Evaluation of the Wind & Solar Resource for Ohio's 9th Congressional District

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Disclaimer

The data from monitoring sites located at Toledo Zoo; Port Clinton, Ohio; NASA Plum Brook Station; Bowling Green, Ohio; Lorain, Ohio; and Sullivan, Ohio presented in this report were obtained using generally accepted wind resource assessment standards as outlined in the *Wind Resource Assessment Handbook* (AWS Scientific, Inc., April 1997). Guidelines from the individual manufacturers were followed concerning the installation and use of the wind monitoring equipment and associated meteorological towers. Though professional standards have been followed, Green Energy Ohio is not and does not claim to be a professional wind resource analysis firm.

Executive Summary

This report, prepared by Green Energy Ohio, details the wind and solar resources in Ohio's 9th congressional district using wind speed and solar radiation maps created by the National Renewable Energy Lab (NREL) and AWS Truepower, wind speed data from Green Energy Ohio's monitoring sites in and near the district, and estimated production data from installed wind, photovoltaic, and solar thermal systems in and near the district.

Wind speed and solar radiation maps for the 9th congressional district were obtained from NREL and AWS Truepower. Wind speed maps are provided in this report at heights of 30 meters and 80 meters. The 30 meter wind speed map is ideal for evaluating a small wind turbine installation for residential or small business use, with an approximate turbine hub height of 30 meters. The 80 meter wind speed map is more appropriate for consideration of mid-sized to utility scale wind turbine installations, where hub heights are closer to 80 meters. Wind speed data was obtained from AWS Truepower for the creation of a more detailed wind speed map of the 9th congressional district. From the wind speed maps and data gathered, the region occupying the 9th congressional district ranges in wind speed, at a height of 80 meters, from 5.2 m/s – 8.2 m/s. The lowest wind speeds were found in, and extending southwest of the city of Toledo, south-central Erie County, and mid-central and south-central Lorain County, and the highest wind speeds were found on the southern edge of Marblehead, northern Catawba Island, the southern half of Kelley's Island and all of South, Middle and North Bass Islands. At a height of 30 meters, the region ranges in wind speed from 3.8 m/s – 7.2 m/s.

Green Energy Ohio, by involvement in the Monitoring Ohio Wind Program, the Ohio Anemometer Loan Program, and state and federal grants, has collected site specific wind speed data, near or at turbine hub heights, from 21 locations throughout Ohio. Three of GEO's past monitoring sites are located in the 9th congressional district. These sites include the Toledo Zoo, Port Clinton, and the NASA Plum Brook Station. GEO also has three monitoring sites that are relatively close to the district, and data from these sites is included in this report. These include monitoring sites in Bowling Green, Lorain, and Sullivan. When comparing GEO's monitoring sites to the wind speed maps, the sites at the Toledo Zoo, NASA Plum Brook, and Sullivan were all in agreement with the estimates in the wind speed maps. Measurements at the monitoring sites at Port Clinton and Lorain, were found to be lower than those predicted by the wind resource map, while the measurements from the Bowling Green monitoring site were found to be higher than predicted.

Production estimates were reviewed from installed wind and solar systems in the district. Initially one of the objectives of this project was to obtain actual production data from installed systems in the region; however, the quality of the available production data was questionable. Some of the factors affecting the validity of the production data included; data gaps due to availability of the system due to maintenance or other unexpected downtimes, the non-uniformity of tracking software/hardware used, ongoing changes to the system configuration, the necessity that the data be in an annual format, and the fact that most systems have not been operating for a year or more. Due to the uncertainty of actual production data in this district, an analysis of this data is not included in this report, however, an analysis of production estimates is included.

Background

Oberlin College retained Green Energy Ohio, as a subcontractor under a grant awarded to Oberlin College from the Department of Energy's National Energy Technology Laboratory, to perform an evaluation of the wind and solar resource for Ohio's 9th Congressional District. The grant is titled *Energy Transmission and Infrastructure Northern Ohio* and contains the following objectives:

1. Identify energy efficiency and saving opportunities for Oberlin residents, and the commercial, industrial, agricultural and transportation sectors
2. Analyze wind and solar potential and deployment applications within Ohio's 9th congressional district
3. Analyze farm (animal and crop) and commercial food processing waste within Ohio's 9th congressional district for generating increased production of biofuels
4. Identify policy, regulatory, and financial barriers which could impede development of renewable energy systems
5. Improve energy infrastructure in three AMP communities

In April 2011, GEO began work on an evaluation of the wind and solar resource in Ohio's 9th congressional district. Following is the scope of work used to complete the evaluation:

1. Comprehensive analysis report detailing the wind and solar resource analysis of the 9th District

    a. Determination of Wind and Solar Resources: GEO will evaluate the available resources to quantify wind potential in the district from reference data including available wind speed maps from National Renewable Energy Lab (NREL) and AWS Truepower, wind speed data from GEO's monitoring sites in the district, and any available wind turbine production data from turbines that have been installed in the district or made available through this grant.

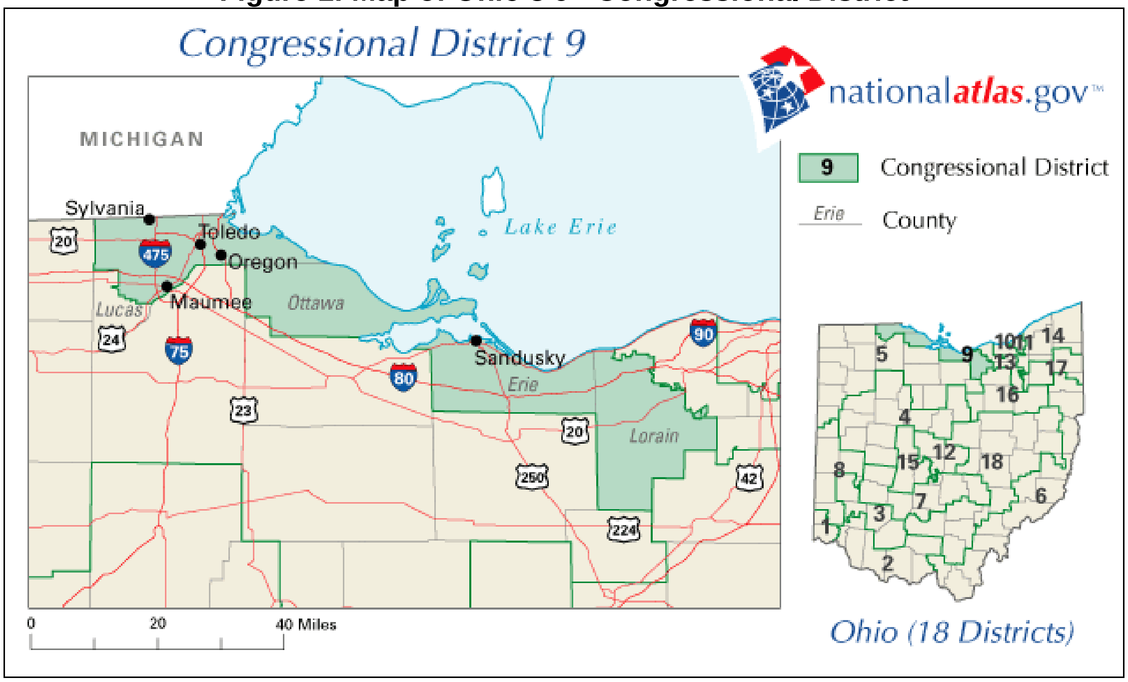
    GEO will evaluate the available resources to quantify solar potential from reference data including maps from NREL and any available solar photovoltaic and solar thermal production data from systems that have been installed in the district.

