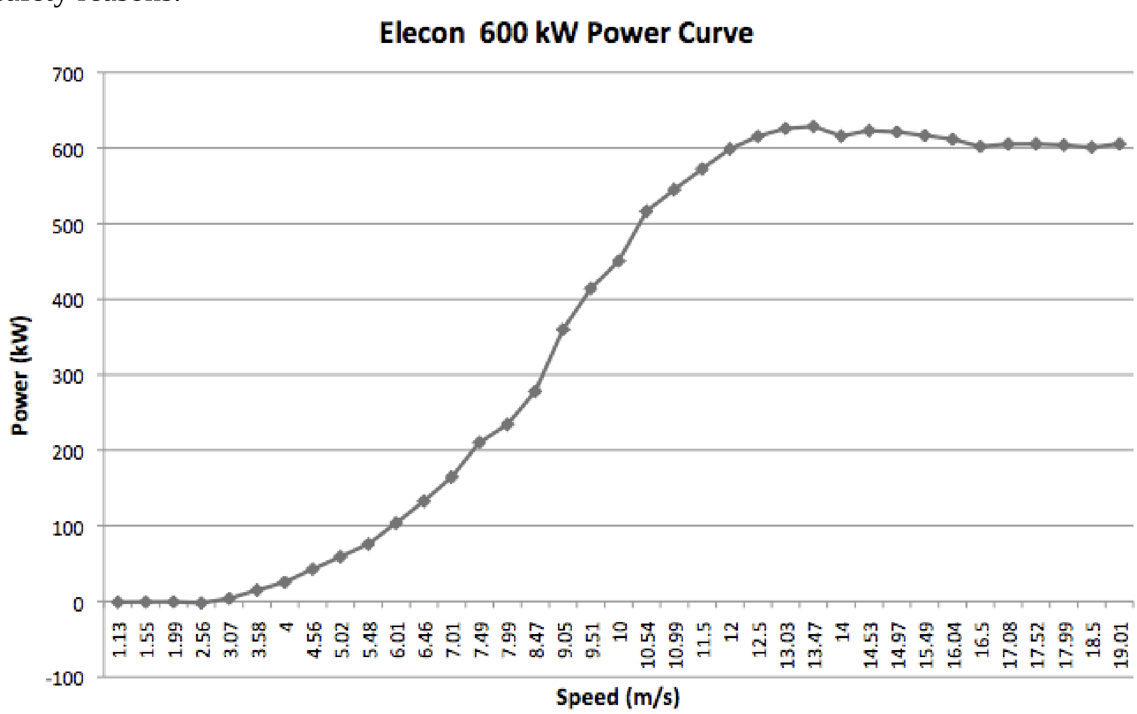
Wind Energy Resouces

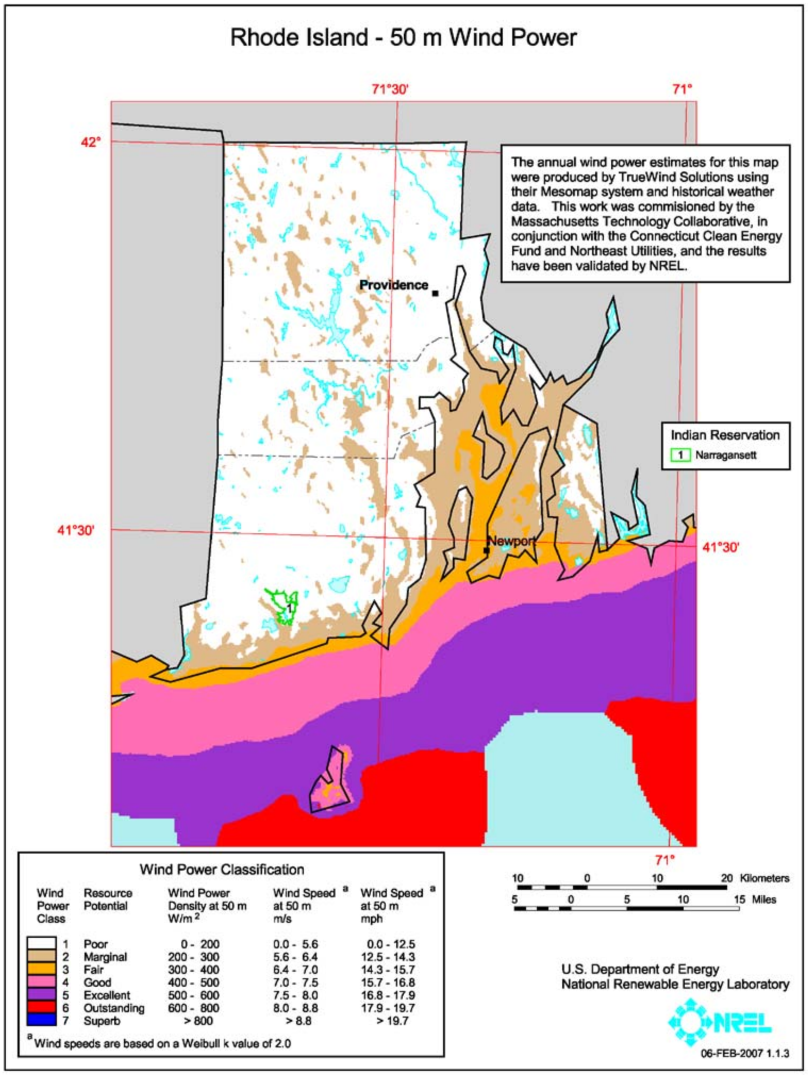
Wind is one of several important renewable sources of energy. A Wind Turbine Generator (WTG) converts the kinetic energy of the wind (physical energy of the moving air mass) into electric energy. The relationship between the input wind speed and the elecrical power output is depicted in a power curve graph. Below is power curve for selcted Elecon WTG. This power curve was produced with hundreds of measurements, comes with error estimates, and was certified by the ECN (Energy Research Center of the Netherlands). When the wind speed is below about 8 miles per hour, it is not practical to generate power and there is no output. Up to the rated maximum output of the WTG, the power increases very rapidly in proportion to the cube of the wind speed. For example, the power output at 15 miles per hour (mph) is about 150 kilowatts (kW). A 20% increase in the wind to 18 (mph) produces about 250 kW, a 67% increase. Once the wind is above about 28 mph, the output reaches its rated maximum of 600 kW (or greater). It is not shown on the graph, but when the wind exceeds about 55 mph, the WTG shuts down for safety reasons.



The amount of energy produced is directly proportional to the duration of the wind.
The best sites for wind power are the plains and coastal areas where the wind (speed and duration) is greatest. At a given site (latitude and longitude), the wind is greater at higher heights above the ground. At a given location (site and height), wind speed varies from hour-to-hour, day-to-day and month-to-month and year-to-year.
over the course of the day, over the course of the year and from year to year. Typically, is characterized on an annual basis to average out much of the variability.

Site Variation

Wind maps are used to display the site variation of wond resources. Maps of wind resources generally display color coded average annual wind, given a particular elevation above ground. For example, see the RI wind map below.



Height Variation

The wind speed varies with the height above ground. Since the energy produced is proportional to the cube of the wind speed, the height of the wind turbine tower can make a substantial difference in the energy produced.

