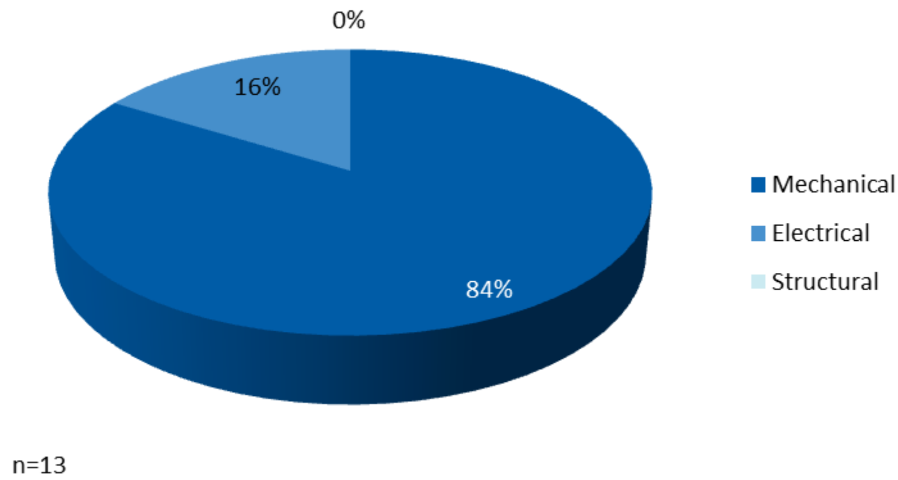
Because the small wind systems funded under the NJOCE programs were not required to monitor operational or weather-related data, we asked each owner several questions about the system's operational history, including dates and lengths of time the system was not operational. Though somewhat subjective, we obtained useful insights into operational and maintenance issues; on the other hand, we considered this information in a broader context when interpreting numerical results.

Of the failure types identified, mechanical failures were, by far, responsible for the most downtime, representing 84% of the total downtime reported for the chosen sample (Figure 13). Nearly half (45%) the system owners reported at least some downtime due to mechanical issues, with an average downtime of approximately 200 days. These included three systems that were not operational during our inspection.

Of the manufacturers in this sample, Entegrity, Endurance, and Leitnerwind turbine owners reported no mechanical failures. WTIC, Xzeres, and Bergey turbines had substantial downtime due to mechanical failures, including:

- One WTIC turbine failed in October 2013 and was replaced by the installer, resulting in seven months of downtime.
- One Bergey Excel turbine was damaged by Hurricane Sandy and replaced after 10 months of downtime with a WTIC/Jacobs turbine.
- One Xzeres 442 turbine had an unbalanced blade that was removed by the installer in October 2012. The turbine remains nonoperational.
- One Xzeres 442 wind turbine caught on fire during a high wind event and was inoperative for three months in early 2010.
- One WTIC turbine had a bearing failure, and the installer took the turbine down in August 2011. To date, the installer has not returned to finish repairs on the turbine.

