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NATIONAL RENEWABLE ENERGY LABORATORY

Technical and Economic Feasibility Study of Utility-Scale Wind at the Doepke-Holliday Superfund Site

A Study Prepared in Partnership with the Environmental Protection Agency for the RE-Powering America's Land Initiative: Siting Renewable Energy on Potentially Contaminated Land and Mine Sites

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Executive Summary

The U.S. Environmental Protection Agency (EPA), in accordance with the RE-Powering America's Land initiative, selected the Johnson County Landfill in Shawnee, Kansas, for a feasibility study of renewable energy production. Citizens of Shawnee, city planners, and site managers are interested in redevelopment uses for landfills in Kansas that are particularly well suited for wind turbines. The purpose of this report is to assess the Johnson County Landfill for possible grid-tied wind electrical generators (wind turbines) and to estimate the cost, performance, and site impacts of various wind turbines. In addition, the report outlines financing options that could assist in the implementation of a turbine.

The feasibility of wind turbines installed on landfills is highly impacted by the available area for the turbine, wind resource, landfill operating status, landfill cap status, distance to transmission and distribution lines, and distance to major roads. The Johnson County Landfill is in a suitable area to have a utility-scale turbine, and the wind resource at the Doepke-Holliday (Doepke) Superfund site is appropriate for wind power generation. The Doepke Superfund site is part of the Johnson County Landfill but is a closed cell (a portion of the landfill that is no longer being filled and is capped), with other cells of the Johnson County Landfill still in use. The findings from this report can also be applied to other landfills in the surrounding area and through North America, depending on wind resource, incentives, siting constraints, and power prices.

Installing wind turbines on landfills is a unique situation and requires penetration of the landfill cap. A landfill is typically sealed from water contamination by covering the refuse with clay or other non-permeable material and soil. The penetration of the landfill cap for the purpose of installing a wind turbine foundation has been successfully accomplished multiple times.[1] The type of foundation required for a wind turbine is site-specific and typically requires vertical piles that penetrate the bedrock beneath the landfill.[2] As such, a lined landfill presents additional technical concerns, and a successful implementation has not yet been attempted. The Doepke Superfund site is not lined, so the technical feasibility of installing a megawatt-scale turbine at the site is achievable. The additional cost of this foundation compared to a typical greenfield installation is dependent on the size of the turbine.

The economics of the potential turbines were analyzed using the current Kansas City Power and Light (KCP&L) electric rate of $0.08391/kWh (average of the summer rate of $0.09469/kWh and the winter rate of $0.07312/kWh, with a 10% escalation)[3] and calculations assume some federal incentives such as the production tax credit (PTC) and 5-year accelerated depreciation (MACRS). The avoided cost scenario assumes only a 5% annual escalation rate in the avoided cost, and thus sale price of energy, and only $0.03/kWh. There currently are not any state or

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[1] Two such examples include Hull, Massachusetts (http://www.hullwind.org/), and Kingston, Massachusetts (http://www.kingstonmass.org/index.asp?SEC=EED177CD-B486-4F21-B2C7-3C545A7A0356&DE=4D0C9B80-B70C-4FA0-BEE9-C711FA2AADFF&Type=B_BASIC).

[2] For more information, see http://www.mass.gov/dep/energy/hull2.pdf.

[3] For more information, see the Section 6 of this report.

utility incentives offered for commercial wind power systems in Kansas for megawatt-scale turbines with the possible ownership scenarios.[4]

The economics of a turbine on the Doepke site depend greatly on the cost of electricity. Based on past electric rate increases in Kansas, the current rate could increase to $0.10/kWh or higher in a relatively short amount of time. Table ES-1 summarizes the turbine performance and economics of potential systems that would use all available areas that were surveyed at the Doepke site. The table shows the annual energy output from the system along with the number of average American households that could be powered from such a system. The table lists results assuming the current electric rate of $0.08391/kWh and shows results assuming a hypothetical rate increase to $0.10/kWh. In the coming years, increasing electrical rates and potential increased demand for clean power will continue to improve the feasibility of implementing turbines at landfill sites.

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[4] "Database of State Incentives for Renewables & Efficiency." U.S. Department of Energy, 2012.
http://www.dsireusa.org/incentives/index.cfm?re=0&ee=0&spv=0&st=0&srp=1&state=KS.

Table ES-1. Turbine Performance and Economics, Including Job Creation Estimates[5]

| Wind System Size[a] (kW) | Annual Output (kWh/year) | Number of Houses Powered[b] | Annual Cost Savings ($/year) | | Annual O&M ($/year) | System Cost without Incentives ($) | Payback Period (years) | | Estimated Potential Construction Job-Years[e] | Estimated Potential Maintenance Jobs[f] |
			With Current Electrical Cost	With Rate Increase			Net Meter Current Electrical Cost[c]	Avoided Cost[d]		
IEC Class III Wind Turbine, 80-m Hub Height, 100-m Rotor Diameter										
1,620	5,098,607[g]	462	$456,470	$544,000	$70,000	$5,440,000	10.4	>20 yr	59	0.4

[a] Data assume a maximum usable area of solely the Doepke site.

[b] Number of average American households that could hypothetically be powered by the turbine when assuming 11,040 kWh/year/household.[6]

[c] Assumes 10 year PTC, 5 yr MACRS, $0.08391/kWh, 10% utility rate escalation, $70,000 annual O&M, 7% debt interest,

[d] Assumes 10 year PTC, 5 yr MACRS, $0.03/kWh, 5 % utility rate escalation, $70,000 annual O&M, 7% debt interest,

[e] Job-years supported by this project capital investment, including direct, indirect, and induced jobs.

[f] Permanent jobs (direct, indirect, and induced) sustained as a result of operation and maintenance (O&M) of the system.

[g] Annual output corrected for long-term annual average, including 15% losses.

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[5] This feasibility study assumes the ability to sell electricity at and above current commercial consumer rates which is very unlikely to be realistic in this case. Most likely only the avoided cost of electricity would be paid which is substantially less than the assumed rates.

[6] "Frequently Asked Questions." U.S. Energy Information Administration. Accessed Oct. 22, 2010: http://www.eia.doe.gov/ask/electricity_faqs.asp#electricity_use_home.

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1 Study Location

The Johnson County Landfill is located in Shawnee, Kansas, which is located to the west of the major metropolitan area of Kansas City, Missouri. As of the 2000 census, Shawnee had a population of approximately 62,000 people. It has a humid climate that is characterized by large seasonal temperature swings. The winters commonly experience temperatures below freezing with moderate snowfall. The summers are humid and commonly experience temperatures around 90°F. The two electric utility companies serving the Johnson County Landfill are Kansas City Power and Light (KCP&L) and Westar Energy.

Under the RE-Powering America's Land initiative, the U.S. Environmental Protection Agency (EPA) provided funding to the National Renewable Energy Laboratory (NREL) to support a feasibility study of wind energy generation at the Doepke-Holliday (Doepke) Superfund site. The Doepke Superfund site is part of the Johnson County Landfill, which is still in operation today. Currently, there are 42 acres of capped landfill area at the Doepke site that can potentially be used for a megawatt-scale wind turbine. Other areas in the Johnson County Landfill that are capped or will possibly be capped in the future could also offer an economy of scale for a wind project, as the purchase of more than one turbine can produce a more cost-effective project in general. The Doepke site includes a former municipal and industrial waste landfill located on an 80-acre parcel of land on the southern bluffs of the Kansas River in Shawnee. The site initially operated as a residential trash disposal service starting in 1952. During the 1950s and 1960s, it received residential, commercial, and industrial waste. The site closed in 1970 and was added to the EPA Superfund National Priorities List in 1983. In 1996, the cap was installed and approved by EPA. Due to the presence of contaminants, landfill sites have limited populated redevelopment potential. Therefore, renewable energy generation is a viable reuse.

One very promising and innovative use of closed landfills is to install wind turbines. Landfills are typically located in areas away from residential zones and can also present the advantage of being higher than the surrounding area, thus offering access to a more energetic wind resource than the surrounding areas. Wind turbines can generate revenue on a landfill site that might otherwise go unused. The Doepke Superfund site and the Johnson County Landfill are owned by Deffenbaugh Industries, which is interested in potential revenue flows from turbines on landfills. Wind turbines on landfills could give other landfill owners a reason to close landfills in a timely manner and to maintain the landfill cap after it is in place.

Like most states, Kansas relies heavily on fossil fuels to operate its power plants. About three-fourths of Kansas's electricity is generated from coal, and the remaining one-fourth is generated from nuclear.[7] The cost of many renewable energy technologies is relatively high compared to conventional alternatives; however, there are many compelling reasons to consider moving toward renewable energy sources for power generation instead of fossil fuels, including:

- Using renewable fuel sources is more sustainable in the long term
- Burning fossil fuels can have negative effects on human health and the environment, such as acid rain

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[7] "Kansas State Profile and Energy Estimates." U.S. Energy Information Administration, 2012. Accessed March 2, 2011: http://www.eia.gov/cfapps/state/state_energy_profiles.cfm?sid=KS.

- Extracting and transporting fossil fuels can lead to accidental spills, which can be devastating to the environment and communities

- Depending on the use of foreign sources of fossil fuels can be a threat to national security

- Fluctuating electric costs are associated with fossil-fuel-based power plants, whereas renewable sources like wind are known to ensure long-term price stability through power purchase agreements (PPAs)

- Burning fossil fuels could contribute to climate change

- Generating energy without harmful emissions or waste products can be accomplished through renewable energy sources

- Using water for power generation is much lower for wind than for coal and nuclear electricity generation

- Utilizing abundant renewable resources available in Kansas, particularly wind energy, can be accomplished.

2 Wind Turbine Technology

Uneven heating of the earth's surface creates motion of the atmosphere and thus kinetic energy in this movement. Variation in heating and factors, such as surface orientation or slope, rate of reflectivity, absorptivity, and transmissivity, also affect the wind resource. In addition, the wind resource can be affected (accelerated, decelerated, or made turbulent) by factors such as terrain, bodies of water, buildings, and vegetative cover.

Wind is air with kinetic energy that can be transformed into useful work via wind turbine blades and a generator. Overall, wind is a diffuse resource that can generate electricity cost effectively and competitively in regions with a good wind resource, high cost of electricity, or both.

2.1 Wind Characteristics

Winds vary with the season, time of day, and weather events. Analysis of wind data focuses on several critical aspects of the data—average annual wind speed, frequency distribution of the wind at various speeds, turbulence, vertical wind shear, and maximum gusts. These parameters allow for estimation of available energy in the wind and the suitability of turbine technology for the site.

The wind speed at any given time determines the amount of power available in the wind. The power available in the wind is given by:

$$P = \frac{1}{2} * A \, \rho V^3$$

where

P = power of the wind [W]

A = windswept area of the rotor (blades) [m^2] = $\pi D^2/4 = \pi r^2$

ρ = density of the air [kg/m^3] (at sea level at 15°C)

V = velocity of the wind [m/s]

As shown, wind power is proportional to velocity cubed (V^3). This matters because if wind velocity is doubled, wind power increases by a factor of eight ($2^3 = 8$). Consequently, a small difference (e.g., increase) in average speed causes significant differences (e.g., increases) in energy production. Examining ways to increase the wind velocity at a particular site should be considered. Normally, the easiest way to accomplish this is to increase the height of the tower. The wind industry has been moving toward higher towers, and the industry norm has increased from 30 m to 80 m over the last 15–20 years.

