The Economic Feasibility of Wind Development for Silver Bay's Eco-Industrial Park

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I. Objective #1: Wind Monitoring

A. Introduction

The City of Silver Bay contracted with us to estimate the economic feasibility of developing their local wind resource for use in their eco-industrial park. In this report, we do this for potential wind development at two scales: 1. A community owned wind farm (1-5MW) located on a prominent peak near, but outside the boundaries of the eco-industrial park; and 2. A small-scale (less than 40 kw) net-metering wind project within the eco-industrial park.

B. Methods

1. Site Selection

1. *Commercial, community owned wind development (1-5MW)*

Choosing an appropriate site for monitoring and future wind development depended primarily on the following criteria: prominent peak with an existing structure at least 100 feet high for monitoring equipment installation, permission and infrastructure to have unlimited access to existing structure, land owner with an interest in our wind development project, easy road access, and proximity to available transmission capacity. Given these criteria, we identified and began monitoring at two sites. The first was Eagle Mountain at the Lutsen Ski Resort (47 degrees N, 90 degrees W, 1730 feet elevation). The Second site was the communication tower (47 degrees N, 91 degrees W, 1260 feet elevation) adjacent to the city water tower located on a fairly prominent peak within the city limits of Silver Bay.

2. Small-scale (less than 40kw) net metering within the eco-industrial Park

In our search for an appropriate site within the existing eco-industrial park we were limited by the availability of an existing structure for our monitoring equipment. Fortunately, the North Shore Mining Company has a sophisticated weather station in operation at a site adjacent (47 degrees N, 91 degrees W, 620 feet elevation) to the eco-industrial park, and agreed to share their wind speed and direction data as a contribution to this project. So, this data was chosen for these economic feasibility calculations.

2. Monitoring

a. Equipment

The wind monitoring component of the project required the following equipment: 1. Anemometers and Wind Vanes for measuring wind speed and direction; 2. Dataloggers for recording the wind speed and direction data; 3. Equipment for mounting the anemometers to the existing towers, and connecting wind sensors to dataloggers; 4. Excel spreadsheets for data analysis and presentation.; and 5. Climbing Gear for tower climbing. We chose a durable and inexpensive anemometer and wind vane made by APRS World LLC. We also chose APRS Worlds data logger for its compatibility with our wind sensors along with its durability, midrange price and 5 port communication capabilities. Pictures, calibration information and a detailed technical description of this wind monitoring equipment can be found on the APRS Wold LLC's website (www.aprsworld.com). Finally, we used standard outdoor cat 5 ethernet cable for connecting our wind sensors to the data logger. We used standard one-inch diameter steel bars along with ¼" 'U' bolts for attaching our anemometers to the existing towers at each site. A standard one-gigabite data card was used to store the data from our dataloggers. The data loggers we're stored in the communications sheds (also provided power supply) located at the base of the towers. The data cards were retrieved approximately once per month, and the data was downloaded into an excel spreadsheet for analysis.

b. Installation

Installation began with obtaining permission for access to the communication towers located on each existing site. Each site was then photographed for use in determining the best method for mounting our anemometers, and safely storing our data logging equipment. Lutsen and Silver Bay monitoring made use of existing communication towers. At these sites we bolted a ten-foot section of 1-inch diameter steel to the towers, and extended the anemometer 6-8 feet from the towers (figures 1 and 2) to minimize any tower interference on wind monitoring. At the Lutsen site anemometers were placed at 30m and 60m heights. At the Silver Bay site, the owners of the existing communication tower did not want our monitoring equipment to interfere with their existing equipment, so we were limited to monitoring below their communication equipment at 30m. We used the Lutsen data to extrapolate results to the desired 60m height.

Finally, the North Shore Mining weather station was logging a wide variety of climatological data at various heights up to 60m. Wind speed and direction data from 10m and 20m heights was e-mailed to us by Jenny Ramsdell approximately once per month in excel format for use in our analysis.