Figure 13. Portion of System Downtime by Failure Category

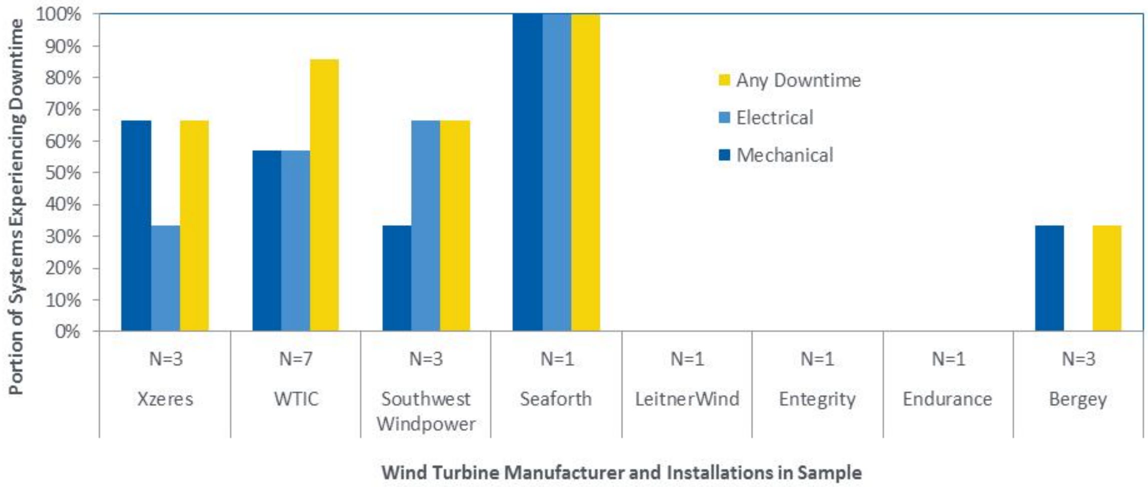


Electrical failures were the second-most common cause of system downtime. Five projects (28%) reported electrical failures resulting in an average downtime of three months—three WTIC, one Seaforth, and one Southwest wind turbine. We estimate that electrical failures accounted for 16% of total downtime reported.

We identified no downtime due to structural failures in the turbine tower, foundation, or other support structures.

We summarized the frequency and type of system failures in Figure 14. This figure should be considered carefully, however, as the data for some of the turbines with either exceptionally low or high failure rates are based on small sample sizes and, in some cases, a single project. These results should not be interpreted too broadly as a commentary on the failure rates of these particular turbines or manufacturers across their entire installed fleets.

Figure 14. Rates of Reported Downtime by Failure Type and Turbine Manufacturer

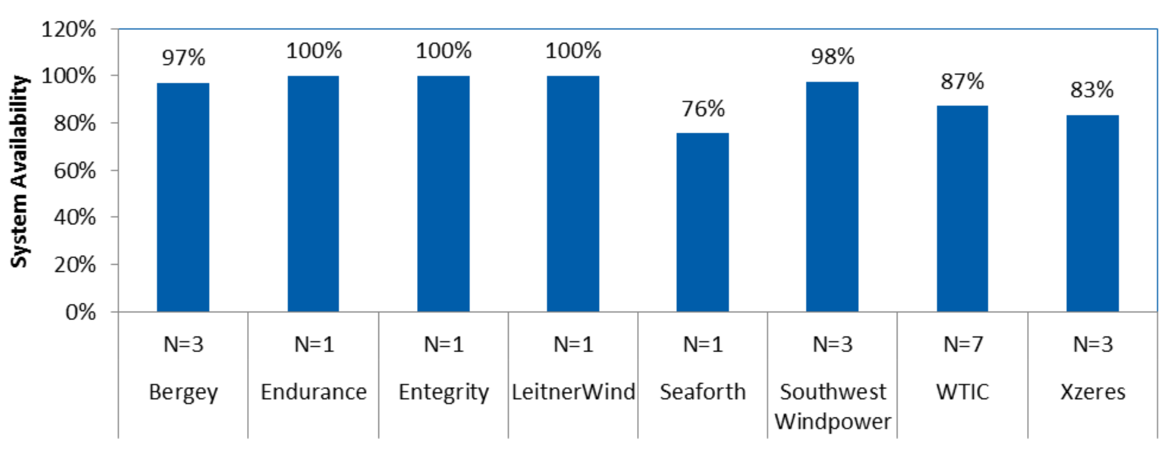


We have not included grid outage-related downtime when calculating the availability of the small wind turbines in the sample because this type of downtime was not related to the small wind turbines under study. We also found no structural issues resulting in turbine downtime.

Overall, after accounting for the reported mechanical and electrical failures, we identified Bergey, Endurance, Entegrity, Leitnerwind, and Southwest Windpower turbines as having the highest operational availability, ranging from 97% to 100%. The manufacturer with the lowest system availability was Seaforth; WTIC and Xzeres also had low system availability.

The fleet's average availability results, by manufacturer, are presented in Figure 15. As noted above, some of these availability figures are based on very small sample sizes. These values reflect the installed systems in our sample but do not necessarily represent the larger fleet of these manufacturers' installed projects.

Figure 15. Availability of Turbines in Sample by Manufacturer



Customer Survey

During the site visit, Cadmus interviewed small wind system owners to gather data on satisfaction, operational history, maintenance events, and customer feedback to improve potential future incentive programs. We had distributed a hardcopy survey, which the Cadmus engineer collected during scheduled site visits and reviewed with the site owner to ensure as accurate and thorough a response as possible.