A map of the national wind resource is shown in Figure 1. Wind maps give a visual approximation of the wind resource in an area but do not provide enough data for estimating annual electricity output at a particular site. On-site wind data collected for a period of 1–3 years is necessary to estimate wind turbine performance. This study used recently collected on-site wind data for its screening-level production estimates and analysis.
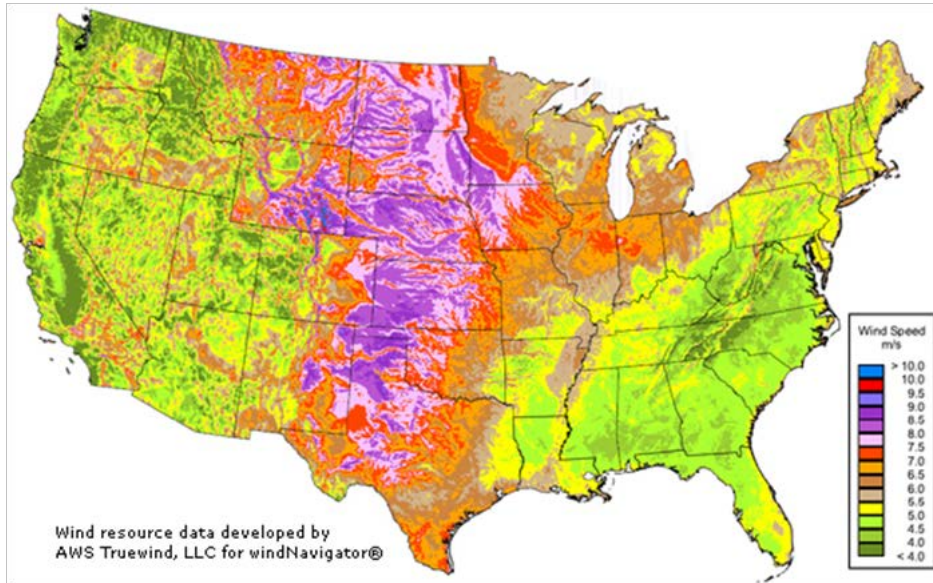
Figure 1. U.S. national wind resource map

Source: NREL, Wind Powering America, 2012
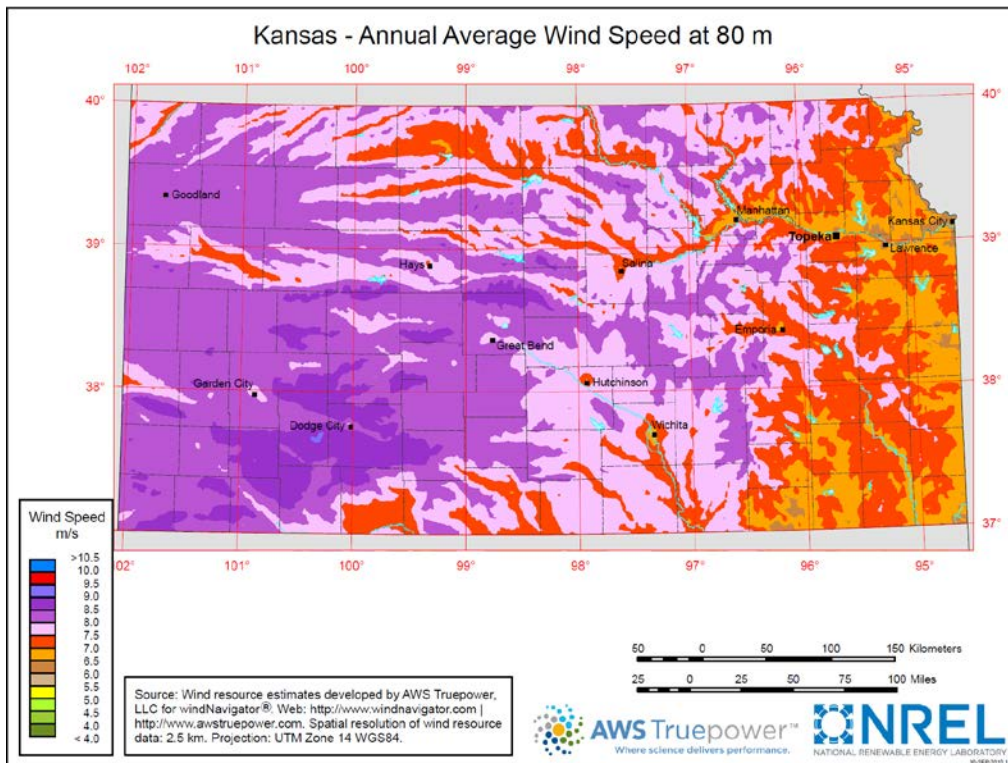
Figure 2. Kansas 80-m annual average wind speed map[8]

Source: NREL 2012

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[8] Accessed May 8, 2013: http://www1.eere.energy.gov/wind/images/wind_speed_map_lg.jpg.

2.2 Wind Turbines

Wind turbines consist of rotating blades that convert the kinetic energy of the wind to electric power. They have a number of moving parts and require regularly scheduled and unscheduled maintenance. Manufacturer warranties cover the first 2–10 years. Professional wind turbine maintenance contractors are recommended after the warranty period. Figure 3 shows large wind turbines that could be considered for the Doepke site.

Figure 3. Modern utility-scale wind turbines. *Photo by Owen Roberts, NREL*

Wind turbines are typically cost effective where the average wind speed is high, where the competing energy costs are high, or a combination of both. Large wind farms of 100–500 MW have been driving the industry because of lower installed costs due largely to economies of scale and improved low wind speed turbine technology, which results in an overall lower cost of energy. Only a single utility-scale turbine is appropriate for the Doepke site due to land, permitting, and neighbor constraints. But expansion to other closed sections of the Johnson County Landfill could be possible to create a larger, more cost-effective project. The small number of turbines and challenging construction sites would result in significantly higher installed costs than the typical rates for the wind farm industry.

2.3 Wind Power History/Background

In the United States, there have been about 58,000 MW of wind power installed.[9] Turbines are available from as small as 250 W to as large as 5 MW. For the size of the wind plants considered here, large turbines in the range of 800 kW to 3,000 kW per turbine would be appropriate.

Wind power became a commercial-scale industry more than 30 years ago. Over that time, wind power has moved from the fringes of the electric power sector to a mainstream resource responsible for 35% of U.S. new power capacity from 2007 through 2011; it is second in new capacity additions only to new natural gas power.[10] In the best resource areas or localities with exceptionally high electricity costs, wind power can be cost effective even in the absence of direct financial incentives or subsidies. Recent technological improvements[11] are expected to significantly lower the lifecycle cost of energy of wind energy. Initial investment costs for wind power are relatively high compared to natural gas or other forms of generation[12]; however, with zero fuel costs and relatively modest fixed annual operations expenditures, wind-generated electricity is often a favorable generation resource over the long term

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[9] Wiser, R.; Bollinger, M. *2011 Wind Technologies Market Report*. Washington, D.C.: Department of Energy, 2011. http://www1.eere.energy.gov/wind/pdfs/2011_wind_technologies_market_report.pdf.

[10] Williams, E.; Hensley, P. *AWEA US Wind Industry Annual Market Report 2012*. Washington, DC: AWEA, 2013.

[11] Wiser, R.; Lantz, E.; Bolinger, M.; Hand, M. (February 2012). *Recent Developments in the Levelized Cost of Energy from U.S. Wind Power Projects*. http://eetd.lbl.gov/ea/ems/reports/wind-energy-costs-2-2012.pdf.

[12] U.S. EIA *Updated Capital Cost Estimates for Utility Scale Electricity Generation Plants*. Washington, DC: EIA, April 2013. http://www.eia.gov/forecasts/capitalcost/pdf/updated_capcost.pdf.

3 Potential Turbine Locations

3.1 Setbacks

The Doepke Superfund site is approximately 42 acres in size. Figure 4 shows the area (in red) that could be considered for siting a turbine when considering these setbacks and topography.[13]

Figure 4. Potential utility-scale turbine construction areas

Illustration done in Google Maps

The topography of the Doepke site generally slopes down as one proceeds to the north, and thus the locations further south will offer a more energetic wind resource. Constraints, such as operations, drainage, and viewshed, will need to be considered when siting a potential turbine. Other considerations, such as the geotechnical conditions at various locations within this area and local turbulence, should be studied before finalizing a location for a turbine.

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[13] Assumes setback of 130 m (the height of a large, utility-scale turbine of 80-m hub height and 100-m rotor diameter) from structures and property owners other than Deffenbaugh Industries.

3.2 Site-Specific Considerations

Figure 5. Views of the feasible area for a utility-scale wind turbine at the Doepke site. *Photos by James Salasovich, NREL*

As shown in Figure 5, the capped landfill area has sufficient space to allow for the installation of a utility-scale turbine. There are electrical points around the site where a turbine could tie into the grid. A detailed interconnection study would have to be conducted before a wind turbine is properly sited. Coordination with other states, such as the Massachusetts Department of Environmental Protection, is recommended, as multiple wind turbine foundations have penetrated the caps of older landfills in the state.

3.3 Permitting

One of the largest constraints to permitting utility-scale wind turbines can be avoiding interference with air traffic, weather radar, and military operations. The Doepke site is not within any direct flight paths that would automatically preclude it from the possibility of installing a utility-scale turbine (see Figure 6).

8
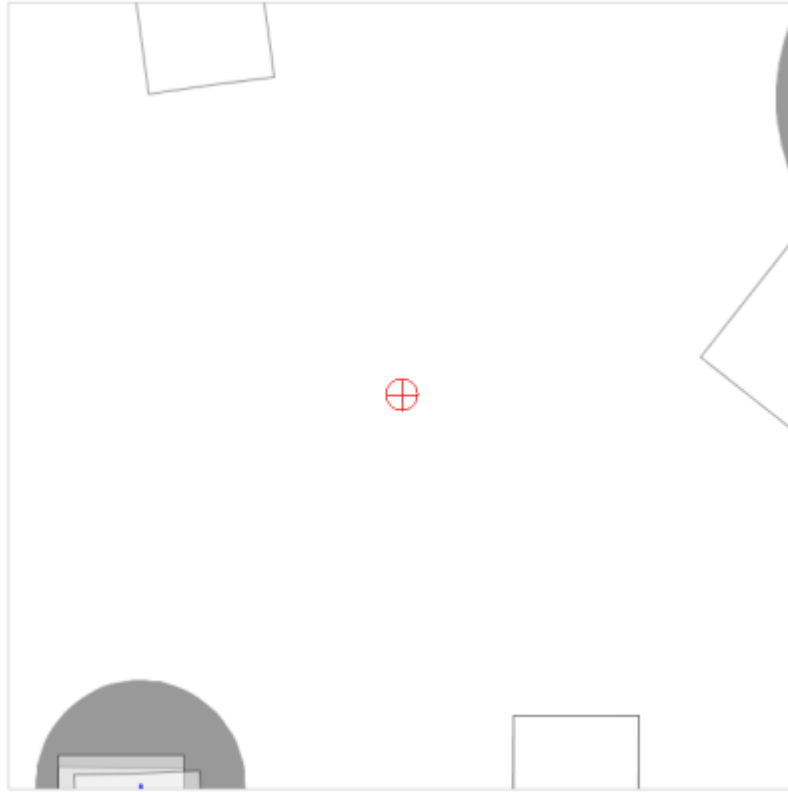
Figure 6. FAA potential impact areas for the Doepke site

Source: Illustration generated using the Federal Aviation Administration's Notice Tool: https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showNoNoticeRequiredToolForm.

Long-range radar can also be affected by the movement of the turbine blades and could cause interference for air traffic control if not mitigated. Figure 7 shows there is a high likelihood of some interference with long-range radar at the Doepke site, but many other considerations should be taken into account, and a full impact study should be conducted as one of the first steps if there is interest in pursuing wind at the Doepke site. Areas in the red-colored zone typically have some significant impacts on local radar, but many wind projects have been built within this high-impact area. Mitigation measures are possible and can vary from ignoring the interference to upgrading the software of the radar to filter this interference.

