Wekweeti Wind Energy Pre-Feasibility Analysis

Prepared for

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March 29, 2010

Executive Summary

Wekweeti is a community of about 150 people whose electrical load is powered by a diesel-electric plant and distribution system owned by Northland Utilities Limited (NUL). It is located on the shore of Snare Lake and is accessible by winter road or by air. In 2009, the plant supplied about 613 megawatt hours (MWh) of net energy generation to the community. The average load in the community was 116 kilowatts (kW) and the recorded peak load is 137kW. The minimum plant load is 89kW. Costs for fuel delivered to the community have been high historically but have been reduced substantially in the last year, the authors were informed, due to changes in approach to the winter road planning and costing. At the end of 2009, diesel fuel cost about $0.94 per litre delivered or $0.27 per kWh.

The wind energy analysis and modeling in this report were based on existing airport meteorological data from the region and the publicly available wind maps. The wind speeds were estimated at 30 meters (m) above ground level (AGL), a common hub height for the wind turbines considered appropriate for this community. Four possible development sites for wind energy were identified on two hilltops near the community. Site 1 is on a hill about 200m north-west of the diesel-electric power plant; site 2 is on a higher portion of the same hill about 400m from the power plant, and site 3 is on the highest portion of the hill about 500m from the power plant. Site 4 is on top of a ridge on the north-east side of the village just north of the road to the airport and is about 400m from a three phase power line. The annual wind speed estimates for the candidate wind project sites range from 5.8 to 6.1m/s. An on-site measurement of the wind resource would be needed if wind power remains a desire for Wekweeti.

Five different wind turbine options were explored in this study. Projects using three wind turbines of 10kW or one of 30kW would result in capital costs of $573,500 and $512,000, respectively, or about $19,117 and $17,067 per kW of capacity, and the resulting cost of energy would be well in excess of $1.00 per kWh. Both 50kW turbine scenarios (one based on a used turbine) and the 100kW wind turbine project all produced energy in roughly the same cost range. A new large rotor 50kW turbine project would cost about $831,000 or $16,630 per kW but its relatively high energy capture would result in energy costing about $0.62 per kWh, while a low cost, small rotor, used 50kW turbine project would cost only $636,000 or $12,720 per kW but its relative low energy capture would result in power costing about $0.68 per kWh. A 100kW wind turbine project would cost about $1,223,000 and would produce power at about $0.70 per kWh. However, the 50kW and 100kW wind turbine projects would result in some surplus power that could not displace diesel generated power as the output would exceed the community electrical load.

As shown above, subsidies of $0.30 to $0.40 per kWh are required for wind energy to make it competitive at present diesel fuel prices. There may be opportunities to reduce capital costs or increase energy capture, but the cost of wind energy would still exceed the present cost of diesel generated electricity. Diesel fuel prices would need to be in excess of $2.00 per litre for wind energy to be competitive.

Introduction

Wekweeti is a community of about 150 people, located on the shore of Snare Lake (the hamlet's former namesake). The community is situated 200km north of Yellowknife (see Figure 1) and is at an altitude of 360m above sea level (ASL). Wekweeti is accessible from Yellowknife by air and winter road.

A diesel-electric generating plant that is owned and operated by the Northland Utilities Limited (NUL) supplies the electrical energy for Wekweeti. There has been interest expressed in displacing the diesel energy with renewable energy.

For wind energy to be viable, a mean annual wind speed of at least 5m/s is typically required, although much depends on factors such as power line, turbine, and installation costs. Typically the more expensive it is to ship the diesel fuel to the site, the more favourable the economics are for wind energy.

The purpose of this report is to examine the potential for wind power generation by providing a selection of potential sites and estimating the mean annual wind speed for those sites. The economic analysis looks at the cost of building a wind project near the hamlet using a selection of different wind turbines. The analysis includes estimating cost per kWh production, subsidy requirements, and greenhouse gas savings.

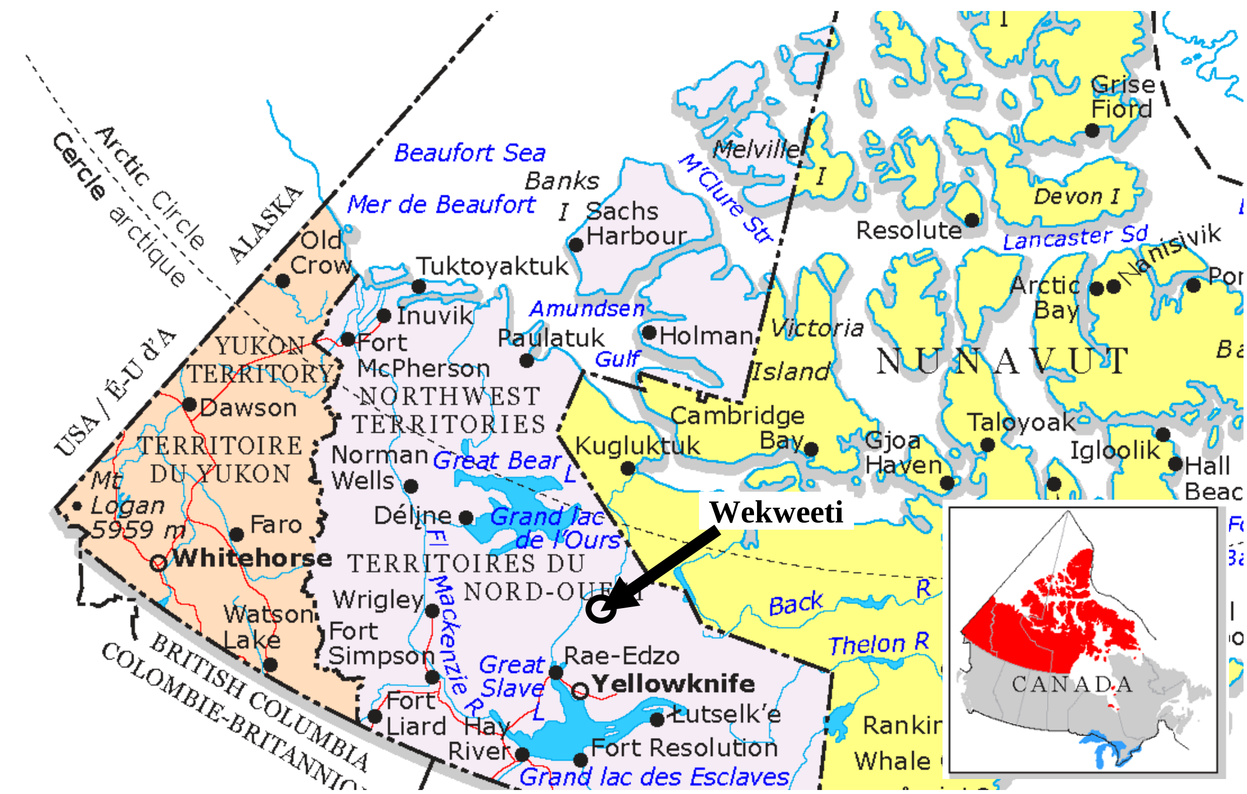

Figure 1: Wekweeti is located 200km north of Yellowknife.

Suitable Sites for Wind Energy Development

While investigating suitable sites for potential wind projects there are several criteria that are strongly desired in order to keep costs low and the project possible. The wind project should be as close to the community and its electrical load as possible, typically within a few hundred metres. The wind project must be outside the limitation of the airspace around the local air field (at least 4km away), as this avoids height restrictions by airport regulations. And the project location must be accessible by road, be acceptable to the community, and not infringe on other land uses. The project location also requires exposure to sufficient wind resources. Typically we find that the best winds are located on hilltops because wind speeds increase with altitude.

The Hamlet of Wekweeti is located on the north shore of Snare Lake as shown in Figure 2. The land relief in the immediate region of the hamlet undulates from the lake elevation of 355m ASL to over 420m ASL. Wekweeti is at about 365m ASL and immediately northwest of the hamlet, a hill rises to 423m ASL, about 55m above the community. A slightly lower ridge to the northeast of the hamlet rises to 413m ASL. The topography of these hills are shown in Figure 3 and they are the tallest within 1km of the Hamlet. These two hills are also located outside of the 4km airfield boundary and therefore will not be subject to height restrictions.

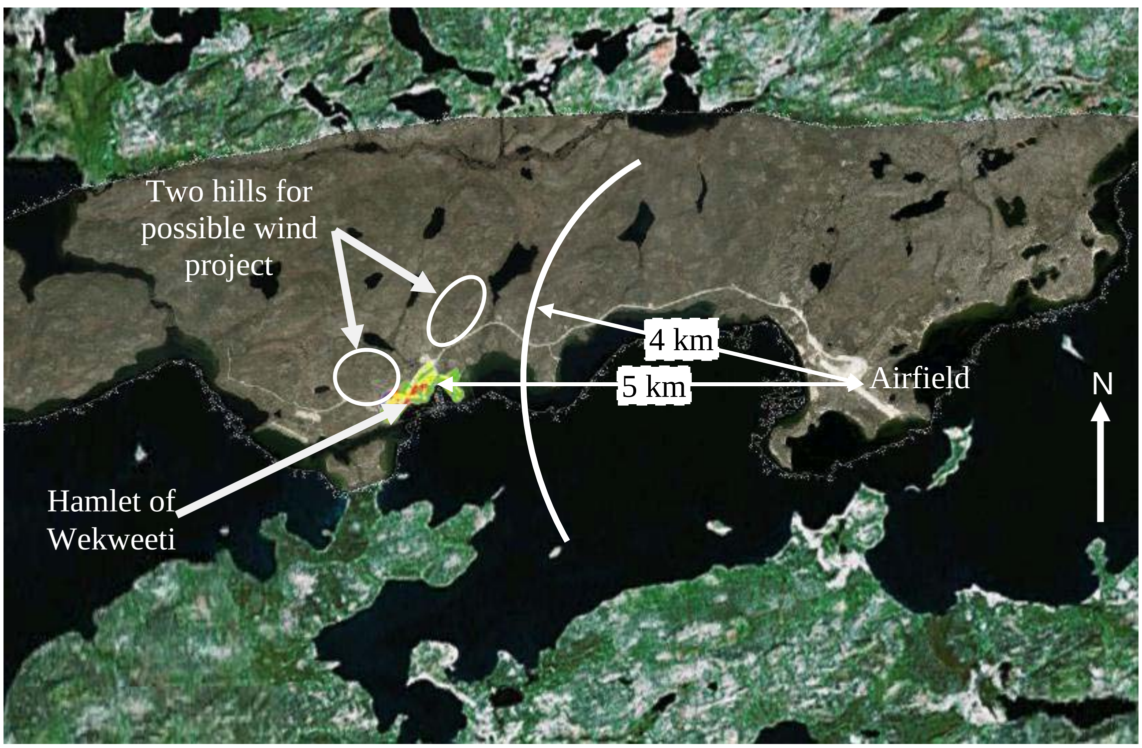

Figure 2: Map of Wekweeti Hamlet with legal boundaries. Note that the airfield is 5km from the Hamlet. Source: Municipal and Community Affairs, Northwest Territories Government.