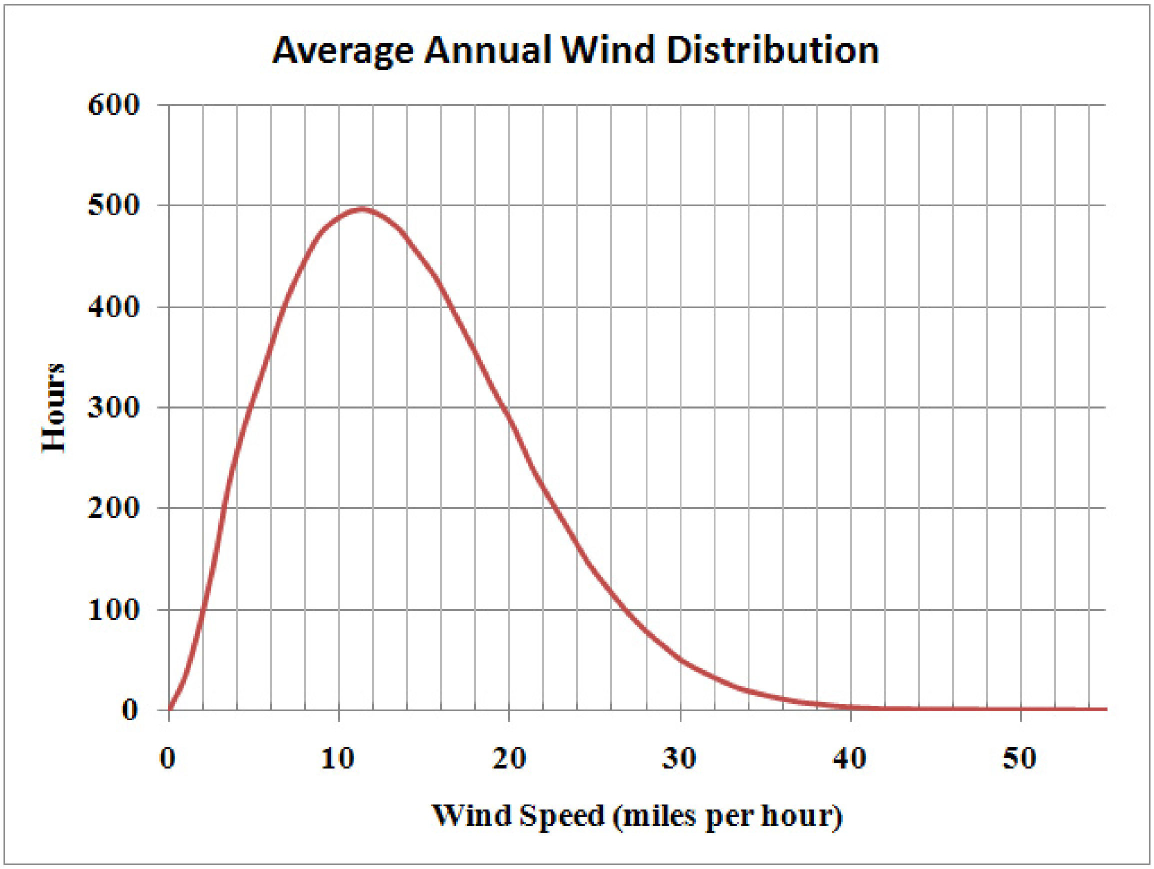
The table below shows the relationships of average wind speed and energy at the various tower heights and wind map data heights under consideration. For reference, the wind at ground level is also shown.

The data in the chart is emperically derived based on data collected over a long period of time; of course there are margins of error.

Height (meters)	Relative Height	Relative Wind Speed	Relative Energy Production
75	1.071	1.010	1.029
70	1.000	1.000	1.000
65	0.929	0.990	0.969
60	0.857	0.979	0.937
55	0.786	0.967	0.904
50	0.714	0.954	0.868
2	0.029	0.608	0.225

