

Lempster Wind Project Shadow Impact Assessment

August 10, 2006

Prepared for
LEMPSTER WIND L.L.C.



by
Superna Energy L.L.C

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Key to Document Status

<i>Document Reference</i>	:	Lempster Wind Project Shadow Impact Assessment
<i>Report Revision</i>	:	1
<i>Report Status</i>	:	Issued to Client
<i>Prepared by</i>	:	Lloyd Pasley
<i>Date Created</i>	:	July 2006

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1. SHADOW EFFECTS AROUND A WIND PROJECT

1.1 SHADOW CASTING FROM WIND TURBINES

When the sun is visible wind turbine generators (WTGs) will cast a shadow on the neighboring areas as the rotor blades pass in front of the sun, causing a flickering (blinking) effect while the rotor is in motion.

This shadow effect can be predicted quite accurately using astronomy and trigonometry producing a "worst case" scenario, i.e. a situation where there are no clouds, when the wind is blowing all the time, and when the wind and the turbine rotor keep tracking the sun by yawing the turbine exactly as the sun passes. However this is not what residents in the area will experience, because: (i) the turbines are aligned to follow the wind and not the sun, (ii) the sky is not clear all day every day, (iii) the human eye functions in such a way that when the sun is low in the sky (i.e. close to the horizon) or only a small percentage of the sun is masked by an obstacle (e.g. a turbine blade) it compensates for the differences in the intensity between shadow-minimum and –maximum unless the observer is looking at the sun.

The following figure was prepared by DEWI (an independent German Wind Consulting group) in 1998¹ in response to public questions about the "worst" case area around a wind turbine that would be affected by shadows. The spots represent the shadow of the highest point of the wind turbine (hub height plus rotor radius), valid for 53° of latitude and calculated in time steps of 10 minutes. The two parabolic edges of the shadow area represent the data of the summer and winter solstices (21 June, 23 December).

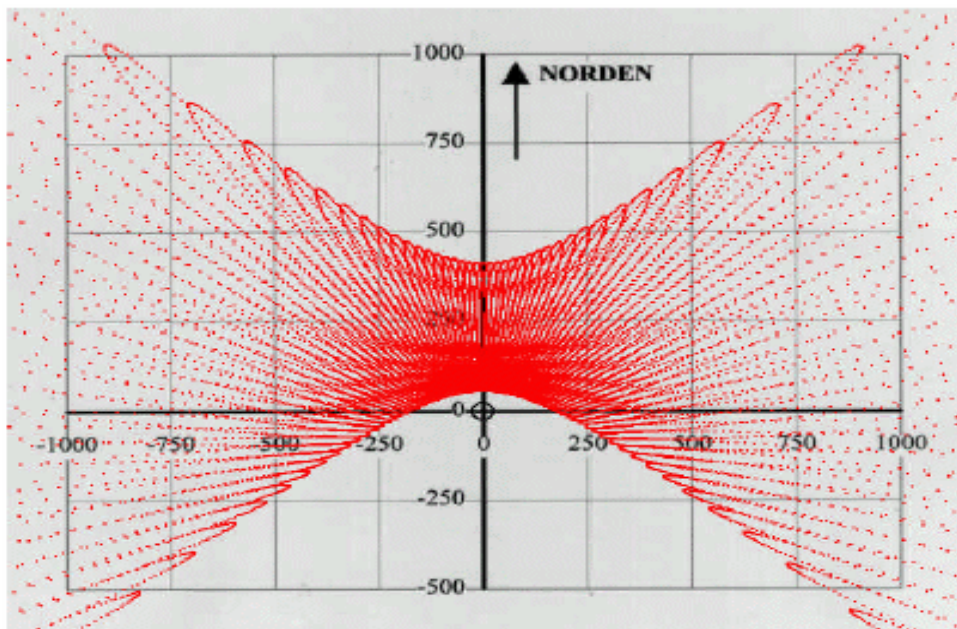


Figure A: The "worst" case area around a wind turbine (total height: 100m) affected by the throw of shadow

¹ Osten, Tjado; Pahlke, Thomas: DEWI Magazin Nr. 13, August 1998: Shadow Impact on the surrounding of Wind Turbines.