As shown in Figure 3 below there are several suitable locations on these two hilltops which range from 410 to 423m ASL. These locations range from about 150 to 500m in horizontal distance from the nearest three phase power lines and the hamlet's diesel plant. The next step in this study is to estimate the wind speeds on these hilltops.

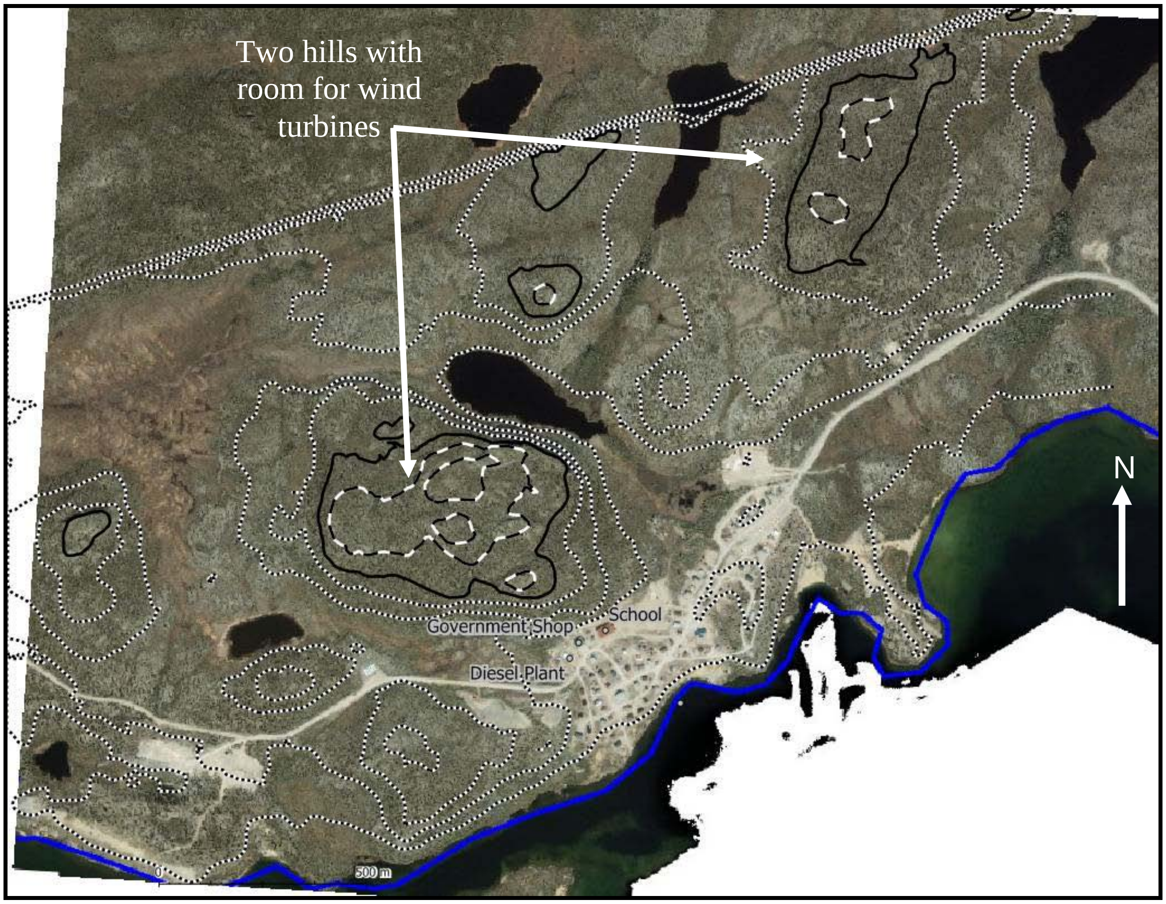

Figure 3: Satellite image of Wekweeti overlain by a contour map. The contour interval is 10m, the lake is 355m ASL. The solid contour line is 400m ASL and the dashed contours represent 410 and 420m ASL.

Estimating the Wind Climate in the Wekweeti Area

To estimate the wind energy potential in Wekweeti wind speed measurements are required. Since there is currently no weather station (known to the authors) in Wekweeti, an investigation of nearby measurements and wind climate models were made here.

The wind data used for the wind analysis was extracted from Environment Canada's (EC) climate data which is available online at their website (www.climate.weatheroffice.ec.gc.ca). According to EC there are no weather stations in Wekweeti, however there are other weather stations within 250km of Wekweeti and they are shown in Figure 4. The data from those stations contain hourly measurements of wind speed and direction, temperature, pressure, humidity, and other parameters. The wind measurements at these stations were all made at 10m above the ground.

In the western part of the region (Figure 4) the measured wind speeds are below 3m/s (all at 10m AGL) whereas to the northeast they are above 5m/s. The Lower Carp is the nearest station to

Wekweeti, being 67km almost due south of the Hamlet. This isolated station consists of temperature and wind sensors on a 10m tower located at 373m ASL on an island in Lower Carp Lake. The mean annual wind speed at this station was 3.7m/s for the five-year period 2005 to 2009. To project those measurements to Wekweeti and to increase our confidence level in those projections, large scale wind climate models were used that are publically available.

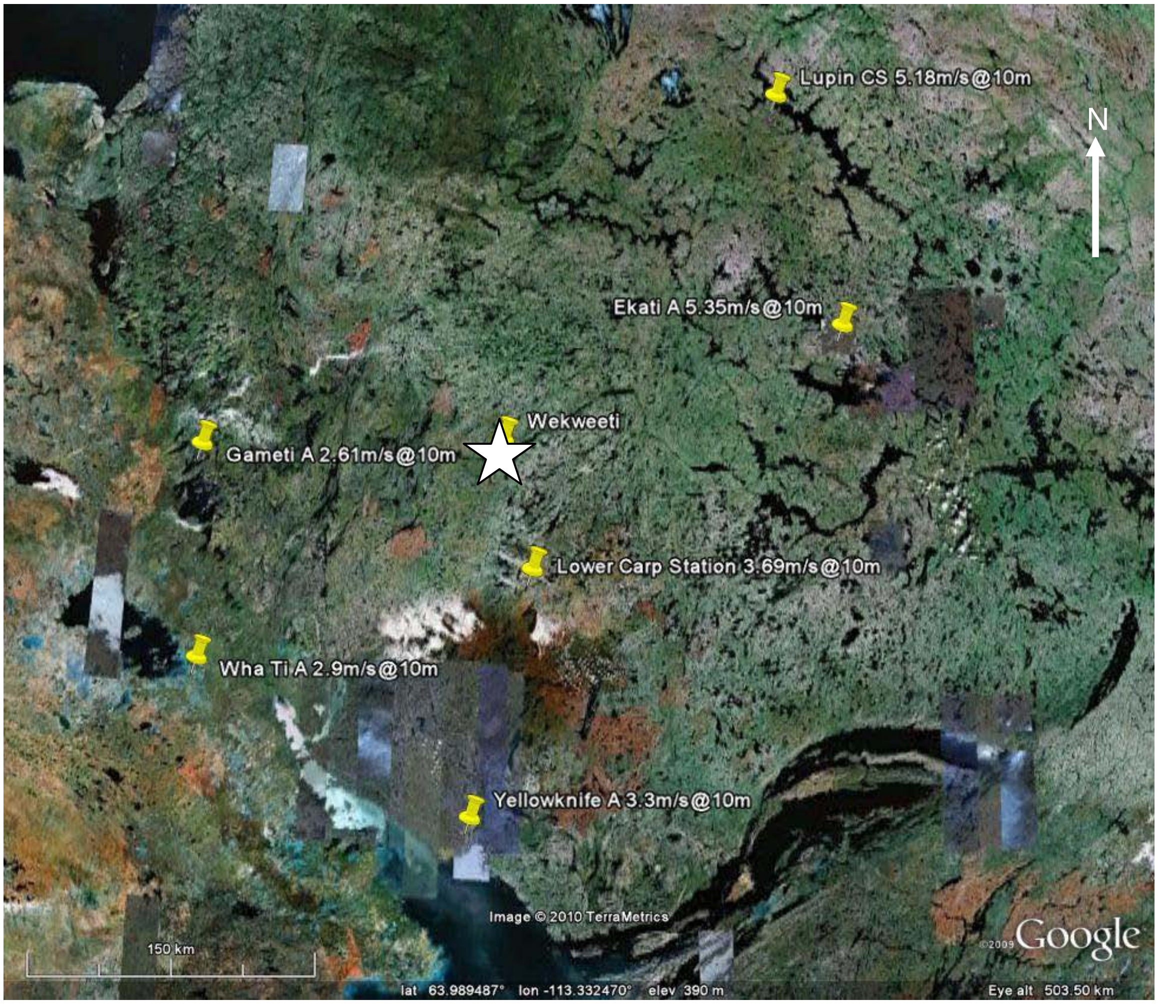

Figure 4: Regional map comparing the measured wind speeds. The wind speeds are an annual average for a five-year period 2005-09.

Large Scale Public Wind Models

Presented below are three wind climate maps that model wind speed estimates for Canada:

- FirstLook (http://firstlook.3tiergroup.com/) is operated by 3TIER, a global consultant in weather-driven renewable energy assessment and forecasting for wind, solar, and hydro power projects.

- WindNavigator (http://navigator.awstruewind.com/) is owned and maintained by AWS Truewind whose core service areas include energy assessment, mapping, and forecasting for both wind and solar energy projects.

- WindAtlas.ca (http://www.windatlas.ca) is maintained by an Environment Canada research group named RPN (Rechèrche en Prévision Numérique).

A description and some comparisons of these models can be found in the *Wind Study for Thor Lake Area* (Pinard 2009). But briefly, these are large computer numerical models that use equations to describe the physics of the atmospheric flow above the Earth's surface. These models use a reanalyzed set of weather data that are collected from surface stations, weather balloons, and other measurements to produce a wind map containing an array of information concerning wind speed and direction information.

For the purpose of this study, the three models are used only to compare the difference in modelled wind speed between Wekweeti and Lower Carp Lake, the nearest weather station. Each of these public models provide mean wind speed information at three elevations AGL and these elevations are different from one model to the next. All of the models however, provide estimates at 80m AGL; so to make a fair comparison we chose this height and compare the differences in the models' estimates of wind speed between Wekweeti and Lower Carp Lake.

