Lopez Community Land Trust

Final Wind Energy Report

July 20th, 2007

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1.0 – Introduction

Lopez Community Land Trust (LCLT) is in the process of building a zero-energy community, located on Lopez Island, WA. To reach the zero-energy goal, LCLT has commissioned Chinook Wind to study the feasibility of a wind energy facility on the community property. This wind turbine and study were sponsored by A World Institute for a Sustainable Humanity (A W.I.S.H) in partnership with the Washington State Department of Community, Trade, and Economic Development through a grant from the U.S. Department of Health and Human Services.

The idea of a zero-energy community is part of a movement, with a number of communities in the US and abroad, working towards this goal.

One example of a community working toward energy independence is Hull, MA. The town of Hull has successfully installed two Vestas turbines (one 660 kW and one 1.8 MW) to power their community. As of July 10th, 2007, their turbines have collectively been generating energy for 2,453 days, producing 13,289,400 kilowatt-hours of electricity. The town of Hull has received many awards, including the Department of Energy's Wind Power Pioneer Award. For more information on Hull, MA, see www.hullwind.org.

Figure 1.1 – Vestas Turbine at Hull, MA project

The project proposed by the LCLT is significantly smaller than the Hull project, and will require less energy production. Solar-electric resources are also being considered. In many situations, a hybrid of wind and solar can be beneficial, as solar production is primarily in the summer, and wind production is primarily in the winter. If a system is grid-tied, with no battery back-up, this is not of concern, but if the system includes battery back-up, diversifying inputs can be very important.

Small wind energy is widely used for many applications, such as small homes, businesses, irrigation, and community power. There are a number of manufacturers who have been producing trustworthy turbines for many years; turbines are also refurbished for further use (see section 4.0). In parts of the country that get lower wind speeds than the ideal locations, unlike utility-scale wind, small wind turbines can be a worthwhile investment. Although wind farms are not generally located in Northwest Washington, there are numerous small wind turbines operating successfully in the area.

2.0– Data Collection and Analysis

2.1– Data Collection Using A Meteorological Tower

When considering the installation of a wind turbine, it is crucial to determine the amount of wind resource present. While local knowledge of general wind patterns is a useful beginning, a detailed analysis of the resource is necessary before investing in a wind turbine.

In order to do this analysis, a meteorological (met) tower was installed on the LCLT site. The tower was installed in August and became operational on August 26th at 13:30, 2006. Data was collected consistently until May 31st, 2007. The site latitude is 48º32'005", longitude is 122º54'150". The site terrain is grass and low trees (50 feet). The tower was 50m, and had sensors for wind speed, wind direction, and temperature.

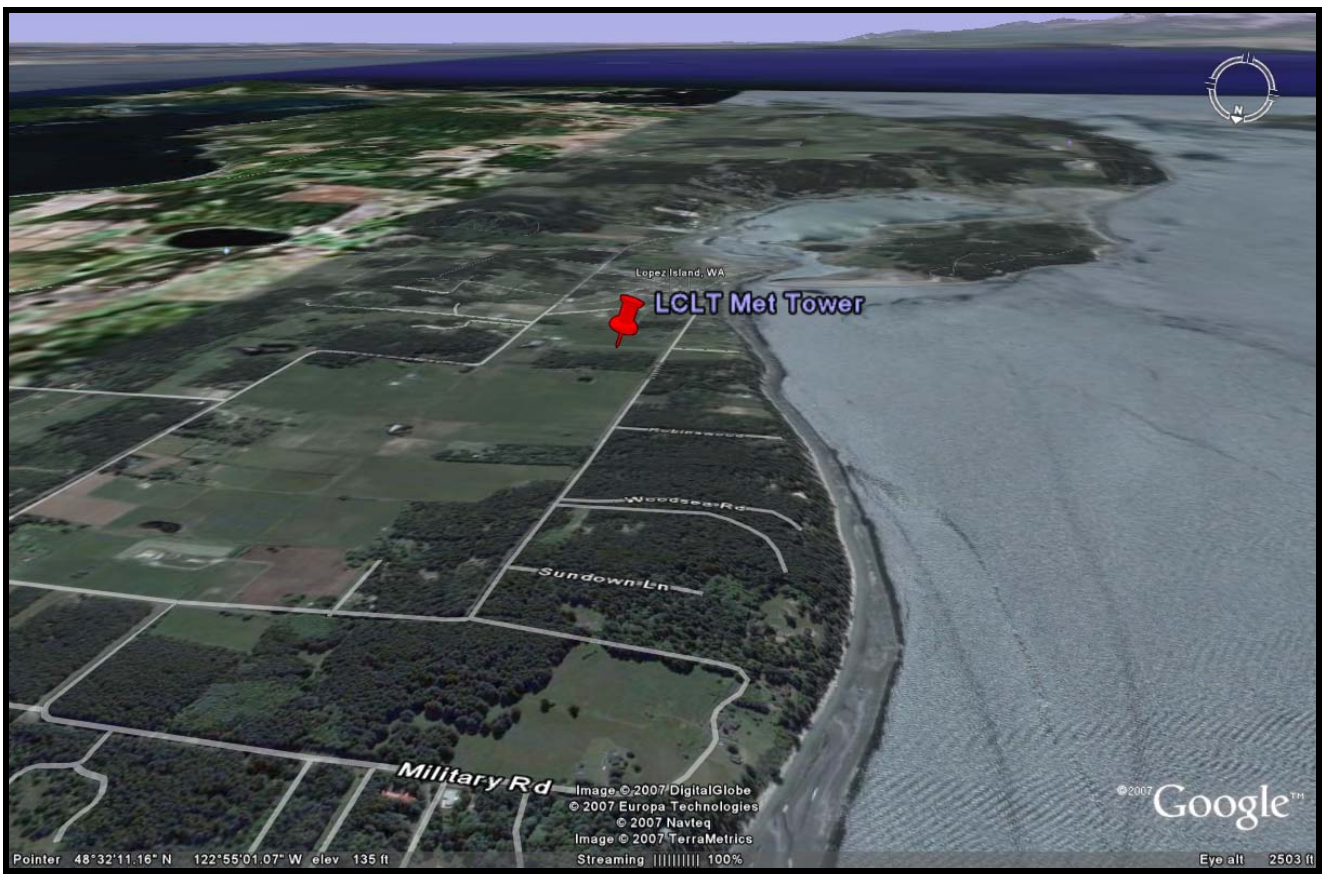


Figure 2.1 – LCLT Met Tower and Surrounding Terrain

The four wind speed sensors were located at 50 meters, 40 meters, and 30 meters. Two were located at 50 meters, one at 270 degrees, and one at 180 degrees, to prevent inaccurate data when the wind blows from directly behind the tower in relation to the sensor. The reason for having sensors at varying heights is to calculate wind shear or wind gradient, which is the amount of wind speed increase with an increase of height. This is very important, because a met tower may be much shorter than a turbine will be, and it is necessary to be able to extrapolate and determine the potential energy at heights above those measured. See Section 3.1 for more information on wind shear. Figure 2.2 shows a wind speed sensor when the tower was being decommissioned.