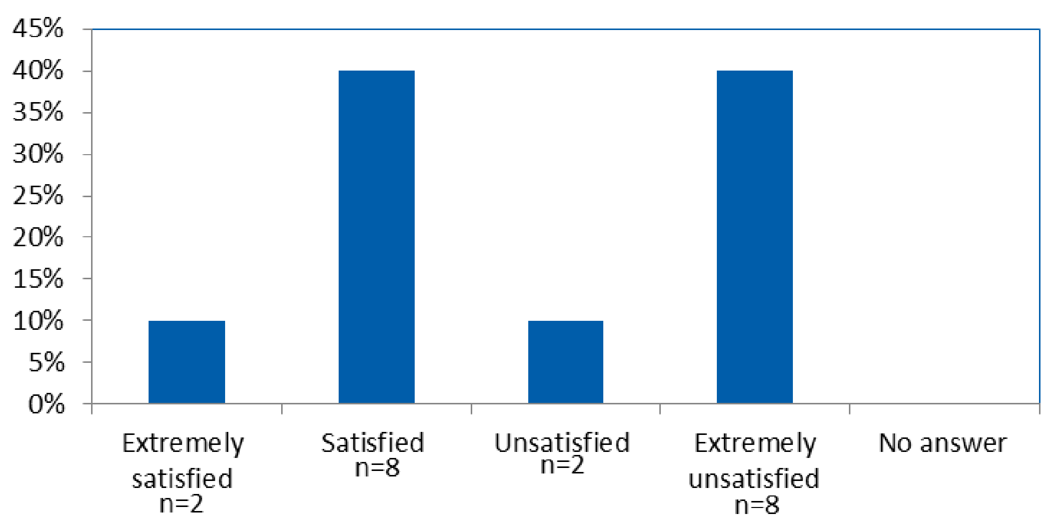
Satisfaction

The survey asked owners several questions related to their satisfaction with their small wind system and their installation company.

Satisfaction with Small Wind Energy System

Owners were split regarding their satisfaction with their small wind turbines—approximately half were satisfied and half were unsatisfied (Figure 16). Forty percent reported being “extremely unsatisfied” compared to only 10% who reported they were “extremely satisfied.” This result, however, could be biased; a number of owners reported negative feedback on the small wind program during our initial contact attempts but were then unwilling to complete surveys or site visits, so their feedback was not formally included in the analysis. This pattern suggests that unsatisfied owners tended to have a stronger opinion and were less inclined to agree to the survey and site visit. There may be substantially more unsatisfied owners than indicated in the surveyed sample.

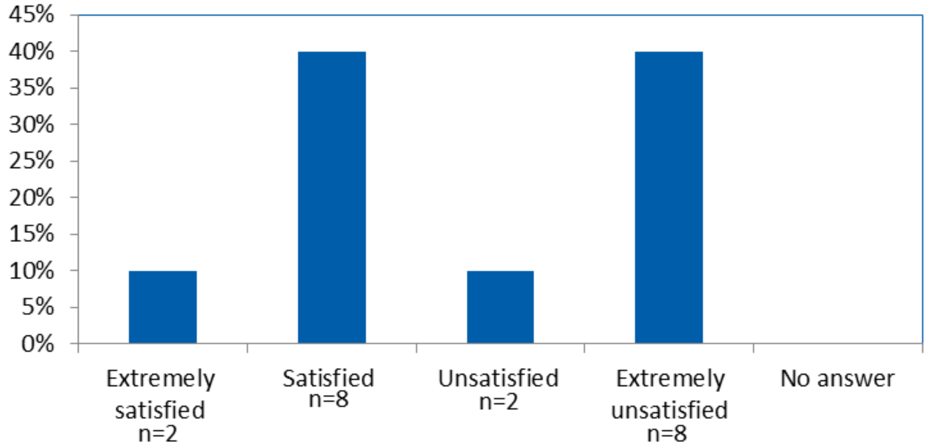
Figure 16. How satisfied were you with your small wind turbine overall?



Satisfaction with Energy Savings

Owners’ satisfaction with their system’s energy savings matched the answers given for overall satisfaction with the system (Figure 17). This indicates that satisfaction with the wind system is very heavily driven by energy savings rather than other factors such as aesthetics or reliability (although this does impact energy savings if the turbine has substantial downtime).