    GEO will identify and utilize appropriate consulting services as needed to complete this process.

    b. Identify Program Parameters. GEO, with assistance from project leaders (Oberlin), will identify the parameters of the desired magnitude of wind and solar deployment, whether it is small/residential, mid-sized/commercial, or utility scale. GEO will identify potential key areas for development within the boundaries of the 9th Congressional District.

Ohio's 9th Congressional District consists of all of Ottawa and Erie counties, and portions of Lucas and Lorain counties. Marcy Kaptur is the current representative for the district. All or part of ten cities (whose population is greater than 5,000) are in the district such as Toledo, Sandusky, Sylvania, Oregon, Maumee, Amherst, Vermilion, Oberlin, Huron and Port Clinton.

Figure 1: Map of Ohio's 9th Congressional District

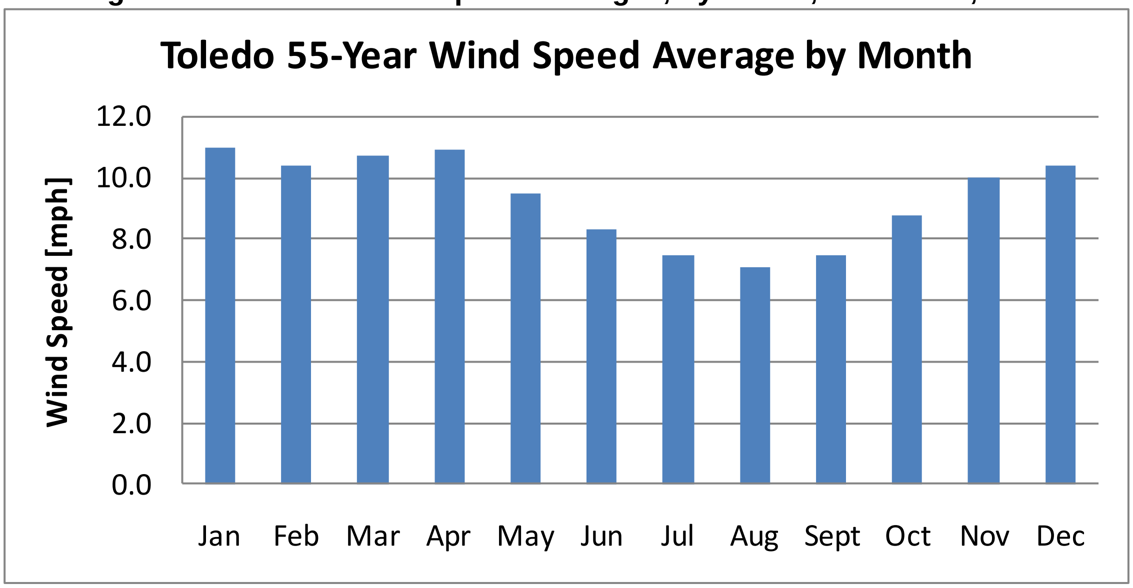


Wind Resource

Wind is created by the unequal heating of the earth's surface. The unequal heating results in the formation of high and low pressure gradients, which then dictate the movement of air parcels (wind) around the world. The strength of the available wind resource, at any given point on the earth's surface, is dependent on the season, the location's altitude, topography, nearby obstructions, and regional weather patterns.

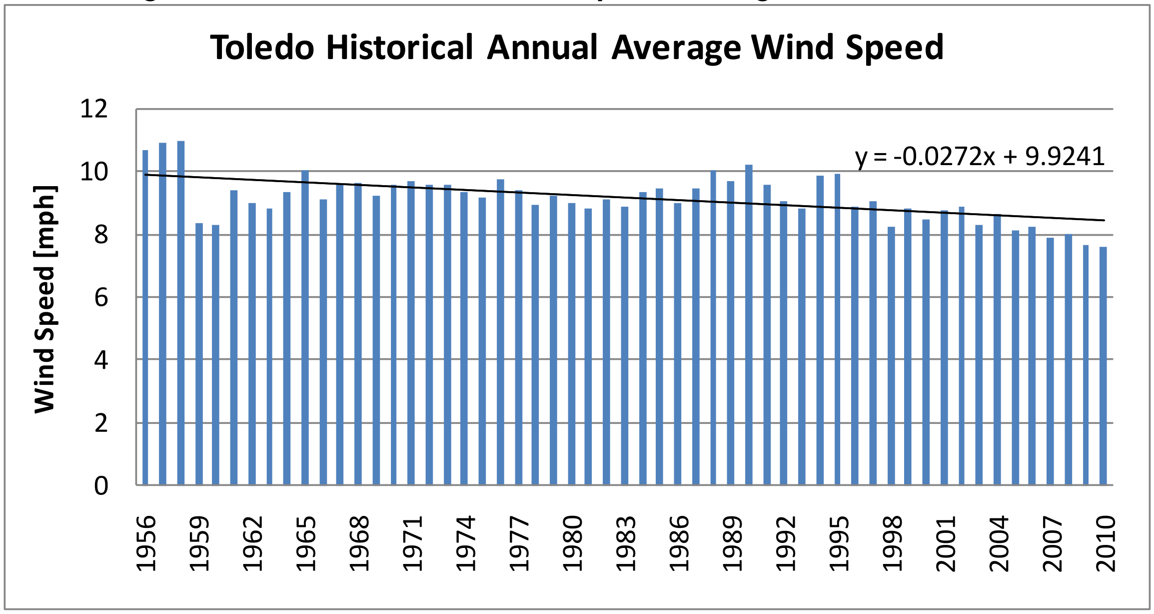
Wind speed varies by season, with winter typically experiencing the highest wind speeds and summer experiencing the lowest wind speeds. The National Climatic Data Center (NCDC) maintains historical weather data sets from various weather stations across Ohio and the U.S. The NCDC also provides some analysis of the data, such as historical wind speed averages by month for the following six cities in Ohio; Cleveland, Columbus, Dayton, Mansfield, Toledo, and Youngstown. Figure 2 below contains the 55-year (ending in 2010) averages of wind speed, by month, from the NCDC site at the Toledo Express Airport.