Table 1: A comparison of modeled annual average wind speeds between Lower Carp Lake and Wekweeti using three publicly available wind maps. The wind speed are in m/s and the comparisons are all made at 80m AGL. The ratio is the wind speed at Wekweeti (Wek) divided by those at Lower Carp Lake (LCL).

Model	Lower Carp Lake m/s@80m AGL	Wekweeti m/s@80m AGL	Ratio Wek/LCL
WindAtlas	6.6	7.1	1.07
FirstLook	5.1	5.5	1.07
WindNavigator	6.6	6.4	0.97

From the ratio column in Table 1, both the Wind Atlas and FirstLook report a 7% increase in wind speed from the Lower Carp Lake area to Wekweeti. The WindNavigator model however, estimates a 3% decrease in wind speed. The FirstLook model underestimates the wind speeds at both sites compared to the other two models.

Project Wind Speeds Vertically

Note that from Table 1 above the wind models estimate a wide range of the wind speeds (annual average) at both sites. None of the models provide wind speed estimates at 10m AGL, the height of the EC weather station measurements. To make a fair comparison at the heights just noted we use the (natural) logarithmic law profile which is an industry standard equation used to define the wind speed profile above the Earth's surface. The equation is:

$$U_2 = U_1 \frac{\ln\left(z_2 / z_o \right)}{\ln\left(z_1 / z_o \right)}$$

where U_1 is the known wind speed at height z_1 in meters AGL and U_2 is the wind speed we wish to know at another elevation of z_2 in meters AGL. The length z_o (in vertical meters) represents the surface roughness of the area around the wind station. The surface roughness is adjusted so that the logarithmic curve (profile) intersects through the known wind speeds at different elevations. This was done using the models' estimated wind speed at Wekweeti and the logarithmic profiles are shown in Figure 5 below.

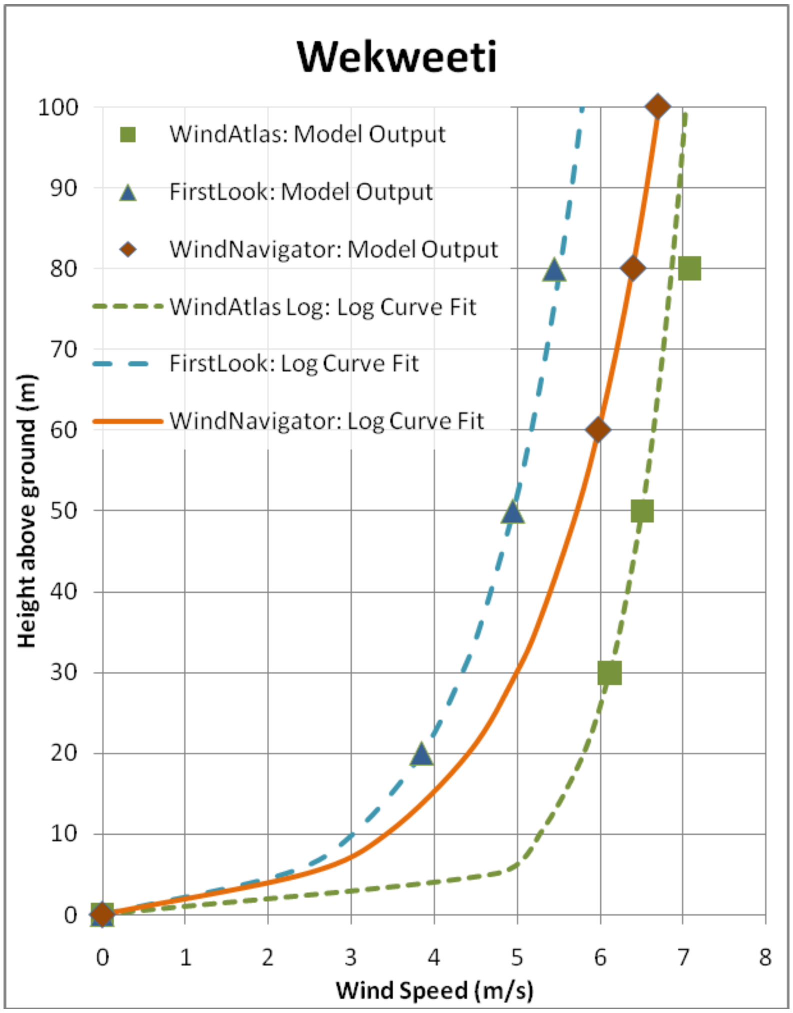

Figure 5: Logarithmic profiles fitted to the wind speed estimates provided at three levels AGL by each of the three wind models.

Table 2 tabulates the wind speed estimates from the three models using the logarithmic equation described above. Focusing on the WindNavigator model results for Lower Carp Lake and Wekweeti, we see that the model's estimated wind speed at Lower Carp Lake is 3.8m/s at 10m AGL, which is less than 3% higher than the measured wind speed at the station. At Wekweeti the model projects the wind speed to be slightly lower at 10m AGL but it is 5m/s at 30m AGL. This projection uses a surface roughness of z_o = 0.9m at Wekweeti, and the assumption is that the area is relatively flat with no hills in the area. Looking at Figure 5 and Table 2 we find that the FirstLook model tends to underestimate the wind speed while the WindAtlas tends to overestimate. This tendency was also the case in other studies (Pinard, 2009). More confidence is placed on the WindNavigator model because it is a higher resolution model (2.5km horizontal grid spacing compared to 5km for the other two models).

Table 2: Estimated wind speeds near the surface using three wind flow models. The values produced by the WindNavigator model are bold to indicate the confidence placed on its output.

Model	Lower Carp Lake m/s@10m AGL	Wekweeti m/s@10m AGL	Wekweeti m/s@30m AGL
WindAtlas	4.6	5.3	6.1
FirstLook	2.8	3.0	4.3
WindNavigator	**3.8**	**3.4**	**5.0**

From the above comparison then, a conservation estimate of the winds at Wekweeti would be that they are similar to those of Lower Carp Lake. For the purpose of this study we will also assume that the measurements of the wind speed and direction, as well as temperature between the two locations are the same. However, a wind monitoring program at Wekweeti would be required to refine these estimates.

Analysis of the Lower Carp Lake Measurements

As noted earlier, the Lower Carp Lake weather station data is the best information that is available for the Wekweeti area. This level of confidence is increased by the estimates of the three public wind models. So from the Lower Carp Lake data we can extract information on the annual mean wind speed as well as wind direction and apply them to the Wekweeti study.

The data set used for Lower Carp Lake was from a five-year period (2005-09). The wind data included hourly records of wind speed and direction as well as temperature and other information. The wind data for this five-year period was processed into a detailed format used for fine scale wind modeling (described in the next section). For this study we provide a summary of the data here.

The five-year average wind speed measured at Lower Carp Lake was 3.7m/s at 10m AGL. When this value is projected to 30m AGL using the logarithmic equation we obtain about 5m/s. The area surrounding the Lower Carp Lake weather station is sparsely forested with large metre-sized boulders around the tower and so a surface roughness of z_o = 0.5m is assumed for the above estimate. If we use the surface roughness of z_o = 0.9m that was derived from the WindNavigator model then the projected wind speed would be 5.37m/s at 30m AGL. We will, however, stay with the more conservative value of 5m/s for the annual average wind speed estimates for Wekweeti.

Wind direction must also be taken into account when considering a wind energy project. A wind rose provides an indication of the dominant wind direction of area and is very useful for planning the location of a wind project to ensure its maximum capture of wind energy. In Figure 6 the wind rose for Lower Carp Lake has a solid shaded area that represents the relative wind energy by direction. The wind energy by direction is calculated as the frequency of occurrence of the wind in a given direction sector multiplied by the cube of the mean wind speed in the same direction. The given wind energy in each direction is a fraction of the total energy for all directions.

According to this wind energy rose, the wind energy at Lower Carp Lake comes from two dominant directions: about a third of the energy is from the east-northeast and about a third is from the south. According to this wind rose, a wind energy project established in the region should have good exposure to the south and the east-northeast.

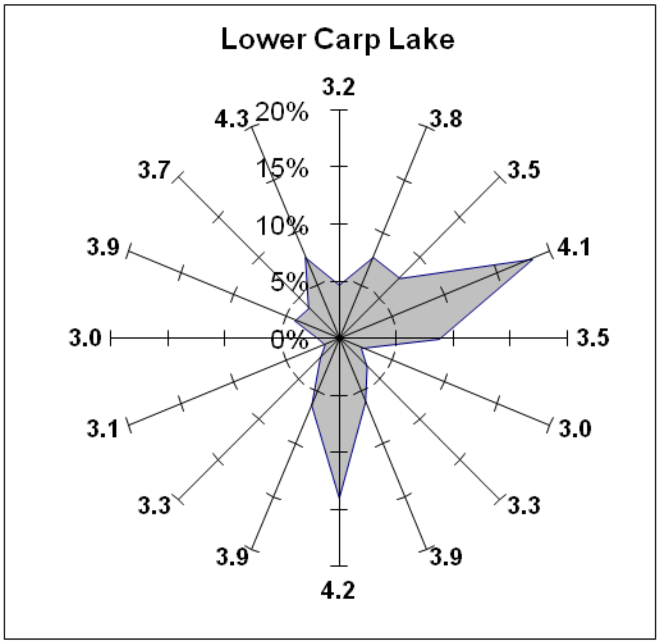

Figure 6: Wind rose of the Lower Carp Lake weather station. The shaded rose which is outlined in grey shows the relative wind energy by direction. The mean wind speed by direction sector is labelled at the end of each axis (m/s). North is towards the top.

Fine-Scale Wind Modelling of the Wekweeti Area

The wind model used to create the wind map for the area is OpenWind by AWS Truewind (www.awstruewind.com). OpenWind uses a mass-consistent wind flow model to project winds from one location to another. As input, the model uses surface elevation data, surface roughness, and a table of wind speed distribution by direction. The elevation data is obtained from the Government of the Northwest Territories' Municipal and Community Affairs website (http://gis.maca.gov.nt.ca/website/wekweti.asp). The surface roughness is assumed to be z_o = 0.5m, which is representative of the area's forest type. The table of wind speed distribution is derived from the five years of wind speed data (2005-2009) obtained from the Environment Canada website for the Lower Carp Lake station.

The wind flow modeling portion of OpenWind creates a wind map for each wind flow direction. The wind speeds in the wind maps are directly associated to the table of wind speed distributions. Wind turbines are placed at desired locations on the map and their annual energy outputs are calculated based on the wind speed map, the table of wind speed distributions by direction, and the power curve of the wind turbine selected for the study.