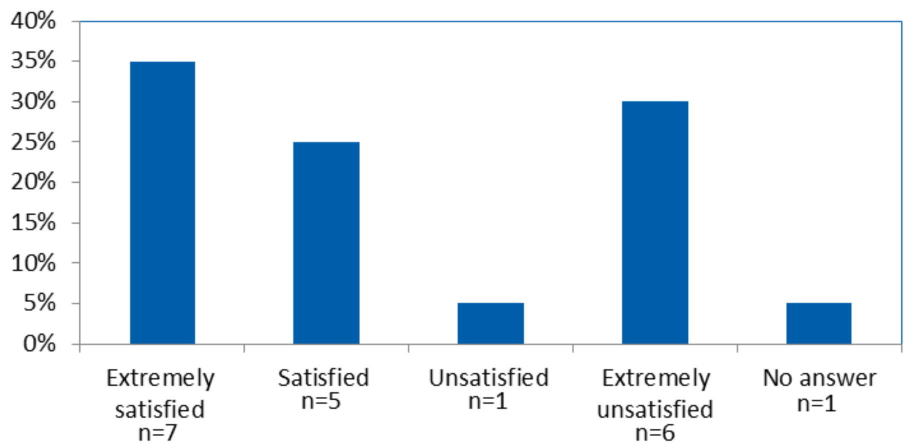
Figure 17. How satisfied are you with the energy savings you have realized from your small wind turbine?



Satisfaction with Installation Company

Owners were generally more satisfied with their installation companies than they were with their systems, with 60% reporting satisfaction with their installer and 35% reporting that they were "extremely satisfied." This suggests that owners believe installers made the best possible effort to provide high quality and productive small wind systems and that dissatisfaction with the system performance may be attributable to other sources (e.g., incorrect wind resource data, the wind turbine manufacturer). These results are shown in Figure 18.

Figure 18. How satisfied were you with the company that installed your small wind turbine?



Motivation

Not surprisingly, financial returns were the primary motivation for owners' choice to install wind energy projects. Most owners also considered other renewable energy options, including solar photovoltaics (PV) and solar thermal systems but chose wind because they believed it provided a more cost-effective option.

Barriers and Challenges to Installation

The majority of owners reported that their neighbors and community were supportive of the project. The customers who did report some concerns from neighbors indicated that the primary concern raised was related to turbine noise. After installation, approximately 25% reported receiving complaints from community members, the majority of which related to turbine noise. Owners also reported complaints related to aesthetics and shadow flicker.

Although permitting and interconnection can sometimes be a challenge for wind projects in general, the owners we interviewed did not report any substantive permitting, interconnection, or other pre-installation challenges associated with their projects.

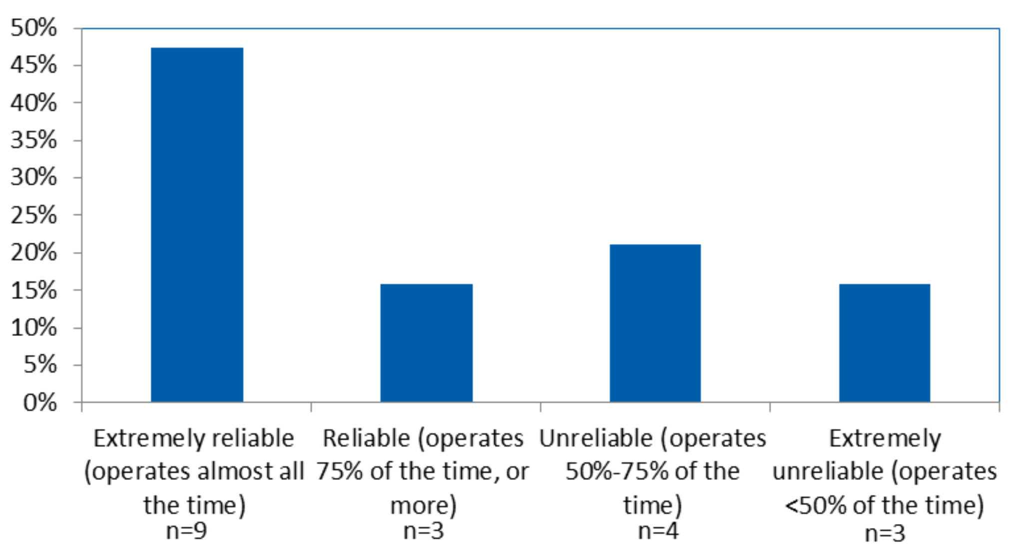
Operations and Maintenance

Reliability is a key consideration for wind turbines because downtime or repair costs can significantly impact the cost-effectiveness of the project, and many manufacturers' marketing depends on the turbine's high reliability and/or low maintenance costs. Slightly more than 60% of the surveyed owners considered their small wind turbines reliable, defined as operational 75% to 100% of the time (Figure 19). One of these owners, however, reported "the reliability of our system is because we constantly stayed on top of maintenance and fixing problems." Three owners (16%), however, classified their system as "extremely unreliable." These are some of their concerns:

