Energy Independent Caroline:

Wind Power Feasibility Study for Preliminary Development

Cornell University
Department of Biological & Environmental Engineering

Coauthors:
Aaron Cunningham, '08
Erik Eibert, '08
Morghan Transue, '08

Faculty Advisors:
Norman Scott, Ph. D.[i]
Louis Albright, Ph. D.

Date Submitted: ______________________

Aaron Cunningham: ________________________________ Date: ___________

Erik Eibert: ______________________________________ Date: ___________

Morghan Transue: _________________________________ Date: ___________

Norman Scott: ____________________________________ Date: ___________

Louis Albright: ___________________________________ Date: ____________

Student Branch Faculty Advisor: ________________________ Date: ____________

[i] Please direct all correspondence to Dr. Norm Scott via Cornell University, 216 Riley-Robb Hall, Ithaca NY, 14853

Report Overview

Choosing the Project

Energy lies at the root of human civilization, supporting everything from industry and transportation to food production and leisure. It allows us to master our surroundings but it also can wreck massive geopolitical, humanitarian, environmental, and economical havoc if supplies run short or fall into the wrong hands. As a result, domestic renewable energy can offer economic stability and a sustainable future when implemented correctly. Energy Independent Caroline's (EIC) wind energy and carbon neutrality ambitions provide a perfect example of such an opportunity. As a rural, community-based sustainability initiative, EIC can provide an example to other communities of how they can take control of their energy usage and energy sources and institute positive change. In addition, it can become a symbol of collaborative effort between small groups and larger entities for the betterment of all. When the opportunity to work with EIC presented itself, its implications and larger message were too significant to ignore. The following report presents our contribution to this movement bringing the larger American community towards a more sustainable energy future.

Abstract

Energy Independent Caroline is a local group concerned with issues of sustainability within the Town of Caroline, New York and the group is currently investigating the possibility of installing wind turbine technology within their town. The goal of this report is to provide accurate and reliable technical information from which Energy Independent Caroline can make informed preliminary decisions concerning wind development within their township. Three primary topics were investigated: a meteorological tower and data collection system, a preliminary site analysis, and the preparation of preliminary wind resource estimates and turbine recommendations. The report has determined that EIC can collect reliable wind and weather data using a meteorological tower system at a cost of approximately $15,700. In addition, preliminary analyses suggest that turbine sites off Speed Hill Road and Bailor Road in Caroline hold the most promise with the fewest wind shading, safety, and accessibility complications. Unfortunately, these sites will require expensive three-phase power lines to be constructed. Finally, preliminary wind resource estimates were generated for the Speed Hill Road site. The analysis predicts that the most probable wind speed occurs at six meters per second while the largest expected power density occurs at speeds of about eleven meters per second. In accordance with these estimates, several turbines were recommended for rated outputs of 1.5 MW, 2.0 MW, and 2.5 MW based on the expected wind resources and the turbine power curves and their outputs and revenues were estimated.

Acknowledgements

We would like to thank our faculty advisors Dr. Norm Scott and Dr. Lou Albright for making this opportunity available and for their support throughout the research and design process. We would also like to thank the members of Energy Independent Caroline for their support, guidance, and expertise as the project progressed. These members include Dominic Frongillo, Robert MacCurdy, and Scott Mcclintock. Thank you also to the following industry representatives who provided invaluable information: Robert Carpenter of Campbell Scientific Inc. and the KBR Rural Public Power District.

Table of Contents

Table of Figures

Introduction

The Town of Caroline, New York

The Town of Caroline is located in hilly Tompkins County in Central New York. According to year 2000 census data[1], the town contains a total population of 2,910 individuals in 470 households. Approximately 68.9% of the population is in the labor force with a median per capita income (1999 dollars) $21,531. Occupations are distributed as shown in Table 1 below.

Table 1: Occupation Distribution in Caroline, New York[2]

Occupation	Number	Percent
Management, professional, and related occupations	644	45.2
Service occupations	201	14.1
Sales and office occupations	285	20.0
Farming, fishing, and forestry occupations	21	1.5
Construction, extraction, and maintenance occupations	105	7.4
Production, transportation, and material moving occupations	170	11.9

Energy Independent Caroline

Energy Independent Caroline is a local group concerned with issues of sustainability within the Town of Caroline. According to their website:

> "Energy Independent Caroline is a collaborative effort between residents, Town Board, and other interested people to effectively use our natural resources to achieve energy independence from fossil fuels on a municipal & residential level. Our mission is to produce power for electricity, heat, and transportation from renewable resources. To accomplish this, we initiate renewable energy projects while educating Caroline residents about energy issues in order to build commitment to reducing energy consumption."[3]

The group was instrumental in leading Caroline to becoming the 8th municipality to purchase wind power to supply its electricity and has run an ongoing outreach project distributing energy efficiency information to community households and surveying public opinion concerning renewable energy and sustainability. The group is now focusing on a carbon neutrality initiative and is investigating potential wind power development within Caroline as a means to accomplish this goal.

Scope of Analysis and Involvement

The goal of this report is to provide accurate and reliable technical information from which Energy Independent Caroline can make informed preliminary decisions concerning wind development within their township. The report focuses on three topic areas:

- Meteorological Tower and Data Collection
- Preliminary Site Analysis and Recommendations
- Preliminary Wind Resource and Turbine Analysis and Recommendations

While public relations, project financing, and energy distribution provide additional and significant challenges, this report does not attempt to address them. Instead it focuses on providing technical solutions and proposals for the three afore mentioned topics, looking to present the most appropriate and reliable products and recommendations for the town as it looks towards wind power development and carbon neutrality.

Problem Definition

Meteorological Tower and Data Collection

The viability of any potential wind project depends heavily on the region's wind resources. Current Caroline wind resource estimates do not provide reliable evidence for determining whether sufficient wind resources exist to support proposed investment. While topographically based estimates suggest that a reasonable resource exists, the project can proceed only after concrete data verify this conclusion. Since power output is proportional to the cube of wind speed, seemingly minor inaccuracies in wind estimates will have significant impacts; reliably collected and analyzed weather data is vital. Given reliable data's necessity, this report aims to recommend the most reliable and cost effective solution for obtaining it.

Preliminary Site Analysis and Recommendations

Wind turbine site locations directly affect both the power output and the project's overall feasibility. When selecting potential sites, one must seriously consider the available wind resource, the site's proximity to residential, commercial, and governmental structures, and the site's accessibility. These three issues determine the site's feasibility and it is therefore important to review their potential impact on energy output, economic viability, and safety. The following report analyzes three potential sites based on these criteria and makes appropriate recommendations.

Preliminary Wind Resource and Turbine Analysis and Recommendations

Site selection, turbine selection, and investment agreements require reliable data collected from a meteorological tower, but it is useful to estimate wind resources based on present information and approximate expected energy production and revenues. This report estimates Caroline's wind resources based on available data and parameters and from these estimates suggests appropriate wind turbines models. Several turbine models are recommended for each of the following power output specifications: 1.5 MW, 2.0 MW, and 2.5 MW. Estimates of annual energy production and revenue are also presented for each turbine.