Local ordinances may also apply to a potential turbine at the Doepke site and should be investigated further, as some local governments have regulations that constrain the overall height of structures for viewshed and other reasons.
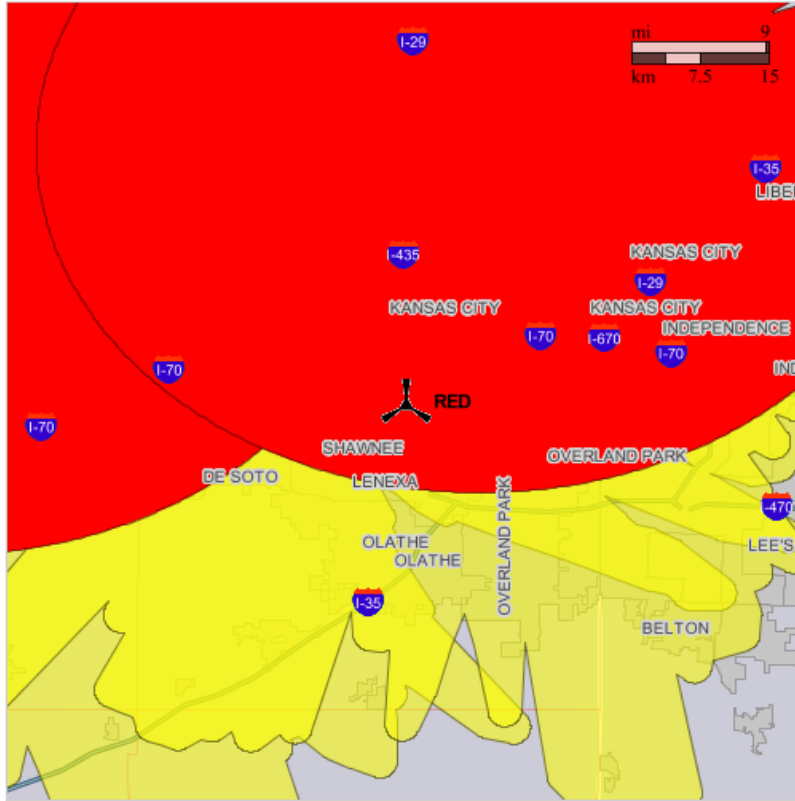
Figure 7. Long-range radar impacts for the Doepke site

Source: Illustration generated using the Federal Aviation Administration's DOD Preliminary Screening Tool: https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showLongRangeRadarToolForm.

Figure 8 shows that the Doepke site has a very low probability of interfering with local weather radar.
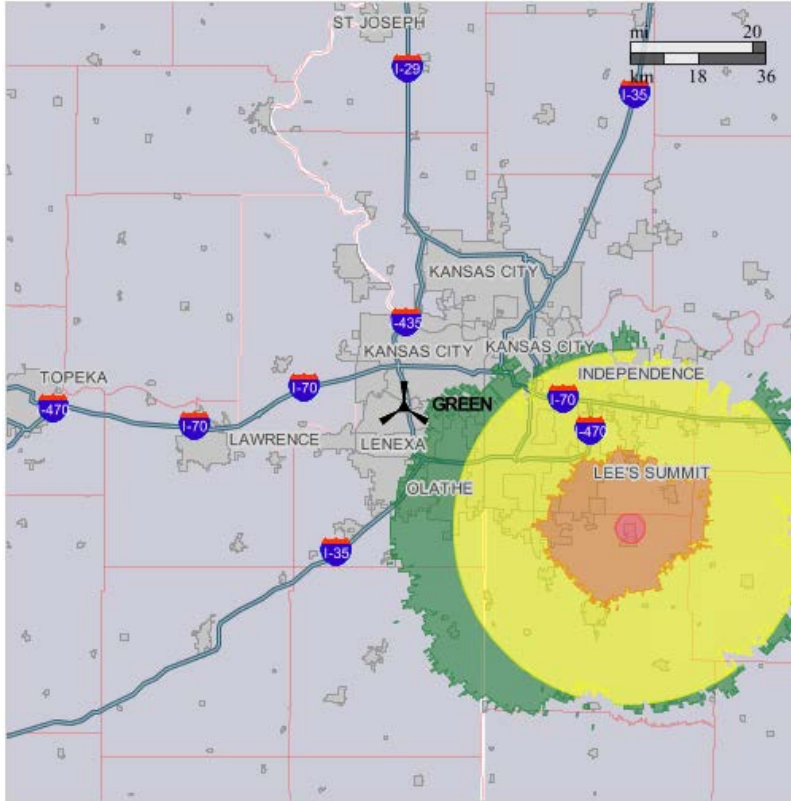
Figure 8. NEXRAD radar impacts for the Doepke site

Source: Illustration generated using the Federal Aviation Administration's Notice Criteria
Tool: https://oeaaa.faa.gov/oeaaa/external/gisTools/gisAction.jsp?action=showNoNoticeRequiredToolForm.

Figure 9 shows that there is a low probability of a wind turbine at the Doepke site interfering with military operations.

Figure 9. Military operation impacts for the Doepke site

Source: Federal Aviation Administration

4 Site-Measured Wind Resource

As previously mentioned, measurement of key parameters, such as wind speed, wind direction, air temperature, and air pressure, are key to understanding and predicting the suitability of a turbine at a specific site, as well as the economic performance of a project. The collection of data at this site greatly adds to the potential feasibility of a wind project on the site.

4.1 Utilization of Existing Communication Tower

Deffenbaugh Industries allowed the utilization of an existing lattice communication tower for collecting meteorological data for the wind and solar resource assessment. The tower is over 85 m tall and allowed data collection of wind speed at three different elevations up to 81 m above the local ground height. The tower presented large advantages compared to a typical 60-m tubular tilt-up tower, which is typically used for wind resource assessment as utility-scale turbines are typically 80 m to 100 m tall. The collection of data at 81 m above ground level eliminated the uncertainty, extrapolating 60-m data to an 80 m tall turbine hub height. The lattice tower is 29 inches wide on a face with a triangular cross section. The solidity of the tower was quite low as the tower interference on the anemometers was minimal as seen in Figure 11. Twelve-foot-long aluminum booms were installed on the tower to place the anemometers farther away from the tower than typical tubular tower booms. The mast-to-face width ratio was approximately 4.5, which is lower than typically recommended, but the low solidity of the tower produced a high quality dataset. Table 1 contains detailed information on the orientation, location, and type of instruments installed on the Doepke tower.

Figure 10. Riggers installing anemometry on the Doepke tower. *Photo from Shelly Brodie, EPA*

Table 1 shows various details of the instrumentation, such as height of the instruments as well as how the data logger is configured.

Table 1. Data Logger Configuration and Tower Information

Tower Type:				Lifting anchor direction, degrees to magnetic north			**n/a**		Guy wire direction, degrees to magnetic north				
Tubular/Lattice	Vendor name	Model		Tower height			Tower width at base			Anchor 1	Anchor 2	Anchor 3	Anchor 4
LATTICE	OKC TOWER	280		#	85.34	meters	29	inches	cm	N/A	N/A	N/A	N/A

Data Logger:	Vendor name	Model			Station identification	Logger time	Logger date	Averaging time				
								1 hour	10 min	other		
Data Logger:	NRG	SYM			2011/KANSAS	CENTRAL	1/17/11		X			

Communications/ Manual Collection:	Vendor name	Type	ESN / IMEI	SIM	PHONE NUMBER	SID	Call Schedule (i.e., Daily, 16:00 MST)	Scheduled Upload time	Service Provider	Signal Strength
Communications Device:	NRG	GSM	890141032243879141999		602-748-3961		DAILY	6:30 AM	AT&T	28

Sensors:	Sensor type (e.g., Anemometer)	Vendor name	Model number	Serial number	Logger slope	Logger offset	Sensor mounting height (ft or m, preferably m)			Boom length (inches)	Upstand (inches)	Boom direction to magnetic N	If vane D-B to MN
Channel C1:	ANEM	NRG	40C	137164	0.755	0.39	266.0	ft	81.07 m	110	22.5	80	
Channel C2:	ANEM	NRG	40C	137166	0.756	0.39	199.0	ft	60.65 m	110	22.5	80	
Channel C3:	ANEM	NRG	40C	135386	0.752	0.40	103.0	ft	31.39 m	110	22.5	80	
Channel C4:	ANEM	NRG	40C	137163	0.755	0.42	266.5	ft	81.22 m	110	22.5	260	
Channel C5:	ANEM	NRG	40C	137169	0.757	0.37	199.5	ft	60.80 m	110	22.5	260	
Channel C6:	ANEM	NRG	40C	137173	0.755	0.36	103.5	ft	31.54 m	110	22.5	260	
Channel C7:	WIND VANE	NRG	200P	N/A			259.0	ft	78.94 m	110	23.0	260	TOWARD
Channel C8:	WIND VANE	NRG	200P	N/A			94.0	ft	28.65 m	110	23.0	260	TOWARD
Channel C9:	TEMP	NRG	110S	N/A			7.0	ft	2.1 m				
Channel C10:	BP	NRG	BP20	N/A			7.5	ft	2.28 m				
Channel C11:	VOLTS							ft	m				
Channel C12:	PYRAN	LI-COR	200	PY69430			10.0	ft	3 m				

4.2 Data Recovery and Validation

The data collected from the retrofitted meteorological tower was transmitted daily to NREL, EPA, and Deffenbaugh Industries. This allowed frequent reviews of the data quality and identification of instrument malfunction or weather-caused data loss, as well as tracking of the seasonal wind resource in near real time.

There were some intermittent instrument failures of one anemometer and one wind vane, but the redundant sensors allowed a robust dataset that quantifies the wind resource consistent with and above current industry standards. There were some periods of lost data due to icing events, which stop the anemometers and wind vanes from reading the actual occurrences, but overall data collection averaged 93.3% for the wind speed sensors. The invalid data were excluded from calculations for each individual icing or erroneous data event.

Tower shading is a phenomenon where the influence of the tower on the wind influences the apparent wind that acts upon the sensors. This phenomenon can skew the wind data to appear higher or lower in velocity than in reality. Tower shading was also excluded for directions that the tower interference or shading was greatest, but the orientation of the tower and instrumentation minimized these occurrences, and the redundancy of the anemometry at each level allowed data to be collected without interruption at a specific instrument level. Figure 11 shows the directions that were most affected by the tower shading, and the data from each specific anemometer were removed when the wind direction caused the illustrated change in the ratio of anemometers at a specific height. The overall peak impacts were quite low at only 2%, which adds to the quality of the dataset.

Figure 11. Tower interference on anemometry

4.3 Wind Resource Assessment Summary

The average annual wind speed at 80 m for the observation period was 6.59 m/s. This annual average wind speed represents a moderately developable wind resource when combined with modern utility-scale turbines. Table 2 shows the statistics for the wind speed sensors for the observation period from January 18, 2011, to January 19, 2012.

Table 2. Wind Speed Sensor Summary Statistics

Variable	Speed 81.2 m	Speed 81.1 m	Synthesized 80 m	Speed 60.8 m	Speed 60.7 m	Speed 31.5 m	Speed 31.4 m
Measurement height (m)	81.2	81.1	80	60.8	60.7	31.5	31.4
Mean wind speed (m/s)	6.7	6.6	6.6	6.2	6.2	5.3	5.3
MoMM[a] wind speed (m/s)	6.7	6.6	6.6	6.2	6.2	5.3	5.3
Median wind speed (m/s)	6.4	6.4	6.3	6	5.9	5	5
Min wind speed (m/s)	0.4	0.4	0.4	0.4	0.4	0.4	0.4
Max wind speed (m/s)	24.9	24.3	28.1	23.6	23.1	21.5	20.3
Weibull k	2.425	2.398	2.383	2.357	2.38	2.172	2.185
Weibull c (m/s)	7.6	7.5	7.4	7	7	6	6
Mean power density (W/m²)	286	281	277	236	233	155	156
MoMM power density (W/m²)	286	281	277	236	233	155	156
Mean energy content (kWh/m²/yr)	2,503	2,465	2,423	2,070	2,044	1,356	1,366
MoMM energy content (kWh/m²/yr)	2,503	2,465	2,423	2,070	2,044	1,356	1,366
Energy pattern factor	1.612	1.627	1.64	1.653	1.644	1.773	1.767
Possible records	52,890	52,890	52,890	52,890	52,890	52,890	52,890
Valid records	47,376	50,051	52,489	47,783	49,094	49,005	49,672
Missing records	5,514	2,839	401	5,107	3,796	3,885	3,218
Data recovery rate (%)	89.57	94.63	99.24	90.34	92.82	92.65	93.92

[a] Mean of monthly means (MoMM) is used to remove seasonal biases when less than complete years are averaged into a dataset.