The OpenWind wind speed map in Figure 7 shows the summarized wind speed contours over a satellite image of Wekweeti. Four possible locations are suggested for turbine placements. Each of these sites are located on the top of a hill or knob. Site #1 is closest to the hamlet at 215m from the diesel plant and there a local trail presently established near this site. The wind speeds modeled at 30m AGL for these selected sites are 5.9m/s at Site #1, 6.1 at sites #2 and #3, and 5.8 at Site #4.

Figure 7: Satellite image of Wekweeti overlaid with wind speed contours. No contours are shown for the areas with wind speeds below 5m/s and the contour interval is 0.2m/s.

OpenWind was also used to calculate energy production from the estimated wind speeds and the power curves given for each turbine which were used in this study's economic analysis.

Power Requirements and Costs

Wekweeti's diesel-electric power plant and distribution system is owned and operated by NUL. In 2009, the plant generated a total of 635,373 kWh (gross) and 613,000 kWh net, with an average net load of 116kW. The recorded net peak load on the plant was 137kW. The minimum plant load was 89kW.

The power plant consists of three Volvo diesel generators, two of 150kW and one of 80kW. The distribution system consists of single and three phase above ground power lines. The plant records indicate that the plant efficiency is 3.42 kWh per litre of diesel fuel. Residual heat is recovered from the diesel generators and used for space heat in the government garage next to the plant.

NUL indicates that the late 2009 fuel deliveries cost about $0.94 per litre, a significant decrease from costs in the previous two years (of about $1.70 per litre) due to reduced costs for the winter road paid for by NUL and their fuel shippers. The cost of fuel is thus about $0.27 per kWh at present and would have been about $0.493 per kWh in the previous two years. As oil prices are hard to predict it is difficult to estimate what the cost of power generated from diesel fuel will be in the coming years. Appendix A contains a table of the fuel portion of electricity cost at different fuel prices.

Wind Power Project

Wind Turbines

Wekweeti is a small community with a small electrical load for which it will be difficult to make a turbine selection. A low penetration wind-diesel system would require quite small wind turbines, as small as 10kW, and a medium or high penetration wind-diesel system could involve a single 50kW to 100kW wind turbine. Other factors include economies of scale (larger turbines are less costly on a per kW basis), complexity of the resulting system (high penetration systems require more equipment and are more costly), and the relatively high fixed costs of doing any project. There was thus no one turbine model that stood out as being the most appropriate.

For these reasons this prefeasibility study has examined a range of turbine sizes from 10kW to 100kW. The smallest turbine considered was a Bergey Excel-S 10kW single phase (an installation of three units was examined), next was a Wenvor 30kW turbine, then an Endurance E-3120 50kW turbine, then a previously used Wind Matic V15 50kW turbine, and finally, the largest, was a Northern Power Systems NorthWind 100kW turbine. This way it is possible to compare the economies of scale of each wind turbine selected and to look at the effect of purchasing a used turbine.

Note that the Endurance wind turbine does not yet have an "Arctic" package option that would allow operation down to -40°C although the authors understand that this is under development. Therefore, an allowance of $20,000 was added to the budget price for this turbine to allow for this option (the supplier could not provide a budget price at this time).

The 50kW wind turbines would result in a medium penetration wind-diesel system, and the NorthWind 100kW unit would result in a high penetration wind-diesel system.

There is a significant variation in the rotor diameters of these turbines with the Wenvor having the smallest swept area per kW of capacity (2.62 m^2 per kW), and in increasing order are the NorthWind 100 (3.46 m^2 per kW), Wind Matic V15 (3.53 m^2 per kW), The Bergey Excel-S (3.85 m^2 per kW), and finally the largest is the Endurance E-3120 (5.97 m^2 per kW).

Although the authors did not specifically consider the Wind Energy Solutions WES18 (80kW) wind turbine in their examination of options for this project, it is a possibility worthy of serious consideration as they have an Arctic package option and also offer a wind-diesel hybrid option.

Energy Production

Energy production at each of the four possible wind project installation sites identified was calculated for each of the five turbines by the wind project modeling program OpenWind. Sites 3 and 2, in that order, are the highest in elevation and thus have the highest wind speeds (6.1m/s for both sites) with site 1 not much lower in altitude or wind speed (5.9m/s, but the closest to the existing diesel plant) and site 4 is the lowest in altitude and wind speed (5.8m/s). Energy production follows wind speed in trend.

For these calculations a turbine hub height of 30 meters was assumed. For some wind turbines tower heights of greater than 30 meters may be available and where these are an option, an economic analysis of the additional costs and the additional energy produced would determine whether these make sense.

The modeling program calculated the ideal (gross) annual energy yield of each of the turbines based on the published power curve and the modeled wind speed distribution. In these calculations the program made energy production adjustments for air density. The net (actual) energy yield was then calculated using the following losses (estimated by the authors) turbine unavailability of 5%, icing and cold weather related losses of 3%, and electrical collector system losses of 5%.

The highest energy capacity factors forecasted were for the Endurance wind turbine, which has the largest swept area per unit of capacity, followed by the NorthWind 100, the Wind Matic V15, the Bergey Excel-S, and finally the Wenvor, which coincidentally has the lowest swept area per unit of capacity. As there was no power curve available for the Wind Matic V15 turbine, the Entegrity EW50 power curve was used as a proxy since rotor diameters are the same and the basic technology is of the same vintage. There are two trends that can be seen from these turbines: the first is that larger turbines tend to produce more energy and the second is that larger swept areas per unit of capacity also tend to increase energy production.

In addition to the net energy yield at the forecasted wind speed at each site for each turbine, the authors examined energy production at wind speeds about 0.5m/s above and below the forecasted wind speed. The complete table of energy yields for the different turbines at each of the sites is provided in Appendix B.

Capital Costs

The capital cost estimates prepared for Wekweeti were based on prefeasibility studies completed by the authors for Beaufort Sea communities. However, since the indications from the developing Tuktoyaktuk wind project are that capital costs could be higher than had been estimated in prefeasibility studies, several line items in the capital cost estimates for Wekweeti wind project possibilities have been increased. These line items relate mostly to the "softer" costs related to projects (design, management, owners costs, etc.) but some "harder" cost estimates have also been increased (transportation, installation related, etc.). Overall the costs appear high, however, until there is sufficient experience with wind projects in Canada's north to be able to estimate costs with greater confidence there will remain significant uncertainty and the authors prefer not to knowingly estimate too optimistically.

Cost estimates for possible projects involving each of the 5 turbines at each of the four possible project sites were prepared (see Appendix C-1). Site 1 is only 200 meters from the power plant (to the north-west) while site 2 is 400 meters from the plant and site 3 is 500 meters from the plant. Site 4 is much further from the power plant to the north-east, but only about 400 meters from a three phase power line, so the project cost estimates for this site are identical to those for site 2.

Some selected capital cost details are listed below and complete details are provided in Appendix C:

1. Capital cost for a project situated at site 1 are $12,230 per kW for a NorthWind 100kW (total $1,223,000); $12,720 per kW for a used Wind Matic 50kW (total $636,000); $16,630 per kW for an Endurance E-3120 50kW (total $831,500); $17,067 per kW for a Wenvor 30kW ($512,000 total); and $19,117 for three Bergey Excel-S 10kW ($573,500).
2. At sites 2 and 4 the costs per kW range from $13,110 per kW for the NorthWind 100 to $22,050 per kW for three Bergey Excel-S turbines.
3. At site 3 the costs range from $13,550 per kW for the NorthWind 100 to $23,517 per kW for the three Bergey Excel-S turbines.

As can be seen from the above and Appendix C-1, the installed cost per kW of wind turbine capacity decreases with larger turbines. Also, are the costs of roads and power lines for sites further from a power system connection are noticeably more expensive, particularly for the smaller capacity projects.

In the authors' view it is possible that an existing business or corporation experienced in completing projects in the north, and in technical matters in particular, may be able to complete a project at lower costs. Examples of possible experienced project proponents include NUL (owners of the power plant and distribution system) and a local First Nations business or development corporation.

A lower management cost version of capital cost estimates were prepared for sites 1, 2, and 4 and is presented in Appendix C-2. It was estimated that reductions of between $50,000 and $100,000 could be realized on smaller to larger projects, respectively. These figures correspond to cost reductions of $2,000 per installed kW to $1,000 per installed kW for smaller to larger projects, respectively.

A lower management cost plus lower installation cost version of capital cost estimates was also prepared for sites 1,2, and 4 and is presented in Appendix C-3. Site 3 was not examined as it offers no real advantages over site 2. This is the most optimistic scenario that the authors can envision. Capital cost reductions of between $100,000 and $200,000 for smaller and larger (in terms of power production capacity) projects, respectively, could be realized. These figures correspond to cost reductions of about $3,500 to $2,000 per installed kW for smaller to larger projects, respectively.

Annual Costs

Annual project costs are composed of capital repayment plus annual operating and maintenance costs. Capital repayment calculations are based on monthly mortgage style payments at an interest rate of 7% per annum. This is intended as a means of levelizing costs over the 20 year project period, and represents a blend of interest on debt and return on equity – in other words the cost of capital. Capital repayments represent the largest portion of annual costs by a large margin. Annual capital repayment costs are shown in appendices C-1 to C-3 near the bottom of each spreadsheet.

The second and smaller component of the annual costs is operating and maintenance (O&M) cost which includes everything from insurance to repairs. For the 30kW Bergey and Wenvor projects an annual O&M cost of $10,000 per year was estimated; for the 50kW Endurance and used Wind Matic projects an annual cost of $15,000 was estimated; and for the 100kW NorthWind project an annual O&M cost of $25,000 was estimated.

Cost of Wind Energy and Economic Analyses

There were four possible project sites examined in this study. Site 1 is located on a hill only about 200 meters north-west of the power plant (on the west side of the community) and has a modeled wind resource of 5.9m/s; site 2 is located on a higher portion of the same hill about 400 meters from the power plant and has a modeled wind resource of 6.1m/s; and site 3 is a marginally higher portion of the hill about 500 meters from the power plant and has a modeled wind resource of 6.1m/s. Site 4 is on the north-eastern corner of the community on a ridge about 400 meters from a three phase power line.

Energy production at wind speeds of about 0.5m/s higher and 0.5m/s lower than modeled were calculated to determine project sensitivity to wind speed. Energy production at the modeled and higher and lower wind speeds for all five turbines examined are presented in Appendix B.

Based on the authors' analyses the cost of wind energy from any of the five turbine and four project site alternatives examined would be higher than the present cost of diesel generated power. The calculated cost of energy assumes that all energy is useful and displaces diesel energy but this would not be true for the two 50kW and the one 100kW turbines examined. The 50kW turbines would represent a medium penetration wind-diesel system and a percentage of the wind energy would likely need to be dumped (typically under high wind – low power load conditions) or used elsewhere. The 100kW wind turbine project would represent a medium to high penetration wind-diesel system and larger percentage of its energy production would be surplus.