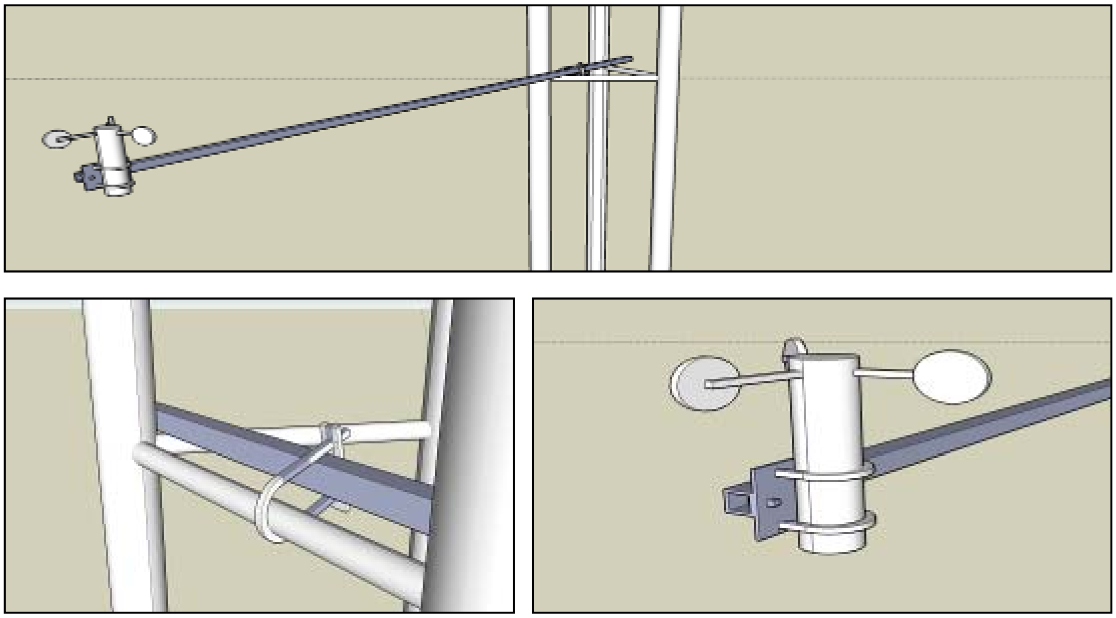


Figure 1. Detailed schematics of the communication tower mounts.

Figure 2. Photo of Lutsen communication tower showing anemometer extending laterally from tower.

c. Data analysis
Data loggers recorded data in 10-minute intervals. This data was analyzed for inconsistencies and converted to daily and weekly averages using pivot tables in excel spreadsheets. The weekly data was used for making the graphs in the results section. The 10-minute interval data was used to quantify the power densities (using WAsP wind development software package) used to calculate annual production and economic revenues (using STELLA computer modeling software).

C. Results

The following graphs (Figures 3-5) depict weekly average wind speed (mph) over the course of the entire study for each site. In addition, the average for the entire data set is indicated in the key. Weekly averages were chosen, so that we could include an entire year of data, and still demonstrate the typical wind speed variability in the study region. The annual averages range from 9.26 mph at the 10m Notrthshore Mining Site to 16.61 mph at the 60m Lutsen Site. All raw data files can be provided upon request.

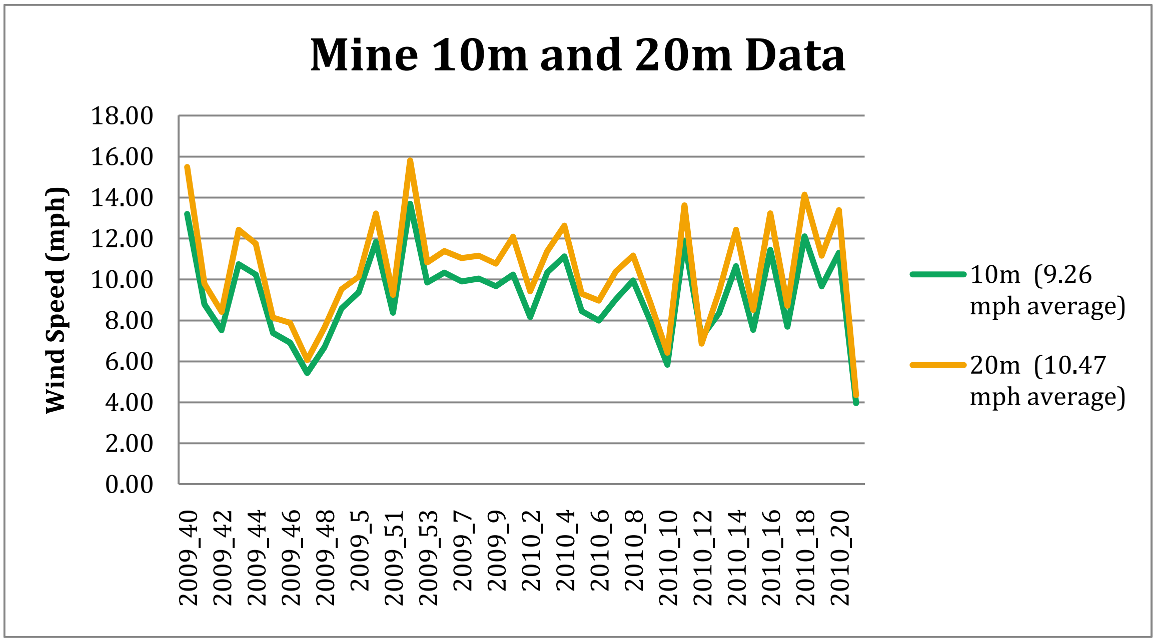


Figure 3. 10 and 20m wind speed data from the Northshore Mining Met Tower. Data collection period (September 2009 – June 2010).