Figure 12 shows that the strongest winds occur during the spring and late fall at the Doepke site. This wind resource does not have the advantage of producing power during typical highest peak demands in the summer, and as such, seasonal pricing might not be as viable.
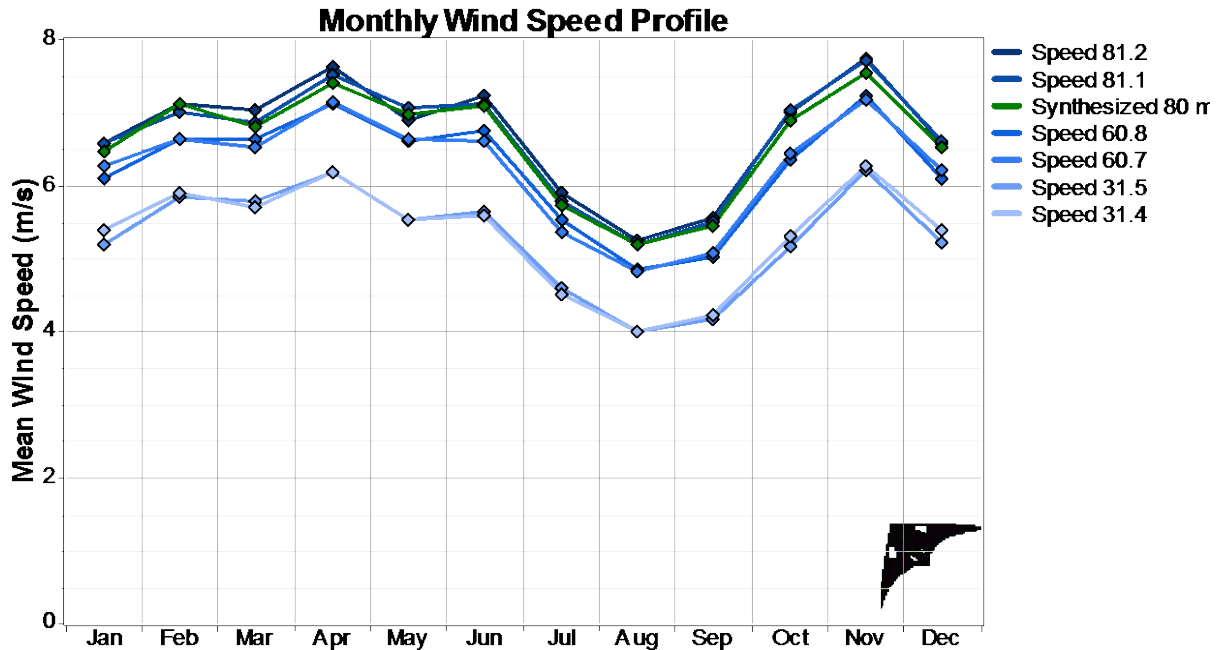
Figure 12. Seasonal wind resource variation

4.3.1 Vertical Wind Shear

Vertical wind shear is defined as the change in wind speed with the change in height. Typically, wind speed increases as the height above the ground increases. This variation of wind speed with elevation is called the vertical profile of the wind speed or vertical wind shear. In wind turbine engineering, the determination of vertical wind shear is an important design parameter because (1) it directly determines the productivity of a wind turbine on a tower of certain height, and (2) it can strongly influence the lifetime of a turbine. Each turbine manufacturer will have their own limits as to how to count average wind shear for a site and the associated suitability of a turbine.[14]

Analysts typically use one of two mathematical relations to characterize the measured wind shear profile:

- Logarithmic profile, also known as *log law*

- Power law profile, also known as *power law*.

For this study, the power law was used.

4.3.2 Power Law

The power law equation is used for estimating wind shear and resultant wind speeds at different heights. Depending on what data are known and what are sought, the power law equation can be manipulated to solve for any of the variables.

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[14] As outlined in IEC 61400-1 (wind turbine generator design requirements).

$$V = V_{ref}\left(\frac{Z}{Z_{ref}}\right)^{\alpha}$$

V = wind speed at height of interest (e.g., hub height)

V_{ref} = wind speed measured at height Z_{ref}

Z = height of interest (e.g., hub height)

Z_{ref} = height of measured data

α = wind shear exponent

The wind shear exponent, α, is often referred to as the vertical wind shear factor (VWSF). It defines how the wind speed changes with height. When the actual wind shear value is not known, a typical value used to estimate the wind shear exponent is 0.14 (or 1/7 power law). Depending upon the type of terrain and surface roughness features, the VWSF can vary from 0.0 to 0.4. When wind speed readings are available at multiple heights, the VWSF can be calculated using the power law equation, as shown in Figure 13.

The average wind shear power law exponent of 0.244 at the Doepke site is relatively high, which increases the financial viability of taller turbines and reduces the financial viability of shorter turbines.
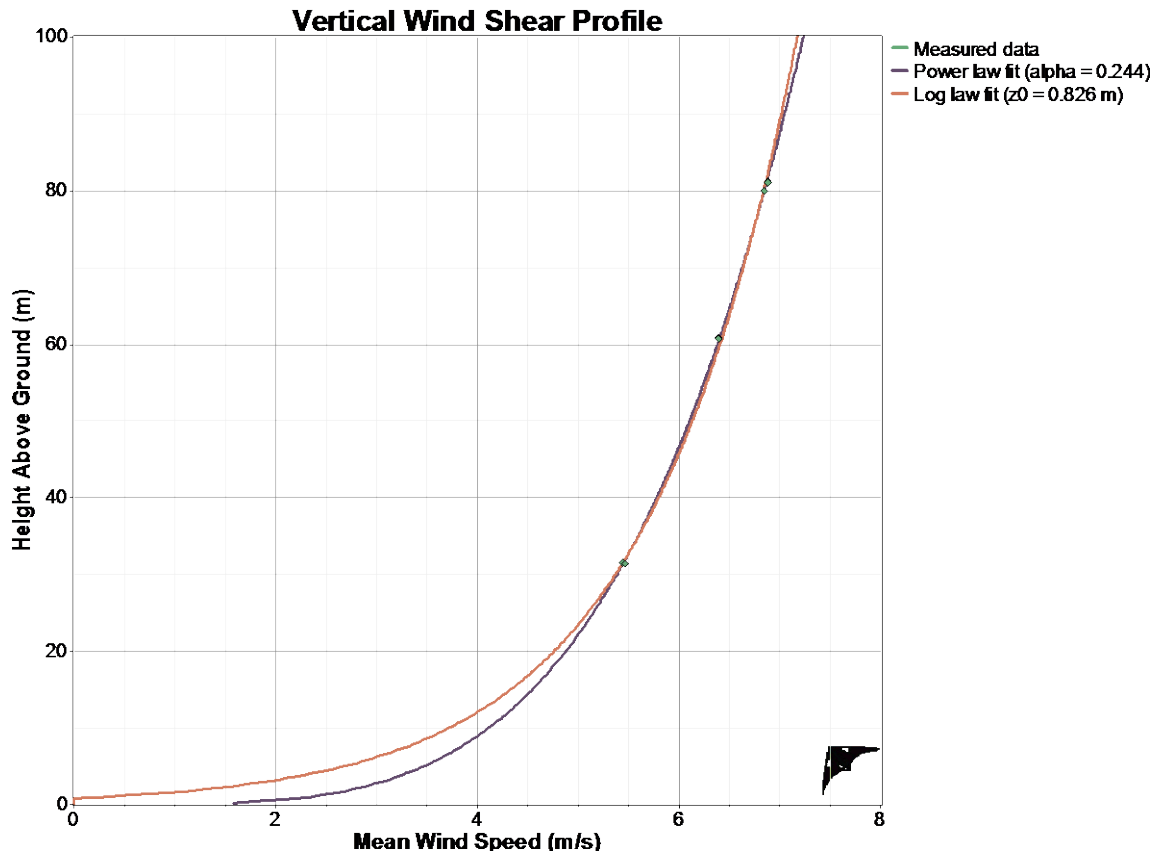
Figure 13. Wind shear profile

Figure 14 shows the strong pattern of higher shears at night compared to the daytime shear values. This meteorological phenomenon is typical of this region of the country due mainly to the nocturnal low-level jet.

Figure 14. Diurnal shear variation

Figure 15 illustrates the daily pattern of wind speeds with the strongest winds at 80 m occurring at night and in the middle of the day.
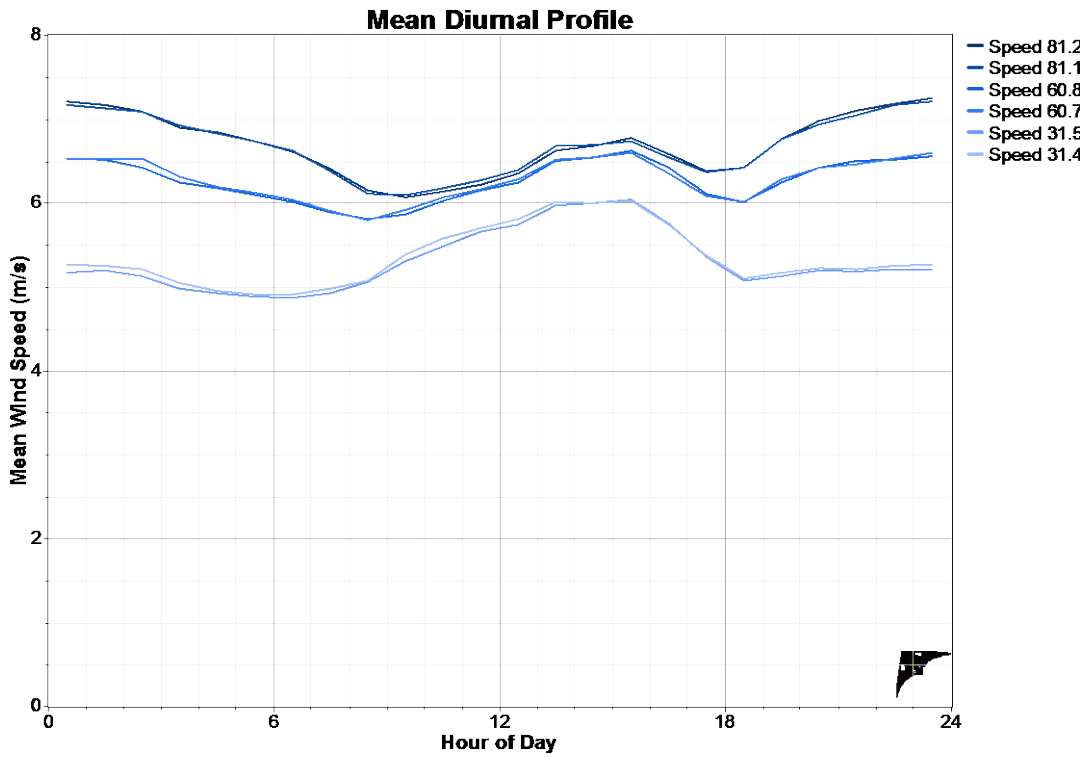
Figure 15. Diurnal wind resource variation

Figure 16 shows the frequency of wind speeds as they occur for the full year of observed data.
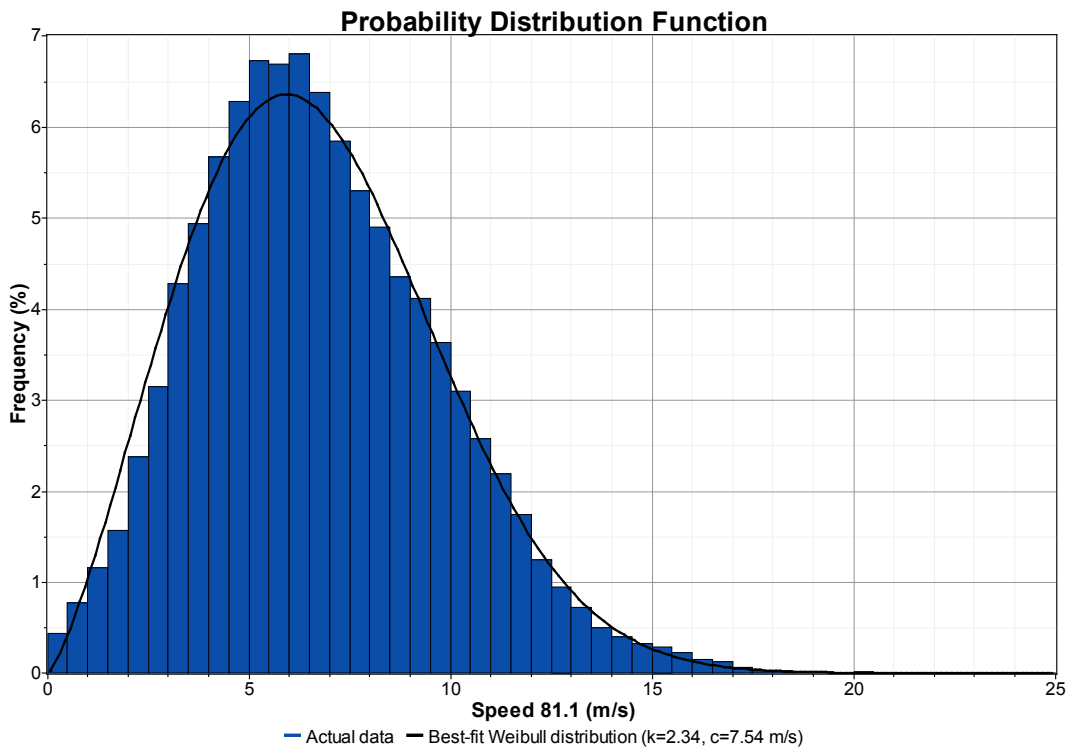
Figure 16. Wind speed frequency distribution