Figure 2: Historical Wind Speed Averages, by Month, for Toledo, Ohio



Wind speed also varies slightly from year to year. Climate patterns such as El Niño effect the global atmospheric circulation and cause variations in annual average wind speeds. Figure 3 below is a plot of annual average wind speeds from the weather station at the Toledo Express Airport, and depicts the annual variation in wind speed. The current weather station at the Toledo Express Airport is an Automated Surface Observing System (ASOS) site. ASOS sites are part of a national surface observing system maintained by the National Weather Service, the Federal Aviation Administration, and the Department of Defense. ASOS sites measure wind speed at a height of 10 meters. It should be noted, in a recent wind potential study performed by AWS Truepower, discussed later in this report, AWS found that pre-ASOS weather station data were found to overestimate wind speeds, especially in low wind resource areas (Brower). The date that the Toledo Express weather station was converted to an ASOS station could not be determined, however, the overestimation of older instruments may be a reason why higher wind speeds were reported during the early portion of the historical record for Toledo.

Figure 3: Historical Annual Wind Speed Averages for Toledo, Ohio

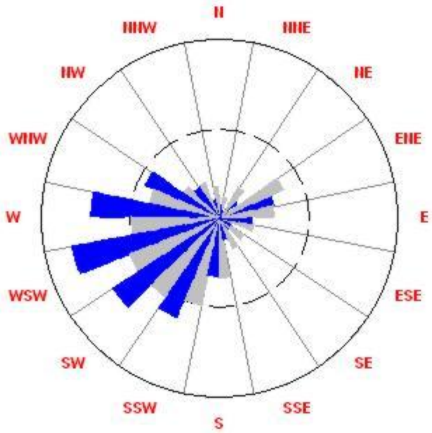


Wind speed is also influenced by altitude. Wind speed increases with height, thus, generally, the higher the altitude of a location, the higher the wind speed. One must also consider local effects of surrounding topography, surface roughness in the form of trees and buildings, and regional weather patterns. Wind speed increases near the crests of hills and ridges as it is forced upward by the topography and constricted by the air above it. Increases in wind speed can also occur as a result of the constriction of flow through valleys. Turbulence is usually created on the leeward side of hills, ridges and cliffs, and as the wind flow is diverted around buildings and trees, with the majority of the turbulence found on the leeward side of the obstruction. For the purposes of wind energy, it is important to avoid turbulent sites, as turbulent air causes stress on a turbine's components and makes for a less efficient energy conversion.

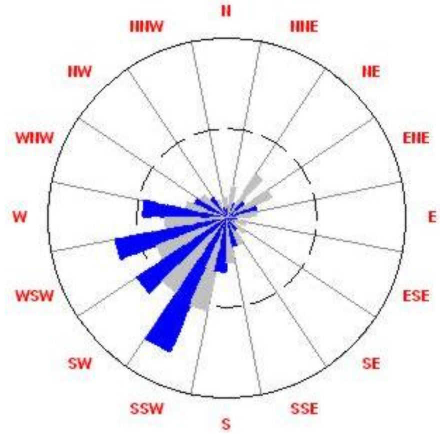
In designating a turbine location, commonly referred to as siting, it is also useful to know from which direction the wind predominantly arrives, and how variable it is. Wind direction studies are useful to determine the effect of blockage by obstructions, including the possibility that one turbine will cause a wake that will disturb another nearby turbine, if several are to be located near one another. As seen in the wind rose diagrams below, the predominant wind direction for the 9th congressional district varies slightly across the district. The predominant wind direction is from the west-southwest (WSW) in Lucas County, western Ottawa County, and southern Lorain County, southwest (SW) in northern Lorain County, and south-southwest (SSW) in eastern Ottawa, and all of Erie County. The wind roses were obtained from the Ohio Wind Resource Explorer, which is currently hosted on the Ohio Power Siting Board's web site (http://maps.opsb.ohio.gov/windmap/welcome.htm), and contains a 5-mile grid of wind roses for the State. The wind roses below represent six locations in the district which are identified on the map below.