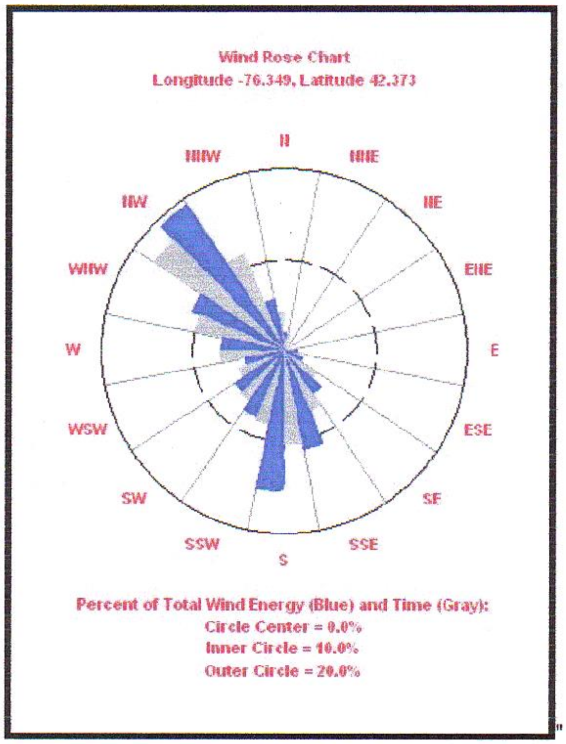
Results and Analysis

Meteorological Tower and Data Collection

Meteorological Tower Design Recommendations

Meteorological towers, commonly known as "Met Towers," provide the most commonly sourced data used to assess wind resources. Towers, including all pertinent sensing equipment, are sited rear a potential site and record all necessary data at multiple elevations. A tower consists of a single "Gin Pole" erected with concentric, anchored support cables radiating outward creating a 100m diameter footprint. The support cables secure the tower from several points but the vast majority of the footprint area consists of open space. The industry standard tower height of sixty meters ensures that topographical obstructions do not interfere with data collection and hence this height is recommended for Caroline. Considerations concerning specific tower placement depend heavily on site suitability (discussed in more detail below) and negotiations with appropriate landowners.

A Met Tower kit purchased with the tower provides all necessary equipment for installation and data collection. The kit includes securing cables, sensors, mounting hardware, power supplies, and data logging software. Data logging equipment, including anemometers, devices measuring wind speeds, are attached to the tower at three ascending intervals, obtaining data for profiling wind sheer effects and the atmospheric boundary layer. Anemometer manufacturers calibrate the sensors within tight tolerances as data reliability is essential for supporting investment negotiations and contracts. It is suggested that wind measurements be taken in 10 minute interval averages to avoid abrupt surges[4]. At least one year of data is necessary to show seasonal trends and variation, and several years of data are preferable. Upon compilation, a wind rose (Figure 1) provides a useful visual representation of directionally related wind power and is suggestive of prevailing orientation. Differences in seasonal averages, as well as daily averages should be taken into account.[ii]



Wind rose image calculated from the nearest data point within 5 km.

Figure 1: Sample Wind Rose for Caroline Region

Costs and Economics

While the cost of Met Tower systems varies, they are generally priced in the neighborhood of $15,000. A specific quote generated for EIC purposes by Campbell Scientific Inc totaled approximately $15,700 (see Table 2 below) [5]. To offset the system cost, rebates may be available for smaller wind projects, covering between 15% - 50% of total cost depending on size and funding availability[6]. As a result, the tower's net cost may ultimately cost considerably less the quoted amount. Installing a Met Tower and collecting data may incur a large initial cost but it is also arguably the most important. Cost cuts that compromise wind data reliability inevitably engender imprudent decisions based on faulty data and may ultimately cost more than the original proposed Met Tower investment. Both community beneficiaries and financial supporters of the project will want to proceed with a firm footing based on reliable data.

[ii] It is important to note that averages are deceiving due to the cubic relationship between wind speed and power output. For this reason, a Weibull distribution is used, summing small incremental averages of power into frequency bins which are calculated individually. For more details see Preliminary Wind Resource and Turbine Analysis below.

Table 2: 60 Meter "Met Tower" Components and Price Quotation

Part Description	Cost	Part Description	Cost
RM Young Wind Monitor 216ft cable/sensor	$1,043.28	109" boom arm and mounting hardware	$68.17
NURAIL Crossover Fitting	$18.24	NRG #40C Anemometer and 53' cable	$324.08
92" boom arm and hardware	$65.33	Fab NRG sensor mount	$22.66
NRG #40C Anemometer	$383.00	3/4*1 in NURAIL Fitting	$15.36
Fab NRG sensor mount	$22.66	133" boom arm with mounting hardware	$72.17
3/4*1in NURAIL Fitting	$15.36	Additional boom rec. for arms >100"	$447.00
92" boom arm and hardware	$65.33	Datalogger Support Software	$542.40
NRG #40C Anemometer w/ 184' cable	$371.00	Measurement and Control datalogger	$1,467.84
Fab NRG sensor mount	$22.66	Keyboard/Display	$273.60
3/4*1in NURAIL Fitting	$15.36	CompactFlash Module	$359.04
92" boom arm and hardware	$65.33	64M Compact Flash Mem	$103.68
RM Young Wind Monitor 118ft cable/sensor	$981.54	12V power supply	$206.40
NURAIL Crossover Fitting	$18.24	Wall Charger	$33.60
109" boom arm and mounting hardware	$68.17	10W Solar Panel 15' cable	$220.80
NRG #40C Anemometer and 118' cable	$347.48	AC conversion module	$144.00
Fab NRG sensor mount	$22.66	Weather-proof enclosure	$259.20
3/4*1 in NURAIL Fitting	$15.36	60m isotruss tower, all required mounting hardware	$7,599.00
Total: $15,700			

Alternative Solutions

Sonar Systems

Sonar wind data collection systems are extremely convenient, portable systems that employ sonar waves to measure wind speed with accuracy across a wide range of altitudes[7]. While they are small, and require very little installation time or effort, they are usually suited for use in isolated areas or where extreme accuracy is warranted. Generally, these systems cost in the range of $40k depending on the application and therefore are not cost effective for the Caroline project.

Communications Tower

The Town of Caroline has access to a communications tower located near one of the proposed wind sites; access has been granted for use up to approximately thirty meters. While its use as a platform for wind measurement sensors would cut costs considerably compared to a Met Tower, its location and height are prohibitive. Not only is the tower adjacent to tall trees but it also resides on the hill's leeward side, hampering functionality as a wind data collection site. Additionally, the access height ends at about half the recommended tower height of sixty meters. As a result, considering the scale of the projected investment, it would not be advisable to proceed based on data collected solely from the communications tower.