Time Variation

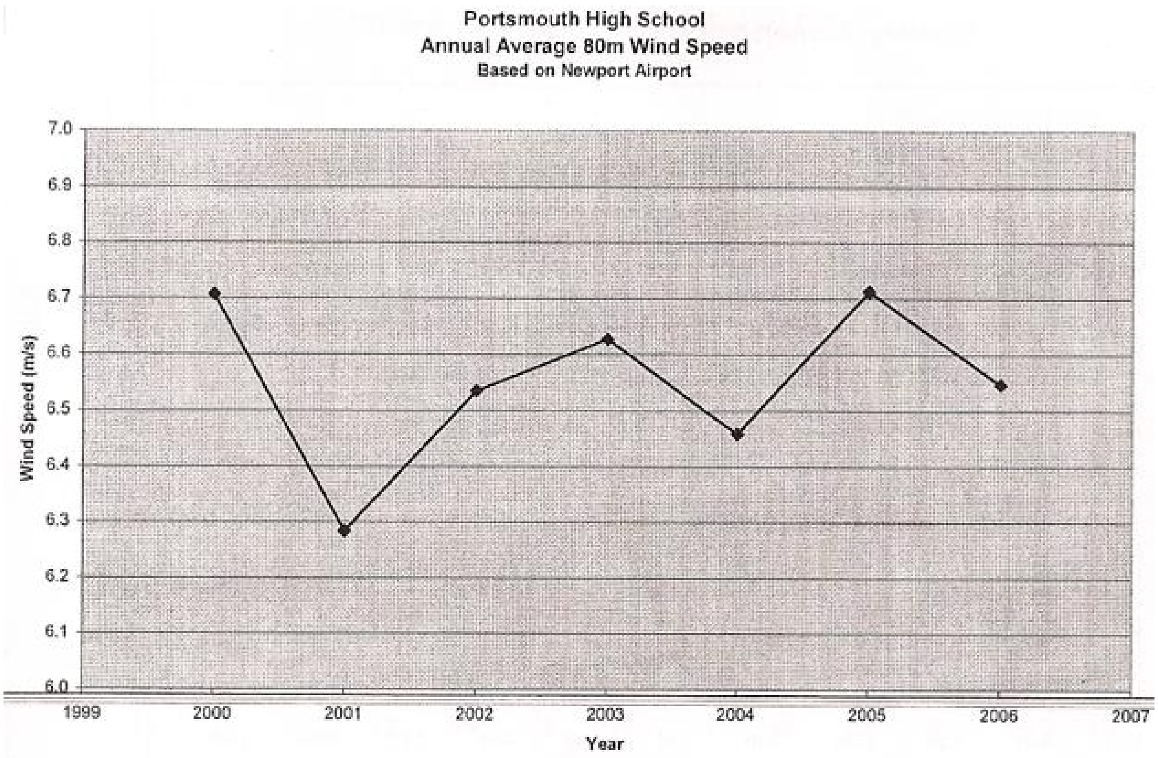
The time variation of the wind is typically described by the distribution of wind speed over the course of a year. As shown in the following figure.



It is a plot of the number of hours that the wind speed is at a given interval. For example, of the 8760 hours in a year, the wind will be at the 15 mph interval for 450 hours (roughly 5% of the time). As one would expect, the very high wind speeds would exist for only a few hours. When the hours at each interval are added together, they total 8760 hours.

Theory and empirial measurements have shown that the wind distribution follows standard mathematical distribution known a Weibull curve. This curve can be characterised by the average annual wind speed and two "shape factors". The major factor is the average annual wind speed, the shape factors do not vary much. The average wind speed for the distribution shown above is 13.4 miles per hour (mph).

The Weibull curve is the **average** annual wind speed. Average wind speed varies substantially year to year – often by 10% as shown in the figure below



Average Annual Energy Production

The expected annual energy production is 1,405,000 kWhs. Fully 90% of this energy will be produced when the wind speed is above average, and more than half of the energy will be produced in the windiest 20% of the year. The energy present in wind increases as the cube of the wind speed. Therefore, it is optimal to configure a turbine for more energy capture at higher speeds, and the above facts do not indicate that the turbine is only appropriate for windier sites.