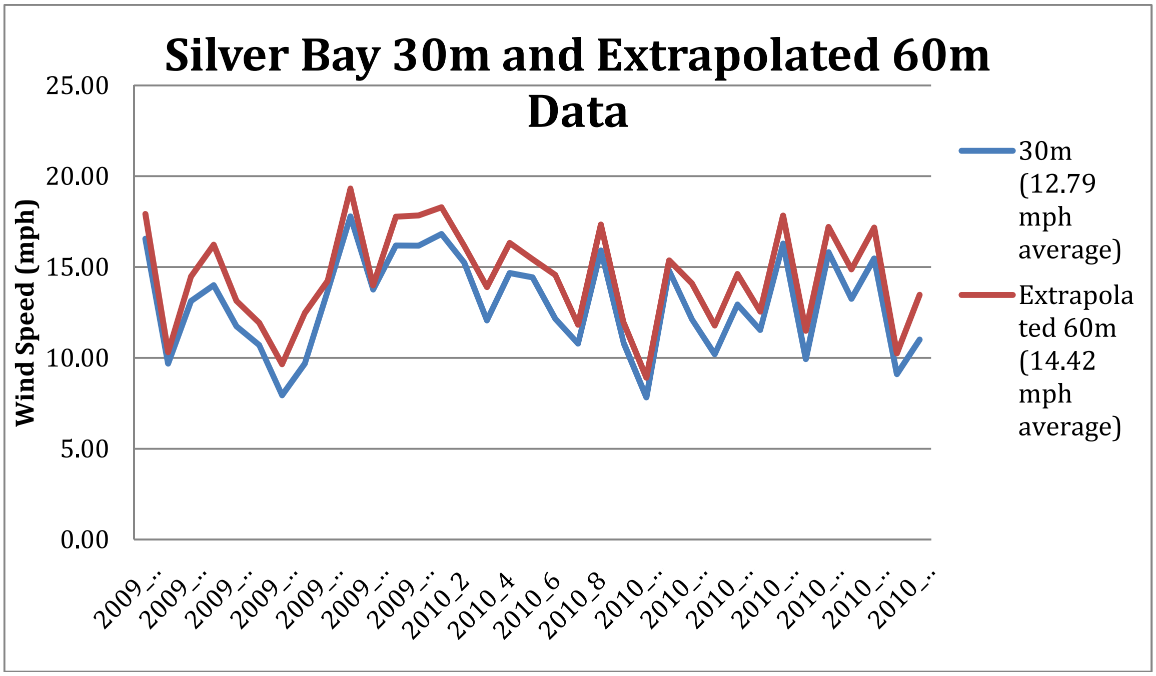


Figure 4. 30 and 60m wind speed data from the Silver Bay Communication Tower. Data collection period (September 2009 – June 2010).