The lowest cost of wind energy was generally produced from site 1 as the cost of an additional 200 meters of road and power line exceeded the benefit of the additional energy from the higher site 2 which was next best. Site 2 was marginally better for larger turbine projects when lower installation costs were assumed (includes reduced road and power line costs).

Table 3 provides the cost of energy calculations for the project options examined for site 1. Appendices D-1 to D-4 provide complete calculation details. As can be seen from this table the lowest cost of energy under the expected case costs are over $0.60 per kWh compared to a present diesel fuel cost of about $0.27 per kWh. Unless the wind resource is substantially better than modeled and capital costs can be reduced significantly a wind energy project would require significant capital subsidies. In the case of the smaller turbines most of the capital cost would need to be subsidized.

Table 3: Cost of energy per kWh at site 1 for various project options.

Wind Turbine	Expected Case	Low Management Cost	Low Management and Low Install Costs	Expected Case with +0.5m/s Wind
Three Bergey 10kW	$1.26	$1.16	$1.07	$1.04
One Wenvor 30kW	$1.55	$1.41	$1.29	$1.27
One Endurance 50kW	$0.62	$0.58	$0.54	$0.56
One used V15 50kW	$0.68	$0.63	$0.58	$0.56
One NorthWind 100kW	$0.70	$0.66	$0.62	$0.60

The lack of economies of project scale in turbine size as well as in the number of turbines required combine to result in high wind energy costs in very small communities such as Wekweeti. The most economical wind generated electricity would be generated by the larger wind turbines that could be used in this wind project in Wekweeti.

The cost of wind generated electricity is projected to be more than twice the cost of diesel generated electricity for the most economical project configurations, and would be several times higher for the smallest wind turbines considered. Diesel fuel would need to cost $2.10 to $2.50 per litre for wind energy from the larger turbines to be competitive without subsidies. Reductions in project management costs or installation costs, or both, by virtue of qualified and experienced developers could reduce the cost of wind generated electricity by about $0.05 to $0.10 per kWh. Depending on the turbine model selected for a project, a wind resource that is about 0.5m/s higher than modeled would cut the cost of wind energy by $0.04 to $0.12 per kWh.

Present diesel fuel costs are about $0.275 per kWh but in 20 years the cost would be about $0.50 per kWh if fuel inflates at 3% per year (1% per year above inflation which is assumed to be 2% per year). If diesel fuel inflates at 4% per year (92% per year above general inflation), the cost of diesel generated electricity will increase to about $0.60 per kWh. Over the same period wind generated electricity would increase in cost by only $0.04 to $0.07 per kWh. This is the O&M portion of costs inflating at 2% per year.

To make a wind project cost competitive in Wekweeti at present would require subsidies of $0.30 to $0.40 per kWh in the early years. Depending on fuel inflation rates relative to general inflation, the subsidies required in the later years of a project of $0.10 to $0.20 per kWh. Alternatively, a capital subsidy of about 80% of the capital cost of a project involving any of the three larger turbines would be required. These figures assume that all of the energy produced would displace diesel generation; however, we know that this will not be the case, so the above are really the most optimistic economic scenarios.

Greenhouse Gas Reductions

Greenhouse gas (GHG) emissions from the combustion of diesel fuel in diesel engines are generally accepted to be 3.0 kg CO_2 equivalent per litre of diesel fuel consumed. Table 2 below outlines the annual GHG reductions that would be achieved from wind projects based on each of the five turbine types examined at each of the four possible project sites identified. The energy production at each site is as modeled (see Appendix B), and the data in the table below assumes that all of the wind energy displaces diesel generated electricity. As previously noted there would be some wind energy from the 50kW projects that would not displace diesel, and a larger amount from the 100kW wind turbine would not directly displace diesel generation. The modeling that would be required to determine the diesel displacing energy and surplus wind energy is beyond the scope of this prefeasibility study.

Table 4: Annual GHG reductions in kg by site and turbine type

Wind Turbine	Site 1	Site 2	Site 3	Site 4
Three Bergey 10kW	152,253	162,639	164,097	143,901
One Wenvor 30kW	113,058	121,452	122,897	105,274
One Endurance 50kW	452,715	475,020	476,970	435,018
One used V15 50kW	329,037	351,672	354,450	310,500
One NorthWind 100kW	599,292	635,232	639,807	570,762

Conclusions

1. Wind resource calculations for Wekweeti were determined by computer modeling using data from some distance away in Lower Carp Lake. If accurate wind resource data is required for the community a wind mast will need to be established at the preferred development site.
2. There are four potential wind project development sites within 500 meters of the power plant or an existing three phase power line.
3. Site 1 would appear to be the best overall development site. Although it has a wind speed of 5.9m/s (at 30 meters AGL) which is lower than site 2 and site 3 at 6.1m/s, it is only 200 meters from the power plant which reduces access and power line costs. Site 2 is 400 meters from the power plant and site 3 is 500 meters away.
4. Capital costs for a 30kW wind project at site 1 are $512,000 for a Wenvor 30kW turbine ($17,067 per kW) and $573,500 for three Bergey Excel-S 10kW turbines ($19117 per kW).
5. Capital costs for a 50kW wind project are $636,000 for a used Wind Matic V15 ($12,720 per kW) and $831,000 for an Endurance E-3120 ($16,630 per kW).
6. Capital costs for a 100kW wind project based on the Northern Power Systems NorthWind 100 turbine are $1,223,000 (12,230 per kW).
7. Wind turbines that have large rotors perform well in terms of energy capture from a wind resource of about 6m/s such as Wekweeti has. These turbines include the Bergey Excel-S 10kW turbine (single phase), the Endurance E-3120 (very large 19.5m rotor), and the NorthWind 100.
8. The lowest expected cost of electrical energy are from the three larger turbines studied and ranges from $0.62 to $0.70 per kWh, still substantially above the present cost of diesel generated electricity which is about $0.275 per kWh.
9. The two 30kW wind project options would produce electricity at substantially higher costs than the larger turbines.
10. The impact of lower project management and/or installation costs would reduce the cost of wind generated electricity by about $0.04 to $0.10 per kWh.
11. A wind resource about 0.5m/s higher than modeled would reduce the cost of wind energy by $0.06 to $0.12 per kWh for the larger three turbines.
12. A wind project in Wekweeti would not be cost effective compared to diesel generation unless diesel fuel cost is in excess of $2.00 per litre.
13. At present diesel fuel prices subsidies of up to $0.40 per kWh would be required or approximately 80% or more of the capital cost would need to be granted to the project.
14. Without direct experience with wind projects in the north, the capital and operating cost estimates remain subject to a significant amount of uncertainty.

15. There are taller towers available for some turbines and the higher wind resource available to turbines on taller towers may well make these cost effective. This will require some detailed analyses when a wind energy project is being seriously considered.

Next Steps

The next steps that would be involved in developing a wind project in Wekweeti are:

1. Consider whether the project subsidies required to make wind generated electricity costs competitive are a possibility. If not, there is no need to proceed until conditions have changed significantly. If there is a potential for capital or operating subsidies the following steps should be considered.
2. A meteorological mast should be installed at one of the potential development sites, following consultation with the community, to accurately measure the wind resource.
3. Potential project developers, including NUL and local First Nations corporations, should be identified.
4. A preliminary examination of the possibility of combining a wind project in Wekweeti with a larger one elsewhere should be undertaken to gain economies of scale in wind turbine and other equipment purchases, as well as project development and management costs.
5. Unless the potential project developer is NUL, those wishing to advance a project should discuss the integration of a wind turbine into the power system with NUL as there will be some significant technical matters to be dealt with.

References:

Pinard, J.P., 2009, **Wind Study for Thor Lake Area.** Prepared for Aurora Research Institute, Inuvik, NT.

This and other related reports are found at:

http://www.nwtresearch.com/resources/publications/wind.aspx

Appendix A

Fuel portion of electricity Cost as a Function of Diesel Cost

Fuel portion of electricity cost as function of diesel fuel cost	
Fuel cost per litre	Diesel fuel cost per kWh, diesel plant efficiency 3.45 kWh per litre
$0.95	$0.275
$1.00	$0.290
$1.10	$0.319
$1.25	$0.362
$1.50	$0.435
$1.70	$0.493
$2.00	$0.580
$2.50	$0.725

Appendix B

Annual Energy Production

Wind turbine annual energy production						
Site	Site Wind Speed & + or - 0.5 m/s, in m/s	Wind turbine energy production, kWh per year				
		Bergey Excel-S 10kW (3)	Wenvor 30kW (1)	Endurance E3120 50kW (1)	Used V15 nominal 50kW (1)	NorthWind 100 (1)
	~5.435	40,601	30,149	132,796	86,646	163,806
Site 1	5.935	50,751	37,686	150,905	109,679	199,764
	~6.435	61,409	45,977	167,505	132,712	233,724
	~5.618	43,370	32,387	139,339	92,607	173,630
Site 2	6.118	54,213	40,484	158,340	117,224	211,744
	~6.618	65,598	49,390	175,757	141,841	247,740
	~5.643	43,759	32,718	139,911	93,339	174,881
Site 3	6.143	54,699	40,897	158,990	118,150	213,269
	~6.643	66,186	49,894	176,479	142,962	249,525
	~5.277	38,321	28,219	127,605	81,765	156,008
Site 4	5.777	47,901	35,274	145,006	103,500	190,254
	~6.277	57,960	43,034	160,957	125,235	222,597