Preliminary Site Analysis and Recommendations

Site Considerations

Wind turbine site locations directly affect both the power output and the project's overall feasibility. Thus, when choosing a site, one must seriously consider the available wind resource, the site's proximity to residential, commercial, and governmental structures, and the site's accessibility. These three issues guide the turbine project's implementation and construction and it is necessary to review their potential impact on energy output, economic viability, and safety.

Maximal Wind Profile

Maximizing the wind profile the primary consideration when selecting a site.[8] The available wind resource dictates the turbine's power output and the project's feasibility; the wind resources within Caroline and at the sites in question were determined via the NYS Wind Resource Map.[9]

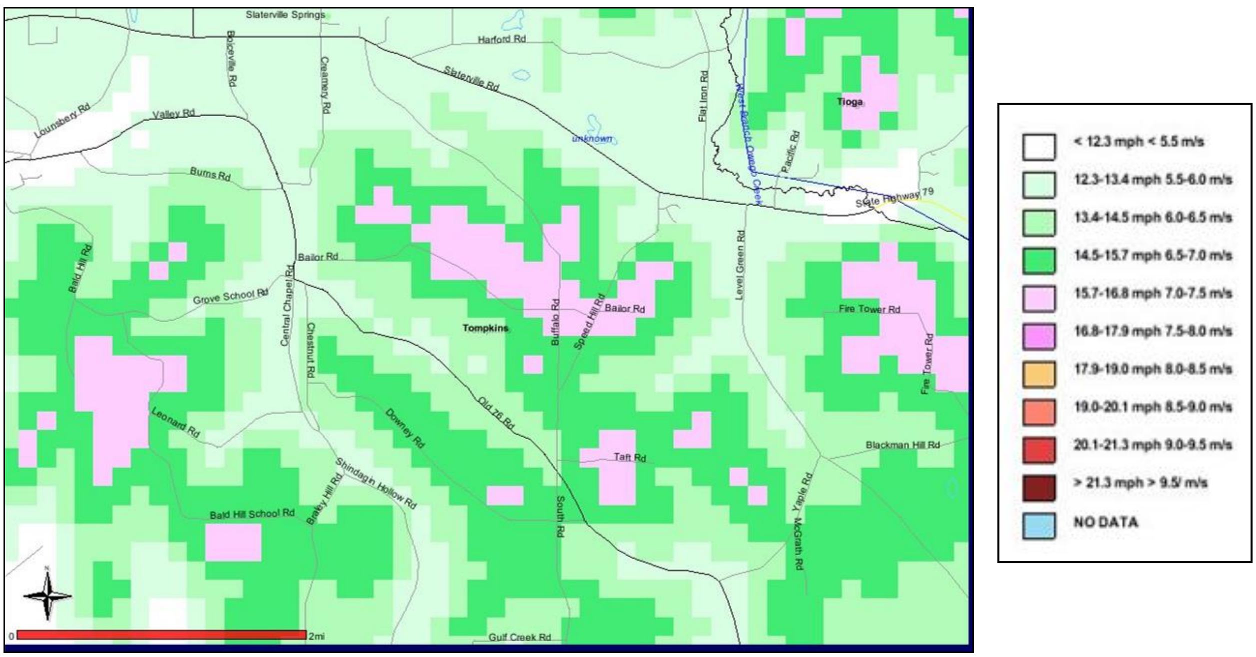


Figure 2: Caroline Wind Resource at 100m

Although these maps (see Figure 2 above) display only rudimentary wind availability estimates, several accessible hilltops within Caroline achieve mean wind speeds of around 7.0 to 7.5 m/s at 100 meter tower heights. Since these zones of relatively high wind speeds reside in only a few areas throughout Caroline, the number of site choices is immediately limited. It is important to remember that much of the wind incident on Caroline originates from the westerly direction (see Figure 1) as this further reduces the viability of several potential sites. A major factor determining wind profiles is the terrain roughness as defined by the Danish Wind Industry.[10] The terrain roughness is defined by many factors but mainly by wind flow obstruction. Increased terrain roughness thickens the boundary layer profile and can create wind shadowing, decreasing the maximal wind speeds. Roughness is defined on a small numerical scale from zero to four where zero represents minimal wind shear (open water) and four represents the greatest sheer (densely packed buildings and forests). Based on this scale, an estimation of based on Caroline's hilly, forested landscape places the town's terrain roughness at about three. The sites ultimately recommended within this report were selected to minimize the roughness and increase distance to obstructions.

Finally, hill effects can also influence wind profiles.[11] As is known from introductory physics, wind compresses as it approaches the windward side of the hill and expands once it reaches the ridge. Dense air combined with the speed up effect of the hill makes such a location an ideal spot for a wind turbine. With these considerations, the wind profiles for Caroline hilltops are promising.

Proximity to Neighboring Structures

Due to potential structural failures, environmental factors, ice shedding, and noise pollution an industry standard exists governing turbine proximity to residential, commercial, and governmental structures. Safety risks from structural failure or lightning strikes present safety hazards within a relatively small radius from the turbine. Since ice will fly further than any turbine component, a comprehensive analysis of ice shedding will provide a much more inclusive wind turbine "safe distance." While the complete formulae for calculating the ice throw distance from wind turbines were calculated by Morgan et al.[12], a simpler approach, shown by Equation 1 is used within the industry. [13]

Equation 1: Turbine Safe Distance Formula

$$Safe\ Dis\tan ce = 1.5 \times (Hub\ Height + Rotor\ \ Diameter)$$

This formula oversimplifies ice shedding dynamics but reliably predicts the area in which the majority of thrown ice will land.[14] In reality, the exact location within the generated safety circle depends on wind direction and velocity (Figure 3).

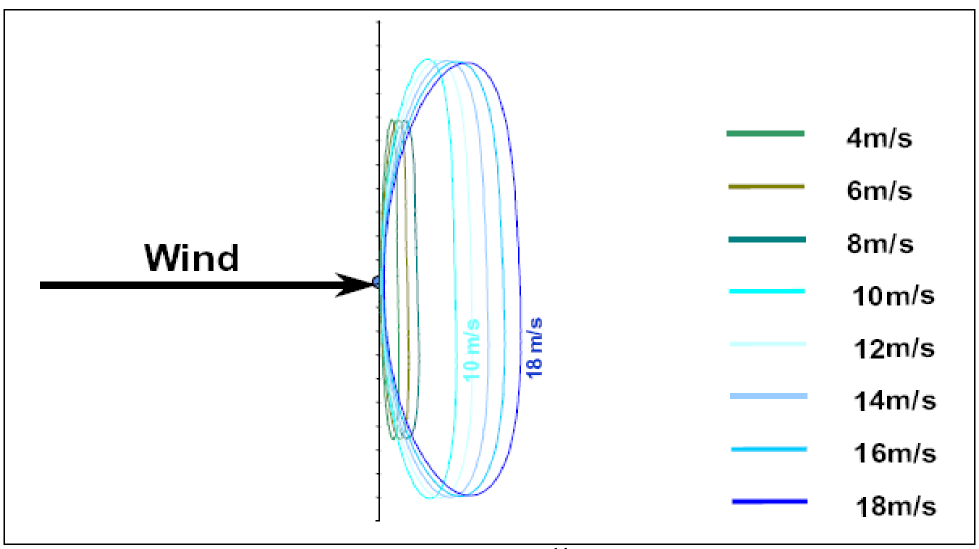


Figure 3: Ice throw area as a result of ice throw calculation[14]. Shows where ice is likely to land as a function of wind speed. Formulated by Seifert et al.