- Two owners said the maintenance for their wind turbines is not cost-effective. One added that the turbine has a bearing seal issue that, when it fails, is expected to cost $20,000 to repair; the owner "will not fix [the turbine] unless we can find a cost-effective way to get the generator motor out of the tower without a crane."
- Four owners reported dissatisfaction with the manufacturer of their wind turbines, specifically manufacturers that failed to honor warranties and did not provide adequate technical support.

Of the owners surveyed, 60% reported receiving regular maintenance for their systems, and 92% of these reported being satisfied with the service they are receiving.

Figure 19. Overall, how would you rate the reliability of your small wind system?



Incentive Program Feedback

Owner reaction to the incentive program was mixed. Although they were generally pleased to receive a rebate, about 35% expressed dissatisfaction with the timeline for receiving incentive payments. When asked to comment on ways that the program could be improved if it were offered again, owners said:

- The low value of wind renewable energy certificates (RECs) compared to solar did not make sense, and most had not bothered to try to sell their RECs.
- Installers should be required to demonstrate appropriate credentials to install wind turbines for the program.
- Wind resource data needs to be more accurate and/or customers need to measure on-site wind speeds before installing a wind turbine.
- Wind turbines need to be better tested, vetted, and/or certified.

On the last point, we note that the NJOCE is a member of the Interstate Turbine Advisory Council (ITAC), an organization of state incentive programs and other stakeholders working to share experiences and develop a unified list of reliable, high quality, wind turbines for state incentive programs to support. As a relatively new organization, ITAC did not exist during the early stages of the NJOCE wind program but would likely play a positive role in any future incentive programs.

Conclusions and Recommendations

Overall, the NJOCE wind program has achieved approximately two-thirds of the expected energy savings, with most of the savings attributable to a single 1.5 MW wind project. Among smaller projects, with nameplate capacities of 50 kW or less, funded systems are generating less than 50% of the pre-installation estimates. This poor performance appears to be attributable to a combination of equipment failures/downtime and inaccurate pre-installation estimates.

In the study sample, 60% of owners' wind energy systems experienced substantive downtime; the average total downtime was 200 days. The frequency of failures varied by wind turbine manufacturer, with WTIC and Xzeres wind turbines experiencing substantially more downtime than other turbine manufacturers in the sample.

Though the energy performance and reliability of the NJOCE-funded small wind projects we studied are not compelling for future programs, the program could achieve greater success by developing projects using larger wind systems (e.g., 1 MW, or greater, in nameplate capacity). Before considering any further wind programs, the NJOCE should consider addressing these challenges:

- The availability of wind resource data is very limited, with few useful options for free or low-cost wind resource data of sufficient resolution and detail for siting distributed wind energy projects in the complex New Jersey terrain. NJOCE should consider commissioning a wind map, or equivalent online tool, that would enable customers, installers, and other stakeholders to accurately assess a site's wind resource and electricity generation potential.
- Monitoring of wind turbine system performance is sometimes used as a condition of incentive programs. NYSERDA, for example, requires that its program participants supply energy production meter readings. They must be collected by the installer or customer once per month and the installer must submit this data to NYSERDA twice per year for two years following interconnection of the system. This may provide some incentive to the installer to be more accountable and future analysis of the performance of the fleet will be vastly simplified if this data is available. In Massachusetts, a portion of the incentive was withheld until these data were reported, as an added incentive to ensure the program administrators received performance data in a timely manner.
- Owners need assistance in identifying and procuring reliable wind energy systems. When most of the owners in this study installed their wind turbines, agencies such as the Small Wind Certification Council (SWCC)[20] did not exist. To date, the SWCC has certified seven small wind turbines through detailed independent testing of power output, noise level, durability, and other factors. By demonstrating compliance with the AWEA testing standards and the SWCC certification process, these turbines are likely to be more reliable and have more predictable energy savings, than non-certified wind turbines. NJOCE's participation in the Interstate Turbine Advisory Council (ITAC) is a positive step and will help address this issue with any future incentive program.