Figure 2.2 – Wind Speed Sensor at 50 Meters and 180 Degrees

The met tower had two wind direction sensors, both pointing true north, one at 50 meters and the other 30 meters. The wind direction sensors provide information about prevailing winds, which help site a turbine or determine obstacles. Wind direction can also be useful in determining what data to use. For example, if the wind is blowing in a direction so that the met tower is blocking a wind speed sensor, data from another sensor can be used. A wind direction sensor at the time of decommissioning is shown in Figure 2.3.

Figure 2.3 – Wind Direction Sensor at 30 Meters

Also measured was the temperature at 3 meters. This was done as a precaution to be able to determine if ice froze any of the sensors, resulting in inaccurate data.

2.2– Data Analysis

Collected data was downloaded monthly. Each month of data was inspected for missing data or other abnormalities and none were found.

In our analysis, some steps were taken to create a representative data set to account for having less than a year of data collection. Data was collected from August 26th, 2006 until May 31st, 2007. The data from the last few days of August was combined with a representative amount of data from September, to create a complete month of data. Because June and July had no data, a sloped approximation between the May output and the August output was created. In this manner, the missing two and a half months of data was created, resulting in a data set for a full year.

3.0 – Characteristics of Wind At LCLT

3.1 – Wind Speeds

The wind speeds at the LCLT site would generally be considered low. Figure 3.1 shows the average monthly wind speeds at 30 meters 50 meters in meters per second (m/s). As is expected, the wind speeds are greater in the winter months, and low in the summer. Recall that the data for June, July, and August is not actual logged data, but extrapolated data (see section 2.2).

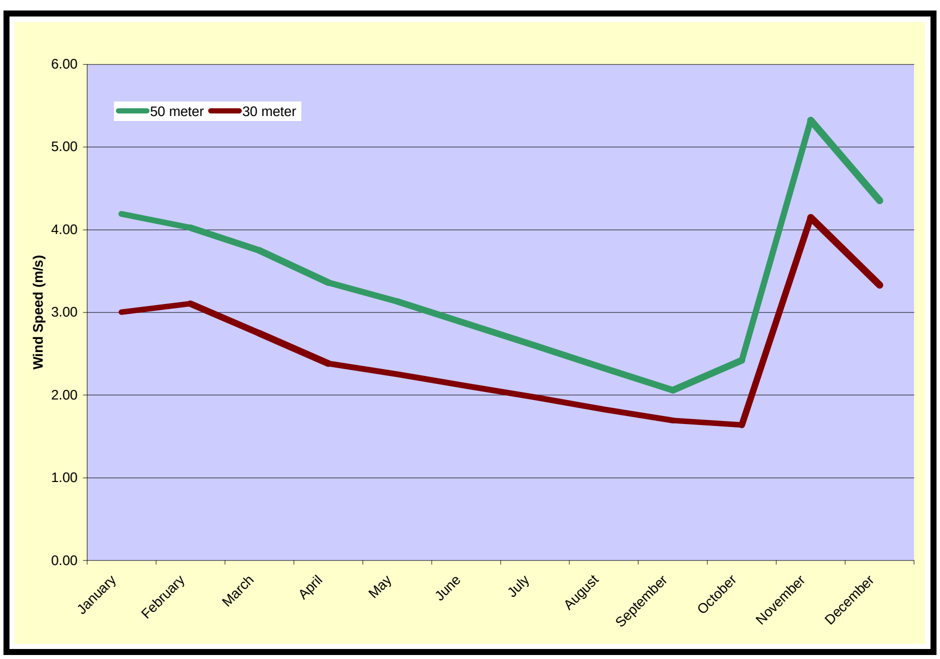


Figure 3.1 – Monthly Wind Speed Averages at 30 and 50 Meters in m/s

The average annual wind speed at 50 meters is 3.37m/s. At 30 meters, the average annual wind speed is 3.11m/s. These annual average wind speeds, along with the visuals in Figure 3.1 illustrate the concept of wind shear. In virtually all situations, the wind is faster higher off the ground. At the LCLT site this is especially true. The national average wind shear exponent is 0.14. At the LCLT site it is 0.57, which is extremely high.

At the LCLT site, the same a turbine 100 ft off the ground will have twice the wind speed of a turbine at 30 ft off the ground. The power in the wind increases with the cube of wind speed, so there would be eight times the power at 100 ft as at 30 ft. More significantly, between the lowest and highest heights considered in this report there is twice as much energy in the wind. Due to the imperfect power curves of wind turbines the actual production difference between the two heights is less than doubled, but still very significant. The above information is to explain that, especially at this site, the higher the wind turbine is placed the more valuable it will be. Figure 3.2 shows how wind speed is estimated to increase with height above ground level.