Figure 4: Example Wind Roses

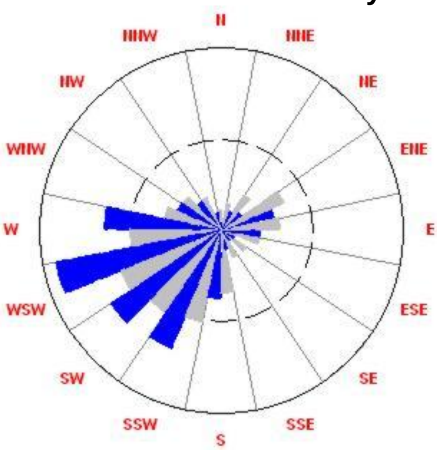
Lucas County



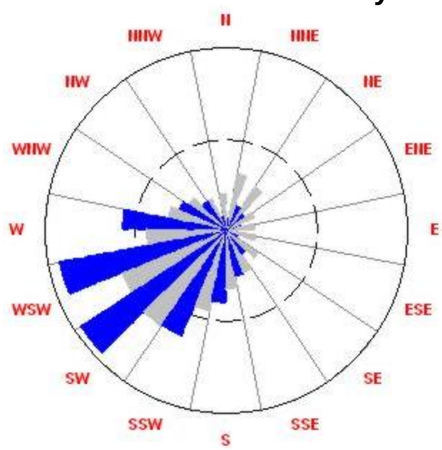
Erie County



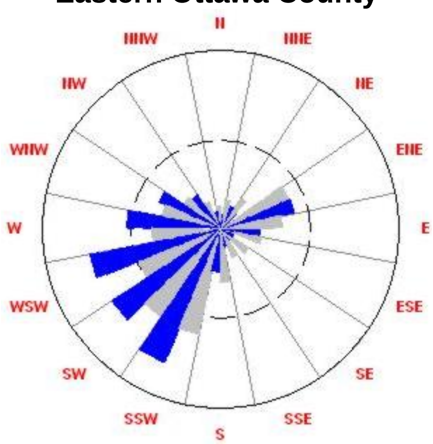
Western Ottawa County



Northern Lorain County



Eastern Ottawa County



Southern Lorain County

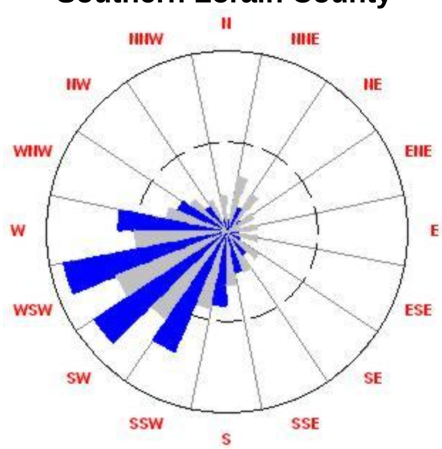


Figure 5: Locations of Example Wind Roses

Wind Speed Data/Maps from the National Renewable Energy Laboratory

The National Renewable Energy Lab (NREL) provides high-resolution wind speed maps through their Wind Powering America Program. The maps are a result of a collaborative project between NREL and AWS Truepower of Albany, New York. AWS Truepower, through their product windNavigator™, and created with their MesoMap® system, uses a mesoscale atmospheric model to simulate weather conditions based on regional weather inputs for a horizontal grid of 2 km. A microscale atmospheric model then refines the wind speed data by capturing the local influences of topography and surface roughness changes at a resolution of 200 m. The modeled data is then fine-tuned with observational data from Automated Surface Observing Systems (ASOS) stations across the U.S., and from wind monitoring stations from both public and private sources (https://www.windnavigator.com/index.php/cms/pages/faq). Green Energy Ohio has contributed several data sets to NREL and AWS Truepower from GEO's wind monitoring campaign for the purpose of validating Ohio's wind speed maps. The U.S. and Ohio wind speed maps below are the latest product from the NREL and AWS Truepower collaboration, which show the predicted mean annual wind speeds at a height of 80 meters, at a spatial resolution of 2.5 km.