Employing Equation 1 for a GE 2.5xl wind turbine with a 100 meter hub height, the recommended safe area requires a 300 meter radius, a distance that must be seriously considered when determining the turbine site and size. The affects of noise pollution should also be accounted for during the turbine site analysis; however, since it has been observed[15] that a car driving at a 400 meter distance is substantially louder than a wind turbine at thirty meters, we can consider noise pollution to be negligible outside the recommended safe distance.

Accessibility

Two main considerations exist in regards to accessibility: distance to three-phase power lines and construction considerations. Large commercial wind turbines require connection to three-phase power and hence access to such lines introduces a critical criterion for site selection. At an additional three-phase line construction cost of $ 8.75 per foot[16], a site's distance from the available line introduces a significant cost variable (Figure 4). A three-phase power line currently exists at the corner of Buffalo Road and Old 76 Road. This location restricts the number of economically feasible sites to within approximately one mile of the intersection.

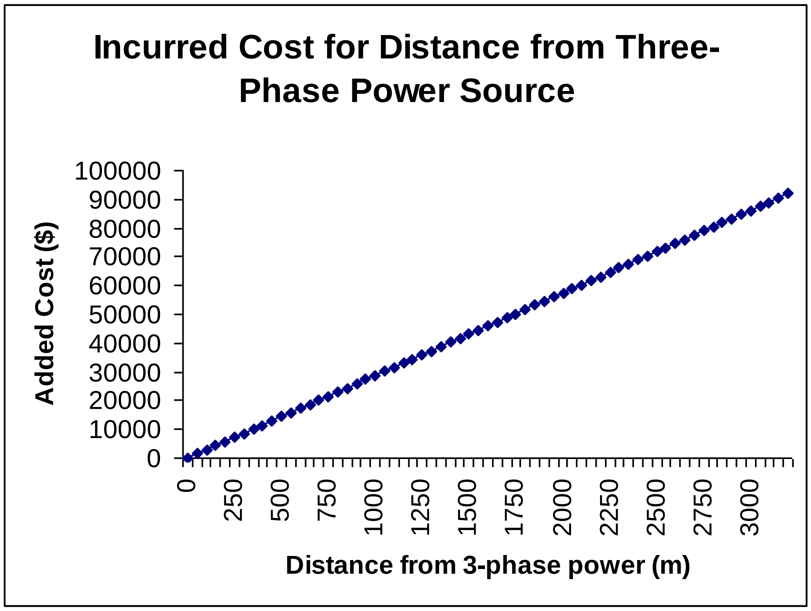


Figure 4: Cost Differential as distance from three-phase power increases

The second accessibility concern involves ease of construction. Since the turbine blades cannot be assembled on site, the approximately fifty meter long blades must be transported to the final location via the local roadway system. Such length presents a significant impediment to transportation and thus requires special considerations. Roads in Caroline were not constructed to accommodate tractor-trailers with 150 ft. long beds, and consequently any turbine installation in Caroline will require some road preparation and modification. Since road reconstruction is inevitable in the long run and no major impediments to road construction exist near the potential sites, we consider this added cost to be comparable for each site. The exact cost of such reconstruction is currently unknown but such road alterations should not be inhibitive.

Site Selection

Based on the criteria discussed above, three preliminary sites were chosen for further analysis (Figure 5). Each of these sites (marked by an orange star) resides in close proximity to the three-phase power source (marked by a green star) and atop hills with Caroline's best wind resources (compare to Figure 2, page 9).

Figure 5: Caroline Map showing three potential turbine sites.

Speed Hill Road

The first potential site, located off Speed Hill Road, sits at an elevation of 1795 feet and a distance of approximately 1.2 miles from the three-phase power source. Located atop a hill on open farmland the site encounters little wind resistance and consequently has a superior wind resource profile compared to the other two sites. Preliminary information suggest a mean wind speed of about 6.5 m/s at 70 meters[17], but some forest located approximately 200 meters away may generate some wind shade. The site's wind profile most likely surpasses the others, but a house is currently located on this plot of land within the designated 300 meter safe radius. It should be noted however that the house is on the turbine's windward side and it is unlikely that ice will be thrown in its direction. Along these lines, two limited-seasonal-use roads (Bailor Road and Speed Hill Road) and one well-maintained road (Buffalo Road) lie within the safety zone. The proximity of these roads to the turbine could present potential icing problems. Finally, the site's 1.2 mile distance from the three-phase power source adds a power line construction cost of about $55,440. Despite this added cost, this site has the greatest potential for value with limited impediments to construction.

Bailor Road

The second site near Bailor Road has a slightly lower elevation of 1785 feet and is further from the three-phase power source at 1.3 miles, adding a line construction cost of $64,680. As a result, the Bailor Road site has the highest additional cost of the three sites. However, because the site is set off the Speed Hill Road site, it takes advantage of an expanse of open farmland that lies below turbine, allowing for the least disturbed wind profile of the three locations. Meteorological data, as discussed previously, will be necessary to determine the accuracy of these estimations. Unfortunately, some safety concerns prevent the site from garnering the highest recommendation. Two houses and a seasonal-limited-use road (Bailor Road) lie within the 300 meter radius safety area. One of the houses and the road lie directly north of the intended site making this house fall within the likely ice-thrown ellipsoid shown in **Error! Reference source not found.**. This presents a significant hazard that cannot be ignored as easily as in the Speed Hill Road case. To correct the problem, the turbine must be located further to the south. Unfortunately shifting the turbine site southward sacrifices altitude and wind speed and introduces forest obstructions. This severely limits the feasibility of this site without adequately addressing the safety concerns.