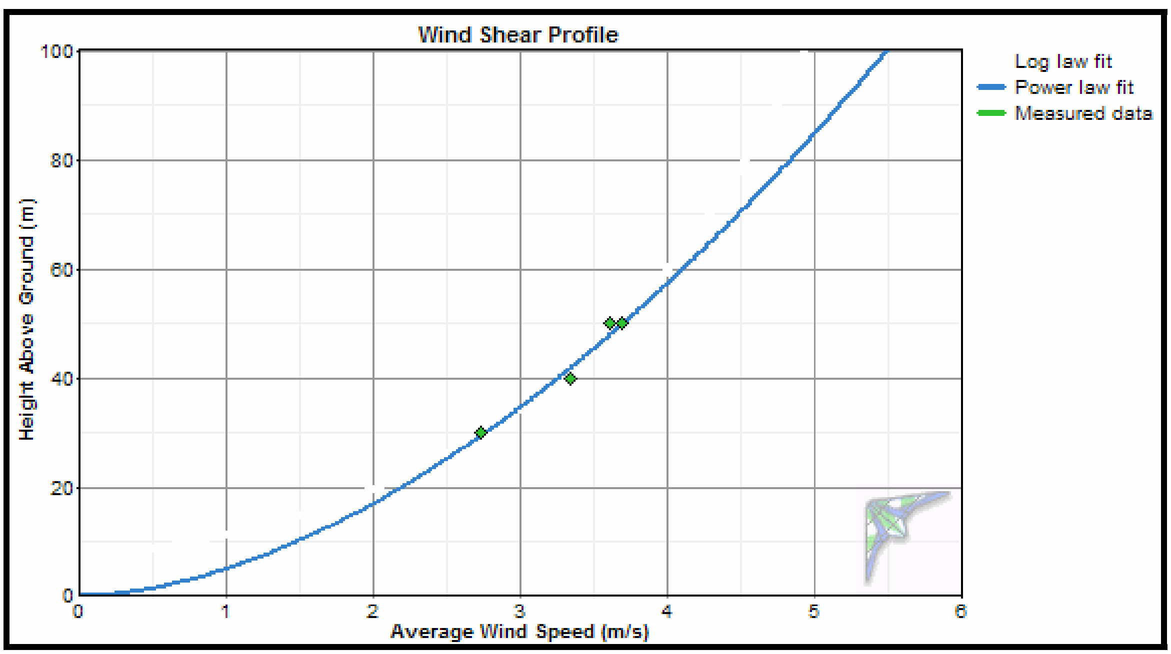


Figure 3.2 – Wind Shear at the Site

Tall towers are especially important if there are trees or other obstacles nearby. A general rule of thumb is that a turbine must be 10 meters above anything within 100 meters of the tower. If the obstacles are trees, future growth must be taken into consideration, because trees grow and towers don't.

Because of the already low wind speeds at this site, our recommendation is to install a very tall tower. Installing a tall tower will allow the turbine to produce a greater amount of electricity. As one wind energy expert is known to say, "putting a wind turbine on a short tower is like putting a solar panel in the shade".

3.2 – Wind Direction

The wind at the LCLT site is almost entirely from the southwest and the southeast. A greater amount is from the southeast. The wind rose, in Figure 3.3 illustrates the percentage of time the wind comes from a given direction.

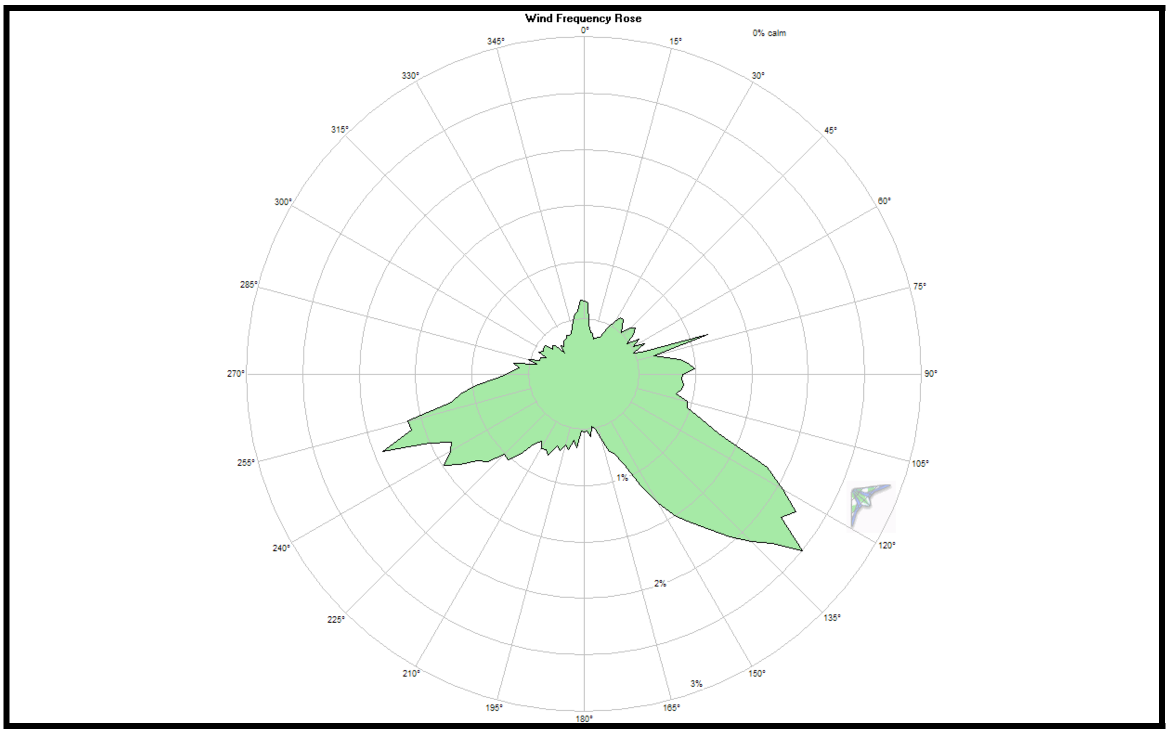


Figure 3.3 – Site Wind Rose

Given that the primary wind directions are from the southwest and southeast, it would be prudent to ensure that there are no obstacles in that direction. Observing Figure 2.1, it can be seen that the nearby obstacles (trees), are all located to the north of the turbine site. Because the primary wind directions are not from the north, in fact very little wind comes from the north, the vicinity of the trees is not a concern as far as creating turbulence in the wind.

The trees do pose a very significant concern in that they slow the wind down in front of them, thus the importance of getting the turbine in above the tops of the trees.

3.3 – Diurnal Patterns

A diurnal wind pattern is the pattern of the wind over the course of 24 hours. The annual diurnal pattern at the LCLT is to have a greater wind speed in the afternoons. This is a very common pattern for coastal areas. As the land heats up during the day, the warm air rises, bringing a cool wind off the ocean.