Figure 6: U.S. Annual Average Wind Speed at 80 meters

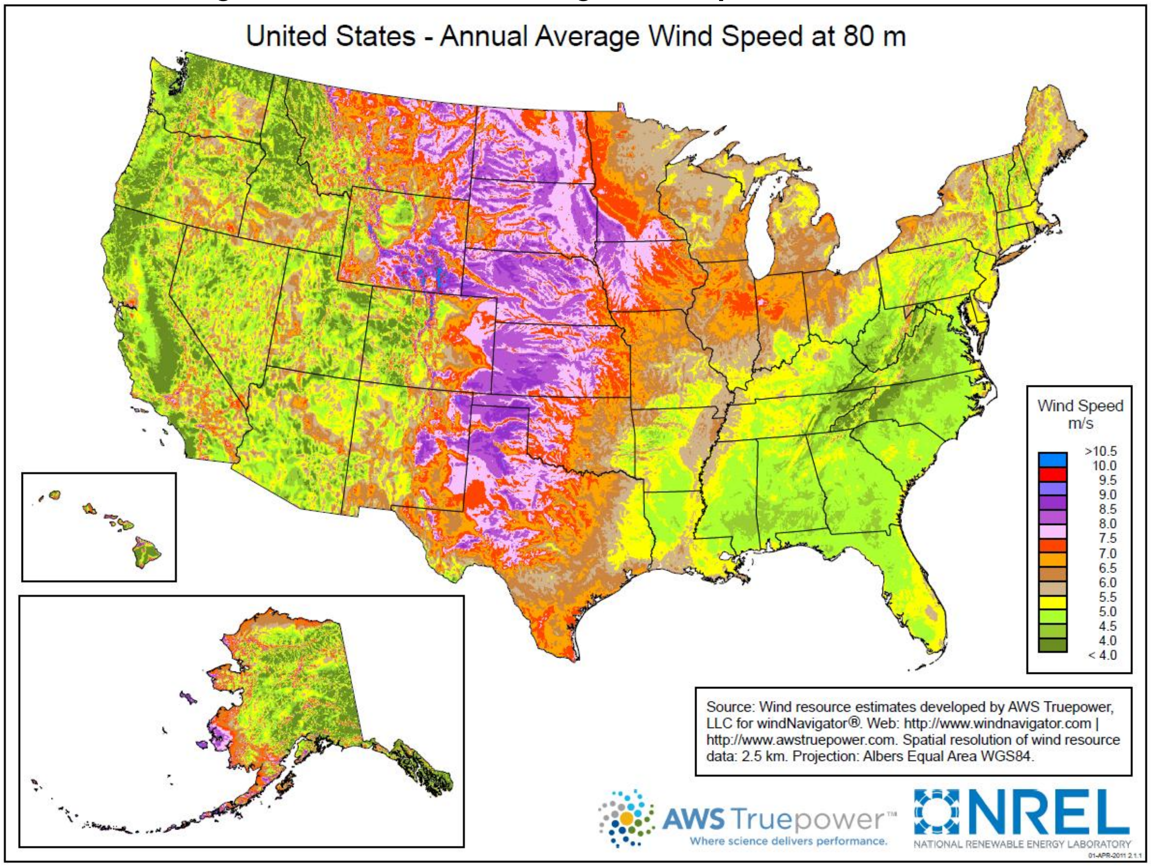
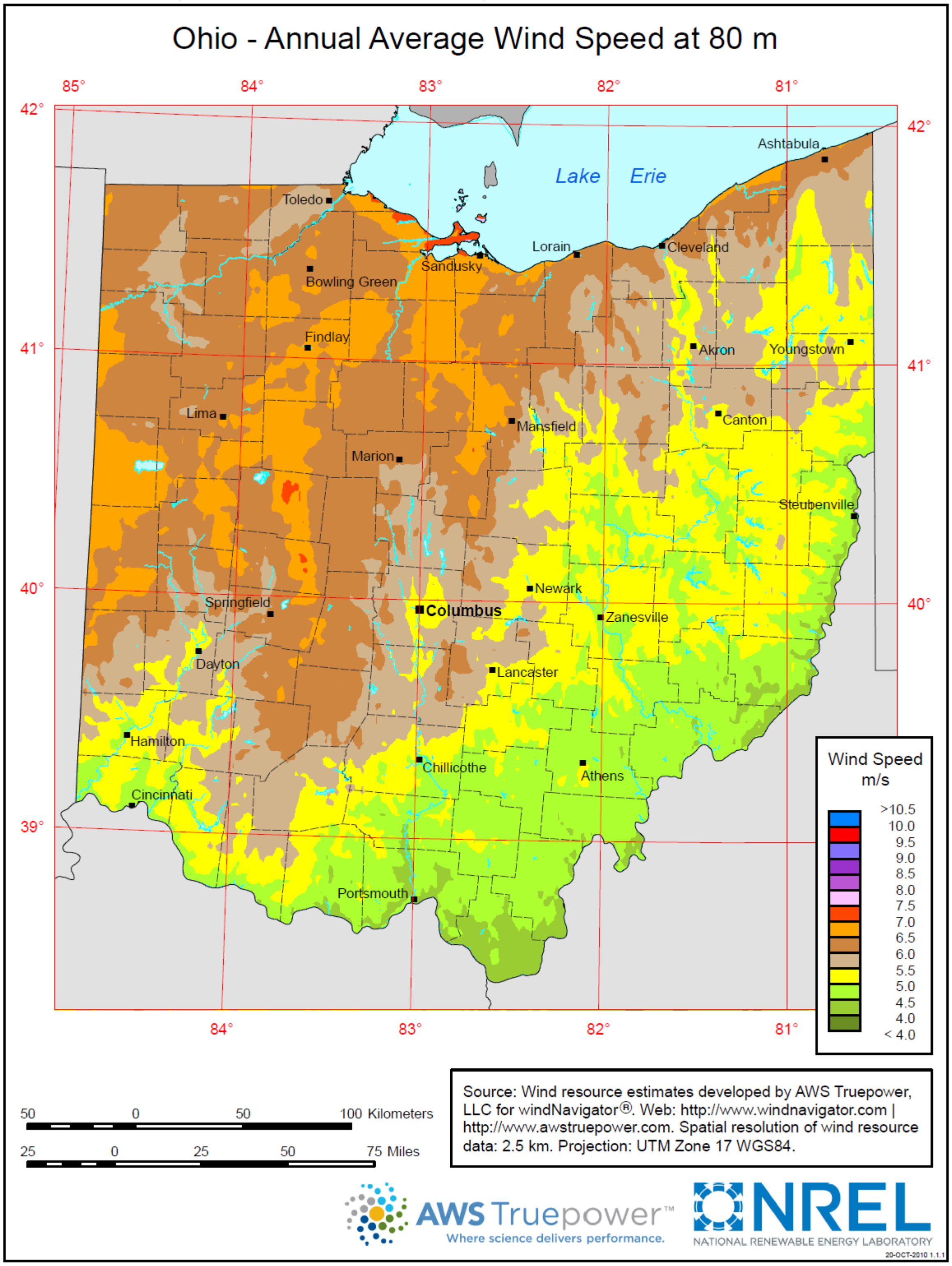
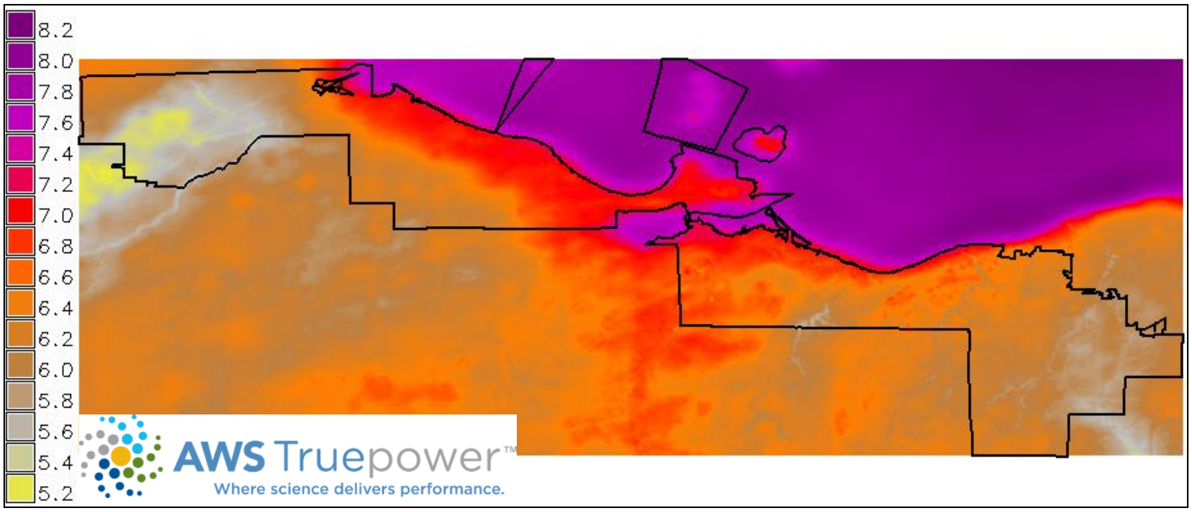


Figure 7: Ohio Annual Average Wind Speed at 80 meters



In order to get a closer look at wind speeds in Ohio's 9th congressional district, wind speed data were obtained, for the region, from AWS Truepower at heights of 30 and 80 meters, and at a spatial resolution of 200 meters. The data were used to create more defined maps of wind speed in the district using shading at 0.20 m/s intervals.

Figure 8: Annual Average Wind Speed at 80 meters for Ohio's 9th Congressional District in m/s



Source: wind resource data developed by AWS Truepower, LLC (www.awstruepower.com)

From the wind speed maps above, the region occupying the 9th congressional district ranges in wind speed from 5.2 m/s – 8.2 m/s, with the lowest wind speeds found in, and extending southwest of the city of Toledo, south-central Erie County, and mid-central and south-central Lorain County, and the highest wind speeds found on the southern edge of Marblehead, northern Catawba Island, the southern half of Kelley's Island and all of South, Middle and North Bass Islands. "Areas with annual average wind speeds around 6.5 m/s and greater at 80-m height are generally considered to have suitable wind resource for wind development (http://www.windpoweringamerica.gov/filter_detail.asp?itemid=2542)."

It should be noted that during the most recent update to the national wind speed maps, AWS Truepower did discover a substantial overestimation observed at several tall towers in the northern part of Ohio, thus previous maps may be overestimating the resource in this area. The average adjustment applied to Ohio was -0.4 m/s (Brower).