Taft Road

The last site, off Taft Road, has the highest elevation at 1845 feet and is located a mere 0.4 miles from the three-phase power source. These characteristics suggest that Taft Road provides the best of the three sites; regrettably, the opposite is true. First, the hill's windward side is completely wooded making a wind shade map useless. Even clearing the top of the hill for the turbine foundation would not do much to alleviate the turbulence generated by the surrounding forest. The nearby trees would increase the boundary layer of the wind profile and result in unknown characteristics of the region. Placing a turbine on the hill's leeward side would decrease the wind resource due to the shading creating by the hill and forestry that rests atop it. Deforesting the entire windward hillside would free up a huge wind potential but such extreme action would likely cause public outrage and environmental concern. In addition two houses and a seasonal-limited-use road that lie on the apex of the hill. Any hilltop site would be well within 100 meters of both of the houses and the road and thus unsafe. As a result, without major hilltop changes, the Taft Road site is neither safe nor practical despite its significant wind potential.

Preliminary Wind Resource and Turbine Analysis and Recommendations

When planning a wind turbine project it is useful to estimate wind resources based on present information and approximate expected energy production and revenues. Such an analysis requires the calculation of wind speed probability distributions and the resulting power densities, the selection of appropriate turbines, and the estimation of energy and revenue generation.

Wind Resource Analysis

To quantitatively predict wind resources at the proposed turbine sites, the Weibull probability distribution was employed. The Weibull distribution (Equation 2) is generally accepted as the most applicable distribution for characterizing wind speeds as it skews towards lower and generally more probably wind speeds.

Equation 2: Weibull Probability Distribution Function[18]

$$f(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} e^{-\left(\frac{v}{c}\right)^{k}}$$

Using available scale and shape parameters (c and k respectively) based on local topography,[9] wind speed probability distributions at different heights were generated as shown in Figure 6 for the Speed Hill Road Site. All sites generated similar probability distributions; as tower heights increase, the distributions grow shorter and wider with the most probable wind speed shifting towards higher values in accordance with boundary layer effects. The most probable wind speed for a 100 meter tower falls at approximately six meters per second.

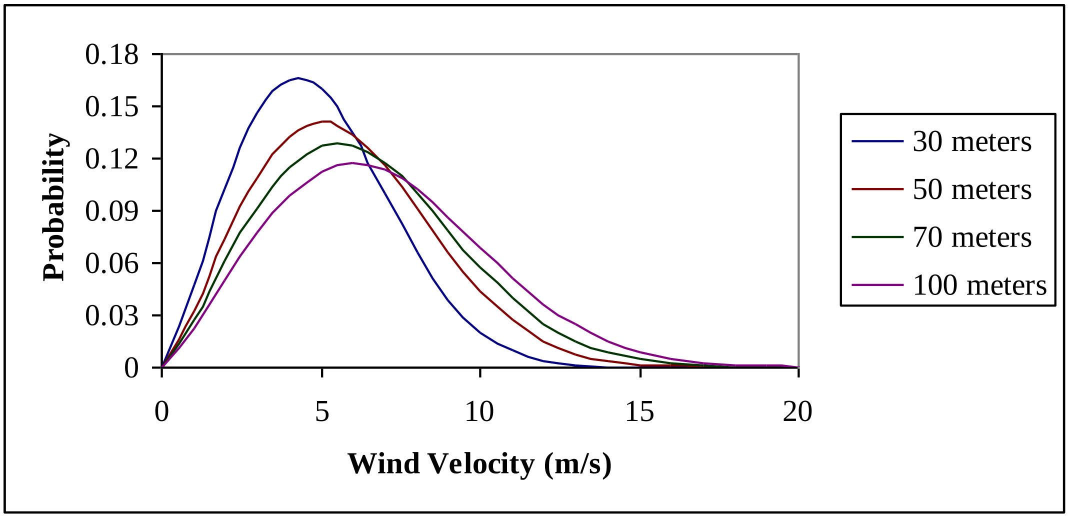


Figure 6: Wind Velocity Probability Distribution for Speed Hill Road Site

To predict the probable power output at each site, the probability distributions were coupled with power density calculations. Power density, measured in watts per square meter of swept area, is a function of air characteristics and the cube of wind velocity (see Equation 3). To determine average power density, power densities for each one meter per second wind speed increment were calculated and multiplied by the corresponding probability value determined via the Weibull distribution.

Equation 3: Power Density Formulae

$$Power\ Density = 0.005 K_A K_T V^3$$

$$K_A = 1 - 3.128 \times 10^{-5} \times Altitude$$

$$K_T = 1.1245 - 0.002007 \times Temperature$$

$$Average\ Power\ Density = \sum PD_i \times probability$$

Figure 7 (below) plots the resultant average power density values at various tower heights for four pertinent sites. The figure demonstrates that the Taft Road and Speed Hill Road sites possess roughly analogous power densities and outperform the other sites, making them eligible for the more detailed site analysis discussed above. Because of the safety concerns and wind shadowing issues present at the Taft Road site, the remaining analyses focus on the Speed Hill Road site and its predicted power output and revenues.

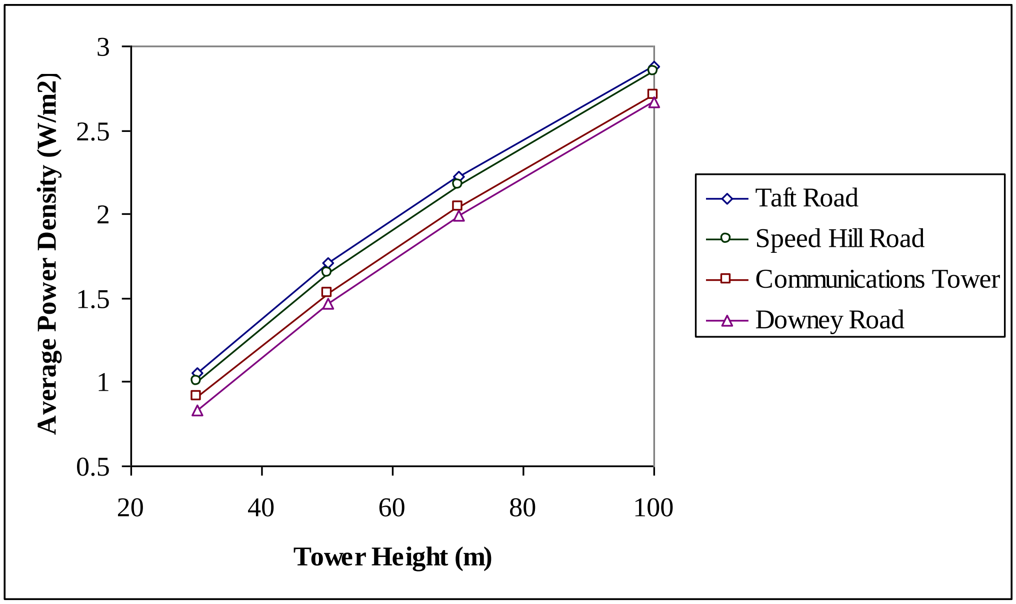


Figure 7: Average power density as a function of tower height

Figure 8 displays expected power density at the Speed Hill Road site over a range of wind speeds and four tower heights. As wind speeds increase with tower height, power density also increases dramatically. Increasing tower height from 70 to 100 meters increases power density by over thirty percent. As a result, the 100 meter tower is recommended and assumed for the turbine selection analysis that follows. Notice that while the most probable wind speed occurs at about six meters per second for a 100 meter tower, the largest expected power density occurs at speeds of about eleven meters per second. This occurs because power density is proportional to the cube of wind speed as shown in Equation 3; while speeds of eleven meters per second are less likely than six, power output is over six times larger, shifting the curves left.