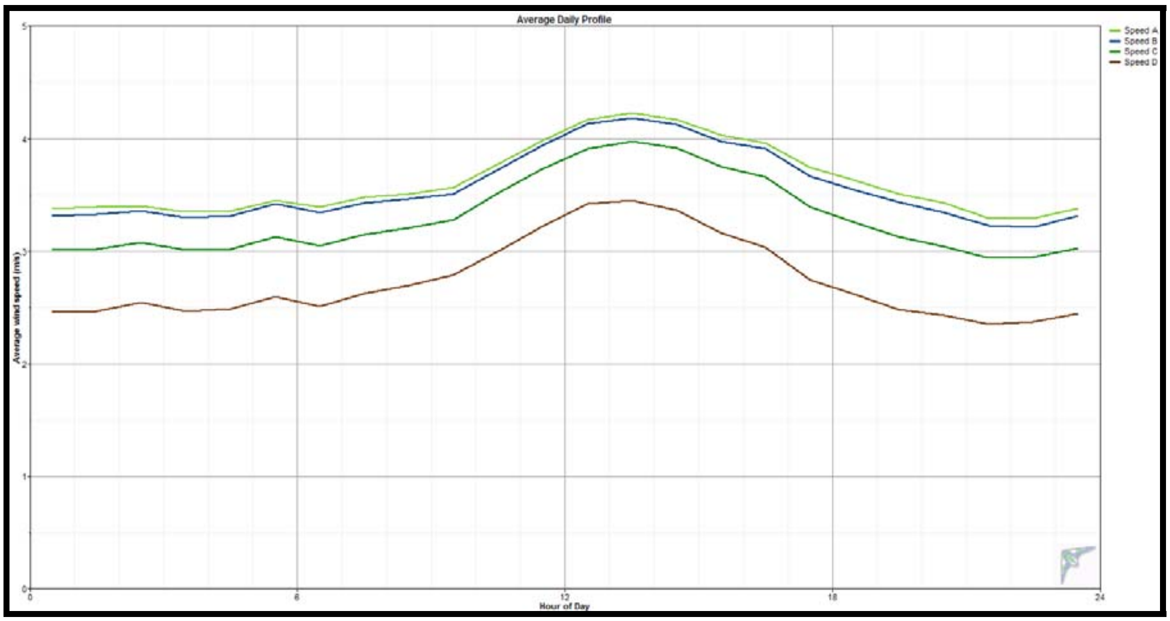


Figure 3.4 – Diurnal Wind Patterns

In a grid-tied system, the diurnal pattern is not very important. In an off-grid situation, it may be important in order to balance the energy inputs. For example, at this site, the wind production peaks in the afternoon, at the same general time as solar energy production peaks. In an off-grid system, all the input would be at the same time, requiring a greater battery capacity to store energy for times without production. In an on-grid system, this is inconsequential because the grid acts as a buffer. Time of production is not as important as the overall annual production.

4.0 – Turbines

There are many turbines on the market. Using knowledge of the various turbines and manufacturers, three turbines were chosen. Each of the turbines has a different rotor diameter and rated output. All three turbines were modeled using the site data, in order to determine the resource available with each turbine. According to the advice given in Section 3.1 the tallest tower height provided for each turbine was used in the modeling.

4.1 - Bergey Excel 10kW

The Bergey Excel is manufactured by Bergey Windpower Co, has a 6.7 meter rotor diameter, a hub height of 42 meters, and a rated output of 10 kW. It is the smallest of the three turbines compared. This turbine has a proven track record across the nation, including many installations in Washington. One of notable installation by Brooks Solar (http://www.brookssolar.com/wind.asp) is the Kingsbury Wind Farm, where two Bergey Excel turbines have been installed.

Figure 4.1 – Bergey Excel Turbines on the Kingsbury Wind Farm

4.2 – Vestas 15

The Vestas 15 is a turbine no longer manufactured by Vestas, due to the demand for larger turbines in the utility scale. The V15 is a very robust turbine. It is a prime candidate for refurbishment, which many companies, such as Halus Wind and Energy Maintenance Systems, do. The V15 has survived the some of the harshest winds for 20 years and after remanufacturing should survive the mild Lopez winds for a long time. The V15 has a relatively simple mechanical structure and much of the maintenance can be performed by someone with the skill level of an auto mechanic. The V15 has a rotor diameter of 15 meters, hub height of 33.5 meters, and a rated output of 65kW.

Figure 4.2 – A Vestas 15, 65kW Turbine

4.3 – Fuhrlander 100

The Fuhrlander 100 is imported from Germany by Lorax Energy Systems (http://www.lorax-energy.com) located in Rhode Island. The turbine pictured below is one of three located in Goldendale, Washington, providing renewable energy for low income households. Fuhrlander continues to build and support this turbine, which has features of larger utility scale turbines. The largest of the three turbines considered, the Fuhrlander has a rotor diameter of 21 meters, a hub height of 50 meters, and is rated at 100kW.

Figure 4.3 – A Fuhrlander 100 Turbine

4.4 – Comparisons of Turbines

	Bergey	Vestas	Fuhrlander
Rotor diameter	**6.7m**	**15m**	**21m**
Swept Area	**141 m^2**	**706 m^2**	**1385 m^2**
Rated Peak Output	**10kW**	**65kW**	**100kW**
Orientation	**Upwind**	**Upwind**	**Upwind**
Blades	**3**	**3**	**3**

Table 4.1 – Comparisons

Although all the turbines are upwind and have three blades, each of them has a different rotor diameter, swept area, and peak output. While the peak output gives a general idea of the limits of the turbine, it doesn't actually show how much energy will be produced. The rotor diameter and swept area are better indicators of this. The swept area of a wind turbine is like the sail on a sailboat. The bigger the sail is, the more wind you can capture. The bigger a rotor is, the greater amount of energy can be produced.

5.0 - Energy Output

5.1 – Rated Outputs vs. Actual Output

Although turbines are generally classified by their peak energy output, this number can be very misleading. A turbine very rarely operates at its peak capacity. The important information to know is the overall energy produced at a specific wind speed, and the amount of time the wind is at each speed. The importance is illustrated in Figure 5.1.