Appendix C-1

Wind Project Capital Costs

Wekweeti Site 1 Project Capital Costs					
Site closest to power plant					
	low penetration	low penetration	medium penetration	medium penetration	high penetration
Cost category	**3 10kW Bergey turbines**	**1 30kW Wenvor turbine**	**1 E-3120 50kW turbine**	**Used V15 50kW turbine**	**1 NPS NW 100kW turbine**
Project Design & Mgmt					
project design	$15,000	$15,000	$20,000	$20,000	$30,000
environmental assessment & permitting	$15,000	$15,000	$15,000	$15,000	$15,000
project management	$20,000	$20,000	$30,000	$30,000	$40,000
Site Preparation					
road construction ($100,000 per km) 200m	$20,000	$20,000	$20,000	$20,000	$20,000
road upgrading ($40,000 per km), nominal only					
powerline construction ($300,000 per km), 200m	$60,000	$60,000	$60,000	$60,000	$60,000
powerline upgrading 1 to 3 ph ($150,000 per km)					
Wind Equipment Purchase					
wind turbines	$111,000	$120,000	$217,500	$75,000	$350,000
towers	$76,500		$32,000		
gin pole					
winch equipment	$10,000	$10,000			
shipping	$20,000	$20,000	$30,000	$30,000	$50,000
transformers					
wind plant master control					
Installation					
foundations & geotehnical	$50,000	$40,000	$105,000	$80,000	$100,000
equipment rental	$10,000	$20,000	$30,000	$30,000	$50,000
control buildings					$10,000
utility interconnection	$10,000	$10,000	$20,000	$20,000	$30,000
commissioning		$5,000	$3,000	$10,000	$15,000
labour - assembly & supervision		$5,000		$15,000	$50,000
travel and accommodation	$8,000	$8,000	$15,000	$15,000	$30,000
Diesel Plant Modifications					
high speed comm. & controller			$10,000	$10,000	$30,000
SCADA					$30,000
dump load			$10,000	$10,000	$20,000
plant modifications	$5,000	$5,000	$15,000	$15,000	$30,000
Other					
initial spare parts	$2,000	$3,000	$5,000	$5,000	$10,000
Insurance	$5,000	$5,000	$10,000	$10,000	$15,000
other overhead costs (contracts etc)	$25,000	$25,000	$40,000	$40,000	$50,000
SUBTOTAL CONSTRUCTION	**$462,500**	**$406,000**	**$687,500**	**$510,000**	**$1,035,000**
Contingency ~10%	**$46,000**	**$41,000**	**$69,000**	**$51,000**	**$103,000**
TOTAL CONSTRUCTION	**$508,500**	**$447,000**	**$756,500**	**$561,000**	**$1,138,000**
Owners Costs					
manage project organization	$25,000	$25,000	$30,000	$30,000	$40,000
negotiate agreements	$25,000	$25,000	$30,000	$30,000	$30,000
staff training	$15,000	$15,000	$15,000	$15,000	$15,000
TOTAL OWNERS' COSTS	**$65,000**	**$65,000**	**$75,000**	**$75,000**	**$85,000**
TOTAL PROJECT COST	**$573,500**	**$512,000**	**$831,500**	**$636,000**	**$1,223,000**
Installed capacity kW	30	30	50	50	100
Installed cost per kW	**$19,117**	**$17,067**	**$16,630**	**$12,720**	**$12,230**
Annual cost of monthly mortgage payments, 7%	$54,024	$48,230	$78,327	$59,911	$115,207
		Includes dealer installation - except travel			

Appendix C-1

Wind Project Capital Costs

Wekweeti Sites 2 & 4 Project Capital Costs

Site closest to power plant

Cost category	low penetration **3 10kW Bergey turbines**	low penetration **1 30kW Wenvor turbine**	medium penetration **1 E-3120 50kW turbine**	medium penetration **Used V15 50kW turbine**	high penetration **1 NPS NW 100kW turbine**
Project Design & Mgmt					
project design	$15,000	$15,000	$20,000	$20,000	$30,000
environmental assessment & permitting	$15,000	$15,000	$15,000	$15,000	$15,000
project management	$20,000	$20,000	$30,000	$30,000	$40,000
Site Preparation					
road construction ($100,000 per km) 400m	$40,000	$40,000	$40,000	$40,000	$40,000
road upgrading ($40,000 per km), nominal only					
powerline construction ($300,000 per km), 400m	$120,000	$120,000	$120,000	$120,000	$120,000
powerline upgrading 1 to 3 ph ($150,000 per km)					
Wind Equipment Purchase					
wind turbines	$111,000	$120,000	$217,500	$75,000	$350,000
towers	$76,500		$32,000		
gin pole					
winch equipment	$10,000	$10,000			
shipping	$20,000	$20,000	$30,000	$30,000	$50,000
transformers					
wind plant master control					
Installation					
foundations & geotehnical	$50,000	$40,000	$105,000	$80,000	$100,000
equipment rental	$10,000	$20,000	$30,000	$30,000	$50,000
control buildings					$10,000
utility interconnection	$10,000	$10,000	$20,000	$20,000	$30,000
commissioning		$5,000	$3,000	$10,000	$15,000
labour - assembly & supervision		$5,000		$15,000	$50,000
travel and accommodation	$8,000	$8,000	$15,000	$15,000	$30,000
Diesel Plant Modifications					
high speed comm. & controller			$10,000	$10,000	$30,000
SCADA					$30,000
dump load			$10,000	$10,000	$20,000
plant modifications	$5,000	$5,000	$15,000	$15,000	$30,000
Other					
initial spare parts	$2,000	$3,000	$5,000	$5,000	$10,000
Insurance	$5,000	$5,000	$10,000	$10,000	$15,000
other overhead costs (contracts etc)	$25,000	$25,000	$40,000	$40,000	$50,000
SUBTOTAL CONSTRUCTION	**$542,500**	**$486,000**	**$767,500**	**$590,000**	**$1,115,000**
Contingency ~10%	**$54,000**	**$49,000**	**$77,000**	**$59,000**	**$111,000**
TOTAL CONSTRUCTION	**$596,500**	**$535,000**	**$844,500**	**$649,000**	**$1,226,000**
Owners Costs					
manage project organization	$25,000	$25,000	$30,000	$30,000	$40,000
negotiate agreements	$25,000	$25,000	$30,000	$30,000	$30,000
staff training	$15,000	$15,000	$15,000	$15,000	$15,000
TOTAL OWNERS' COSTS	**$65,000**	**$65,000**	**$75,000**	**$75,000**	**$85,000**
TOTAL PROJECT COST	**$661,500**	**$600,000**	**$919,500**	**$724,000**	**$1,311,000**
Installed capacity kW	30	30	50	50	100
Installed cost per kW	**$22,050**	**$20,000**	**$18,390**	**$14,480**	**$13,110**
Annual cost of monthly mortgage payments, 7%	$62,313	$56,520	$86,617	$68,201	$123,496
	(highlighted)	Includes dealer installation - except travel			

Appendix C-1

Wind Project Capital Costs

Wekweeti Site 3 Project Capital Costs					
Site closest to power plant					
	low penetration	low penetration	medium penetration	medium penetration	high penetration
Cost category	**3 10kW Bergey turbines**	**1 30kW Wenvor turbine**	**1 E-3120 50kW turbine**	**Used V15 50kW turbine**	**1 NPS NW 100kW turbine**
Project Design & Mgmt					
project design	$15,000	$15,000	$20,000	$20,000	$30,000
environmental assessment & permitting	$15,000	$15,000	$15,000	$15,000	$15,000
project management	$20,000	$20,000	$30,000	$30,000	$40,000
Site Preparation					
road construction ($100,000 per km) 500m	$50,000	$50,000	$50,000	$50,000	$50,000
road upgrading ($40,000 per km), nominal only					
powerline construction ($300,000 per km), 500m	$150,000	$150,000	$150,000	$150,000	$150,000
powerline upgrading 1 to 3 ph ($150,000 per km)					
Wind Equipment Purchase					
wind turbines	$111,000	$120,000	$217,500	$75,000	$350,000
towers	$76,500		$32,000		
gin pole					
winch equipment	$10,000	$10,000			
shipping	$20,000	$20,000	$30,000	$30,000	$50,000
transformers					
wind plant master control					
Installation					
foundations & geotehnical	$50,000	$40,000	$105,000	$80,000	$100,000
equipment rental	$10,000	$20,000	$30,000	$30,000	$50,000
control buildings					$10,000
utility interconnection	$10,000	$10,000	$20,000	$20,000	$30,000
commissioning		$5,000	$3,000	$10,000	$15,000
labour - assembly & supervision		$5,000		$15,000	$50,000
travel and accommodation	$8,000	$8,000	$15,000	$15,000	$30,000
Diesel Plant Modifications					
high speed comm. & controller			$10,000	$10,000	$30,000
SCADA					$30,000
dump load			$10,000	$10,000	$20,000
plant modifications	$5,000	$5,000	$15,000	$15,000	$30,000
Other					
initial spare parts	$2,000	$3,000	$5,000	$5,000	$10,000
Insurance	$5,000	$5,000	$10,000	$10,000	$15,000
other overhead costs (contracts etc)	$25,000	$25,000	$40,000	$40,000	$50,000
SUBTOTAL CONSTRUCTION	**$582,500**	**$526,000**	**$807,500**	**$630,000**	**$1,155,000**
Contingency ~10%	**$58,000**	**$53,000**	**$81,000**	**$63,000**	**$115,000**
TOTAL CONSTRUCTION	**$640,500**	**$579,000**	**$888,500**	**$693,000**	**$1,270,000**
Owners Costs					
manage project organization	$25,000	$25,000	$30,000	$30,000	$40,000
negotiate agreements	$25,000	$25,000	$30,000	$30,000	$30,000
staff training	$15,000	$15,000	$15,000	$15,000	$15,000
TOTAL OWNERS' COSTS	**$65,000**	**$65,000**	**$75,000**	**$75,000**	**$85,000**
TOTAL PROJECT COST	**$705,500**	**$644,000**	**$963,500**	**$768,000**	**$1,355,000**
Installed capacity kW	30	30	50	50	100
Installed cost per kW	**$23,517**	**$21,467**	**$19,270**	**$15,360**	**$13,550**
Annual cost of monthly mortgage payments, 7%	$66,458	$60,665	$90,762	$72,346	$127,641
		Includes dealer installation - except travel			