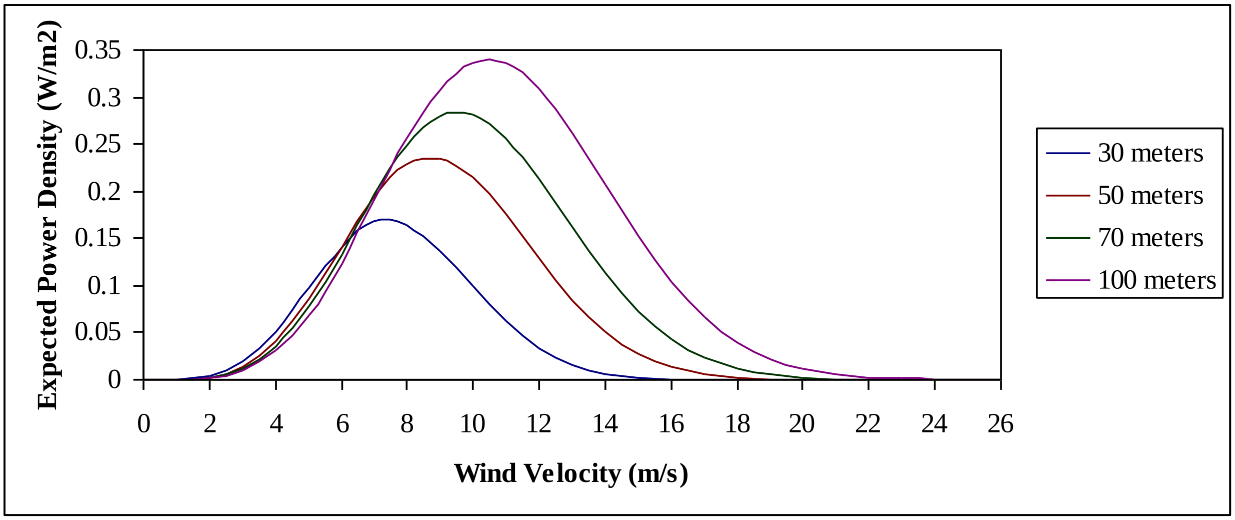


Figure 8: Height Variable Power Density at Speed Hill Road Site

Wind Turbine Recommendations

In order to identify the most suitable turbines for the Speed Hill Road site, turbine models from all major manufacturers were judged based on their power curve's fit to the power density curves described above. Because wind speeds between ten and twelve meters per second maximize power density at 100 meters, turbine power curves must plateau within or slightly below that region to be considered. Turbines with 100 meters tower that meet this criterion fall into three output categories: 1.5 MW, 2.0 MW, and 2.5 MW. The top three to four turbines in each category were analyzed for energy output and revenue generation. The ultimate turbine and output size selections will depend on Caroline's output goals and financial restraints.

Predicted energy outputs for each turbine were calculated based on the turbine's power curve (kW versus wind speed) and the Weibull wind speed probability distribution, scaled to one year. Expected revenues were derived from this expected energy output and a weighted average of 2006 wholesale electric prices that came to $0.0695 per kWh.[19] The expected revenue values listed in this report serve to illustrate potential revenues, but as electricity prices fluctuate over the next few years, these numbers will change. Please note that while revenue estimates are included in this analysis, turbine and construction costs are not. Turbine and construction costs depend heavily on contract negotiations with suppliers and are liable to change during the several years that inevitably lie between this report and any turbine or construction contracts.

1.5 MW

The GE 1.5xle,[20] the Nordex S77,[21] and the Fuhrländer FL 1500[22] turbines represent the 1.5 MW turbines that best suit Caroline's predicted wind resources (see Figure 9). The GE 1.5xle provides the highest annual energy output and revenue at about 5,066,560 kWh and $352,075 respectively. The Nordex and Fuhrländer models produce lower outputs of 4,543,415 and 4,423,516 kWh annually and $315,722 and 307,390 each year in revenue.

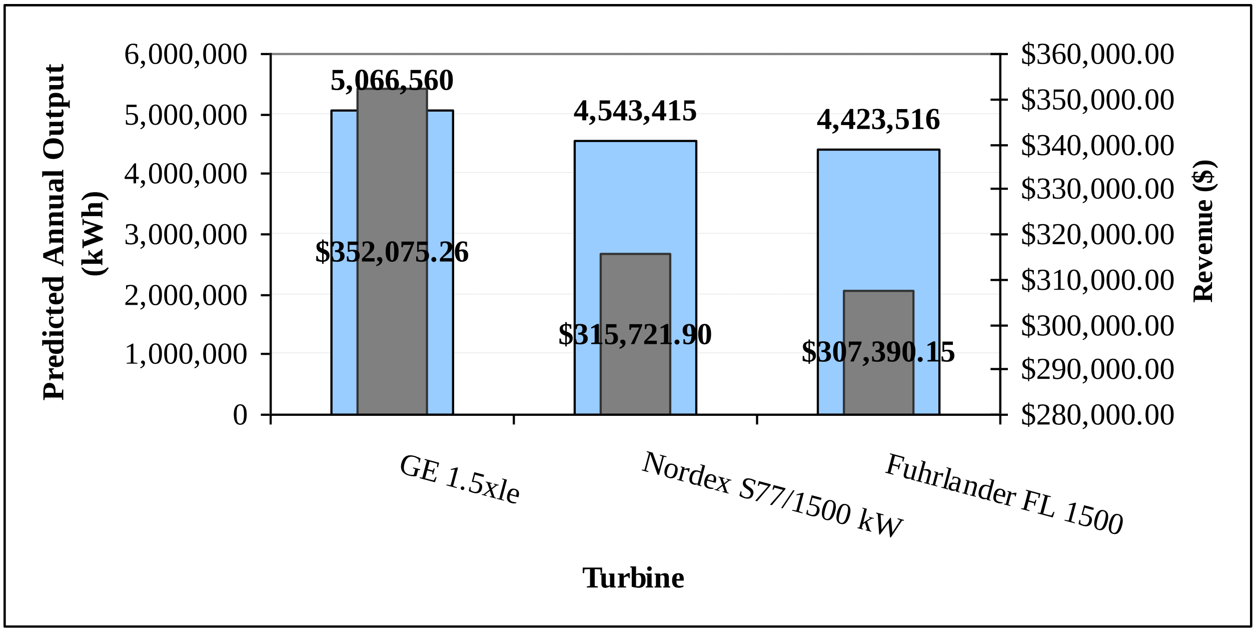


Figure 9: Projected output and revenue from recommended 1.5 MW turbines

2.0 MW

For the 2.0 MW category, the Gamesa G90,[23] the Vestas V90,[24] the Gamesa G87,[25] and the AAER A-2000 (84 meter diameter)[26] turbines provide the best fits to the Speed Hill Road power density curves (see Figure 10). The Gamesa G90 turbine produces 6,538,111 kWh and $454,333 annually while its sister turbine, the Gamesa G87, produces significantly less at 6,185,377 kWh and $429,822. The Vestas V90 out performs the Gamesa G87 with 6,303,042 kWh and $437,998 but falls short of the Gamesa G90. The AAER A-2000 generates only 6,045,769 kWh and $420,121 annually but remains in range of the other turbines.