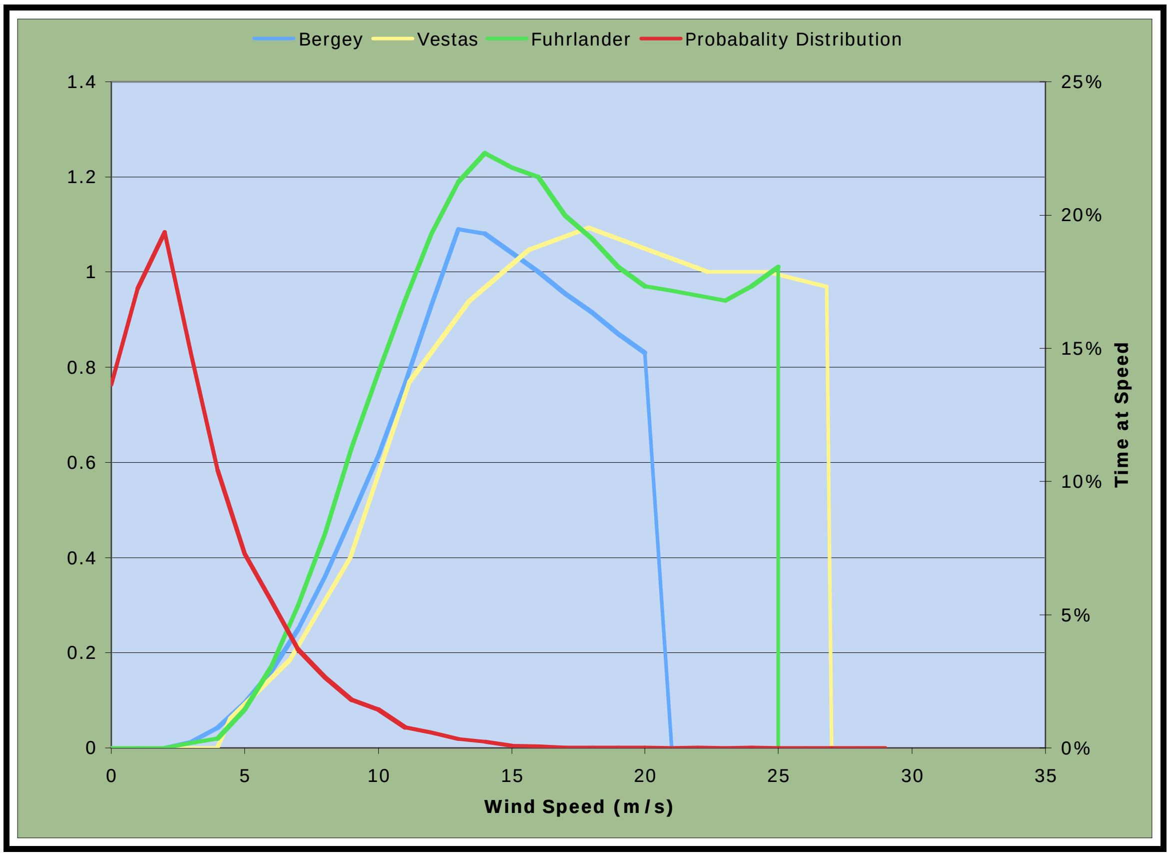


Figure 5.1 – Normalized Power Curves and Probability Distribution

Shown in Figure 5.1 are power curves for each turbine. These are tested and published by the turbine manufacturers, and reflect the actual power output (scale on the left) for each turbine at each wind speed (scale on the bottom). The power curves have been ‘normalized’, to give a proper comparison to account for each turbine having a different rated output. This is done by dividing the values on the curve for each turbine by the turbine’s rated output. In this manner, the turbines can be compared on equal ground.

Also shown is a probability distribution. This information is taken directly from the data measured on the site. A probability distribution shows the amount of time the wind is at a given speed (scale on the right). At the peak of the line is the wind speed found the greatest amount of the time. That point shows that 20% of the time, the wind speed is approximately 2.5m/s, which is too low a wind speed for any of the turbines to be producing. Only less than 1% of the time, does the wind speed reach the rated output of any of the turbines.

The only time that power is being generated is in the areas under both a power curve and the probability distribution. The wind speeds are great enough to be producing measurable energy about 25% of the time.

5.2 – Energy Outputs at the LCLT Site

Using the collected data, a model was created of the output of each turbine. This allows a side-by-side comparison of each of the possible turbines. Also included in the comparisons are two photovoltaic (PV) arrays, rated at 10kW and 50kW.

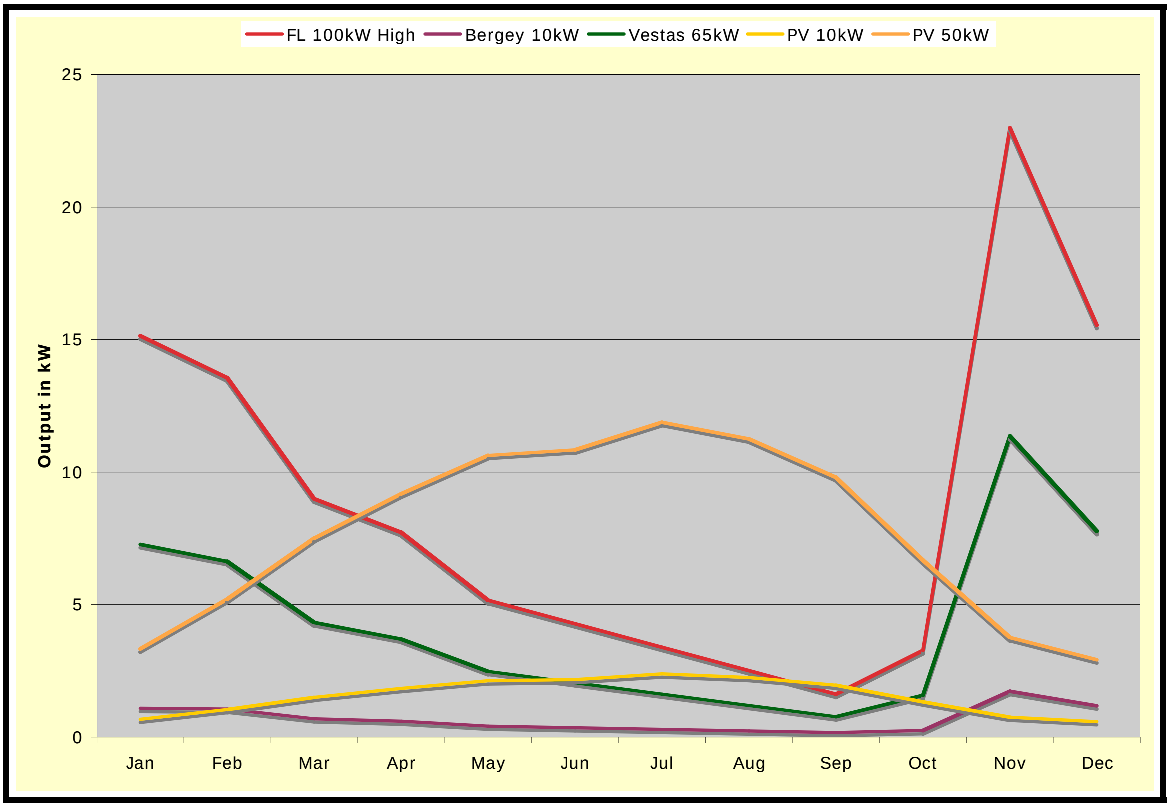


Figure 5.2 – Monthly Average Outputs

The monthly average generation for five potential energy sources is shown in Figure 5.2. The greatest solar production is in the summer, and the greatest wind production is in the winter. This complementary behavior of the two resources, though not critical in a grid tied system, is still attractive, especially if the system is to have a back up component. It should be noted that although the annual pattern of production is likely to remain the same, the value for each month is likely to change from year to year. During the year of measurement November was the windiest month, but in future years another month might have a higher production. Although the figure gives a general idea of the outputs, looking at the numbers, especially Annual Energy Production (AEP), is very important.

	Bergey	Vestas	Fuhrlander	PV 10	PV 50
January	1.083	7.26	15.14	0.55	2.75
February	1.047	6.62	13.56	0.86	4.30
March	0.692	4.32	8.99	1.24	6.20
April	0.6	3.69	7.72	1.51	7.57
May	0.407	2.48	5.16	1.76	8.78
June	0.347	2.05	4.275	1.79	8.95
July	0.287	1.62	3.39	1.96	9.81
August	0.227	1.19	2.505	1.86	9.30
September	0.167	0.76	1.62	1.62	8.09
October	0.243	1.57	3.27	1.10	5.51
November	1.73	11.36	22.99	0.62	3.10
December	1.178	7.77	15.53	0.48	2.41
Average (kW)	**0.67**	**4.22**	**8.68**	**1.28**	**6.40**
CF (%)	**6.7%**	**6.5%**	**8.7%**	**12.8%**	**12.8%**
AEP (kWh)	**5,800**	**37,000**	**76,000**	**11,200**	**56,200**

Table 5.1 –Production (kW) from Measured Data

Shown in Table 5.1 is the numbers behind Figure 5.2, as well as the annual average, and the capacity factor (CF). The annual average is simply an average of the monthly averages, and gives a general idea of what the output would be if the resource was consistent 24-7 year round. The Fuhrlander has the greatest annual average, and the Bergey has the lowest.