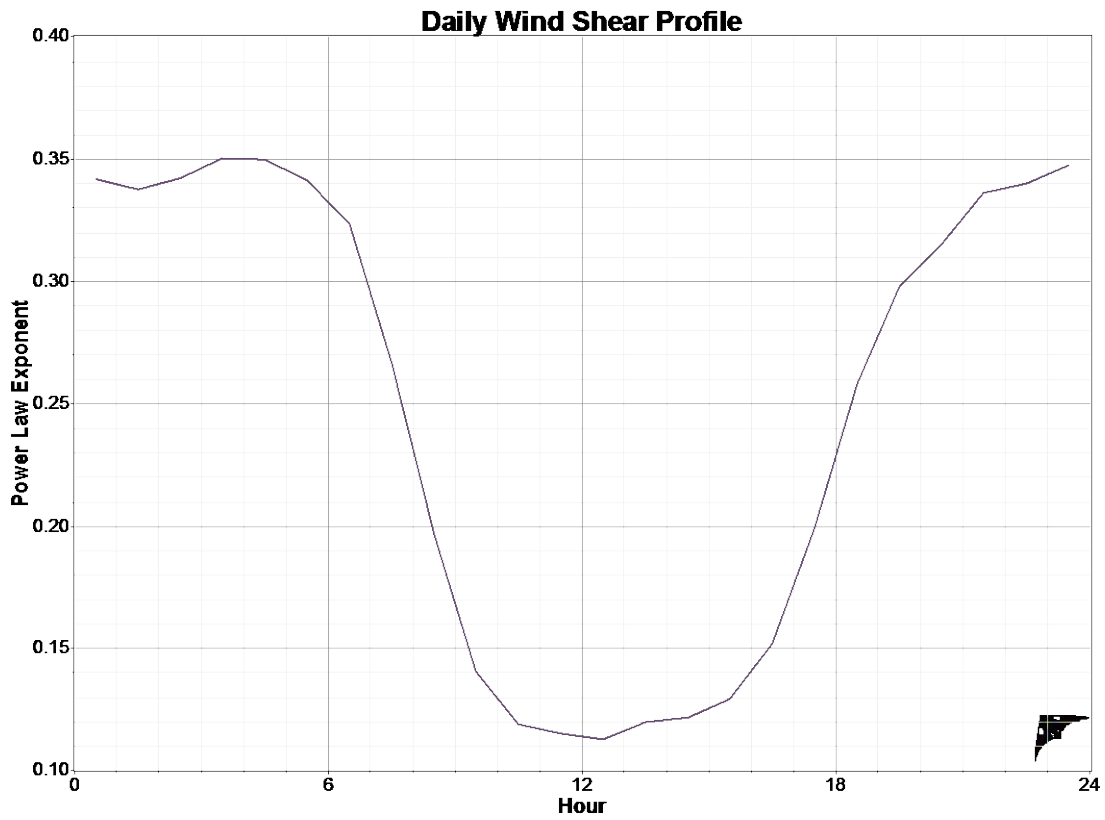Figure 17 shows the frequency of energy in the wind relative to the direction that the winds come from. The predominant winds are from the south with another large portion of the energy in the wind from the north.

Proportion of Total Wind Energy vs. Direction 78.9
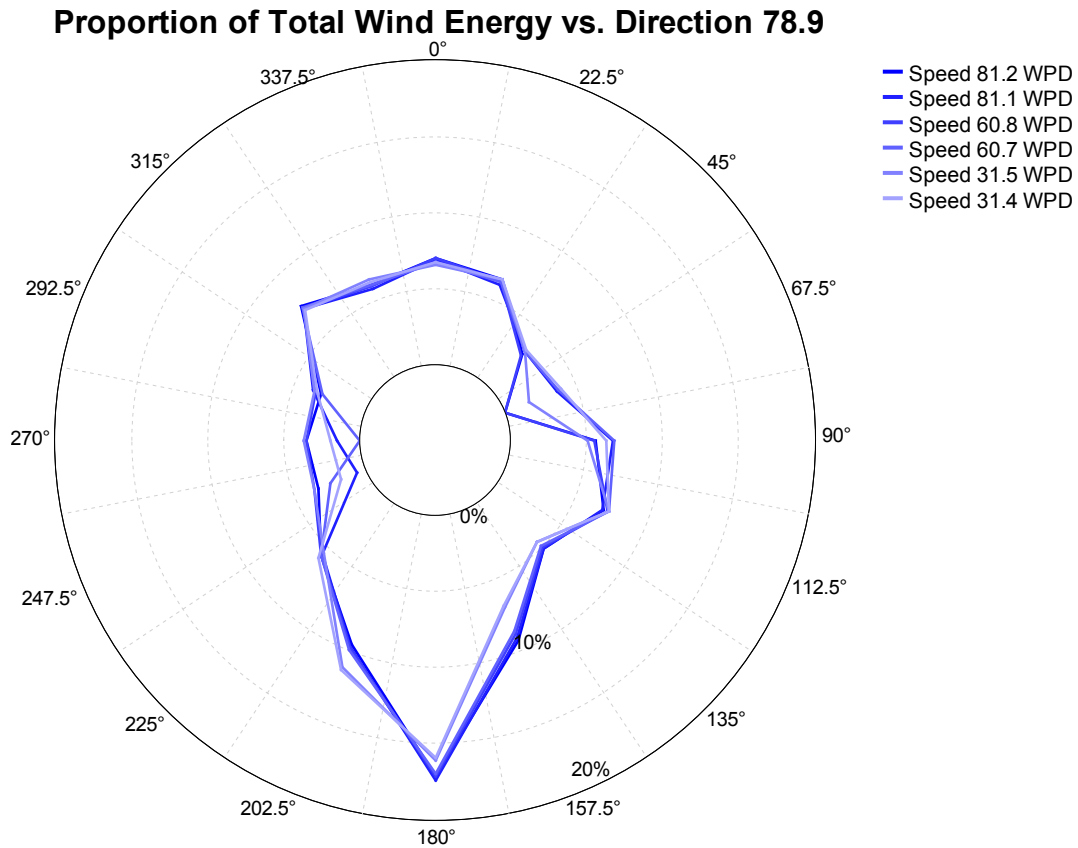
Figure 17. Wind energy rose