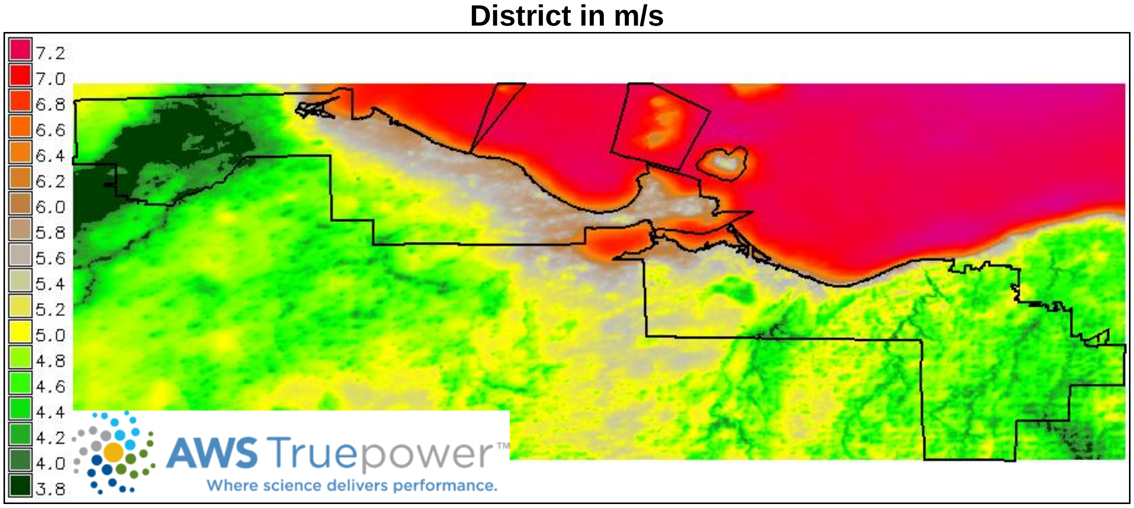
In addition to revising the annual average wind speed, AWS Truepower and NREL also created estimates of gross capacity factor for 200 meter grid points in the lower 48 states. Previously, sites have been categorized using their annual average wind power density, which is a measure of the amount of energy available for conversion to electricity and measured in Watts per square meter [W/m^2]. Capacity factor is the ratio of the amount of power actually produced by the turbine to the amount of power the turbine would produce if it was operating at its rated capacity. The capacity factor is more representative of the power output from a utility scale wind turbine, while the wind power density is a measure of the theoretical energy available in the wind. NREL and AWS singled out locations throughout the U.S. that were estimated to have a gross capacity factor of 30 % or greater at 80 meters. NREL then conducted an analysis of the total available windy land, by eliminating areas unlikely to be developed such as wilderness areas, parks, urban areas, airfields, and water features. The table below shows the results of their analysis for the State of Ohio. Ohio has the potential for 54,919.7 megawatts (MW) of installed wind energy capacity, and an estimated annual production of 151,881 gigawatt hours (GWh). In this latest analysis Ohio ranks as 19th in wind energy potential, when compared to the other 49 states (Estimates of Windy Land Area and Wind Energy Potential).

Table 1: Estimates of Windy Land Area and Wind Energy Potential for Ohio

	Windy Land Area ≥ 30% Gross Capacity Factor at 80 m					**Wind Energy Potential**	
State	**Total (km^2)**	**Excluded (km^2)**	**Available (km^2)**	**Available % of State**	**%of Total Windy Land Excluded**	**Installed Capacity (MW)**	**Annual Generation (GWh)**
Ohio	17,189.9	6,205.9	10,983.9	10.28%	36.1 %	54,919.7	151,881

The above maps, which depict wind speed estimates at a height of 80 meters, are most useful when evaluating the feasibility of utility scale wind turbines which have hub heights near 80 meters. Below is a map of wind speeds at a height of 30 meters, which is more useful when evaluating the feasibility of small or residential scale wind turbines which would be installed at or near 30 meters.

Figure 9: Annual Average Wind Speed at 30 meters for Ohio's 9th Congressional District in m/s

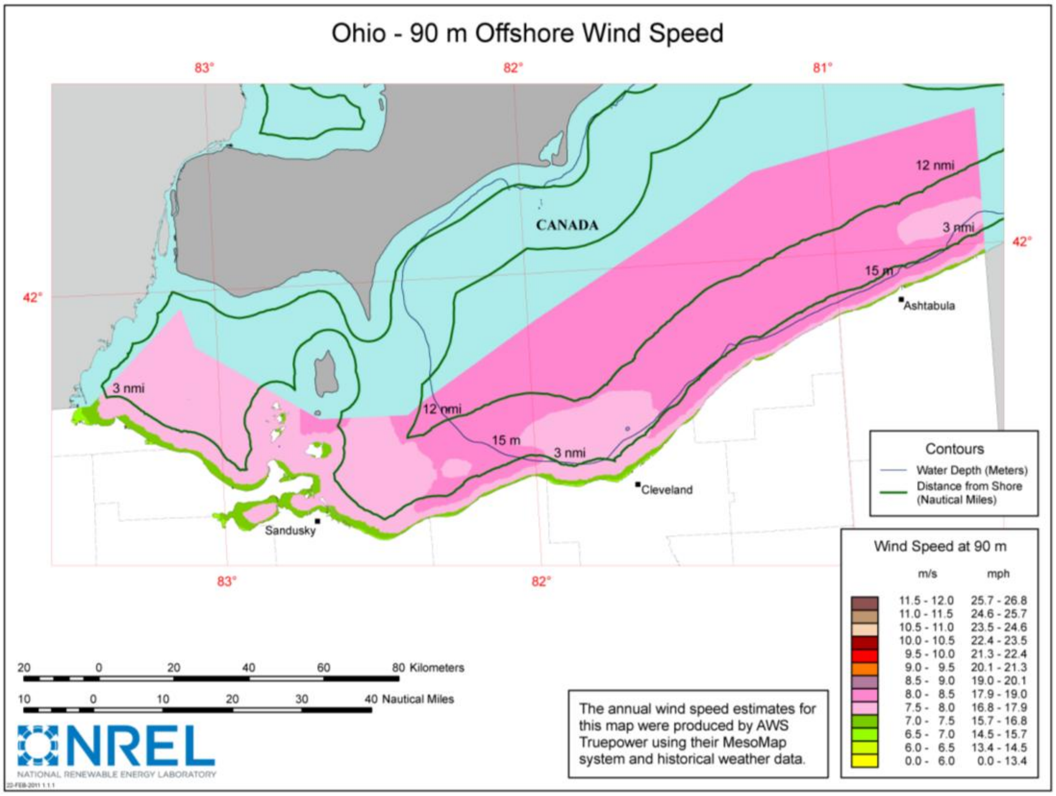


Source: wind resource data developed by AWS Truepower, LLC (www.awstruepower.com)

The region occupying the 9th congressional district ranges in wind speed from 3.8 m/s – 7.2 m/s, at a height of 30 meters.