Capacity factor, shown in the next to bottom row, calculates the amount of possible production with the given equipment, and how much of that is potential is used. This is especially useful when calculating the economics of each option.

Any estimate of energy production based on a solely a full year's data is not entirely reliable, since the year of measurement may be an abnormally high or low wind year. A significant correlation was found between the data at the site and the Friday Harbor airport anemometer. This means that the Friday Harbor data, which begins in 2000, can be used to modify the measured data to represent a typical year. This is important in order to get a more reliable estimate of how much energy (and therefore value) will be generated over the long term.

Figure 5.3 shows the correlation between Friday Harbor airport and the LCLT met tower. The data points from both sites are plotted, with the wind speed at Lopez (in m/s) on the vertical axis, and the wind speed at Friday Harbor (in m/s) on the horizontal axis. Each dot represents the wind speed at a specific time. This shows, using a significant outlier as an example, that at one point on Lopez the wind speed was measured at about 1 m/s, while at the Friday Harbor site, it was measured about 6.5 m/s. In this way, all of the data points from one site are compared to the data points at the other site, giving an idea of the similarity of the wind speeds.

If the correlation were perfect, all the data points would form a diagonal line, where at every speed measured at one site, the exact same speed was measured at the other. A perfect correlation may not actually have the exact same speed, but must have the exact same ratio of speeds, creating a consistent diagonal line. A trend line is computed and drawn so that it is at the slope which has the closest fit to the data point. In the case of this model, judging from the origin of the trend line, the speeds at the Lopez site tend to be about 1.5 m/s greater than the speeds at the Friday Harbor site. The slope of the line indicates the ratio between wind speeds.

Rarely is it the case that a correlation is perfect, so there must be some measurement of the degree to which the data correlates. The R^2 value is a statistical measurement of the strength of a correlation, or the goodness of fit of a line. In simple terms, it gives a number to describe the fit of the correlation. A perfect correlation has a fit of 1.0. The R^2 value of 0.62 found in this correlation is not as good a correlation as would be hoped for, but good enough for our purposes.

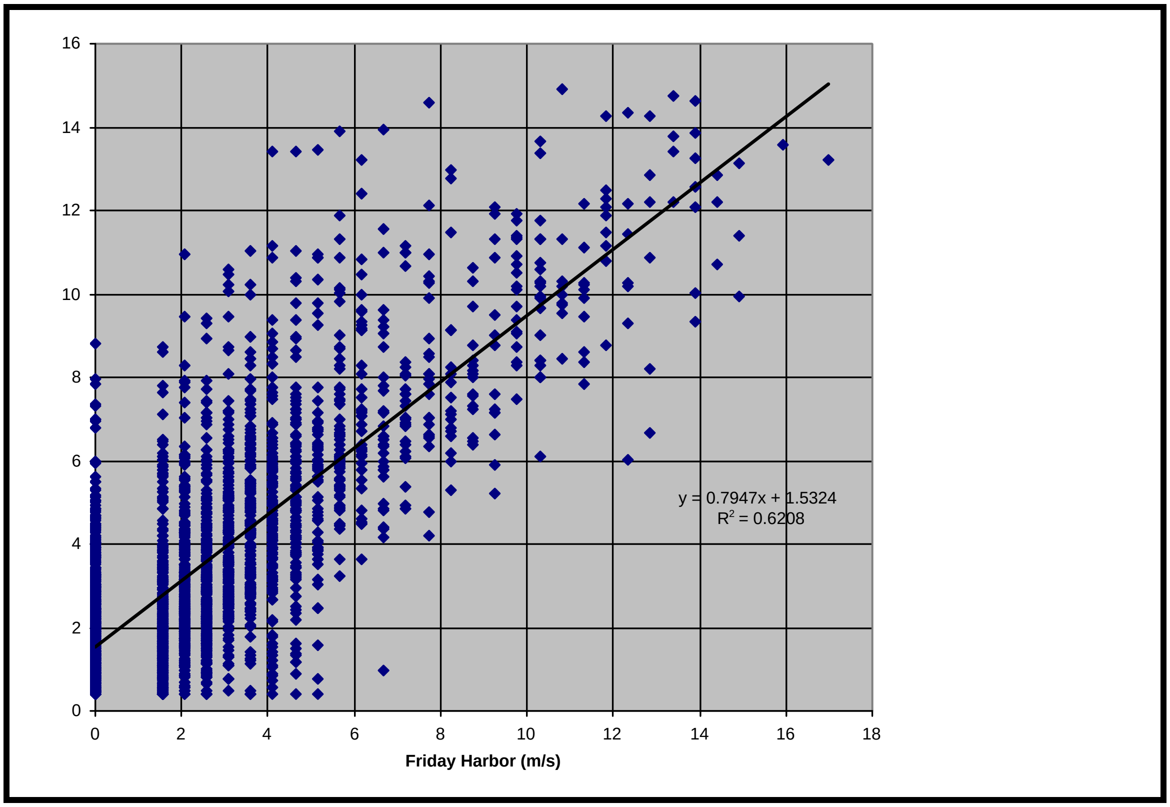


Figure 5.3 – Correlation Between Friday Harbor and LCLT Winds

For each month during our period of measurement, we compared to the long term average for that month and scaled that month's data accordingly to create a 'typical year' data set. It turns out that the measured data (and estimates for the months not measured) were generally a bit lower than a typical year. Figure 5.4 shows that generally wind speeds increased by 4% from our data to the typical year data set, although some months were increased and some decreased by correcting to the long term average.