It is seen that: (i) the most significant impact is north of the turbine (in the northern hemisphere) and within an area approximating 3 times the “tip” height of the turbine; (ii) the northerly impact ceases at approximately 4 times the “tip” height; (iii) as the observer moves further east and west of the turbine the impact rapidly decreases for a single location.

1.2 BASIC CONSIDERATIONS

The degree to which the shadows effect people is determined by the amount of light reaching the eye (the luminance), the contrast between the shadow and the background, the rate of intensity change as an object passes in front of the sun, and the amount of the sun that is blocked (masked) at any one time.

Thus the effect of the shadow cast by WTGs on residents originates mainly from the shadow of the rotor blades, as the narrow, slowly moving shadow of the tower corresponds to other normal human experiences (such as the shadows cast by high buildings and communications towers) which are not felt to be an issue.

The shadow effects associated with moving WTG blades originate from three factors:

1. the difference of the radiation-intensity between shadow-minimum and shadow–maximum (i.e. the difference in the intensity between the lightly shaded areas to heavily shade areas). The area impacted in this way is defined by (i) the WTG’s height and the rotor blade’s chord length, (ii) by the sun elevation angle and (iii) the geometrical alignment between observer(s), the WTG and the sun;
2. the temporal course of the intensity change (i.e the rate of change in the depth of the shadow). The area impacted in this way is governed by (i) the height of the sun above the horizon (see section 1.2.1) (ii) the speed of rotation of the rotor and (iii) the geometrical alignment between observer(s), the WTG and the sun;
3. the daily/yearly duration of the shadow casting resulting from (i) the position of the sun above the horizon (ii) the local climate/weather and (iii) the geometrical arrangement between observer(s), the WTG and the sun;.

1.2.1 Horizon Affects

As solar radiation passes through the atmosphere it is scattered and absorbed by the air and suspended particles. The amount of absorption and scattering (attenuation) increases exponentially with the amount of air-mass penetrated. Thus there is more attenuation with decreasing sun elevation (i.e. when the sun is closer to the horizon). The following table shows this effect for various sun elevations (i.e. above the horizon) in terms of the increase in the solar radiation path length relative to the air mass when the sun is directly above the observer. From the table it is noted that when the sun is 3 degrees above the horizon the solar radiation path through the atmosphere is 15 times that when the sun is directly overhead; a 50% increase from the path length when the sun is 5 degrees above the horizon. It has become generally accepted in the industry that when the sun is less than 3 degrees above the horizon the amount of solar radiation absorbed or scattered is such that the difference of the radiation-intensity between shadow-minimum and shadow–maximum is so low that the people don’t notice it.

Sun elevation (°)	90	70	60	50	40	30	20	15	10	5	3
True air-mass	1.0	1.06	1.15	1.3	1.55	2.0	2.9	3.8	5.6	10.4	15.4

Table A: Penetrated air-mass with respect to the sun elevation (at sea level)

The attenuation of the radiation intensity is additionally influenced by (i) observer's elevation above sea level, however this effect is minimal until the observer's elevation is >2000ft above sea level and (ii) the water vapor and dust content of the atmosphere.

1.2.2 Masking Affects

There are two types of shadows (i) a kernel shadow (when 100 percent of the sun is masked by an obstacle) and (ii) a diffuse shadow (when only a portion of the sun is masked by an obstacle)

When the sun is greater than 3 degrees above the horizon people notice situations when the sun is completely masked by the turbine blade (kernel shadows) due to the large difference of the radiation-intensity between shadow-minimum and shadow-maximum. However as the sun gets higher and as less of it gets masked by the turbine blade more solar radiation passes around the blade thus decreasing the difference in the radiation-intensity between shadow-minimum and shadow-maximum. It is generally accepted in the industry, refer to Dobesch and Kury (2001)² and "out-of-the-box" wind project analysis software packages such as WindPro, that when less than 20% of the sun is masked by the turbine blades the difference of the radiation-intensity between shadow-minimum and shadow-maximum is so low that the people don't notice it unless they are looking directly at the sun.