The energy output is calculated as follows. We calculate the Weibull distribution for a year in intervals of 0.5 meters/second. In other words, for each wind speed 0, 0.5, 1, etc up to 15 m/s the Weibull model gives an expected number of hours annually at that speed. For example, the wind speed is expected to be between 9.5 and 10 m/s (21.4 and 22.5 mph) for 280 hours a year (see Figure 4). For each of these speeds we have a tested power output for the turbine. For example the power output at 9.5 m/s is 414 kW with an error of 38 kW and the power output at 10 m/s is 450 kW with an error of 33 kW. Combining this information, we see that the annual energy expected to be produced when the winds are between 9.5 and 10 m/s is 108,000 kWhs (assuming an even distribution of the speeds between 9.5 and 10 m/s), with an error from the power curve of 5000 kWhs. The expected annual energy production is the sum of the expected energy productions at each speed.

Elecon Turbowind T600-48DS: Legion Way at 65 meters					
	Average Wind Speed		6		m/s
	Wiebull c parameter		6.86		
	Annual Output		**1,405,000**		**kWh/yr**
	Operating Efficiency		26.8%		
wind m/s	Power(kW)	power curve error	wind prob (Wiebull)	Hours at speed	energy
0.5	0	0	0.53%	46	0
1	0	0	1.57%	137	0
1.5	0	0	2.56%	224	0
2	0	0	3.47%	304	0
2.5	0	0	4.28%	375	0
3	3.8	7	4.96%	435	826
3.5	15	7.6	5.50%	482	4531
4	25.5	7.8	5.90%	516	10458
4.5	42.65	8.7	6.14%	538	18324
5	59.15	9.5	6.24%	546	27810
5.5	75	9.8	6.20%	543	36433
6	103.6	12.82	6.04%	529	47281
6.5	132.7	15.96	5.79%	507	59878
7	164.6	15.69	5.44%	477	70894
7.5	210.5	24.27	5.04%	442	82830
8	234	15.53	4.60%	403	89508
8.5	277.9	26.67	4.13%	362	92622
9	359.9	42.9	3.66%	321	102224
9.5	**413.97**	**37.87**	**3.20%**	**280**	**108357**
10	450.42	32.7	2.76%	241	104315
10.5	516.3	38	2.34%	205	99229
11	544.98	24.32	1.97%	172	91461
11.5	572.3	21.6	1.63%	143	79817
12	598.87	22.33	1.34%	117	68488
12.5	615.34	16.93	1.08%	95	57408
13	625.88	11.13	0.86%	76	46868
13.5	628.53	7.79	0.68%	60	37372
14	615.79	16.97	0.53%	46	28901
14.5	623	9.65	0.41%	36	22165
15	621	7.5	0.31%	27	16945
			Total Energy		1404944.23