An offshore map of wind speeds in Lake Erie, at a height of 90 meters, was also obtained from NREL. The western basin of the Lake bordering the 9th congressional district experiences the weakest wind speeds, due to the slowdown effects upwind of the region where the wind encounters the surface roughness from onshore. Locations in the central and eastern portions of the Lake see stronger wind speeds as the wind picks up momentum moving across the Lake as a result of much less surface roughness in the Lake.

Figure 10: Offshore Annual Average Wind Speed at 90 meters for Ohio



Wind Speed Data from GEO's Wind Resource Assessment Studies

Green Energy Ohio, through the Monitoring Ohio Wind Program, the Ohio Anemometer Loan Program, and various state and federal grants, has collected site specific wind speed data, near or at turbine hub heights, from 21 locations throughout Ohio. GEO reviewed site specific wind data collected at three monitoring sites located within Ohio's 9th congressional district. These sites include the Toledo Zoo, Port Clinton, and the NASA Plum Brook Station. GEO also reviewed data collected at sites near the district; these sites include Bowling Green, Lorain, and Sullivan. Below is a map identifying the location of each site. The full data reports for each site discussed in this report are available to Oberlin College upon request.

Figure 11: Map of GEO Wind Monitoring Sites in and near the 9th Congressional District

1. Wind Speed Data from GEO's Monitoring Site at the Toledo Zoo

GEO reviewed wind data that were collected at the Lucas County EMS tower from November 14, 2007 through February 27, 2009, to evaluate the feasibility of wind power at and near the Toledo Zoo.

This monitoring study used an existing 91.5-meter (300-foot) communications tower owned by Lucas County EMS. Measurements were collected at approximately 43, 61, and 79 meters (140, 200 and 260 feet, respectively) above the ground surface for a period of 16 months.

Figure 12: Aerial Image of the Toledo Zoo Test Site

In summary, the Toledo Zoo/Lucas County EMS monitoring site was categorized as a class 1 wind site (Wind Classification rating system developed by the National Renewable Energy Laboratory [NREL]) based on a 50 meter (m) *extrapolated* annual average wind speed of 4.8 meters per second (m/s) (10.7 mph) and a measured 61 m annual average wind speed and wind power density of 5.1 m/s (11.4 mph) and 132.3 Watts per square meter (W/m^2), respectively.

Table 2: NREL Classes of Wind Power Density[1]

Wind Power Class	10 m (33 ft)		50 m (164 ft)	
	Wind Power Density (W/m^2)	Speed[(b)] m/s (mph)	Wind Power Density (W/m^2)	Speed[(b)] m/s (mph)
2	100	4.4 (9.8)	200	5.6 (12.5)
3	150	5.1 (11.5)	300	6.4 (14.3)
4	200	5.6 (12.5)	400	7.0 (15.7)
5	250	6.0 (13.4)	500	7.5 (16.8)
6	300	6.4 (14.3)	600	8.0 (17.9)
7	400	7.0 (15.7)	800	8.8 (19.7)
8	1000	9.4 (21.1)	2000	11.9 (26.6)

Based on these results, GEO noted in the report that the commercial buildings located west of the monitoring site and the residential structures located north, east and south of the monitoring site appeared to significantly affect wind data collected during the study period (i.e., high wind shear and turbulent intensity values). Data from the monitoring site were found to be representative of the wind speeds experienced in the Toledo area over the last 10 years based on comparison to a long term reference site. Below is a summary of 12-month wind statistics for the Lucas County EMS tower site at each height monitored.

Table 3: Toledo Zoo Wind Resource Assessment Summary Statistics

Toledo Zoo Summary Statistics (1/1/08-12/31/08)			
	43 m (140 ft)	**61 m (200 ft)**	**79 m (260 ft)**
Average Wind Speed [mph]	10.1	11.4	12.5
Average Wind Speed [m/s]	4.5	5.1	5.6
Cubic Average Wind Speed [mph]	11.9	13.2	14.3
Cubic Average Wind Speed [m/s]	5.3	5.9	6.4
Prevailing Wind Direction	WSW	W	WSW
Turbulent Intensity [std dev / m/s]	0.22	0.19	0.17
Wind Power Density [W/m^2]	97.3	132.3	160.7
	43 m to 61 m	**61 m to 79 m**	
Wind Shear Exponent	0.3671	0.3443	

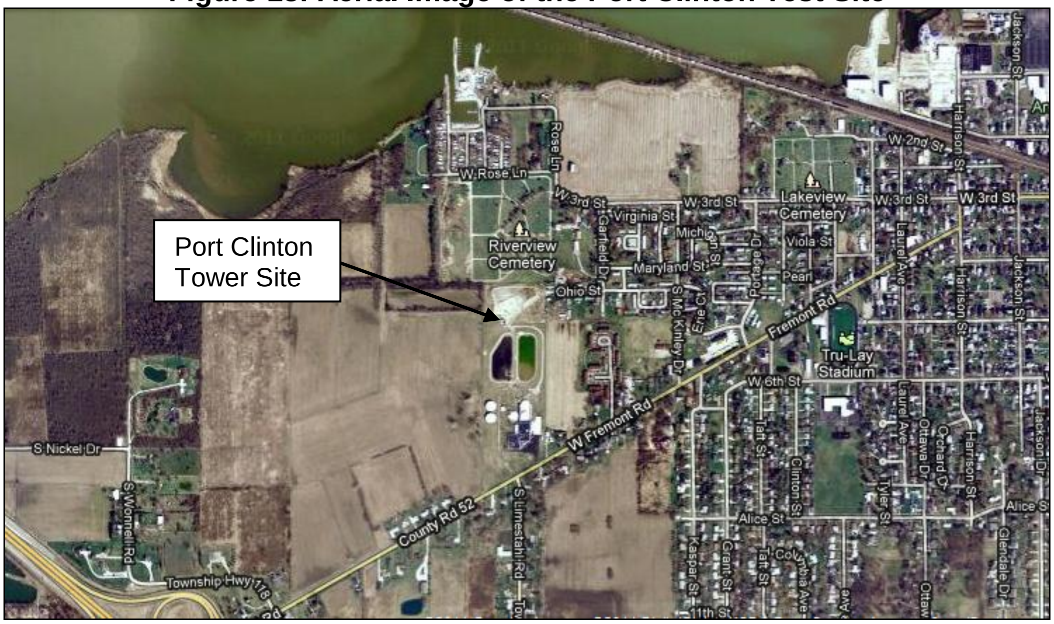
The 79 meter wind speed of 5.6 m/s, measured at the Toledo Zoo, is in agreement with the latest wind speed map shown above, which estimates the annual average wind speed at 80 meters, to be in the range of 5.5 – 6.0 m/s near the site.