² Dobesch and Kury (2001), Central Institute for Meteorology and Geodynamics (ZAMG) Vienna, Austria: "Basic Meteorological Concepts And Recommendations For The Exploitation Of Wind Energy In The Atmospheric Boundary Layer"

2. SHADOW MODELLING FOR LEMPSTER WIND PROJECT

Modeling Approach

The shadow-flicker results presented have been modeled using standard assumptions, terrain input, turbine dimensional data, etc. No site-specific assessments have been made to confirm the shadow-flicker model results. There are several scenarios reflected in the model analysis:

- When obstacles are present (terrain, trees, buildings etc.) between the wind turbines and a potential shadow-flicker receptor, then shadow-flicker time and/or intensity is reduced (or not applicable) at such receptors; this factor is not incorporated in the model.
- The model considers terrain around the project boundaries to a distance of approximately 5 miles out. The terrain would have to be at least 1383 feet higher in elevation than the land in the project (based on rolling hills) at this distance before the terrain would have an impact on the calculated shadow-flicker time due to the fact that there is no perceptible shadow impact when the sun is lower than 3 degrees above the horizon. The terrain within 5 miles of the project consists of mountainous terrain of the similar elevation or lower, and thus is not expected to impact the calculated results.
- In most areas cloud cover (or fog), if present, is likely to occur in the morning and evening hours rather than during the day. However, the analysis treats cloud cover as an average (hours per day) and thus the analysis may underestimate this reduction in shadow hours as most of the shadow impact is in the morning and evening hours when the sun is low in the sky.
- Wind turbine run hours are also averages (stated in hours per day). Wind patterns change over the day, however, while the model considers the calm wind periods (where turbines do not run) to be distributed equally. This may also cause the analysis to over estimate the number of hours of shadow impact.

Model Inputs

The shadow impact of the Lempster Wind Project was modeled using the following assumptions:

- All WTG locations were used (see Appendix C)
- The rotor diameter and hub height for the Gamesa G87 were used (ie 78m hub height and 87m rotor diameter)
- USGS DEM (height contours)
- The annual wind rose depicted in the Table 1 of Appendix B was used to determine the directional frequency of directions the WTG would face
- The average monthly cloud cover values for Concord, NH depicted in Table 2 of Appendix B where used with the following definitions: (i) Cloudy being equivalent to 80% coverage; and (ii) Partly Cloudy being equivalent to 50% coverage (this is likely to be conservative as meteorologists use Cloudy to indicate coverage is >80%)
- ~12% of the time the wind turbines are not operating because the wind is below or above generation speeds

- There is no shadow impact when the sun's elevation <3 degrees above the horizon
- There is no shadow impact when less than 20% of the sun is masked by the turbine blades
- Shadow isolines were calculated using a 50m x 50m grid based on USGS DEM

Model Output

The model calculates the shadow-flicker time for all the 50 x 50m grid nodes taking into account the cumulative affect of all the wind turbines. The software calculates the shadow time as follows: (i) the sun's path from the turbine location and the cast shadow derived over the day; (ii) the run-time for the turbine is derived from the wind speed data; (iii) then from the wind direction data, the direction of the wind turbine (seen from the grid node) is calculated along with the reduced shadow-flicker time; (iv) finally the extent of cloudiness is applied (no direct sun means no shadow flicker would occur) to determine the total shadow impact at each node.

Based on the above assumptions and calculation methodology, isolines (i.e. total number of hours per average year contours) were calculated and superimposed onto the site map see Appendix A.

Model Accuracy

It is expected that the results of this analysis, as shown by the contours, will be conservative as the analysis assumes the observer has unrestricted views in all directions at all times, i.e. there are no trees, buildings, or other obstructions between the observer and the turbine shading the sun.