FIGURE 4

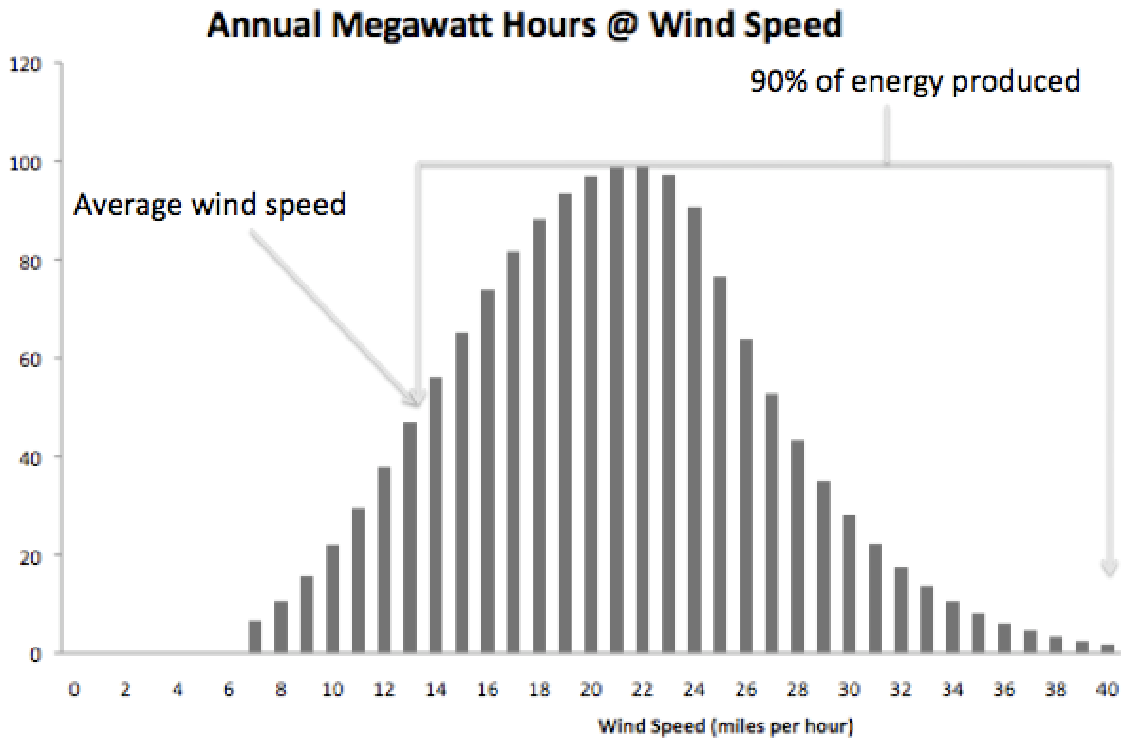


FIGURE 5

Determination of Wind Resources

There are three methods to determine the wind resources at a particular location (site and height) – meterorological towers, SODAR data and wind maps

Meteorological Towers

Until fairly recently, placement of a 40 or 50 meter meteorological tower to collect data for one or more years was the standard wind resource validation technique. However, a single year is too short to cover wind variation – it is not unusual for annual average wind speeds to vary by as much as 10%.
A met tower will cost between $3000 and $20,000 depending on availability of a tower, on a loan and/or the availability of external funding, and would require at least one year for data collection. In addition, it is impractical to erect a meterological tower at the desired height for the wind turbine. One must rely on wind maps to extrapolate measurements to the desired height.
Placement of a met tower comes with substantial risks –in the form of relevance, money spent and time taken. The risks outweigh the rewards.

SODAR Measurements

SOnar Detection And Ranging, or SODAR, provides a complete vertical profile of horizontal wind speeds to a height of 200 meters with 10 meter vertical resolution. It works by emitting chirps at a frequency of 4500 Hz and then measuring the doppler shift in the echo. Windfarms often use SODAR for periods of 2-3 weeks in order to obtain highly accurate snaphots. These snapshots can be used in tandem with met towers and sitewind/mesomap models.

SODAR costs approximately $20,000 for a 2-3 week test. The testing can be very annoying to neighbors. Although we think it is appropriate technology for larger projects, it is not appropriate for projects less than 1 MW, especially in urban-sited areas

AWS TrueWind Mesomap

Wind data from AWS Truewind's Mesomap technology has been independently validated with data from over 1000 stations worldwide with an established accuracy range of 5-7% in mean speed at hub height – and less than 5% in geographically simple locations.