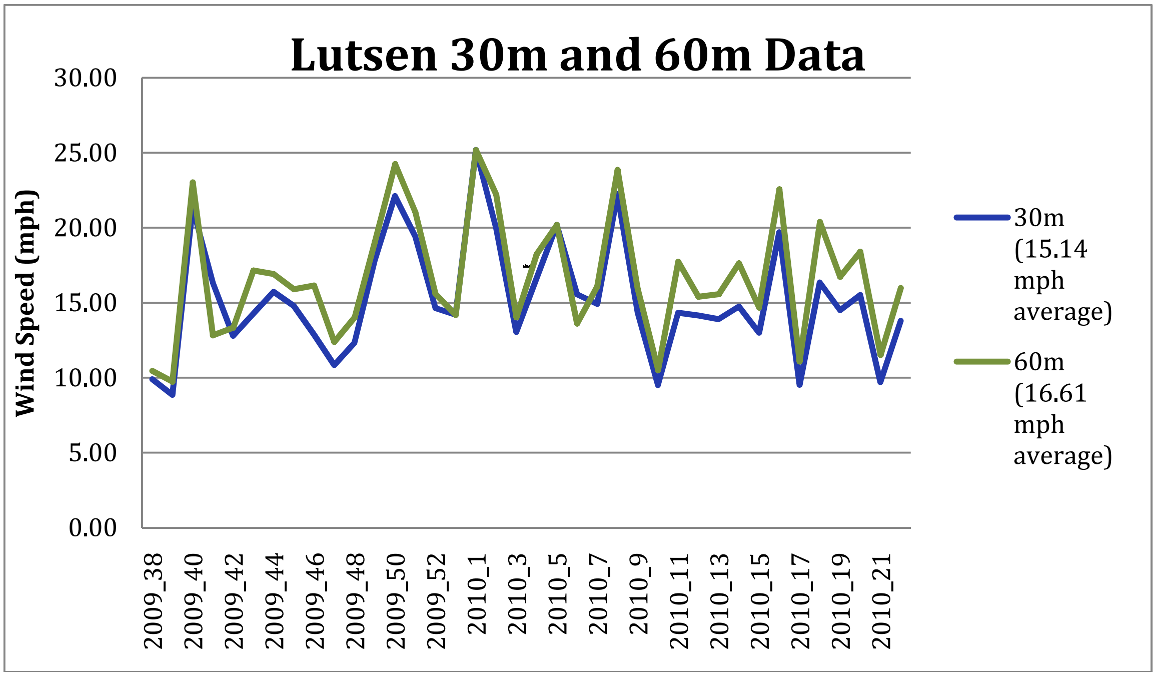
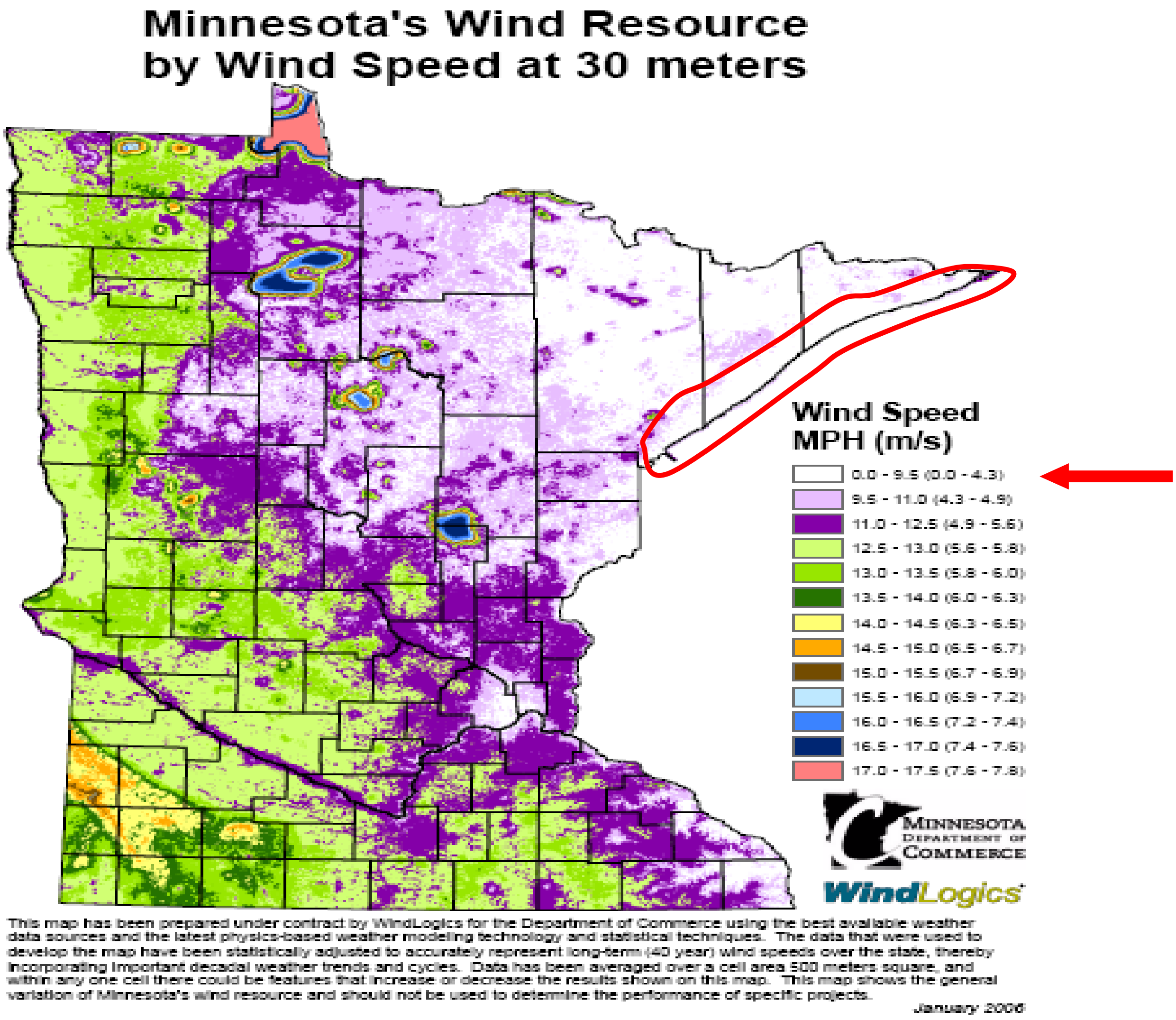


Figure 5. 30 and 60m wind speed data from the Lutsen Ski Resort Communication Tower. Data collection period (September 2009 – June 2010).

D. Dicussion/Conclusion

As we found in a previous study (Mageau et al., 2008) the wind speeds along the Northshore of Lake Superior appear far higher than the MN state wind maps (30m) published by the MN Department of Commerce (www.mndoc.state.gov) indicate (Figure 6). According to Figure 6, our study region should contain average wind speeds of 11 mph or less. We found wind speeds up to 16.61 mph at the 60 m Lutsen site. In our 2006-2008 study we found 16.5 mph annual average wind speeds at our 30m Lutsen site indicating that our 2009-2010 data (15.14 mph at Lutsen 30m) may represent a lower than average wind year. Not only do these wind speeds exceed those estimated by the MN Department of Commerce, but our windiest sites (16-17 mph) rival those of the well-developed Buffalo Ridge in SE MN, and the recently developed Taconite Ridge on MN's Iron Range just north of Virginia, MN.



This map has been prepared under contract by WindLogics for the Department of Commerce using the best available weather data sources and the latest physics-based weather modeling technology and statistical techniques. The data that were used to develop the map have been statistically adjusted to accurately represent long-term (40 year) wind speeds over the state, thereby incorporating important decadal weather trends and cycles. Data has been averaged over a cell area 500 meters square, and within any one cell there could be features that increase or decrease the results shown on this map. This map shows the general variation of Minnesota's wind resource and should not be used to determine the performance of specific projects.

January 2006

Figure 6. MN State wind map at 30 m. Estimated by WindLogics and published by the MN Department of Commerce in January of 2006 (www.mndoc.state.gov).

Objective 2: Estimating Economic Feasibility

A. Introduction

The wind monitoring data was used to estimate the economic feasibility of wind resource development at each monitoring site.