Appendix C-2

Wind Project Capital Costs

Wekweeti Site 1 Project Capital Costs					
Site closest to power plant, lower management costs					
	low penetration	low penetration	medium penetration	medium penetration	high penetration
Cost category	**3 10kW Bergey turbines**	**1 30kW Wenvor turbine**	**1 E-3120 50kW turbine**	**Used V15 50kW turbine**	**1 NPS NW 100kW turbine**
Project Design & Mgmt					
project design	$10,000	$10,000	$15,000	$15,000	$20,000
environmental assessment & permitting	$5,000	$5,000	$5,000	$5,000	$5,000
project management	$15,000	$15,000	$20,000	$20,000	$30,000
Site Preparation					
road construction ($100,000 per km) 200m	$20,000	$20,000	$20,000	$20,000	$20,000
road upgrading ($40,000 per km), nominal only					
powerline construction ($300,000 per km), 200m	$60,000	$60,000	$60,000	$60,000	$60,000
powerline upgrading 1 to 3 ph ($150,000 per km)					
Wind Equipment Purchase					
wind turbines	$111,000	$120,000	$217,500	$75,000	$350,000
towers	$76,500		$32,000		
gin pole					
winch equipment	$10,000	$10,000			
shipping	$20,000	$20,000	$30,000	$30,000	$50,000
transformers					
wind plant master control					
Installation					
foundations & geotehnical	$40,000	$30,000	$100,000	$80,000	$100,000
equipment rental	$10,000	$20,000	$30,000	$30,000	$50,000
control buildings					$10,000
utility interconnection	$10,000	$10,000	$20,000	$20,000	$30,000
commissioning		$5,000	$3,000	$10,000	$10,000
labour - assembly & supervision		$5,000		$10,000	$40,000
travel and accommodation	$8,000	$8,000	$15,000	$15,000	$20,000
Diesel Plant Modifications					
high speed comm. & controller			$10,000	$10,000	$30,000
SCADA					$30,000
dump load			$10,000	$10,000	$20,000
plant modifications	$5,000	$5,000	$15,000	$15,000	$30,000
Other					
initial spare parts	$2,000	$3,000	$5,000	$5,000	$10,000
Insurance	$5,000	$5,000	$10,000	$10,000	$15,000
other overhead costs (contracts etc)	$20,000	$20,000	$30,000	$30,000	$40,000
SUBTOTAL CONSTRUCTION	**$427,500**	**$371,000**	**$647,500**	**$470,000**	**$970,000**
Contingency ~10%	**$43,000**	**$37,000**	**$65,000**	**$47,000**	**$97,000**
TOTAL CONSTRUCTION	**$470,500**	**$408,000**	**$712,500**	**$517,000**	**$1,067,000**
Owners Costs					
manage project organization	$20,000	$20,000	$25,000	$25,000	$30,000
negotiate agreements	$20,000	$20,000	$25,000	$25,000	$25,000
staff training	$10,000	$10,000	$10,000	$10,000	$10,000
TOTAL OWNERS' COSTS	**$50,000**	**$50,000**	**$60,000**	**$60,000**	**$65,000**
TOTAL PROJECT COST	**$520,500**	**$458,000**	**$772,500**	**$577,000**	**$1,132,000**
Installed capacity kW	30	30	50	50	100
Installed cost per kW	**$17,350**	**$15,267**	**$15,450**	**$11,540**	**$11,320**
Annual cost of monthly mortgage payments, 7%	$49,031	$43,144	$72,770	$54,353	$106,634
		Includes dealer installation - except travel			

Appendix C-2

Wind Project Capital Costs

Wekweeti Sites 2 & 4 Project Capital Costs					
Site closest to power plant, lower management costs					
	low penetration	low penetration	medium penetration	medium penetration	high penetration
Cost category	**3 10kW Bergey turbines**	**1 30kW Wenvor turbine**	**1 E-3120 50kW turbine**	**Used V15 50kW turbine**	**1 NPS NW 100kW turbine**
Project Design & Mgmt					
project design	$10,000	$10,000	$15,000	$15,000	$20,000
environmental assessment & permitting	$5,000	$5,000	$5,000	$5,000	$5,000
project management	$15,000	$15,000	$20,000	$20,000	$30,000
Site Preparation					
road construction ($100,000 per km) 400m	$40,000	$40,000	$40,000	$40,000	$40,000
road upgrading ($40,000 per km), nominal only					
powerline construction ($300,000 per km), 400m	$120,000	$120,000	$120,000	$120,000	$120,000
powerline upgrading 1 to 3 ph ($150,000 per km)					
Wind Equipment Purchase					
wind turbines	$111,000	$120,000	$217,500	$75,000	$350,000
towers	$76,500		$32,000		
gin pole					
winch equipment	$10,000	$10,000			
shipping	$20,000	$20,000	$30,000	$30,000	$50,000
transformers					
wind plant master control					
Installation					
foundations & geotehnical	$40,000	$30,000	$100,000	$80,000	$100,000
equipment rental	$10,000	$20,000	$30,000	$30,000	$50,000
control buildings					$10,000
utility interconnection	$10,000	$10,000	$20,000	$20,000	$30,000
commissioning		$5,000	$3,000	$10,000	$15,000
labour - assembly & supervision		$5,000		$15,000	$50,000
travel and accommodation	$8,000	$8,000	$15,000	$15,000	$30,000
Diesel Plant Modifications					
high speed comm. & controller			$10,000	$10,000	$30,000
SCADA					$30,000
dump load			$10,000	$10,000	$20,000
plant modifications	$5,000	$5,000	$15,000	$15,000	$30,000
Other					
initial spare parts	$2,000	$3,000	$5,000	$5,000	$10,000
Insurance	$5,000	$5,000	$10,000	$10,000	$15,000
other overhead costs (contracts etc)	$20,000	$20,000	$30,000	$30,000	$40,000
SUBTOTAL CONSTRUCTION	**$507,500**	**$451,000**	**$727,500**	**$555,000**	**$1,075,000**
Contingency ~10%	**$51,000**	**$45,000**	**$73,000**	**$55,000**	**$107,000**
TOTAL CONSTRUCTION	**$558,500**	**$496,000**	**$800,500**	**$610,000**	**$1,182,000**
Owners Costs					
manage project organization	$20,000	$20,000	$25,000	$25,000	$30,000
negotiate agreements	$20,000	$20,000	$25,000	$25,000	$25,000
staff training	$10,000	$10,000	$10,000	$10,000	$10,000
TOTAL OWNERS' COSTS	**$50,000**	**$50,000**	**$60,000**	**$60,000**	**$65,000**
TOTAL PROJECT COST	**$608,500**	**$546,000**	**$860,500**	**$670,000**	**$1,247,000**
Installed capacity kW	30	30	50	50	100
Installed cost per kW	**$20,283**	**$18,200**	**$17,210**	**$13,400**	**$12,470**
Annual cost of monthly mortgage payments, 7%	$57,321	$51,433	$81,059	$63,114	$117,467
		Includes dealer installation - except travel			

Appendix C-3

Wind Project Capital Costs

Wekweeti Site 1 Project Capital Costs

Site closest to power plant, lower management and installation costs

Cost category	low penetration **3 10kW Bergey turbines**	low penetration **1 30kW Wenvor turbine**	medium penetration **1 E-3120 50kW turbine**	medium penetration **Used V15 50kW turbine**	high penetration **1 NPS NW 100kW turbine**
Project Design & Mgmt					
project design	$10,000	$10,000	$15,000	$15,000	$20,000
environmental assessment & permitting	$5,000	$5,000	$5,000	$5,000	$5,000
project management	$15,000	$15,000	$20,000	$20,000	$30,000
Site Preparation					
road construction ($50,000 per km) 200m	$10,000	$10,000	$10,000	$10,000	$10,000
road upgrading ($40,000 per km), nominal only					
powerline construction ($150,000 per km), 200m	$30,000	$30,000	$30,000	$30,000	$30,000
powerline upgrading 1 to 3 ph ($150,000 per km)					
Wind Equipment Purchase					
wind turbines	$111,000	$120,000	$217,500	$75,000	$350,000
towers	$76,500		$32,000		
gin pole					
winch equipment	$10,000	$10,000			
shipping	$15,000	$15,000	$25,000	$25,000	$40,000
transformers					
wind plant master control					
Installation					
foundations & geotehnical	$40,000	$30,000	$90,000	$70,000	$90,000
equipment rental	$10,000	$20,000	$30,000	$30,000	$40,000
control buildings					$10,000
utility interconnection	$10,000	$10,000	$20,000	$20,000	$30,000
commissioning		$5,000	$3,000	$10,000	$10,000
labour - assembly & supervision		$5,000		$10,000	$40,000
travel and accommodation	$8,000	$8,000	$12,000	$12,000	$15,000
Diesel Plant Modifications					
high speed comm. & controller			$10,000	$10,000	$30,000
SCADA					$30,000
dump load			$10,000	$10,000	$20,000
plant modifications	$5,000	$5,000	$15,000	$15,000	$30,000
Other					
initial spare parts	$2,000	$3,000	$5,000	$5,000	$10,000
Insurance	$5,000	$5,000	$10,000	$10,000	$15,000
other overhead costs (contracts etc)	$20,000	$20,000	$30,000	$30,000	$40,000
SUBTOTAL CONSTRUCTION	**$382,500**	**$326,000**	**$589,500**	**$412,000**	**$895,000**
Contingency ~10%	**$38,000**	**$33,000**	**$59,000**	**$41,000**	**$89,000**
TOTAL CONSTRUCTION	**$420,500**	**$359,000**	**$648,500**	**$453,000**	**$984,000**
Owners Costs					
manage project organization	$20,000	$20,000	$25,000	$25,000	$30,000
negotiate agreements	$20,000	$20,000	$25,000	$25,000	$25,000
staff training	$10,000	$10,000	$10,000	$10,000	$10,000
TOTAL OWNERS' COSTS	**$50,000**	**$50,000**	**$60,000**	**$60,000**	**$65,000**
TOTAL PROJECT COST	**$470,500**	**$409,000**	**$708,500**	**$513,000**	**$1,049,000**
Installed capacity kW	30	30	50	50	100
Installed cost per kW	**$15,683**	**$13,633**	**$14,170**	**$10,260**	**$10,490**
Annual cost of monthly mortgage payments, 7%	$44,321	$38,528	$66,741	$48,325	$98,816
		Includes dealer installation - except travel			

Appendix C-3

Wind Project Capital Costs

Wekweeti Sites 2 & 4 Project Capital Costs

Site closest to power plant, lower management and installation costs

	low penetration	low penetration	medium penetration	medium penetration	high penetration
Cost category	**3 10kW Bergey turbines**	**1 30kW Wenvor turbine**	**1 E-3120 50kW turbine**	**Used V15 50kW turbine**	**1 NPS NW 100kW turbine**
Project Design & Mgmt					
project design	$10,000	$10,000	$15,000	$15,000	$20,000
environmental assessment & permitting	$5,000	$5,000	$5,000	$5,000	$5,000
project management	$15,000	$15,000	$20,000	$20,000	$30,000
Site Preparation					
road construction ($50,000 per km) 400m	$20,000	$20,000	$20,000	$20,000	$20,000
road upgrading ($40,000 per km), nominal only					
powerline construction ($150,000 per km), 400m	$60,000	$60,000	$60,000	$60,000	$60,000
powerline upgrading 1 to 3 ph ($150,000 per km)					
Wind Equipment Purchase					
wind turbines	$111,000	$120,000	$217,500	$75,000	$350,000
towers	$76,500		$32,000		
gin pole					
winch equipment	$10,000	$10,000			
shipping	$15,000	$15,000	$25,000	$25,000	$40,000
transformers					
wind plant master control					
Installation					
foundations & geotehnical	$40,000	$30,000	$90,000	$70,000	$90,000
equipment rental	$10,000	$20,000	$30,000	$30,000	$40,000
control buildings					$10,000
utility interconnection	$10,000	$10,000	$20,000	$20,000	$30,000
commissioning		$5,000	$3,000	$10,000	$15,000
labour - assembly & supervision		$5,000		$15,000	$50,000
travel and accommodation	$8,000	$8,000	$12,000	$12,000	$15,000
Diesel Plant Modifications					
high speed comm. & controller			$10,000	$10,000	$30,000
SCADA					$30,000
dump load			$10,000	$10,000	$20,000
plant modifications	$5,000	$5,000	$15,000	$15,000	$30,000
Other					
initial spare parts	$2,000	$3,000	$5,000	$5,000	$10,000
Insurance	$5,000	$5,000	$10,000	$10,000	$15,000
other overhead costs (contracts etc)	$20,000	$20,000	$30,000	$30,000	$40,000
SUBTOTAL CONSTRUCTION	**$422,500**	**$366,000**	**$629,500**	**$457,000**	**$950,000**
Contingency ~10%	**$42,000**	**$37,000**	**$63,000**	**$46,000**	**$95,000**
TOTAL CONSTRUCTION	**$464,500**	**$403,000**	**$692,500**	**$503,000**	**$1,045,000**
Owners Costs					
manage project organization	$20,000	$20,000	$25,000	$25,000	$30,000
negotiate agreements	$20,000	$20,000	$25,000	$25,000	$25,000
staff training	$10,000	$10,000	$10,000	$10,000	$10,000
TOTAL OWNERS' COSTS	**$50,000**	**$50,000**	**$60,000**	**$60,000**	**$65,000**
TOTAL PROJECT COST	**$514,500**	**$453,000**	**$752,500**	**$563,000**	**$1,110,000**
Installed capacity kW	30	30	50	50	100
Installed cost per kW	**$17,150**	**$15,100**	**$15,050**	**$11,260**	**$11,100**
Annual cost of monthly mortgage payments, 7%	$48,466	$42,673	$70,886	$53,035	$104,562
		Includes dealer installation - except travel			