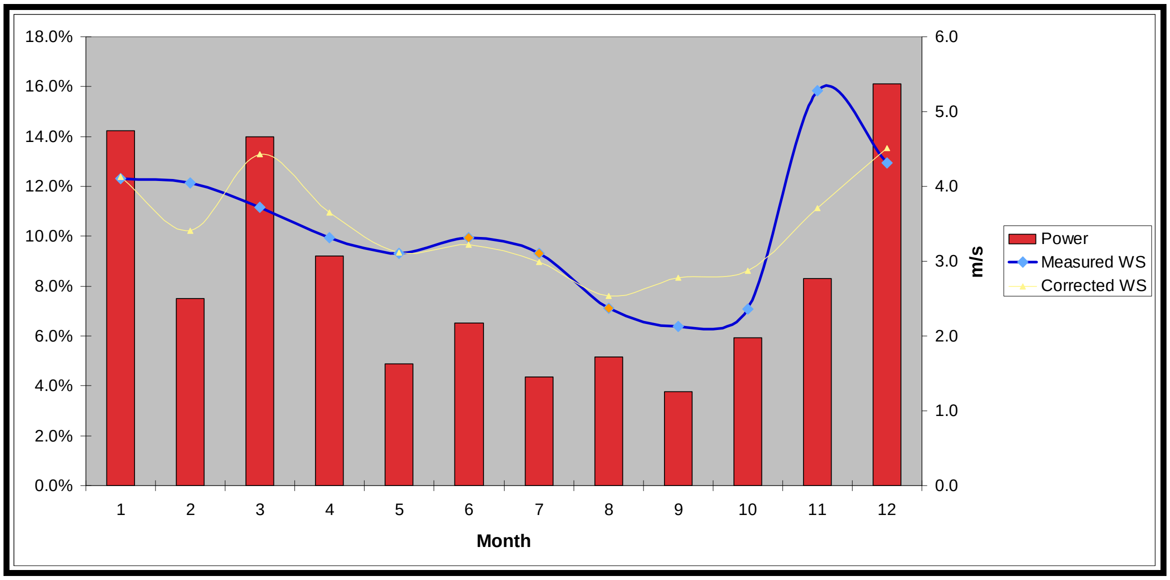


Figure 5.4 – Monthly Wind Speed Corrections and Power Output

It can be seen from Figure 5.4 that the winds in November 2006 were much higher than typical for November, but for many other months the winds were lower than typical.

6.0 – Economic Comparisons

	kW	Height AGL	$/kW	CF	Capital Cost	AEP kWh	Payment	Value
Bergey	10	42	5000	6.9%	$50,000	6044	$3,100	$0.51
Vestas	65	33.5	1500	6.7%	$97,500	38150	$8,775	$0.23
Fuhrlander	100	50	3000	9.0%	$300,000	78840	$21,000	$0.27
Solar	10	5	8500	12.8%	$80,000	11239	$3,433	$0.31
Solar	50	1	8000	12.8%	$400,000	56195	$16,333	$0.29

Table 6.1 – Economic Comparison

Table 6.1 shows an economic comparison of the three turbines modeled alongside two PV options. The economic comparison does not take into account the many tax, feed in tariff, grants, and other forms of incentive for renewable energy projects. How these incentives may be utilized depends on the ownership structure of the generating units.

For each case, the kW rating was stated as well as its height above ground level (AGL). A cost per kW was estimated for each scenario and was used to calculate the capital cost. Also presented is the capacity factor and annual energy production (AEP) calculated in Section 5 using the typical year. An annual payment is given for each case which assumes a 20 year simple payback (0% interest) and sixty dollars per kW rating in maintenance costs. The annual payment divided by the AEP gives a cost per kWh. Retail electricity from the utility is approximately $0.08 per kWh.

It can be seen that using the above assumptions that solar power has a value of approximately $0.30 per kWh. The Bergey 10 kW turbine does not provide a good value at this site, the capacity factor is low and the cost per kW is relatively high. The remanufactured Vestas 65 kW turbine has a similar capacity factor but a much lower cost per kW, providing the lowest energy cost at $0.23 per kW. If a taller tower for this turbine can be obtained, it will become an even more attractive option. The Fuhrlander 100 kW turbine has a higher capacity factor but also has a higher cost per kW. The Fuhrlander would provide a value similar to the solar options, but would require a lot less space than the solar.

7.0 – Conclusions

The winds at the site are quite low from a general perspective, but will provide power for the same or lower cost than PV panels (the effect of government incentives has not been included). Considering the exceptionally high wind sheer at this site, it is clear that placing a turbine on as tall a tower as possible would be preferable. The three turbines used were modeled using the tallest tower heights supplied by their respective manufacturers. It appears that the best solution may be a remanufactured turbine both for the low cost, high reliability, and ease of maintenance it will offer. Another viable option is a smaller utility scale turbine such as the Fuhrlander 100kW turbine. The site in question is overall not a very good wind site.

At the request of LCLT, resources elsewhere on the island have been explored. A model of the potential wind energy on Lopez Island was created. Figure 7.0 shows the results of this model at 50m. Figure 7.1 shows the results at 80m. This again reinforces the importance of a tall tower. Note that, especially at 50m, the area where the wind was measured is a very low resource area.