B. Methods

There are several different common approaches to conducting this sort of economic feasibility analysis. We took a unique approach using a STELLA computer simulation model because of its value as a community educational tool, and its ability to incorporate the uncertainty associated with key system parameters. We began by exporting our 10-minute interval wind speed data in excel. These 10-

minute averages were then exported from excel into a text file, and then inputed into the WAsP wind modelling software package. WAsP then bins these 10-minute interval average wind speeds into 1 m/s wind speed bins, and sums the number of 10-minute intervals (graphed as relative frequency) in each wind speed bin. The result is the statistical distribution illustrated in figure (7). WAsP then calculates the wiebel-k constant based on the shape of this distribution. The more skewed the distribution to the right (higher wind speed bins) the smaller the weibel-k constant, and the greater the power density. Finally, WAsP calculates the power density (P) (w/m2) for each bin and sums them to arrive at the total power density found in the wind from the particular monitoring site. This total power density value was then entered in the STELLA model. This process was repeated for each monitoring site.

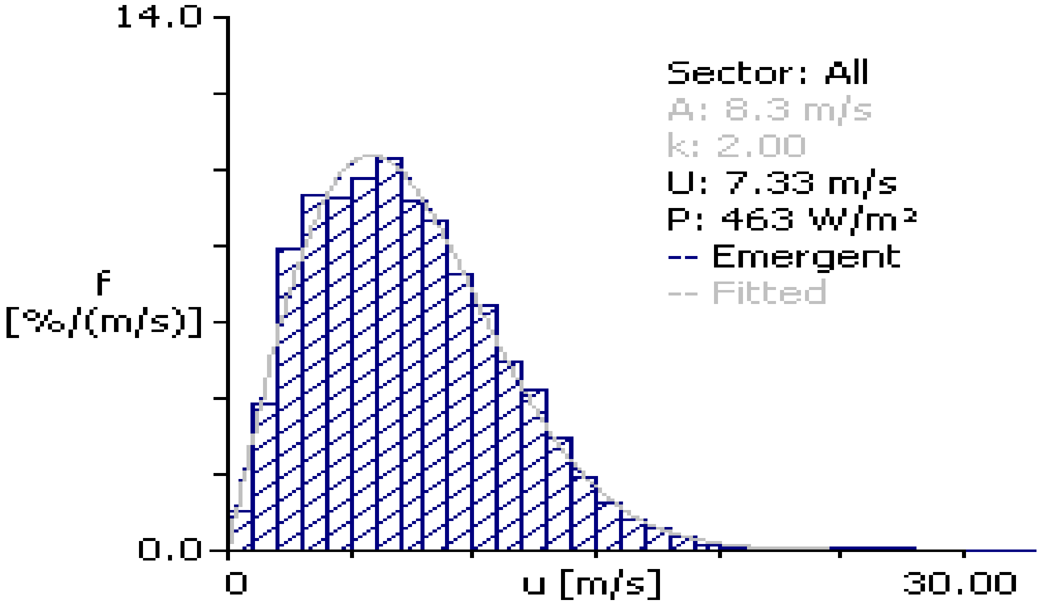


Figure 7. The wind speed distribution, k-value and power density (P) from the Lutsen 60m monitoring site as calculated by WaSP wind development software.

The STELLA model developed to estimate economic feasibility is illustrated in figure 8. The mathematical equations governing the relationships between the key parameters can be seen in the working model included as a project deliverable. The model was designed to calculate and compare the annual revenues associated with a given wind development project and the associated annual costs. To calculate annual revenues the power density (PD) value (w/m2) computed by WAsP is adjusted for the difference between the anemometer monitoring height and future turbine hub height as well as the wind shear exponent associated with the monitoring sites surface roughness (adj PD). The adjusted PD is then multiplied by the proposed wind turbines swept area which is calculated from its turbine diameter along with the proposed number of turbines. The result is the total turbine output in watts. This output is then converted to kilowatt hours (kwh) per year by dividing by 1000 and multiplying by the number of hours in a year and the turbines rated efficiency. The turbines annual output (kwh/year) is then multiplied by the electricity price (cents/kwh) to arrive at annual revenue. In addition, because the price per kw paid by the community partner is in many cases equal to the price they can expect from the electricity their turbine generates (net-metering scenario) the annual revenue value can be expected to increase by an annual percentage as the price of electricity increases. The model multiplies annual revenue by an annual electricity rate inflation value to achieve this effect.