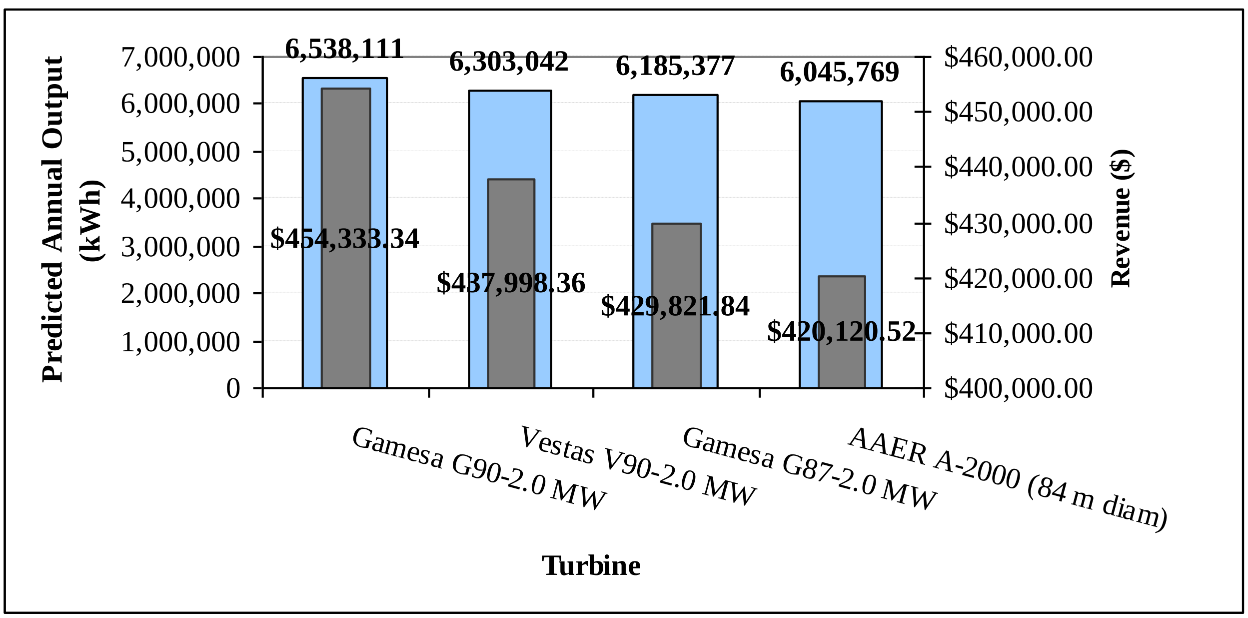


Figure 10: Projected output and revenue from recommended 2.0 MW turbines

2.5 MW

For the 2.5 MW turbines, the Fuhrländer FL 2500,[27] the Nordex N100,[28] and the GE 2.5[29] turbines should perform best in Caroline compared to their 2.5 MW counterparts (see Figure 11). The Fuhrländer and Nordex turbines perform roughly equivalently. The Fuhrländer FL turbine generates 8,064,040 kWh and $560,370 annually while the Nordex N100 turbine produces 7,986,048 kWh and $554,950 annually. The GE 2.5 does not fair as well, producing only 7,418,805 kWh and $515,533 each year.

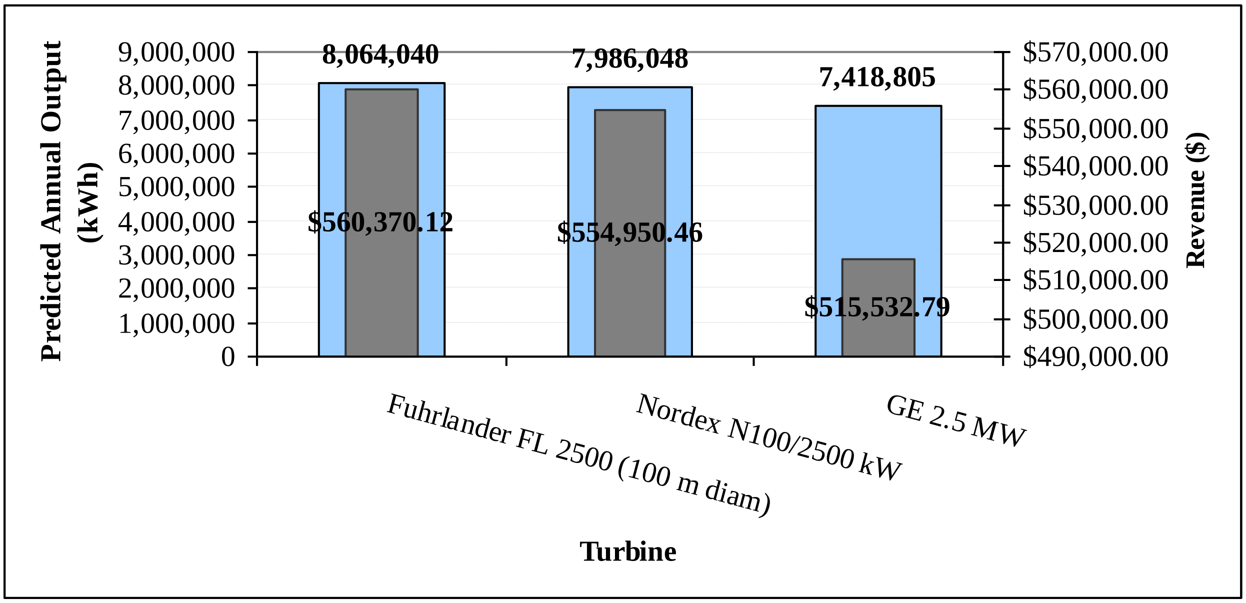


Figure 11: Projected output and revenue from recommended 2.5 MW turbines

Conclusions and Future Work

At the conclusion of our analysis, it was determined that a meteorological tower will meet EIC's data logging needs for approximately $15,700. In addition, preliminary analyses suggest that turbine sites off Speed Hill Road and Bailor Road in Caroline hold the most promise with the fewest complications. Finally, wind resources were estimated at the Speed Hill Road site and the most probable wind speed occurs at six meters per second while the largest expected power density occurs at speeds of about eleven meters per second. Several turbines were recommended for rated outputs of 1.5 MW, 2.0 MW, and 2.5 MW and their outputs and revenues were estimated accordingly.