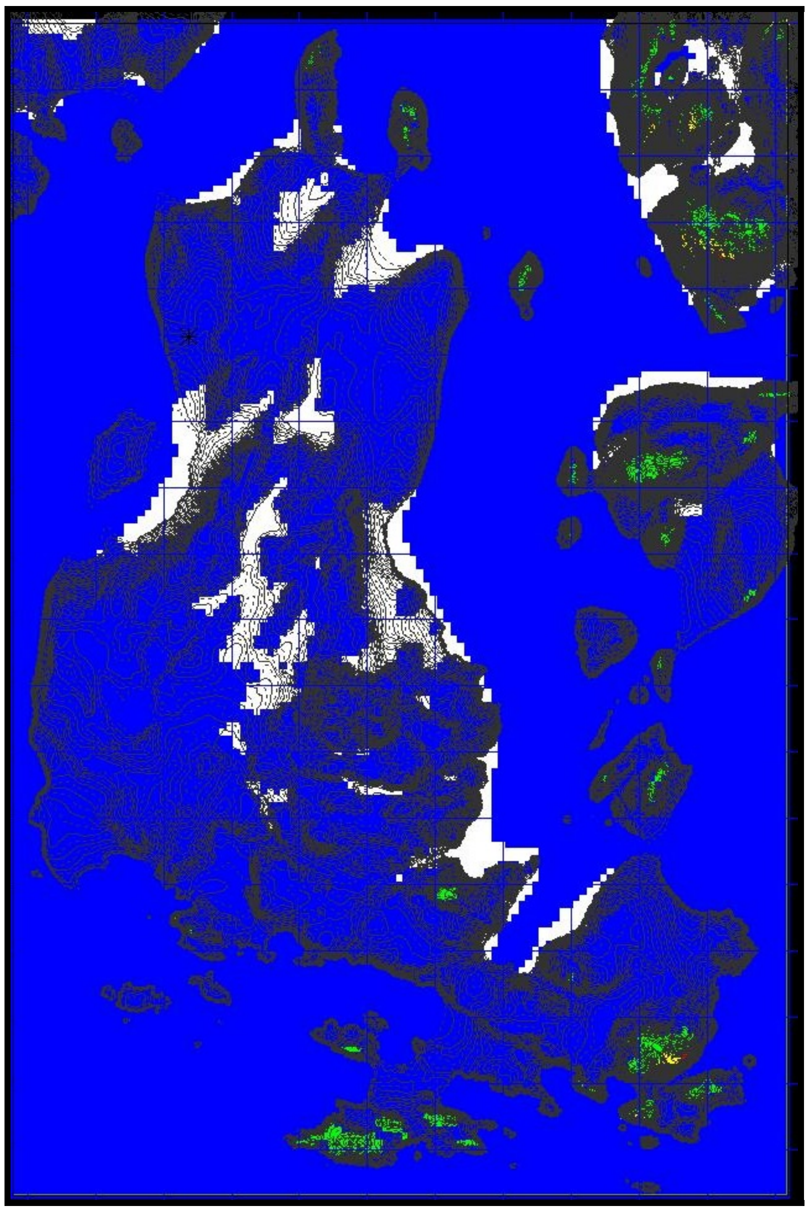


Figure 7.1- Wind Energy Potential at 50m

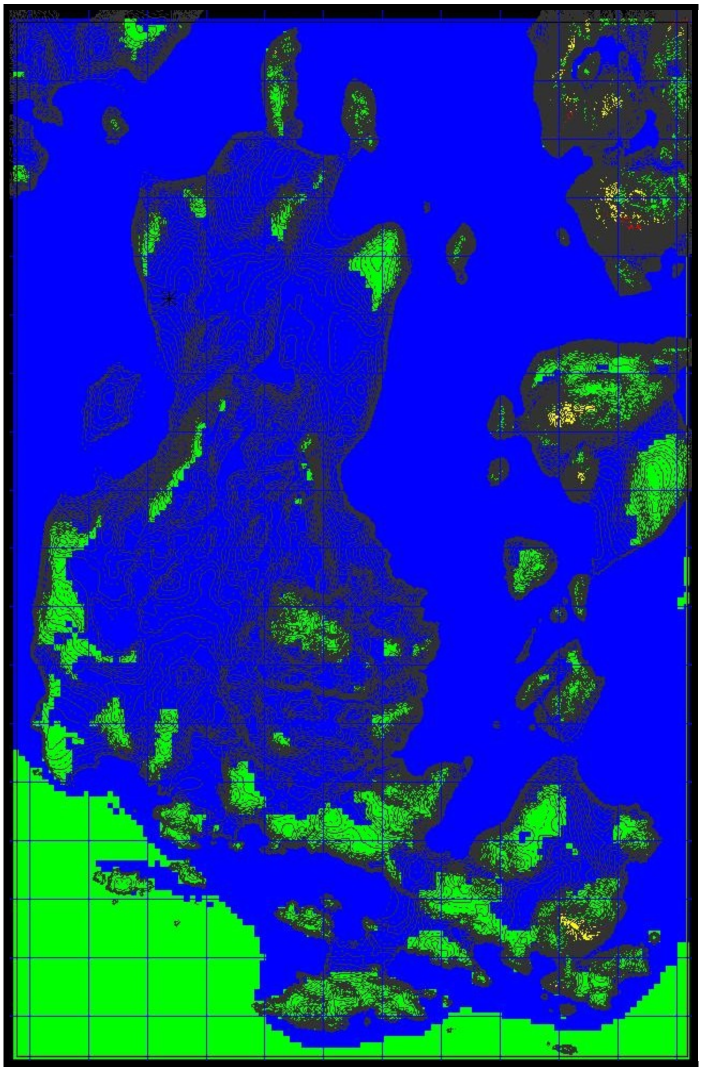


Figure 7.2- Wind Energy Potential at 80m

The above figures use a color scale to show potential energy. This model in itself is only a guideline for future resource assessment, and is not detailed enough to warrant installation of turbines on any of the mapped locations. The scale begins with white, being the lowest energy potential, moving to blue, green, and yellow, which represents the highest potential. Areas with a higher potential may be worth further consideration for development.

The authors look forward to aiding LCLT in implementing wind power generation, and remain available to answer questions and provide further analysis as needed.

Appendix A – Pre-Installation Checklist

50 Meter MET Tower Worksheet

Pre Installation Check list:

Project Name: Lopez Island (LCLT)

Site: 01

Tower Number: 01

Cell Phone Number: N/A

Magnetic Site Declination: 21E

Tower Stand Direction: 253

True North (+(West) or -(East)) Declination 360 +/- **21E** = **339** Degrees

Tower stand direction +/- True North = on ground offset = **86 / 4**

Pre Lift Checklist:

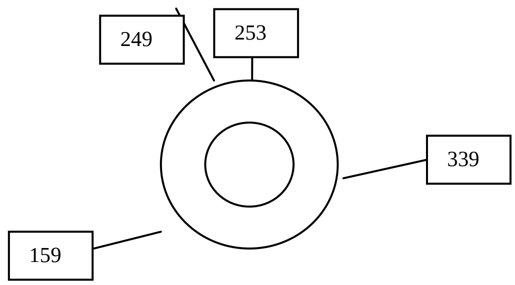
Channel	Sensor	Height	Degrees	Notes	Reading
1	Anemometer	50m (164’)	270 West	Scale –0.765/offset—03.50/units m/s	4.56 m/s
2	Anemometer	50M (164’)	180 South		4.56 m/s
3	Anemometer	40M (131’)	180 South		4.84 m/s
4	Anemometer	30M (98.5’)	180 South	**(No Card Installed)**	
5	Anemometer				
6					
7	Vane	50M (164’)	True North	Zero notch aligned to true North	289
8	Vane	30M (98.5’)	True North	Zero notch aligned to true North	304
9	Temp	3M (10’)		Install (**No Card Installed)**	
10	Voltmeter			Voltmeter / --0.021 / 0 / volts	
11					

12

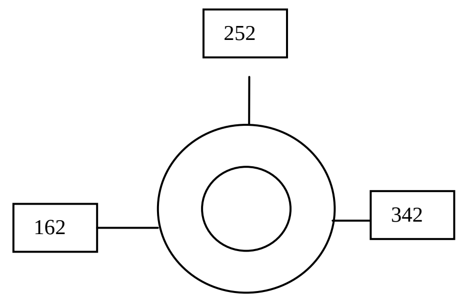
Antenna

test

Prior to lift



After lift



Logger Information:

Site Latitude 48-32-005N Longitude 122-54-150W Elevation ________

Terrain Grass / Low Trees Tree height: 50’

Date: 26 Aug 2006 Time of activation: 1330

Logger Serial Number: ____

ESN Number: ____

I-Pack S/N: ____

Set clock / Set units to metric / Set site number / Shelter box lock combo ____________

Pictures Up tower N & S / from tower N, NW, W, SW, S, SE, E, NE & whole tower.