[20] For more information on the SWCC: www.smallwindcertification.org

Application Review

Cadmus compiled a database of information found in application materials for the 17 rebate recipients for which the NJOCE maintained records. These data, recorded in a tracking spreadsheet, included site location, biopower system specifications, system installer, system cost, predicted annual electricity generation, customer contact information, and other details.

Telephone Interviews

Cadmus attempted to contact each owner via phone and e-mail, at minimum three times, to schedule and conduct phone interviews. We were able to conduct interviews with seven of the 17 systems in our database. Given the objective and scope of our investigation, we elected not to visit any of the biopower sites because any additional value was limited. Instead, we focused on collecting a wide variety of information during the phone interviews. Some of these data were:

- Operational status of the system
- Major downtime or equipment failure issues
- Availability of system performance data
- Approximate system start-up date
- Maintenance needs and provider
- Satisfaction with system, installer, and the NJOCE program
- Motivation for installing a biopower system
- Any feedback from community and abutters (properties that abut the project site) regarding installation

Interview Findings

Our findings of the biopower interviews are presented in Table 6.

Table 6. Interview Findings: Biopower System

Project	Capacity (kW)	Configuration	Fuel Stock	Annual Power Generation (kWh/year)	Operational Status
Landis Sewerage	175	CHP	A/D: Wastewater	924,000 (estimated)	Operational
Ridgewood Department of Public Works	240	CHP	A/D: Wastewater and FOG	1,080,000	Operational
South Monmouth Sewerage Authority	280	CHP	A/D: Wastewater	1,501,536	Operational
Bergen County Utilities	2,800	CHP	A/D: Wastewater, FOG (planned)	19,975,000	Operational
Cape May County	2,450	CHP (450 kW); Power (2 MW)	A/D: Landfill Gas	17,999,164	Operational
Joint Meeting of Essex & Union Counties	3,200	CHP	A/D: Wastewater	19,000,000 (rounded)	Operational
Rutgers University Greenhouse	250	CHP	A/D: Landfill Gas	N/A	Non-operational (2011)

A/D = anaerobic digester
CHP = combined heat and power
FOG = fats, oils, and greases

Fleet Production

Cadmus estimated the fleet-wide production from information collected during interviews. It should be noted that the sample size (interview pool) is insufficient for determining total fleet-wide production with high confidence. Still, the results of this analysis are useful for approximating more detailed production information.

We conducted interviews with system representatives at seven of the 17 biopower sites. These seven sites represent a total installed generating capacity of 4,085 MW-e and a total annual electricity generation of 39,956 MWh. We calculated these figures from metered data, billing data, and estimates provided by site representatives. Based on the calculated factor of 71% for the sampled portion of the fleet, and a total fleet capacity of 12,970 MW-e, we estimate that the total annual generation of the fleet is 81,164 MWh.

All biopower systems featured at least one CHP application, with 100% of generated heat used on the site.

Conclusions and Recommendations

In our analysis and interviews with biopower customers, we found that:

- Customers were overwhelmingly satisfied with the biopower installations.
- In general, the biopower projects do not pose a concern to local abutters. In one case, a local abutter complained about the idling of trucks during fats/oils/greases (FOG) delivery (idling is necessary to pressurize holding tanks).
- The majority of systems are anaerobic digesters with a constant, zero-cost supply of wastewater or landfill gas, enabling host sites to pass on energy savings to their community.
- All sites were found to be using most or all of the produced energy on site.
- The inclusion of FOG in the system feedstock has been shown to have a positive impact on the methane generation rate of digesters by boosting energy production.
- Overall, customers were satisfied with the incentive process, though some customers expressed concern over the length of time necessary for processing rebates. For some projects, it took years to finalize approvals and pay out rebates.
- Obtaining air permits from the DEP was a major obstacle for some systems. Despite being much cleaner than diesel generators, biopower generators were treated as standard combustion engines and therefore subject to the same rigorous permitting process. One customer described the DEP air-permit process as “out of this world,” and another explicitly pointed to the process as needing improvement in future incentive programs. Costs associated with obtaining these permits appeared to be covered by RECs and program rebates; however, some future projects may be affected if the incentive structure changes.
- Biopower systems represent a viable technology for energy resiliency; however, several customers pointed out that their utility requires that they disconnect their biopower system in the event of a grid outage. Another customer (Joint Meeting of Essex & Union Counties) said the utility allowed the plant to operate during Hurricane Sandy. Given the plant’s access to wastewater, it was able to maintain wastewater treatment throughout the storm. This customer also said that wastewater treatment plants should make a concerted effort to look into biopower as reliable backup power.
- One customer expressed concern that 100%-export projects were not offered at the time of project development. He stated that more of these systems might become viable if export-only projects were allowed.
- One customer noted that a parallel reciprocating engine could provide power during O&M activities scheduled for the biopower generator.
- Given the complexity of these systems, maintenance programs can be difficult to arrange because they require a wide range of expertise. Often a manufacturer is very adept at one type of maintenance but inexperienced with another. A few customers advised arranging an independent maintenance program through a variety of contractors.