In addition if the observer is in a building the shadow impact is further reduced as shadows will only be observed through the restricted viewshed of the window (e.g. an east facing window will not be impacted by shadows from turbines in the south or west, and a north facing window would have no impact at all).

3. SHADOW MODELING CONCLUSIONS

Our research shows that there are no local or national regulations in regard to shadow impacts caused by wind turbines; however, the following three sources would indicate that shadow impact should be kept below 30 hours per year:

1. Dobesch and Kury (2001)³ recommend that no more than 30 hours of shading be allowed per year
2. The European Wind Energy Association⁴ publication “Wind Energy –The Facts⁵ Vol4 Environment” states “In Germany, a court has ruled that the maximum allowable shadow flicker a year is 30 hours (Danish Wind Industry Association, 2003)”.
3. The State of Victoria, Australia guidelines for the development of wind projects⁶ states: “The shadow flicker experienced at any dwelling in the surrounding area must not exceed 30 hours per year as a result of the operation of the wind energy facility.”

The map in Appendix A shows the calculated number of hours during an average wind and cloudiness year throughout the project area. It is shown that:

1. All the areas that would experience more than 30 hours of shadow impact for an average year are located in the vicinity of the proposed wind turbines and on the associated ridge.
2. Areas that may experience shadow impact including Nichols Road, Maplewood Drive, Guilford Lane, Fifield Drive and Sugarhouse Drive are not projected to receive more than 10-20 hours of impact per year.
3. All of the identified areas of particular interest: Goshen-Lempster School, Lempster Town Hall, Pillsbury State Park Entrance, Webb Residence, Dwyer/O'Grady Residence, and Long Pond, are shown to experience much less than 10 hours of shadow impact in an average year.

Thus it is believed that the project complies with the generally accepted norms.

³ Dobesch and Kury (2001), Central Institute for Meteorology and Geodynamics (ZAMG) Vienna, Austria.” Basic Meteorological Concepts And Recommendations For The Exploitation Of Wind Energy In The Atmospheric Boundary Layer”