Figure 18 shows the average turbulence intensity measured at 81.2 m above the ground. This level of turbulence intensity might require a turbine that is designed to withstand these turbulent winds, but it is worth noting that the turbulence from the predominant wind directions, both north and south, is somewhat lower than the average turbulence intensity as seen in Figure 19 and Figure 20.
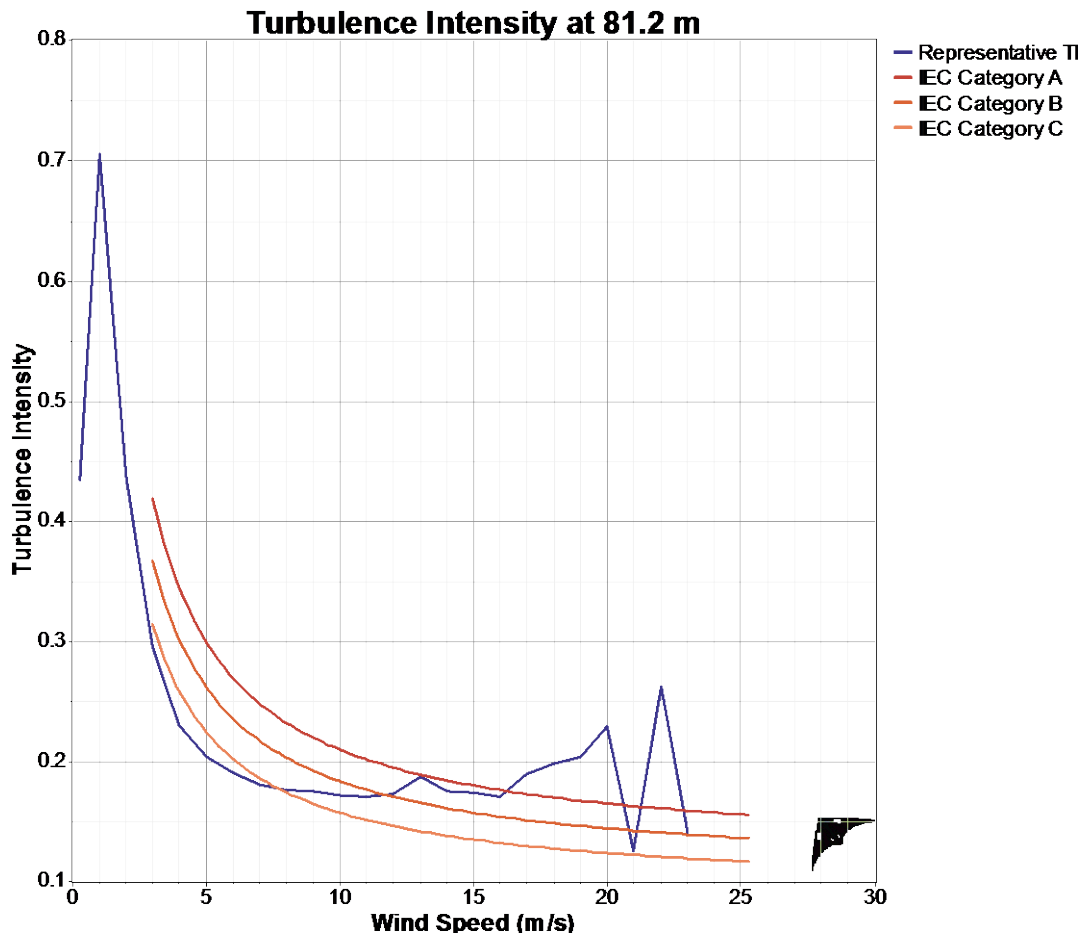
Figure 18. Average measured turbulence intensity at 81.2 m
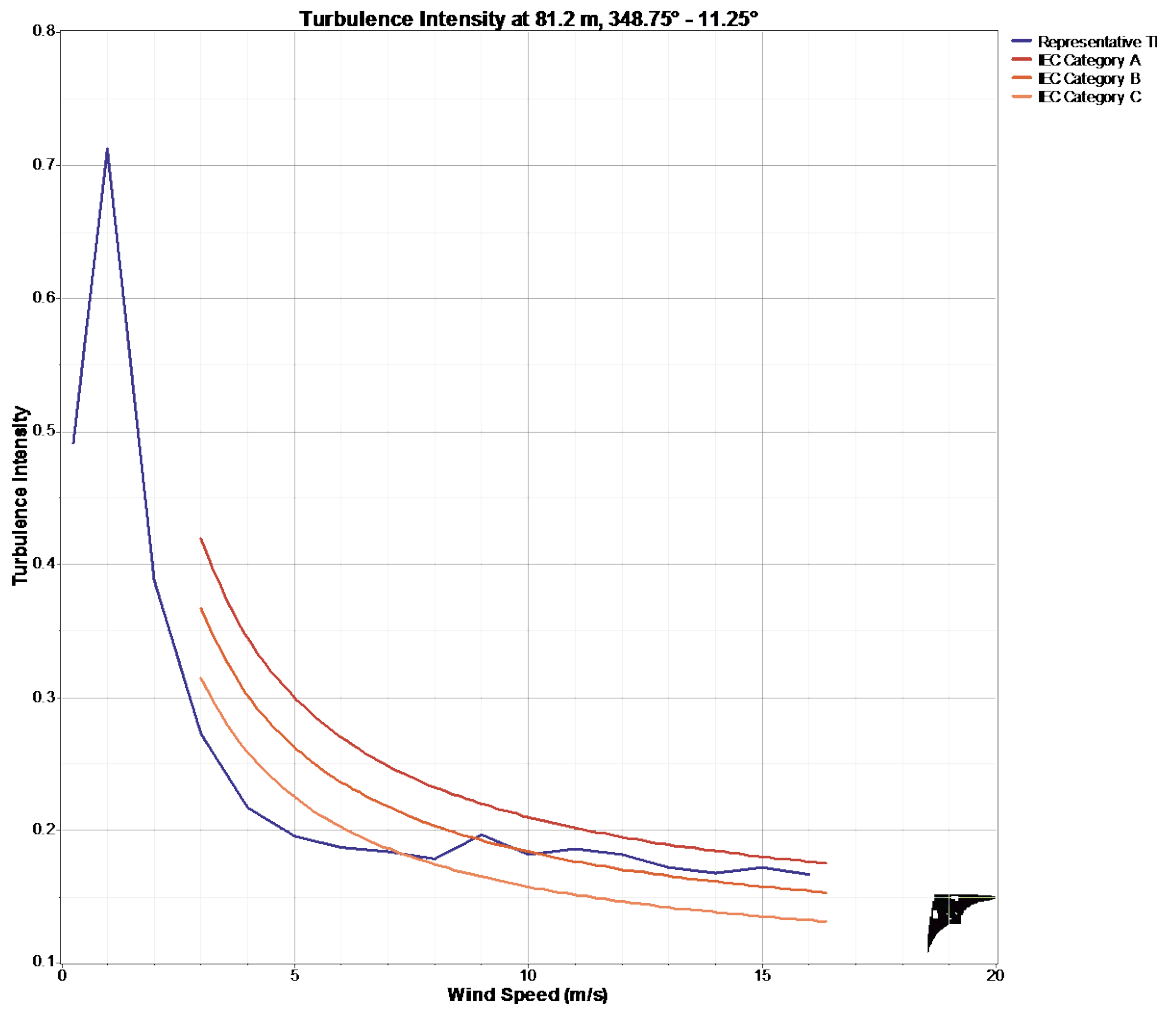
Figure 19. Average turbulence intensity from the north
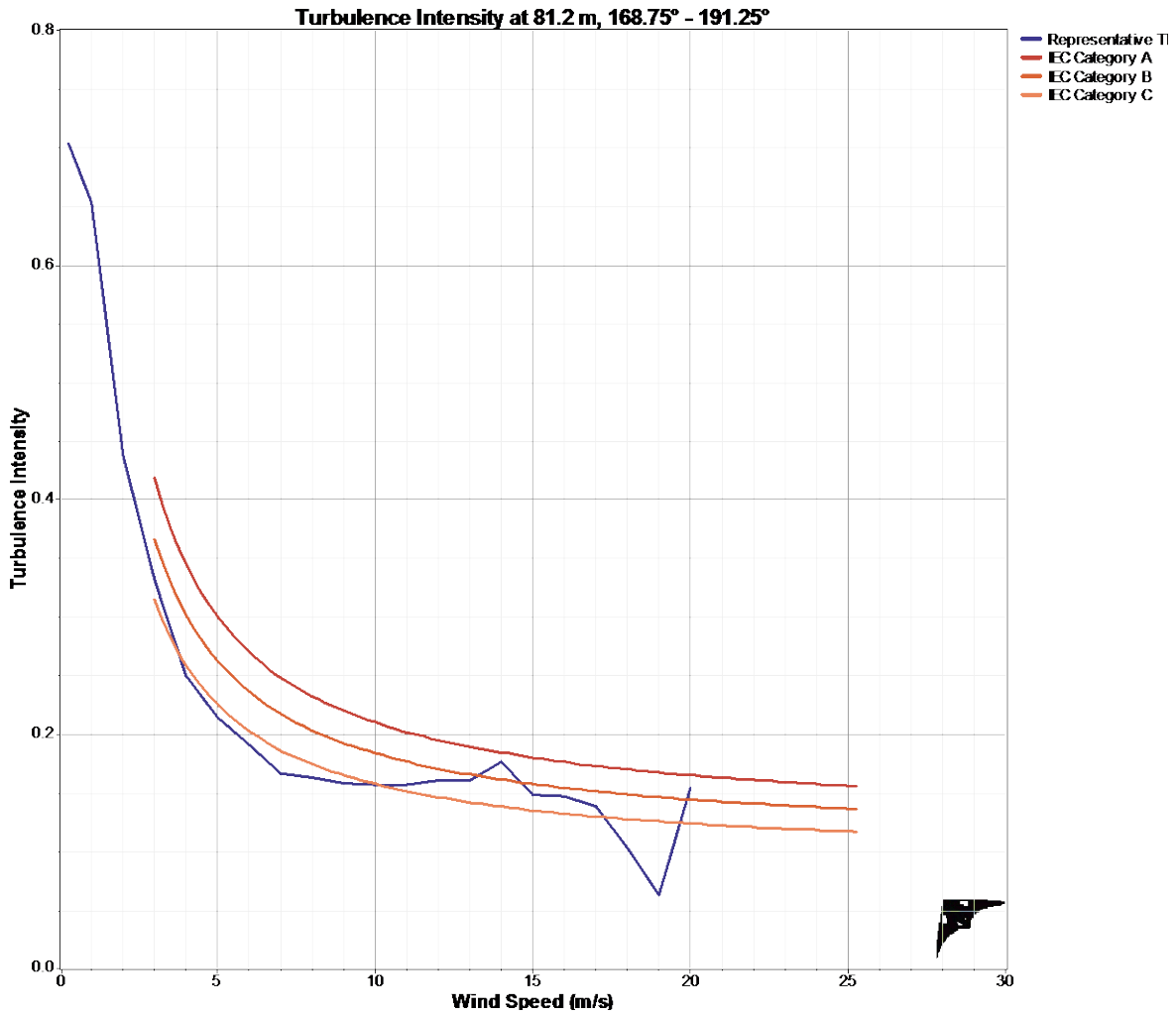
Figure 20. Average turbulence intensity from the south

4.4 Long-Term Data Adjustment

The observation period from January 18, 2011, to January 19, 2012, was used for the economic performance calculations and the long-term comparison and correction. This full year of data was compared to multiple long-term reference stations, and the station with the highest correlation with appropriate data quality and recovery rates was chosen.
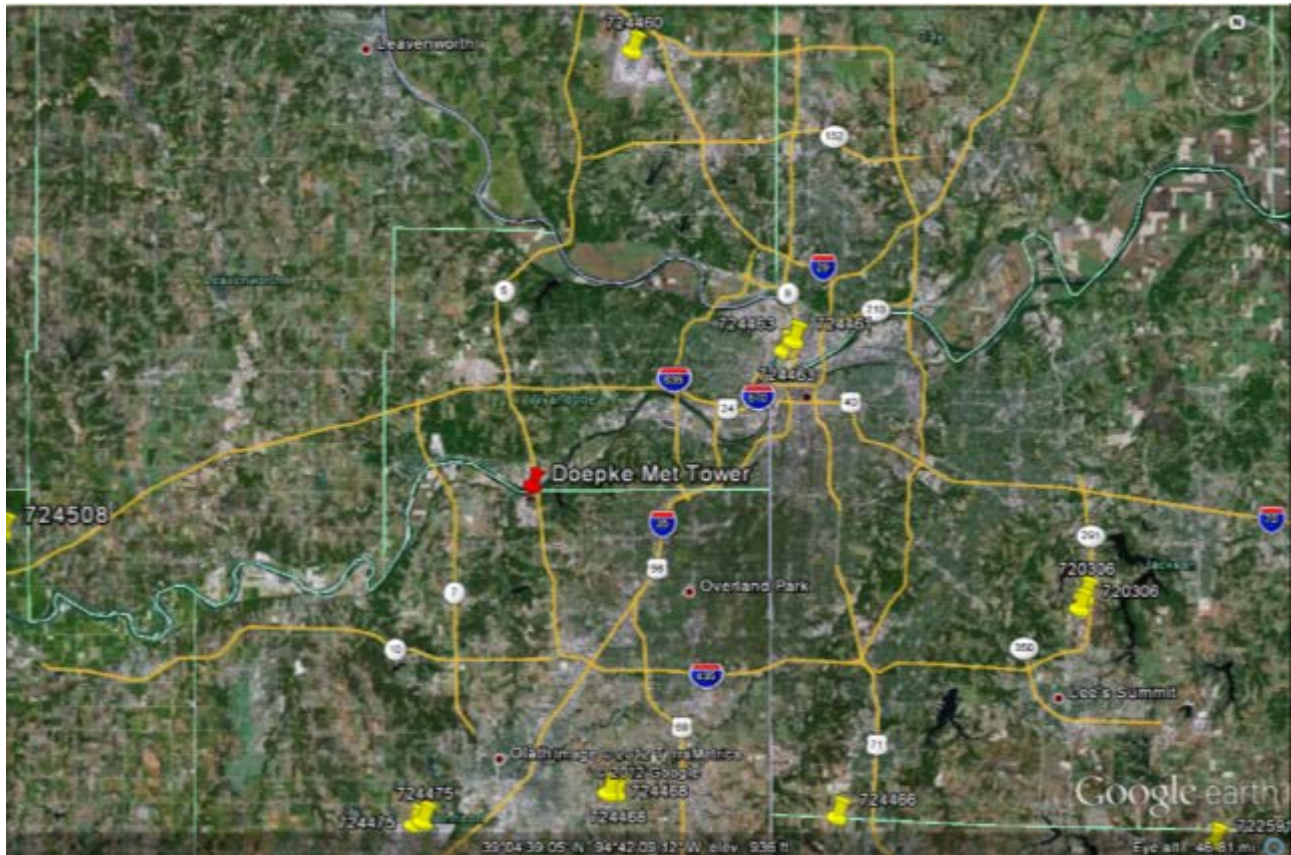
Figure 21. Long-term reference station locations

Illustration done in Google Maps

The Kansas City International Airport (site 724460) produced the highest correlation coefficient and also had the highest data recovery rate, and thus was the chosen reference station to determine how the observation period compared to the 12 years of data from the reference station. This backward prediction of a local wind resource is an industry-standard method for determining if the observation period will indicate either excessive or underperformance of the turbines at a given site. This prediction is typically very important for large wind farm developments because the financial performance of the wind farm is dependent on the production of the turbines, and the financiers need to understand how the wind farm will, on average, perform in the coming years.

The chosen algorithm was the Matrix Method due to its small mean bias and mean absolute error in predicting the turbine performance.[15] The algorithm had a mean bias error of only -7.27 kW; that is to say the algorithm, on average, under-predicted the power production from a sample International Electrotechnical Committee (IEC) Class III turbine by 7.27 kW. The annual variations in this same sample IEC Class III turbine were compared to identify how the observation period (collected data) compared to the previous 12 years of data from the reference station. Table 3 shows that the generic Class III turbine power output for the 2011 observation

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[15] Lybech Thøgersen, M.; Motta, M.; Sørensen, T.; Nielsen, P. *Measure-Correlate-Predict Methods: Case Studies and Software Implementation.* Aalborg, Denmark: EMD International A/S. http://www.emd.dk/files/windpro/Thoegersen_MCP_EWEC_2007.pdf.

period was roughly 1.76% higher than the average turbine output for the 12-year long-term average. Thus, for this generic IEC Class III turbine, the annual power production for the observation period will be 1.76% greater than on average, and the standard deviation of annual turbine output for this Class III turbine is 3.94%.