Appendix D-1

Wekweeti cost of wind power base case

Wekweeti: 3 Bergey Excel-S 10kW (30kW total) project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$54,024	$62,313	$66,458	$62,313
Annual operating cost	$10,000	$10,000	$10,000	$10,000
Total annual cost	$64,024	$72,313	$76,458	$72,313
Annual energy in kWh (predicted ws)	50,751	54,213	54,699	47,901
Predicted cost per kWh	**$1.26**	**$1.33**	**$1.40**	**$1.51**

Appendix D-1

Wekweeti cost of wind power base case

Wekweeti: 1 Wenvor 30kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$48,230	$56,520	$60,665	$56,520
Annual operating cost	$10,000	$10,000	$10,000	$10,000
Total annual cost	$58,230	$66,520	$70,665	$66,520
Annual energy in kWh (predicted ws)	37,686	40,484	40,897	35,274
Predicted cost per kWh	**$1.55**	**$1.64**	**$1.73**	**$1.89**

Appendix D-1

Wekweeti cost of wind power base case

Wekweeti: 1 Endurance E-3120 50kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$78,327	$86,617	$90,762	$86,617
Annual operating cost	$15,000	$15,000	$15,000	$15,000
Total annual cost	$93,327	$101,617	$105,762	$101,617
Annual energy in kWh (predicted ws)	150,905	158,340	158,990	145,006
Predicted cost per kWh	**$0.62**	**$0.64**	**$0.67**	**$0.70**

Appendix D-1

Wekweeti cost of wind power base case

Wekweeti: 1 used V15 turbine 50kW (Wind Matic) project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$59,911	$68,201	$72,346	$68,201
Annual operating cost	$15,000	$15,000	$15,000	$15,000
Total annual cost	$74,911	$83,201	$87,346	$83,201
Annual energy in kWh (predicted ws)	109,679	117,224	118,150	103,500
Predicted cost per kWh	**$0.68**	**$0.71**	**$0.74**	**$0.80**

Appendix D-1

Wekweeti cost of wind power base case

Wekweeti: 1 NPS NorthWind 100kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$115,207	$123,496	$127,641	$123,496
Annual operating cost	$25,000	$25,000	$25,000	$25,000
Total annual cost	$140,207	$148,496	$152,641	$148,496
Annual energy in kWh (predicted ws)	199,764	211,744	213,269	190,254
Predicted cost per kWh	**$0.70**	**$0.70**	**$0.72**	**$0.78**

Appendix D-2

Wekweeti cost of wind power low management cost

Wekweeti: 3 Bergey Excel-S 10kW (30kW total) project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$49,031	$57,321		$57,321
Annual operating cost	$10,000	$10,000		$10,000
Total annual cost	$59,031	$67,321		$67,321
Annual energy in kWh (predicted ws)	50,751	54,213		47,901
Predicted cost per kWh	**$1.16**	**$1.24**		**$1.41**

Appendix D-2

Wekweeti cost of wind power low management cost

Wekweeti: 1 Wenvor 30kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$43,144	$51,433		$51,433
Annual operating cost	$10,000	$10,000		$10,000
Total annual cost	$53,144	$61,433		$61,433
Annual energy in kWh (predicted ws)	37,686	40,484		35,274
Predicted cost per kWh	**$1.41**	**$1.52**		**$1.74**

Appendix D-2

Wekweeti cost of wind power low management cost

Wekweeti: 1 Endurance E-3120 50kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$72,770	$81,059		$81,059
Annual operating cost	$15,000	$15,000		$15,000
Total annual cost	$87,770	$96,059		$96,059
Annual energy in kWh (predicted ws)	150,905	158,340		145,006
Predicted cost per kWh	**$0.58**	**$0.61**		**$0.66**

Appendix D-2

Wekweeti cost of wind power low management cost

Wekweeti: 1 used V15 turbine 50kW (Wind Matic) project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$54,353	$63,114		$63,114
Annual operating cost	$15,000	$15,000		$15,000
Total annual cost	$69,353	$78,114		$78,114
Annual energy in kWh (predicted ws)	109,679	117,224		103,500
Predicted cost per kWh	**$0.63**	**$0.67**		**$0.75**

Appendix D-2

Wekweeti cost of wind power low management cost

Wekweeti: 1 NPS NorthWind 100kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$106,634	$117,467		$117,467
Annual operating cost	$25,000	$25,000		$25,000
Total annual cost	$131,634	$142,467		$142,467
Annual energy in kWh (predicted ws)	199,764	211,744		190,254
Predicted cost per kWh	**$0.66**	**$0.67**		**$0.75**

Appendix D-3

Wekweeti cost of wind power low management and installation costs

Wekweeti: 3 Bergey Excel-S 10kW (30kW total) project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$44,321	$48,466		$48,466
Annual operating cost	$10,000	$10,000		$10,000
Total annual cost	$54,321	$58,466		$58,466
Annual energy in kWh (predicted ws)	50,751	54,213		47,901
Predicted cost per kWh	**$1.07**	**$1.08**		**$1.22**

Appendix D-3

Wekweeti cost of wind power low management and installation costs

Wekweeti: 1 Wenvor 30kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$38,528	$42,673		$42,673
Annual operating cost	$10,000	$10,000		$10,000
Total annual cost	$48,528	$52,673		$52,673
Annual energy in kWh (predicted ws)	37,686	40,484		35,274
Predicted cost per kWh	**$1.29**	**$1.30**		**$1.49**

Appendix D-3

Wekweeti cost of wind power low management and installation costs

Wekweeti: 1 Endurance E-3120 50kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$66,741	$70,886		$70,886
Annual operating cost	$15,000	$15,000		$15,000
Total annual cost	$81,741	$85,886		$85,886
Annual energy in kWh (predicted ws)	150,905	158,340		145,006
Predicted cost per kWh	**$0.54**	**$0.54**		**$0.59**

Appendix D-3

Wekweeti cost of wind power low management and installation costs

Wekweeti: 1 used V15 turbine 50kW (Wind Matic) project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$48,325	$53,035		$53,035
Annual operating cost	$15,000	$15,000		$15,000
Total annual cost	$63,325	$68,035		$68,035
Annual energy in kWh (predicted ws)	109,679	117,224		103,500
Predicted cost per kWh	**$0.58**	**$0.58**		**$0.66**

Appendix D-3

Wekweeti cost of wind power low management and installation costs

Wekweeti: 1 NPS NorthWind 100kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$98,816	$104,562		$104,562
Annual operating cost	$25,000	$25,000		$25,000
Total annual cost	$123,816	$129,562		$129,562
Annual energy in kWh (predicted ws)	199,764	211,744		190,254
Predicted cost per kWh	**$0.62**	**$0.61**		**$0.68**

Appendix D-4

Wekweeti cost of wind power 0.5m/s higher wind

Wekweeti: 3 Bergey Excel-S 10kW (30kW total) project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$54,024	$62,313	$66,458	$62,313
Annual operating cost	$10,000	$10,000	$10,000	$10,000
Total annual cost	$64,024	$72,313	$76,458	$72,313
Annual energy in kWh (predicted ws)	61,409	65,598	66,186	57,960
Predicted cost per kWh	**$1.04**	**$1.10**	**$1.16**	**$1.25**

Appendix D-4

Wekweeti cost of wind power 0.5m/s higher wind

Wekweeti: 1 Wenvor 30kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$48,230	$56,520	$60,665	$56,520
Annual operating cost	$10,000	$10,000	$10,000	$10,000
Total annual cost	$58,230	$66,520	$70,665	$66,520
Annual energy in kWh (predicted ws)	45,977	49,390	49,894	43,034
Predicted cost per kWh	**$1.27**	**$1.35**	**$1.42**	**$1.55**

Appendix D-4

Wekweeti cost of wind power 0.5m/s higher wind

Wekweeti: 1 Endurance E-3120 50kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$78,327	$86,617	$90,762	$86,617
Annual operating cost	$15,000	$15,000	$15,000	$15,000
Total annual cost	$93,327	$101,617	$105,762	$101,617
Annual energy in kWh (predicted ws)	167,505	175,757	176,479	160,957
Predicted cost per kWh	**$0.56**	**$0.58**	**$0.60**	**$0.63**

Appendix D-4

Wekweeti cost of wind power 0.5m/s higher wind

Wekweeti: 1 used V15 turbine 50kW (Wind Matic) project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$59,911	$68,201	$72,346	$68,201
Annual operating cost	$15,000	$15,000	$15,000	$15,000
Total annual cost	$74,911	$83,201	$87,346	$83,201
Annual energy in kWh (predicted ws)	132,712	141,841	142,962	125,235
Predicted cost per kWh	**$0.56**	**$0.59**	**$0.61**	**$0.66**

Appendix D-4

Wekweeti cost of wind power 0.5m/s higher wind

Wekweeti: 1 NPS NorthWind 100kW project cost of power				
Component	**Site 1**	**Site 2**	**Site 3**	**Site 4**
Cost of Capital (monthly mortgage payments at 7%)	$115,207	$123,496	$127,641	$123,496
Annual operating cost	$25,000	$25,000	$25,000	$25,000
Total annual cost	$140,207	$148,496	$152,641	$148,496
Annual energy in kWh (predicted ws)	233,724	247,740	249,525	222,597
Predicted cost per kWh	**$0.60**	**$0.60**	**$0.61**	**$0.67**