[The error from the mesomap system] is comparable to the error margin associated with one year of measurements from a 50-meter mast. SOURCE

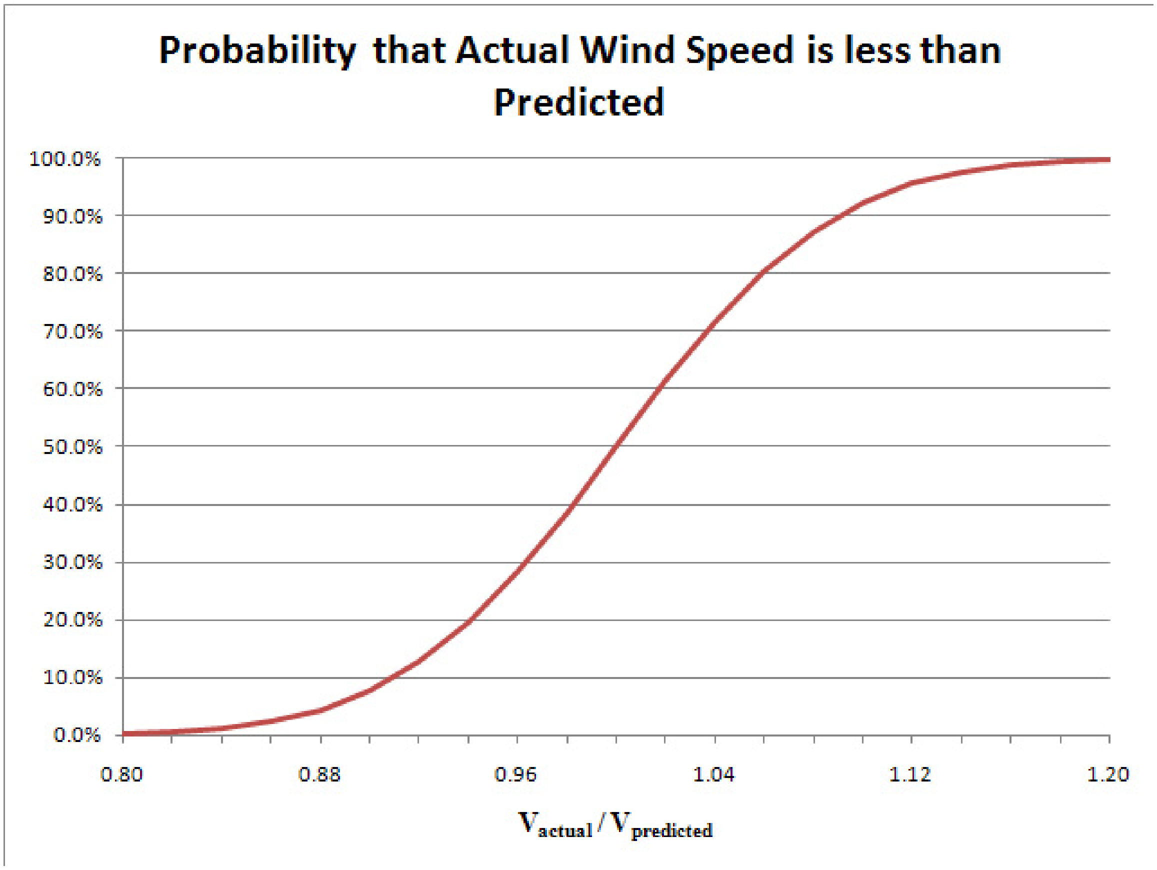
The statistical atmospheric models used by mesomap are essentially computational fluid dynamic models that have been configured to efficiently and accurately simulate atmospheric processes, based on empirical quantitative relationships between atmospheric and non-atmospheric (such as topographic) variables. The model produces reliable results without surface wind measurements, instead relying on numerical calculations based on a mesoscale weather model (Mesoscale Atmospheric Simulation System, or MASS) and a microscale wind flow model. The key metereological inputs to MASS are reanalysis and rawinsonde data; using these data as a starting point MASS simulates the evolution of the atmosphere for 366 different days, sampled from a 15-year historical period. The microscale windflow model then sharpens the resolution to 200 meters or finer, taking into account localized effects of large-scale terrain and surface roughness.

The leading error is grid resolution and local variations in vegetation and topography.