⁴ the European equivalent of the AWEA

⁵ refer to p185 of EWEA Wind Energy –The Facts Volume 4 Environment

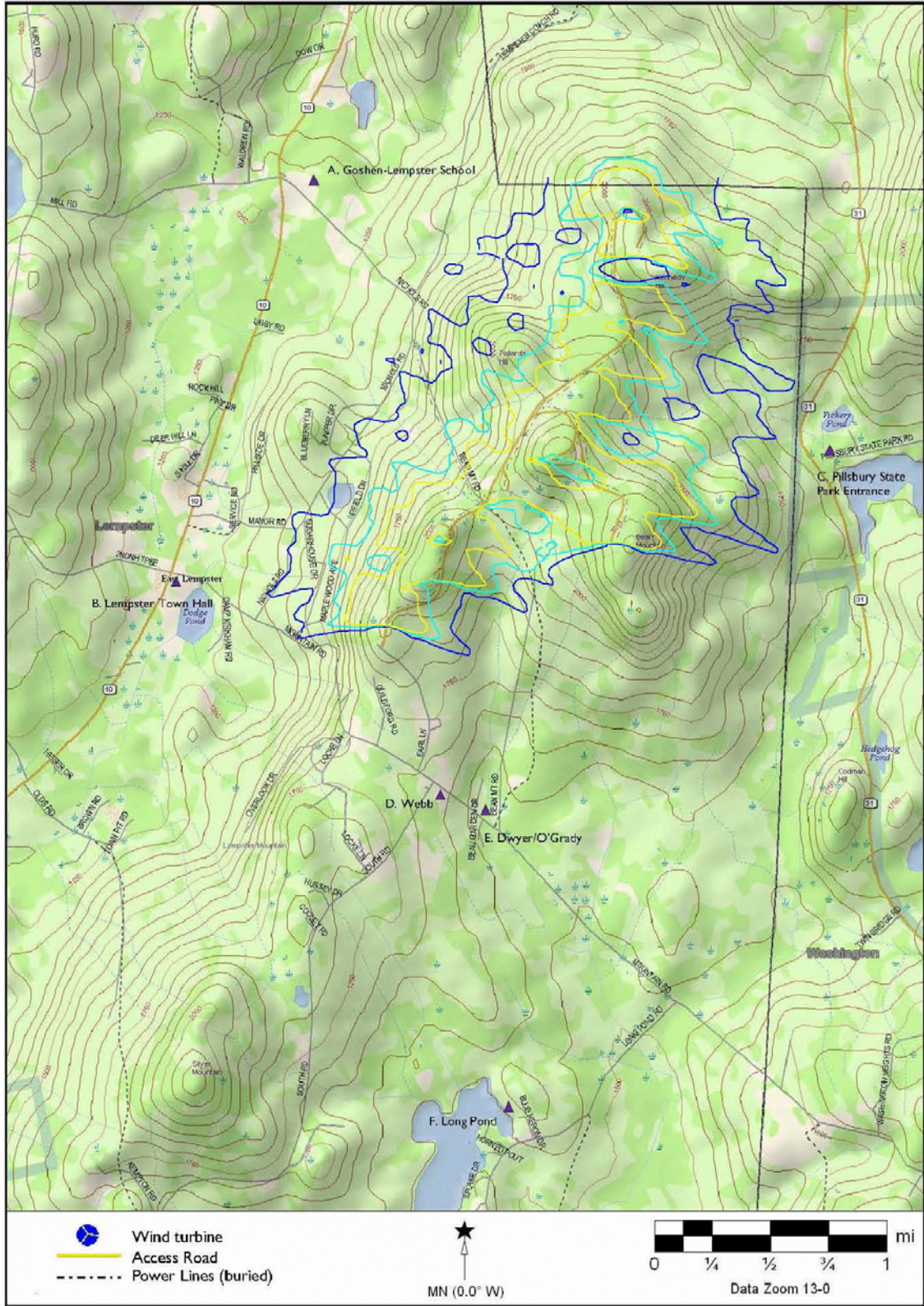
⁶ refer to p26 “Policy and planning guidelines for development of wind energy facilities in Victoria” May 2003

APPENDIX A: SHADOW CONTOUR MAP

The following map should be read as follows: the contours mark the boundaries.

Thus the area inside the cyan line is calculated to experience more than 20 hours of shadow effect (on a 360 degree basis) during an average wind and cloudiness year. The areas outside the cyan line are calculated to experience less than 20 hours of shadow effect.

Alternatively the area between the blue and cyan lines is calculated to be impacted between 10 and 20 hours per average year.



- 10 hours per average year
- 20 hours per average year
- 30 hours per average year

APPENDIX B: WIND ROSE & CLOUDINESS DATA

Sector	0	30	60	90	120	150	180	210	240	270	300	330
Frequency	8.8%	2.6%	3.1%	6.5%	5.3%	5.2%	8.2%	10.7%	9.3%	13.8%	14.0%	12.5%

Table 1: Wind Rose (Frequency -% of time- wind comes from a given sector). These values need to be reduced to take into account the times the wind speed is below cut-in or above cut out

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Clear	9	8	8	7	6	6	7	8	9	9	6	8	90
Partly Cloudy	7	8	8	8	10	12	12	11	9	9	8	8	109
Cloudy	15	13	15	15	15	12	12	12	12	13	16	15	166

Table 2: Average Monthly Cloudiness for Concord, NH (days per month)

APPENDIX C: WTG LOCATIONS

WTG #	Easting (m)	Northing (m)	Elevation (m)	Elevation (ft)
1	732255	4792165	634	2080
2	732342	4791830	639	2095
3	732269	4791395	591	1940
4	732136	4791044	628	2060
5	731975	4790731	647	2123
6	731803	4790432	687	2253
7	731054	4789835	619	2031
8	730999	4789540	628	2061
9	730668	4789216	588	1929
10	732421	4790089	678	2226
11	732291	4789829	691	2268
12	731514	4790126	609	1998

Table 1. Wind Turbine Locations in UTM NAD27 zone 18