- Average maintenance cost appears to be around $150/kW annually (from $53 to $234)
- Overall, these sites were producing energy on par with installer estimates. Exceptions were single nonoperational system and a single system that was producing about 50% of installer predictions.
- All customers we contacted expressed a willingness to provide further information regarding the performance of their biopower systems.

Fuel Cell Program Evaluation

Identify Target Fuel Cell Facilities

Cadmus compiled a database of information found in application materials for the eight fuel cells that took part in the CORE program between 2003 and 2010. These eight fuel cells accounted for 1.5 MW. The NJOCE maintained records for these systems, including site location, fuel cell system specifications, system installer, system cost, predicted annual electricity generation, customer contact information, and other details. We compiled these data in a tracking spreadsheet. However, given the age of these systems, and the relatively short economic life of fuel cells (five to eight years), some of these data were outdated by the time we began contacting customers for interviews. For this reason, we also drew relevant system data from a report carried out by the New Jersey Hydrogen Learning Center in 2007 that profiled a few of the same systems.[21]

Fuel Cell Owner Phone Survey

Cadmus developed a fuel cell performance survey with guidance from an internal fuel cell expert. After the NJOCE approved this survey, we contacted representatives for all eight fuel cells. However, because most (possibly all) had been decommissioned, it was very difficult to track down representatives who had relevant knowledge of the fuel cells' performances. We were able to contact three customers that represented five of the 8 fuel cell systems and nearly 70% of total program capacity. Their representatives answered a series of questions across these categories:

- Motivation
- System specifications
- Maintenance and downtime
- User satisfaction

Cadmus did not limit the scope of these representatives' answers, and the data collected ranged from quantitative to anecdotal.

[21] Center for Energy, Economic & Environmental Policy (CEEEP). "New Jersey Hydrogen Learning Center Year One Report".

Fuel Cell Performance Assessment

Our findings are based on the customer phone surveys and shown in Table 7.

Table 7. Fuel Cell Performance

Project	Capacity (kW)	Fuel	Power Generation (kWh/year estimated)	Currently Operational (Yes/No)
Richard Stockton University	200	Natural Gas	1,520,000	No (2008)
Sheraton Parsippany	250	Natural Gas	1,590,000	No (2009)
College of New Jersey (3 fuel cells)	600	Natural Gas	3,800,000	No (2011)
Total	**1,050**		**6,910,000**	

Findings

All five fuel cells discussed in these interviews had been decommissioned after five to eight years. This made it difficult for us to track down a knowledgeable representative of the system. Three were available for an interview and they represented five of the eight fuel cell systems. All brought up some common challenges associated with fuel cells.

Overall, customers were highly satisfied with the rebate and incentive application process. Most said they would not have considered the technology had it not been for the resources received from the NJOCE or the New Jersey Board of Public Utilities (BPU). Participants in the CORE program received $3.13/watt, and this funding was clearly a driving force for many of the projects. According to the customers we contacted, four of the five fuel cells covered the balance by a direct purchase after receiving approval for the rebate. At the time of the program, there was significant interest in grid resiliency, primarily for security reasons, and with the CORE program's resources, these customers could invest in fuel cells as a first step toward possible grid independence. However, these fuel cells were not permitted by the utility to operate when the grid was down.

Fuel cells were a leading edge technology when this program began in 2003, another draw for some of the customers we interviewed. Four of the five fuel cells were installed on college campuses where an educational element was also planned in the project. As outlined in the CEEEP Report, several professors played key roles in bringing the technology to campus. However, according to our customer interviews, the educational implementation had mixed results; in some cases the technology was beyond the scope of the institution's science and engineering curriculum. We note, however, that understanding the educational value of fuel cell technology is significant when gauging the motivation of participants in the CORE program.