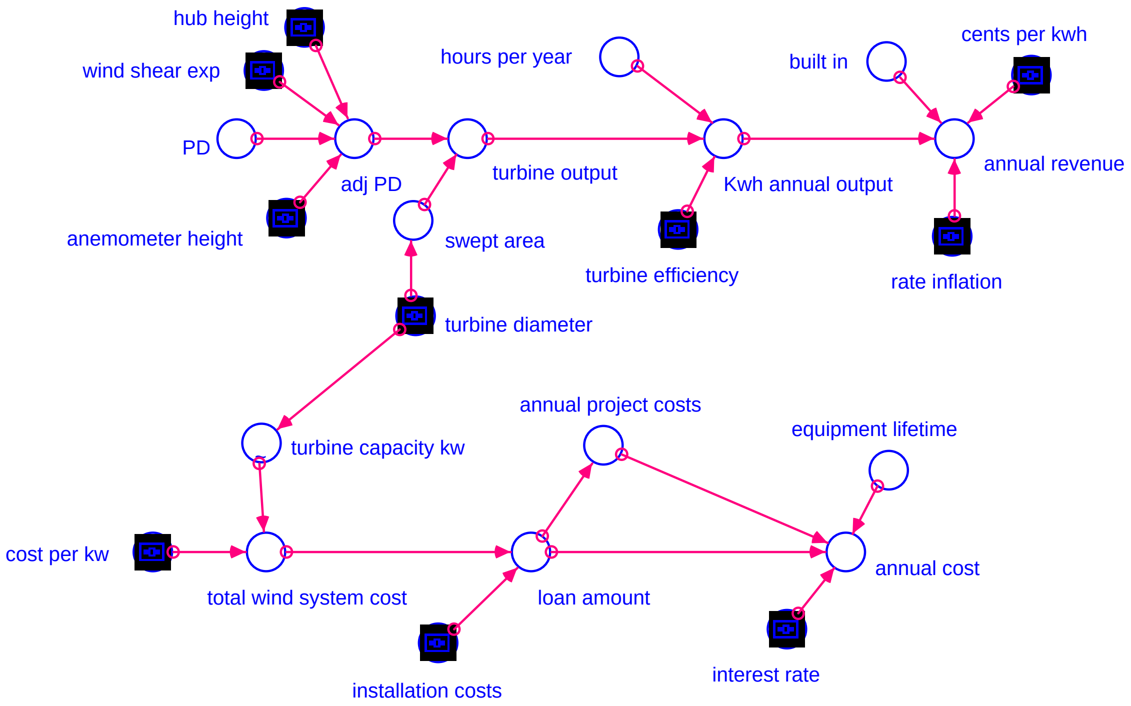


Figure 8. Diagram of the STELLA model used to calculate and compare annual wind system costs and revenues for community economic feasibility.

The annual costs associated with the wind generation system chosen above are simultaneously calculated. The turbine diameter is linked to turbine capacity in kw by a graphical function that relates these two values. Total wind system cost is then calculated by multiplying the turbine capacity in kw by an average cost per kw of capacity and the number of turbines. This total system cost embodies the complete cost of the turbines and their towers. Added to this cost to arrive at total up front project costs, is the total installation cost (includes: predevelopment consulting fees, site prep, turbine/tower installation, legal, permitting, interconnect, MISO etc…). These installation costs typically vary considerably, and we attempted to estimate these costs as a percentage of total wind system costs for each site given their unique characteristics. The cost data used in our model comes from a survey of many installed projects (Gipe 2004), and Windustries 2009 'Community Wind Toolbox' (www.windustry.org). In addition, the annual operation and maintenance costs are calculated based on the total system cost and added to the annual payment on a loan to arrive at the total annual wind system cost. The term of the annual loan is equal to or less than the expected equipment lifetime. The annual cost for the wind system is then a function of the total system cost, the interest rate and the term of the loan. Finally, the annual revenues are compared with the annual costs to determine economic feasibility given the sites wind resource.

The problem with conducting economic feasibility studies for wind development in this manner is that just about every variable mentioned above changes from site to site and over the course of the typical 20 year lifetime of any given project. This is the reason for using STELLA. It allows the user to adjust all the key model parameters (interest rates, system costs, surface roughness etc…) to determine their individual effects on overall economic feasibility. If this type of model experimentation is conducted in front of a community interested in the potential for local wind development it becomes not only a very useful planning tool, but a great educational tool as well. Sample output from the STELLA model, and all the key adjustable variables (parameters) are shown in figures 9 and 10.