Table 3. Wind Resource and Turbine Performance Annual Average Variation

Year	Mean (m/s)	Weibull k	Class III turbine Output Fraction from Average
2000	6.7	3.05	105.02%
2001	6.5	2.967	99.71%
2002	6.6	2.933	101.83%
2003	6.6	2.889	101.16%
2004	6.6	2.961	102.01%
2005	6.4	2.884	95.82%
2006	6.7	3.012	105.69%
2007	6.4	2.756	96.73%
2008	6.6	2.776	101.08%
2009	6.4	2.801	94.80%
2010	6.3	2.778	93.28%
2011	6.5	2.517	101.76%
Average	6.5	2.845	Standard Deviation 3.94%

4.5 Energy Production Estimates

The industry trend for utility-scale wind turbines is toward larger rotor diameters and smaller electrical nameplate capacities for lower wind speed regimes. This has been shown to be cost effective, especially for lower wind speed sites, as shown in Figure 22.[16]

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[16] Wiser, R.; Lantz, E.; Bolinger, M.; Hand, M. (February 2012). *Recent Developments in the Levelized Cost of Energy from U.S. Wind Power Projects.* http://eetd.lbl.gov/ea/ems/reports/wind-energy-costs-2-2012.pdf.
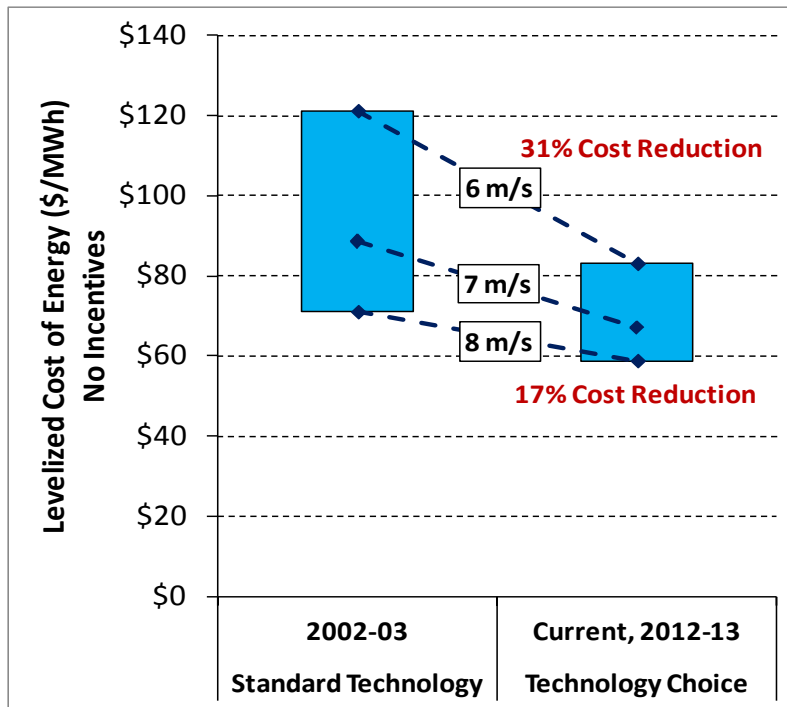
Figure 22. Levelized cost of energy comparison of modern turbines with historical performance[17,18]

These data show that for turbines currently produced and installed in North America, the cost of energy, especially for lower wind speed sites, such as the Doepke site, now have a much better chance at producing cost-effective electricity, depending on incentives and project and turbine costs. It appears that the industry is continuing in this direction, and the next generation of turbines already being tested and installed could have a similar impact on the cost of energy as rotors become even larger. It is yet to be seen where turbine pricing for these new machines will fall. It is also worth noting that modern IEC Class III turbines with larger rotor to nameplate electrical capacity typically reduce the volatility of annual variations in the wind resource.

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[17] Wiser, R.; Lantz, E.; Bolinger, M.; Hand, M. (February 2012). *Recent Developments in the Levelized Cost of Energy from U.S. Wind Power Projects.* http://eetd.lbl.gov/ea/ems/reports/wind-energy-costs-2-2012.pdf.

[18] This model assumes current turbine and installation pricing, reduced O&M costs, production tax credits (PTC) and modified accelerated cost-recovery system (MACRS) tax incentives, increased turbine availability, and the comparative capacity factors for the current and previous generation turbine technologies.

5 Economics and Performance

5.1 Assumptions and Input Data for Analysis

It was assumed that the installed cost of an 80-m hub height 100-m rotor diameter IEC Class III wind turbine at the Doepke site for a single turbine installation, purchase, and interconnection is approximately $3,450/kW of nameplate capacity. This cost includes the turbine, turbine transport, and the balance-of-system components for the project and installation.

The economics of a potential turbine at the Doepke site depend greatly on the cost of electricity. The average KCP&L electric rates of $0.08391/kWh are similar to those found in other Midwestern cities in the United States. The Database of State Incentives for Renewables and Efficiency (DSIRE) provides a summary of net metering, interconnection rules, and other incentives available to Kansas utility customers.[19] Renewable energy systems, including commercial wind farms, are subject to interconnection and net-metering rules promulgated at the state level. Interconnection rules for Kansas were found on the DSIRE website. The turbine size limit for interconnection is 25 kW for residential and 200 kW for nonresidential systems. Similarly, the turbine size limit for net metering is 25 kW for residential and 200 kW for nonresidential systems. The capacity values for the interconnection limits are very low, and the owner of a larger turbine project would have to work out an arrangement with KCP&L before proceeding. This feasibility study assumes the ability to sell electricity at and above current commercial consumer rates which is very unlikely to be realistic in this case. Most likely only the avoided cost of electricity would be paid, which is substantially less than the assumed rates.

There is little to no electricity use at a closed landfill, and all of the electricity generated by a proposed turbine is assumed to be sold back to the utility. There are possible electricity uses at the quarry operation where the electricity from a turbine could be used. From an economic standpoint, the current net-metering laws in Kansas are not advantageous for a turbine that can generate large amounts of excess energy because of the relatively low system size limit of 200 kW for commercial systems. Setting up a PPA where KCP&L would agree to buy back electricity from larger turbines should be explored. The economics of the potential systems were analyzed assuming that a PPA with KCP&L would be used, and KCP&L would buy back the electricity at a rate of $0.08391/kWh.[20]

5.2 Incentives and Financing Opportunities

State incentives or local utility incentives are not currently offered for commercial wind turbines in Kansas. It was assumed for this analysis that federal incentives are not received due to the complexities of ownership, power markets, profit margins, and demand for renewable energy. Identifying and leveraging state and federal incentives and grants is an important part of making a wind project cost effective. A private, tax-paying entity that owns wind projects can qualify for

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[19] "Kansas Incentives/Policies for Renewables & Efficiency." Database of State Incentives for Renewables & Efficiency, 2013. Accessed March 2011:
http://www.dsireusa.org/incentives/index.cfm?re=1&ee=1&spv=0&st=0&srp=1&state=KS.

[20] This feasibility study assumes the ability to sell electricity at and above current commercial consumer rates, which is very unlikely to be realistic in this case. Most likely only the avoided cost of electricity would be paid, which is substantially less than the assumed rates.

a 30% federal business energy investment tax credit (ITC) or a production tax credit (PTC) and accelerated depreciation on the wind project. Because the federal government does not pay taxes, private ownership of the wind project is required to capture tax incentives or U.S. Treasury Section 1603 grant payments.[21]

The system facilitator could potentially pursue an agreement with KCP&L that would negotiate both a higher price for the electricity produced by the potential system and the potential to sell renewable energy certificates (RECs). Any power that is produced by a wind project will help the state reach its renewable portfolio standard (RPS) and would be an opportunity for KCP&L to accelerate the diversification of their energy mix with clean energy. It has been demonstrated across the country that people are willing to pay a premium for certified clean energy,[22] and KCP&L could start a voluntary green power purchase pilot program with energy from the landfills in Kansas.[23]

Technical assistance to support project development is available through the U.S. Department of Energy's (DOE) Office of Energy Efficiency and Renewable Energy (EERE). Technical assistance is provided to commercial power developers and other technology projects involving liquid fuels developed from biomass. EERE also makes information available to the public on renewable energy applications. EERE can assist commercial wind and solar developers by providing detailed renewable resource maps, interfacing with Kansas utilities, and contacting local economic developers.

There are several options for financing a solar wind project. A potential alternative financing option is the third-party ownership PPA. This type of agreement works by having a wind developer install, finance, and operate the wind project while the utility company purchases the electricity generated by the system. The wind project is financed by the wind developer, and the payments are paid by the revenue from selling the generated electricity and RECs to the utility. In this configuration, the land that the wind project is on would need to be leased to the owner of the project for the duration of the contract.

Another gap financing tool that could be available is tax increment financing (TIF). Connecticut, Iowa, Michigan, and Wisconsin have been leaders in structuring state-facilitated TIF financing as an effective and efficient means to enhance site reuse and redevelopment programs and to obtain successful cleanup and redevelopment results. Municipalities are good candidates for TIF because it is an incentive they can implement under their own control.

5.3 Wind Project Employment

The Council of Economic Advisors (CEA) calculated the number of jobs (direct, indirect, and induced) from federal spending using economic models developed with real-world data. CEA found that $92,000 in federal spending is equivalent to one job-year. According to CEA, this

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[21] "Kansas Incentives/Policies for Renewables & Efficiency." Database of State Incentives for Renewables & Efficiency, 2013. Accessed March 2011: http://www.dsireusa.org/incentives/index.cfm?re=1&ee=1&spv=0&st=0&srp=1&state=KS.
[22] "NREL Highlights Utility Green Power Leaders." Transmission & Distribution World, 2009. Accessed July 20, 2010: http://tdworld.com/customer_service/doe-nrel-utility-green-power-0409/.
[23] An example of such a program is Xcel Energy's Windsource program. For more information, see http://www.xcelenergy.com/Colorado/Company/Environment/Renewable%20Energy/Pages/Wind_Power.aspx.

means that for every $92,000 of federal money that is spent, there is one job created that can be sustained for one year. Table 4 shows an estimate of jobs supported by a wind project at the Doepke Superfund site. This project represents a large amount of money that would support a significant number of jobs. A portion of these jobs, including the installation and system maintenance jobs, would be within the community. The short-term jobs column refers to the number of job-years that would be created as a result of the one-time project capital investment. This means that the jobs will be created and sustained for one year. The long-term jobs column refers to the number of jobs that would be sustained as a result of the O&M of the system. These jobs will be sustained for the life of the system due to the annual cost to keep the system operating.

Table 4. Doepke Wind Project Estimated Job Creation

	Short-Term Jobs Potential[a] (job-years or jobs lasting one year)	Long-Term Jobs Potential[b] (number of long-term jobs)
IEC Class III Turbine, 80m Tower 100m Rotor	59	0.4

[a] Job-years created as a result of project capital investment, including direct, indirect, and induced jobs.
[b] Jobs (direct, indirect, and induced) sustained as a result of O&M of the system.

6 Avoided Cost Electric Rate

As there are no RPS or other state incentives for this project it is also very unlikely that the turbine would be able to be net-metered. Utilities will pay the avoided cost of energy (which is much lower than the billed rate) for any generator connected to their system. Table 5 shows a summary of the system economics when assuming a hypothetical buyback electric rate of $0.03/kWh with federal incentives.

Table 5. Wind Project Performance and Economics Assuming Avoided Cost

Wind System Size[a] (kW)	Annual Output (kWh/year)	Annual O&M ($/year)	System Cost without Incentives ($)	Net Meter Current Electrical Cost Payback (years) [c]	Avoided Cost Payback (years)[d]	Estimated Potential Construction Job-Years[e]	Estimated Potential Maintenance Jobs[f]
IEC Class III Wind Turbine, 80-m Hub Height, 100-m Rotor Diameter							
1,620	5,098,607[g]	$70,000	$5,440,000	10.4	>20	59	0.4

[a] Data assume a maximum usable area of solely the Doepke site.

[b] Number of average American households that could hypothetically be powered by the turbine when assuming 11,040 kWh/year/household.[24]

[c] Assumes 10-year PTC, 5-year MACRS, $0.08391/kWh, 10% utility rate escalation, $70,000 annual O&M, 7% debt interest

[d] Assumes 10-year PTC, 5-year MACRS, $0.03/kWh, 5 % utility rate escalation, $70,000 annual O&M, 7% debt interest,

[e] Job-years supported by this project capital investment, including direct, indirect, and induced jobs.

[f] Permanent jobs (direct, indirect, and induced) sustained as a result of operation and maintenance (O&M) of the system.

[g] Annual output corrected for long-term annual average, including 15% losses.

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[24] "Frequently Asked Questions." U.S. Energy Information Administration. Accessed Oct. 22, 2010: http://www.eia.doe.gov/ask/electricity_faqs.asp#electricity_use_home.

7 Conclusions and Recommendations

The Doepke site appears technically feasible for the installation of a utility-scale wind turbine. Using obtainable and accessible land that is unavailable for other purposes allows for reuse of land that would not otherwise contribute to productivity for Kansas. Installing a wind project and the associated facilities on landfills rather than on undeveloped land relieves "greenfields" of land-use impacts. Developing wind projects on landfills can provide an economically viable reuse option for landfills. The Doepke site has existing distribution voltage lines, roads, industrial zoning, and all other critical infrastructure in place for a wind project. One obstacle to wind projects on landfills is that landfills require little to no electricity once they are capped and closed. Therefore, finding a use for the electricity generated by the wind project is a key element. Another major obstacle is the very low interconnection and net-metering rules in Kansas, which limits a commercial size wind project to 200 kW. An arrangement with KCP&L would have to be worked out prior to installing a utility-scale wind turbine at the Doepke site.