Despite these results, many additional issues must be addressed before EIC can initiate a wind turbine project in Caroline. These issues include but are not limited to

- Analysis and summarization of data collected from the meteorological tower
- Addressing interconnection issues and transformer station requirements with NYSEG
- Arranging energy distribution and pricing with NYSEG
- Approaching landowners concerning potential sites
- Addressing public acceptance of wind power within their town
- Acquiring financing and other project support

These issues fell outside this report's scope but present interesting challenges for Energy Independent Caroline as they pursue their carbon neutrality goals. These issues may spawn future projects and allow other students to participate in a collaborative effort to bring wind power to the town of Caroline.

---

[1] "Caroline town, Tompkins County, New York, Census 2000 Demographic Profile Highlights" U.S. Census Bureau, Accessed 12/4/07
http://factfinder.census.gov/servlet/SAFFFacts?_event=Search&geo_id=&_geoContext=&_street=&_county=Caroline&_cityTown=Caroline&_state=04000US36&_zip=&_lang=en&_sse=on&pctxt=fph&pgsl=010&show_2003_tab=&redirect=Y
[2] "DP-3. Profile of Selected Economic Characteristics: 2000," Census 2000 Summary File 3 (SF 3) –Sample Data. Geographic Area: Caroline town, Tompkins County, New York. Accessed 12/4/2007
http://factfinder.census.gov/servlet/QTTable?_bm=y&-geo_id=06000US3610912606&-qr_name=DEC_2000_SF3_U_DP3&-ds_name=DEC_2000_SF3_U&-_lang=en&-redoLog=false&-_sse=on
[3] "Energy Independent Caroline" Accessed 12/4/07 http://www.townofcaroline.org/energyindependent/
[4] Danish Wind Industry Association: "Wind Speed Measurement in Practice" Accessed 12/03/07
http://www.windpower.org/en/tour/wres/wndsprac.htm
[5] Carpenter, Robert. Campbell Scientific Inc. Logan, Utah. Email exchange
[6] Small Wind in New York, "Local and State Incentive Programs for Wind Energy." Accessed 12/03/07
http://www.awea.org/smallwind/newyork.html
[7] Bailey, Desmond T. [6 1987] (2 2000). "Upper-air Monitoring", *Meteorological Monitoring Guidance for Regulatory Modeling Applications*, John Irwin, Research Triangle Park, NC: United States Environmental Protection Agency, pp. 9-9 to 9-11. EPA-454/R-99-005.
[8] Vestas – American Wind Technology Inc. "Key Aspects in Developing a Wind Power Project" Accessed 12/5/07
http://www1.eere.energy.gov/tribalenergy/guide/pdfs/developingwindpower.pdf
[9] AWS Truewind LLC "New York State Wind Resource Explorer" Accessed 12/5/07
http://www.windexplorer.com/wre/CORE/MAIN.ASP?MAP_SERVICE=WRE_NEW_YORK.
[10] Danish Wind Industry Association "Roughness and Shear" Accessed 12/5/07
http://www.windpower.org/en/tour/wres/shear.htm
[11] Danish Wind Industry Association "The Hill Effect" Accessed 12/5/07
http://www.windpower.org/en/tour/wres/hill.htm
[12] Morgan, C. & Bossanyi, E. of Garrad Hassan (1996) "Wind Turbine Icing and Public Safety – A Quantifiable Risk?" www.easthavenwindfarm.com/filing/feb/ehwf-ml-reb4.pdf Accessed 12/5/07
[13] Wahl, D. & Giguere P. (2006) "Ice Shedding and Ice Throw – Risk and Mitigation" GE Energy, www.gepower.com/prod_serv/products/tech_docs/en/downloads/ger4262.pdf Accessed 12/5/07
[14] Seifert, H., Westerhellweg, A., Kröning, J. (2003) "Risk Analysis Of Ice Throw From Wind Turbines"
http://web1.msue.msu.edu/cdnr/icethrowseifertb.pdf Accessed 12/5/07
[15] Cunningham, A. – Personal Observation
[16] KBR Rural Public Power District, http://www.kbrpower.com/customer.asp
[17] See endnote 9 above
[18] "Weibull Probability Density Function" ReliaSoft Corporation. Accessed 12/5/07.
http://www.weibull.com/LifeDataWeb/weibull_probability_density_function.htm
[19] "nepool06" EIA, Accessed 12/8/2007 http://www.eia.doe.gov/cneaf/electricity/wholesale/nepool06.xls
[20] "1.5MW Series Wind Turbine" GE , Accessed 11/18/2007,
http://www.gepower.com/prod_serv/products/wind_turbines/en/downloads/ge_15_brochure.pdf
[21] "S70/1500 KW S77/1500 KW" Nordex. Page 7, Accessed 11/18/2007
http://www.nordex-online.com/fileadmin/MEDIA/Produktinfos/EN/Nordex_S70-S77_GB.pdf
[22] "Fuhrländer wind turbines 2.500 kW-1.500 kW" Fuhrländer, Page 4. Accessed 11/18/2007
http://www.fuhrlaender.de/pdf/technicalbrochure/technical-brochure-en.pdf
[23] "Gamesa G90-2.0 MW" Gamesa, Page 5, Accessed 11/18/2007. http://www.gamesa.es/files/File/G90-ingles.pdf
[24] "V90-1.8 MW V90-2.0 MW" Vestas, Page 3, Accessed 11/18/2007 from
http://www.vestas.com/en/wind-power-solutions/wind-turbines/2.0-mw
[25] "Gamesa G87-2.0 MW" Gamesa, Page 5, Accessed 11/18/2007. http://www.gamesa.es/files/File/G87-ingles.pdf
[26] "A-2000 2000 kW Wind Turbine" AAER, Page 3, Accessed 11/18/2007.
http://www.aaersystems.com/files/AAER/aAER_051_2000_17_04_007.pdf

[27] "Fuhrländer wind turbines 2.500 kW-1.500 kW" Fuhrländer, Page 3. Accessed 11/18/2007 http://www.fuhrlaender.de/pdf/technicalbrochure/technical-brochure-en.pdf

[28] "N100/2500 KW" Nordex, Page 7. Accessed 11/18/2007, http://www.nordex-online.com/fileadmin/MEDIA/Produktinfos/EN/Nordex_N100_Produktbroschuere_EN.pdf

[29] "2.5 MW Wind Turbine" GE, Accessed 11/18/2007 http://www.gepower.com/prod_serv/products/wind_turbines/en/downloads/ge_25_brochure.pdf