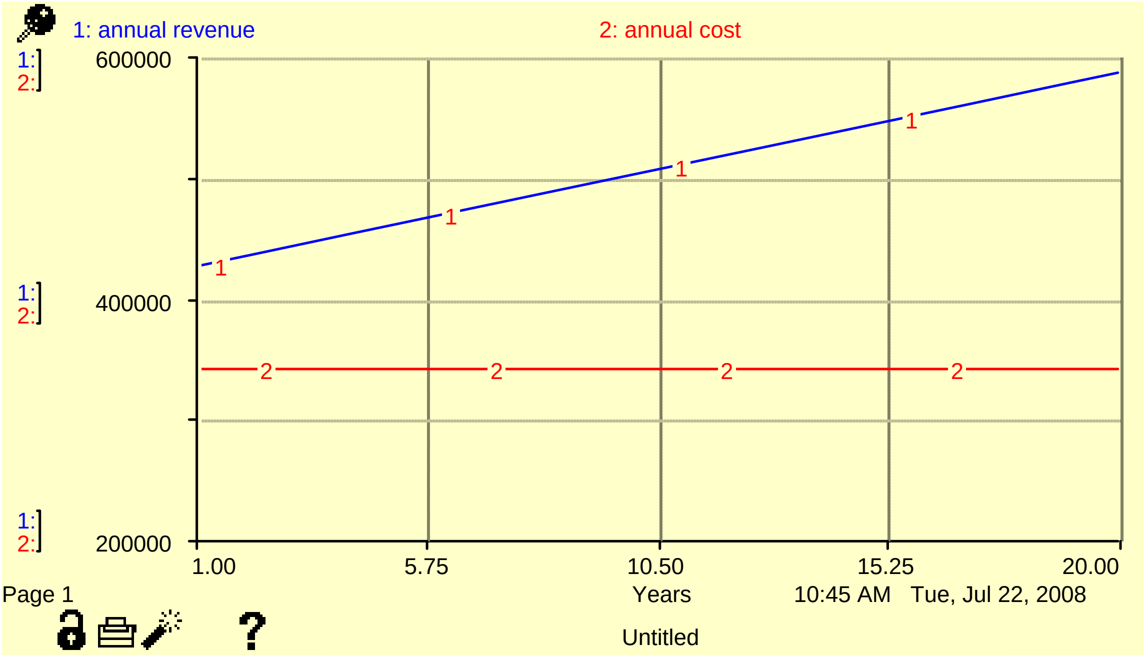
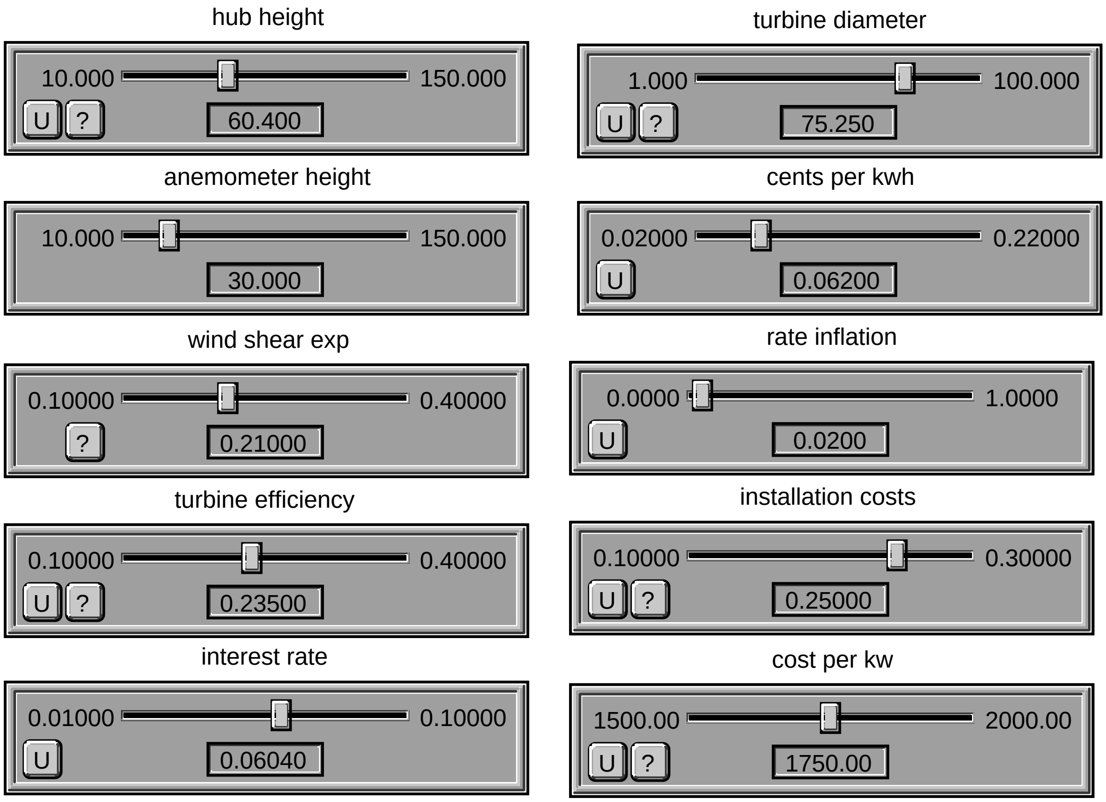


Figure 9. Sample of typical graphical output comparing annual costs to annual revenues using data from the Lutsen Site, and a positive value (2%) for utility rate inflation.



hub height
10.000 150.000
60.400

turbine diameter
1.000 100.000
75.250

anemometer height
10.000 150.000
30.000

cents per kwh
0.02000 0.22000
0.06200

wind shear exp
0.10000 0.40000
0.21000

rate inflation
0.0000 1.0000
0.0200

turbine efficiency
0.10000 0.40000
0.23500

installation costs
0.10000 0.30000
0.25000

interest rate
0.01000 0.10000
0.06040

cost per kw
1500.00 2000.00
1750.00

Figure 10. The key model parameters (and their typical values) included in our specific simulations.

C. Results

Table 1 indicates the average annual wind speed (m/s), weibel-k constant, resulting power density (w/m2) and the estimated installation costs (as a percentage of total wind system costs) for each monitoring site. Windustry's 'Community Wind Toolbox' (www.windustry.org) estimates installation costs are typically 10-30% of total project costs. Installation costs depend primarily on available infrastructure at the site (roads and foundation) and the distance to available transmission lines or point of consistent electricity use. We assigned installation cost percentages for each site based on these considerations. These values are reported in table 1 and used in the site-specific simulation runs described in the next section.