It is recommended that the party ultimately responsible for facilitating the implementation wind project contact KCP&L and attempt to set up an agreement in which KCP&L would purchase the electricity generated at the site.

For this feasibility study, system calculations and sizes were based on the specific site area; however, actual system installation should be based on the availability of funds or on the amount of power that can be sold. Installing a small demonstration system could be advantageous, but the basic economics of turbine size work against this option. When the project goes out to bid, a design-build contract should be issued that requests the best performance (kWh/year) at the best price, and that allows vendors to optimize system configuration and turbine type. A third-party ownership PPA provides a feasible way for a system to be financed on these sites. Estimation by a third-party developer/owner of similar projects is recommended to examine the sensitivities of current or future power markets and current and future federal incentives, for example.

In the coming years, increasing electrical rates and potential increased demand for clean power will continue to improve the feasibility of implementing wind projects at these sites due to transmission constraints and local motivation to generate renewable energy.

Appendix A. Measure-Correlate-Predict Matrix Method

Below is an explanation of the Matrix Method used in the long-term correlation of the data in this feasibility study, as described by Tom Lambert of Mistaya Engineering.[25] The Matrix Time Series (MTS) algorithm is an adaptation of the classic Matrix Method, modified to produce realistic time series data. The algorithm comprises the following steps:

1. Build the Joint Probability Distribution

The fundamental idea behind matrix-based MCP methods is to use the complete two-dimensional joint probability distribution (JPD) of the target and reference wind speeds to generate the predicted wind speed data. Not only does this allow the algorithm to model arbitrary nonlinear relationships between the target and reference site, it also preserves information about the variance in each variable (as opposed to, for example, basic linear regression, which maps a single specific target wind speed to every given reference wind speed value). Therefore, the first step of the MCP method is to build this JPD.
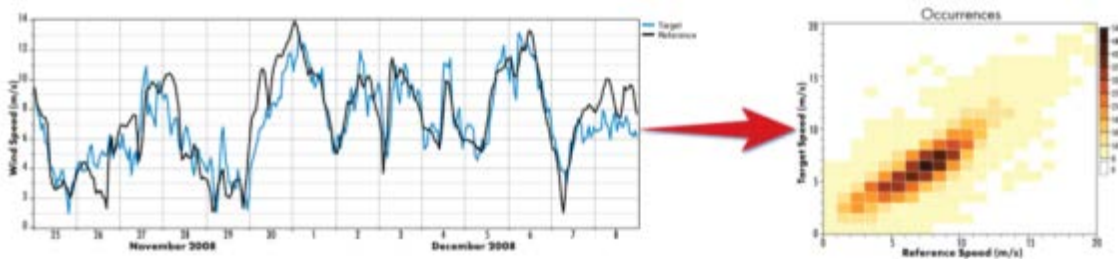
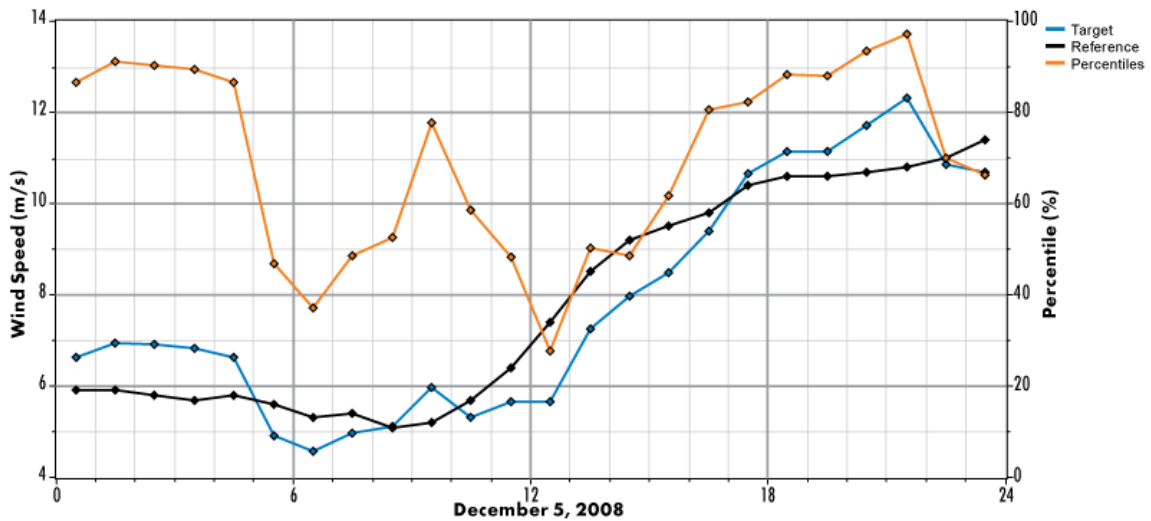## 2. Build the Percentile Time Series

The next product of the MTS algorithm is the percentile time series. This is another set of time series data points that Windographer generates as an intermediate output of the MTS algorithm. In each time step, Windographer takes the concurrent target and reference wind speeds, chooses from the JPD the column corresponding to the appropriate reference speed bin, and from that constructs the cumulative distribution function (CDF) of target wind speeds observed in that bin. Finally, from this CDF, Windographer calculates the percentile value corresponding to the observed target wind speed. The percentile time series can be viewed using the percentiles graph radio button.
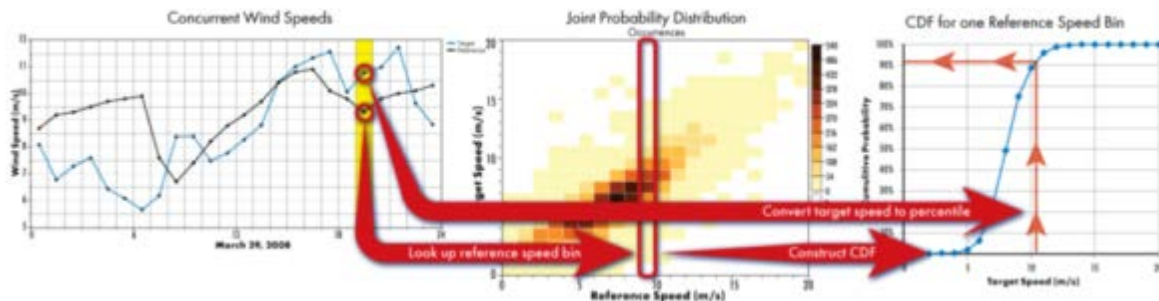
A simple way to think of the percentile time series is that each percentile value represents how windy the target site is compared to how windy we would expect it to be, given the current

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[25] The material in this appendix was obtained using the Windographer software by Mistaya Engineering: http://www.windographer.com/.

reference wind speed. Therefore, a percentile value of 0.5 or 50% means that, in this time step, the target wind speed is exactly the average of what we would expect, given the reference wind speed in that time step. In the same way, a percentile value of 90% would indicate an unusually windy target site, and a value of 10% would indicate an unusually calm target site. Because the distribution of target wind speeds will vary depending on the range of reference wind speeds considered, the same value of the percentile time series can, of course, represent different target site wind speeds in different time steps.


3. Synthesize Percentile Time Series Data

In this step, Windographer uses its built-in gap-filling algorithm to fill gaps in the percentile time series. The synthesized data respects the seasonal and diurnal patterns in the original percentile time series, as well as the characteristic autocorrelation, and matches up with the edges of any gaps in the original target site data.
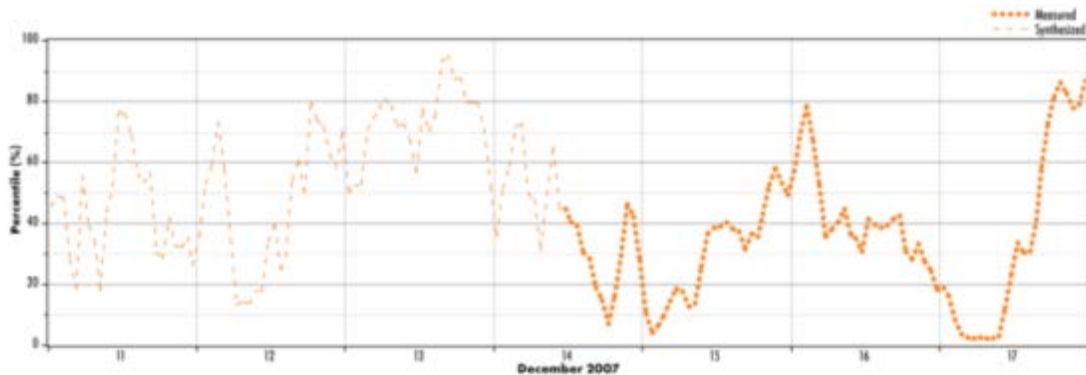
4. Transform Percentile Time Series Into Target Wind Speeds

The final step is for Windographer to transform the synthetic percentile time series values into synthetic target wind speed values. Windographer does this by referring back to the JPD and using it to calculate the expected target wind speed value for the given percentile value and reference wind speed in each time step, essentially reversing the "build the percentile time series" step. Once again, Windographer calculates the CDF of target wind speed values for the

given reference wind speed, only this time it uses the percentile value to look up the predicted target wind speed value for that time step. Whereas the previous step was concerned with preserving the seasonal and diurnal patterns and autocorrelation of the data, it is really this step that is concerned with preserving the statistical relationship between target and reference wind speeds, as it does by consulting the JPD.
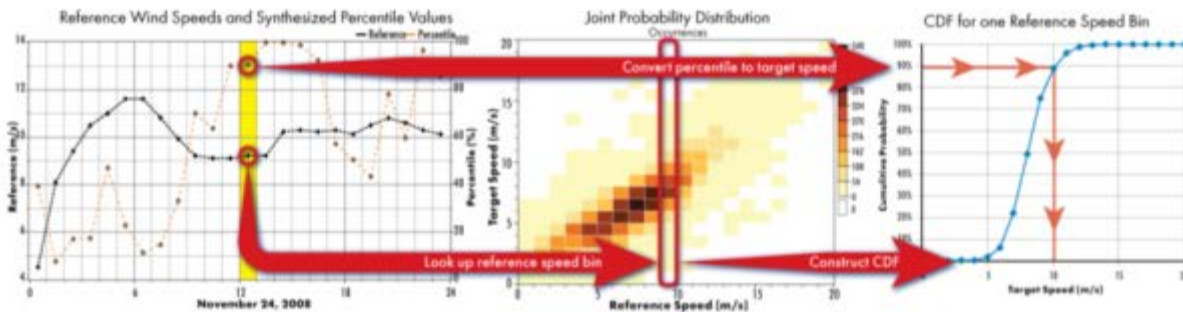
Options

The MTS algorithm supports the following options:

The **Direction sectors** drop-down box controls the number of direction sectors the data is split into for analysis. If this value is greater than one, the data in each time step is split up according to the value of the reference wind direction in that time step. Windographer calculates a separate JPD for each direction sector, but all of the percentile values are still put into the same percentile time series. Then, when the time comes to transform the percentile data into target wind speeds, the JPD to use for each time step is again determined based on the reference direction in that time step.

Reference speed bin size and **Target speed bin size** refer to the sizes of the bins used to produce the JPD. Smaller bins will produce a more fine-grained JPD, but if the bins are too small then the JPD will begin to suffer from sparsity problems (i.e., some bins will have little or no data).

The **Moving average window** controls the size of the moving average used when calculating the percentile time series. Because the percentile values are calculated based on a CDF of target wind speeds (as explained above), the percentile values can sometimes vary erratically, especially at high and low values where data is scarce. Therefore, Windographer offers the ability to smooth the percentile time series by calculating a moving average. For example, if the time step is 60 minutes and the moving average window is set to 3 hours, each percentile value will really represent the average of 3 percentile values (one central time step and one on either side). Figure B-6 shows the effect of increasing the moving average window on the smoothness of the percentile time series (in order, no moving average, 3 hours, 5 hours).

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