More relevant to overall customer satisfaction were challenges associated with system O&M. Some sites were ill equipped to manage unforeseen maintenance issues because staff had so little experience with this new technology. Furthermore, for the size of these systems (between 200 kW and 250 kW per module), maintenance costs were relatively high—$50,000/year or higher according to the customers we interviewed. This struck most as too high and contributed to their overall dissatisfaction with the technology.

Customers also expressed disappointment in energy cost savings. Certain factors, common to all of the fuel cell customers we interviewed, led to cost-effectiveness shortfalls. One factor we encountered in talking to customers was the inefficiency of retrofit systems. Customers installed with the intention of offsetting heating and electricity expenses, and several encountered issues in capturing waste heat. In some cases, waste heat capture was as low as 26%, which fell well below expectations.[22] On one hand, Cadmus attributes this to faulty projections. However, waste heat capture is a crucial aspect to consider when exploring future incentive programs. Based on customer testimony, and fuel cell data, fuel cells are only viable when applied in a CHP configuration. To improve projections, and mitigate the risk of major savings shortfalls, the CEEEP Report recommends more educational outreach regarding fuel cells so that "potential users [can] understand both [fuel cell technology's] benefits and limitations".[23] Based on our customer surveys, this seems like a good strategy for improving customer awareness, and thus satisfaction, with the technology.

Because fuel cells last only five to eight years before the stacks need to be replaced, there is a tight payback period with slim margins. Given maintenance challenges, along with partnerships with relatively new manufacturers and installers, the overall costs of these systems rose well above what was anticipated. Rebates and energy savings were not adequate to cover these expenses. Furthermore, replacing a fuel cell's stacks can cost two thirds of the price of the fuel cell. If the fuel cell does not show cost effectiveness in that first term, customers are unlikely to re-commission the system.

Shortfalls may also have occurred because projections for these systems were misguided, or overly optimistic. A common assumption in the projection was that these systems operated continuously. Thus, some customers did not incorporate general maintenance outages in their projections.

Conclusions and Recommendations

The fuel cells we researched all performed well below customer expectations. None of the three representatives we interviewed would choose to install a fuel cell if given the chance again. Because of the high cost of fuel cell O&M and the low cost of natural gas at this time, these systems do not appear to offer energy cost savings and, in some cases, operate at a significant loss.

[22] The Richard Stockton University of New Jersey. "Fuel Cell Demonstration Project". Available Online: http://intraweb.stockton.edu/eyos/energy_studies/content/docs/fuel_cell_report.pdf

[23] Center for Energy, Economic & Environmental Policy (CEEEP). "New Jersey Hydrogen Learning Center Year One Report" p. 24.

These interviews comprise a very small sample size—three customers representing five fuel cell systems—therefore, the data are not statistically significant. However, the experiences and challenges described by these representatives appeared to be common across the eight systems and illustrate the significant issues facing any future fuel cell incentive program. Again, these issues are:

- High maintenance costs significantly affect fuel cell cost effectiveness.
- Inefficient waste heat capture, especially for retrofit systems, caused energy savings to fall below projections.
- Systems were not large enough to provide grid independence and in many cases were not able to operate when the grid was down.
- Satisfaction of the customer ranged from unsatisfied to extremely unsatisfied.

Cadmus noted that the incentive process was very effective in garnering interest and investment in fuel cells. All of the customers we interviewed were very pleased with the application process and would most look into future programs pursued by the BPU. However, at this time, it does not appear that a similar fuel cell incentive program would generate significantly better results than the previous program. In order to improve fuel cell rebate programs in the future, Cadmus recommends the Office

- Make O&M contracts mandatory for the life of the system. That way, customers are able to predict system costs towards the end of stack life when maintenance issues become more frequent, and often more costly.
- Work with utilities to allow fuel cell systems to operate when the grid is down. Many of these customers chose fuel cell technology for its ability to provide energy resilience.
- Though it may limit the fuel cell market, Cadmus believes only fuel cells that support CHP application (e.g., molten carbonate and phosphoric acid) should be included in any future rebate program.
- Create an educational element for future rebate programs, which provides educational resources to potential customers. A series of webinars may allow customers to gauge the potential effectiveness of a fuel cell system in their new construction, or existing load.
- Since fuel cell technology has gained traction amongst local universities, it could be worth providing a higher education component to the rebate program, which allows local colleges to access a wide variety of funding resources. Since fuel cells seem to have had the most success in that market, it is advisable to cultivate that interest in the technology in that community.

Appendix A: Small Wind Customer Survey and Field Inspection Template