Table 1. Average annual wind speed (m/s), weibel-k constant, resulting power density (w/m2) and the estimated installation costs (as a percentage of total wind system costs) for each monitoring site.

Site	**avg (m/s)**	**weibel-k**	**PD (w/m2)**	**install cost**
Northshore Mining 10m	4.3	1.69	82	20
Northshore Mining 20m	4.6	1.68	101	20
Silver Bay 30m	6.2	1.85	212	15
Silver Bay 60m	7.1	1.94	316	15
Lutsen 30m	7.4	1.91	351	18
Lutsen 60m	8.3	2.0	463	18

Table 2 indicates the annual revenues, annual costs and the resulting net revenues for each site assuming no utility inflation rate. For the small wind turbine (Jacobs 20kw) in the eco-industrial park the following parameters were used: 1. 20kw wind turbine with a 10 m blade diameter; 2. Hub height and anemometer height of 10m; 3. Wind Shear Exponent of .21; 4. 20 year equipment lifetime; 5. Loan interest rate of 5%; 6. Electricity cost of 7.8 cents per kwh (net metering); 7. Cost per kw of installed capacity of $2,000 and installation costs of 20% of total project costs; and 8. Turbine efficiency of 23.5%. These typical cost estimates (model parameters) were obtained from (Gipe, 2004), various wind turbine manufacturers, local electricity bills and Windustries 2009 'Community Wind Toolbox' (www.windustry.org). The wind sheer exponent was calculated using data from anemometers installed at two different heights at the Lutsen site.

For the large wind turbine at the Silver Bay and Lutsen sites the following parameters were used: 1. 2 MW wind turbine with an 80 m blade diameter; 2. Hub height of 80m and anemometer height of 30 m and 60m; 3. Wind Shear Exponent of .21; 4. 25 year equipment lifetime; 5. Loan interest rate of 5%; 6. Electricity cost of 6 cents per kwh; 7. Cost per kw of installed capacity of $1,800 and installation costs of 12-18% of total project costs; and 8. Turbine efficiency of 26.5%. These typical cost estimates (model parameters) were obtained from (Gipe, 2004), various wind turbine manufacturers, local electricity bills and Windustries 2009 'Community Wind Toolbox' (www.windustry.org). The wind sheer exponent was calculated using data from anemometers installed at two different heights at the Lutsen site. In addition to the exemplary static results reported in this section, the entire dynamic STELLA model is available upon request.

Table 2. Annual revenues, annual costs and the resulting net revenues for each site assuming no utility inflation rate.

Site	**Annual Revenues**	**Annual Costs**	**Net Revenue**
Northshore Mining 10m	$1,015	$6,241	-$5,226
Northshore Mining 20m	$1,250	$6,241	-$4,991
Silver Bay 30m	$270,922	$433,810	-$162,888
Silver Bay 60m	$403,827	$433,810	-$29,983

Lutsen 30m	$448,554	$445,860	$2,693
Lutsen 60m	$591,683	$445,860	$145,822

D. Discussion/Conclusions

The results of the economic feasibility calculations largely parallel the average annual wind speed and resulting power density from each monitoring site. This was expected given the power embodied in the wind is a cubic function of the average annual wind speed. Therefore a 2 mph increase in average wind speed results in 8x the electricity generated from a given wind turbine.

Small wind development within the eco-industrial park in not economically feasible due to low wind speeds. However, we have recently begun experimentation within the park aimed at exploring the possibility of funneling the wind between buildings to increase the wind speeds and associated power densities to the point of achieving economic viability. If successful, this will allow Silver Bay to take advantage of small wind development located within the park.

The economic viability regarding large (2MW) wind turbines on the higher regional peaks is mixed. The Silver Bay site does not appear economically viable using either the 30m or extrapolated 60m wind speed data. The lower wind speeds recorded at this site are most likely the result of its lower elevation, and the proximity of adjacent peaks with equal or greater elevations. The 30m and 60m Lutsen sites do appear economically viable given our specific parameter estimates. Our electricity production estimates (revenues) are the most accurate available given the wind speed data gathered during this study and regional electricity pricing. However, our comparative cost estimates are more general. As previously described in the report, they are based on typical values given the geology, transmission capacity, road availability and sources of nearby electricity consumption. More detailed site-specific cost estimates are possible, but beyond the scope of this project.

We took a fairly conservative approach in estimating costs, and believe there is significant room for improving on our reported project economics given the following considerations: 1. We have begun to pursue a potential development site in Finland, MN that we anticipate would have higher wind speeds, and lower installation costs; 2. By comparison with our previous study (2007-2008) it appears the average annual wind speeds we recorded for this study were 1-2 mph slower. This indicates we can expect slightly higher average annual wind speeds over the 20-25 year study period. 3. Wind turbine design and construction is improving, and we can expect more than the 20-year lifetime we modeled; and 4. The price per kwh obtained by small community owned wind developments seems to be improving, and all indications suggest that this trend will likely continue with new legislation.

The data gathered over the course of this study, and its integration using our modeling methods not only indicate the possibility for economically feasible wind development projects in NE Minnesota, but they can be used to facilitate the community decision making process. The STELLA Model can now be used to facilitate more detailed site-specific project exploration and the corresponding community decision-making process regarding future wind development.

References:

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