It is of note that mesomap technology is also useful after turbines are built, because it can be used to forecast future conditions. Forecasting wind power is critical for optimizing the operation of the grid, and high quality forecasting can improve the optimized economic performance of large wind farms by close to 50%. SOURCE

Error in Wind Map Data

The sources of errors in the wind map estimation are in the average wind speed and Weibull parameters at this site and height. The root mean square error in the wind speed for the mesoscale AWS Truewind wind map is published as 7%.
Using an average wind speed error of 7%, the probabilty of the average annual wind speed can be calculated as shown on the right. It shows that there is a 50% probability that the actual wind speed will be below the predicted value, but there is only a 3% probability that the actual wind speed will be below 85% of the predicted value.



In order to assess the accuracy of the Weibull distribution for predicting energy output, we looked at data collected from a meteorological tower at Field's Point by the Narragansett Bay Commission over a period of 18 months. Note that although we chose to use Rhode Island data for this calculation, we were not using this wind data to predict average wind speeds in Barrington; rather, we were using the data to help assess the accuracy of the Weibull model. Using the average speed and Weibull parameters associated to this data, we calculated the energy output via the method described above. We then calculated the energy output using the Elecon power curve data in conjunction with the distribution of hours at different wind speeds given directly by the meteorological data. The resulting two energy outputs were within 3% of each other. Although this only represents a single sanity check, we are confident that the wind model is reasonably accurate.

Validation of Wind Map Data

> *Site-specific measurements using anemometers are considered by some to be the most reliable estimates of the wind resources for a project. However, they can be quite costly and require from one to several years to complete. Other methods also exist where large scale computer weather models are created to extrapolate wind conditions at a specific site from historical data. Many times these computer models of a sites wind resource can be less expensive than taking meteorological readings for a year or more.* **As scientists and lending institutions are beginning to understand weather modeling and the wind industry better this method of resource assessment is becoming more accepted by lenders**, *but sometimes they may require a combination of site specific meteorological measurements coupled with computer models from long-term weather data for validation of conditions at the site.* – windustry.org

National Grid, or other power suppliers required to buy the electricity, need to have a prediction of seasonal power production. They will generally not rely on a year of met data but rather require Sitewind technology in order to provide a reasonably accurate seasonal forecast.

If a community wishes to own a fraction of a windfarm in partnership with a developer, the developer will again generally not rely on meteorological data supplied by the community. Instead, they will verify the wind resources on their own or with the assistance of a third party (again, like AWS Truewind). It is of note that several of the bids in response to the Barrington RFP offered a developer/owner arrangement, although this was not mentioned in the RFP; this is essentially a vote of confidence in the wind resources at the proposed site.
Finally, the town – both the council and the residents – want verification that the project is low risk. There is concern in Barrington over moving away from the protocol of a met tower. We hope that this report helps alleviate that concern. We also hope that the argument made here becomes widely endorsed by a variety of stakeholders involved in projects of this size.

The Portsmouth energy data for its 600 kW turbine was based upon an average of 6.593 meters per second (at 50 meters), producing 1,541,000 kWhs. We are predicting an average annual wind speed of 6.0 meters per second (at 65 meters), producing 1,405,000 kW-hours. The Elecon turbine we recommend has a better power curve (see below) than the one modeled by ATM.

Additional Wind Resource Studies

If the town council wishes to pursue additional site specific wind resource studies, the recommendation of the committee is to use the AWS Truewind virtual met mast. This micrositing model refines the mesomap model by using on-site measurements of the terrain. It also uses a higher resolution in both the mesoscale weather model and the microscale wind flow model. SiteWind technology is too computationally intensive to produce a worldwide atlas: 3 weeks are required to calculate the data for a particular location. Sitewind technology will produce lower error than one year of measurements from a 50-meter mast.

The cost for this service is approximately $6,000 and the time required is 3 weeks. Assuming the town chooses to move ahead, these studies would be required by National Grid in order to assess likely seasonal variations; therefore they are included below under interconnection studies.