[1] http://rredc.nrel.gov/wind/pubs/atlas/tables/A-8T.html (a) Vertical extrapolation of wind speed based on the 1/7 power law. (b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 3%/1,000 m (5%/5,000 ft) elevation.

2. Wind Speed Data from GEO's Monitoring Site at Port Clinton

Wind monitoring equipment was installed on a 645-foot existing communication tower owned by the Ottawa County Board of Commissioners located in Port Clinton, Ohio. Measurements were collected at approximately 38, 73, and 101 meters (168, 238 and 305 feet, respectively) above the ground surface. Data were collected and analyzed between May 14, 2008 and June 7, 2010.

Figure 13: Aerial Image of the Port Clinton Test Site



In summary, the analysis of measured data showed the site to be a high class 1 wind site based on a 50 m extrapolated annual wind speed average of 5.5 m/s (12.2 mph). A historical comparison of the measured data to a long term reference site showed that the period of monitoring (2009) was a low wind speed period. When the measured data was normalized using results of the historical analysis, the 50 m annual average normalized wind speed was 5.9 m/s (13.2 mph), which classifies the site as a class 2 wind site. Thus, a typical year at the site would see an annual average closer to 5.9 m/s, while some years may experience a lower or higher wind speed average.

Table 4: Port Clinton Site Summary Statistics

Port Clinton Summary Statistics (2009)			
	38 m	**73 m**	**101 m**
Average Wind Speed [mph]	11.3	13.7	15.3
Average Wind Speed [m/s]	5.0	6.1	6.8
Cubic Average Wind Speed [mph]	13.3	15.7	17.6
Cubic Average Wind Speed [m/s]	5.9	7.0	7.9
Prevailing Wind Direction	WSW	N/A	SW
Turbulent Intensity [std dev / m/s]	0.18	0.14	0.11
Wind Power Density [W/m^2]	143.3	234.8	328.7
	38 m to 73 m	**73 m to 101 m**	
Wind Shear Exponent	0.2941	0.3772	

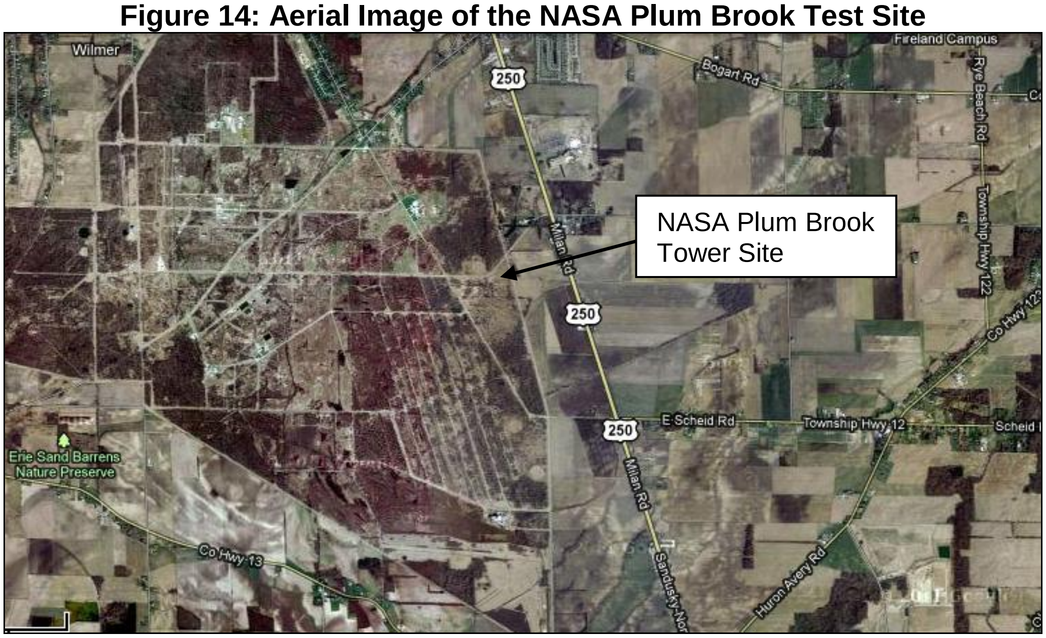
Extrapolating the 73 meter measured wind speed of 6.1 m/s to 80 meters, using the wind shear value of 0.3772, yields an 80 meter extrapolated average wind speed of 6.3 m/s. Applying the percent difference of 7.3 %, determined from the historical comparison yields a value of 6.8 m/s which is slightly below the range estimate depicted in the wind speed map above; 7.0 – 7.5 m/s.

3. Wind Speed Data from GEO's Monitoring Site at the NASA Plum Brook Station

In August 2007, GEO completed successful wind monitoring instrumentation on a 164 foot (50 meter) meteorology tower erected at the NASA Plum Brook Station (PBS) in Huron, Ohio. The site is located in the east-central portion of the PBS and is approximately 1,200 feet south-southwest of the intersection of Fox and Patrol Roads. Thirty-nine months of wind speed, directional and temperature data were collected at the site at heights of 30, 40, and 50 meters.

In summary, the site was found to be a Class 1 wind site based on the 50 m annual wind speed averages of the 3 twelve month periods; 12/1/07 – 11/30/08, 12/1/08 – 11/30/09, 12/1/09 – 11/30/10, which were 4.9, 4.9, and 4.8 m/s, respectively. This rating is confirmed by the annual average Wind Power Density values for each twelve month period of 119.2, 123.4, 113.1 Watts per square meter (W/m^2), respectively.

Figure 14: Aerial Image of the NASA Plum Brook Test Site



Analysis of the collected data suggests that the wooded areas located north, west and south of the monitoring site appeared to significantly affect wind data collected during the study period (i.e., high wind shear and turbulent intensity values). Therefore, the results of this study may not be representative of the potential wind resource available at or near other areas of Plum Brook Station.

Table 5: NASA Plum Brook Station Site Summary Statistics

Plum Brook Summary Statistics			
Average Wind Speed [mph]	**30 m**	**40 m**	**50 m**
2007-2008	8.8	9.9	11.1
2008-2009	9.1	10.0	11.0
2009-2010	9.0	9.9	10.8
Average Wind Speed [m/s]			
2007-2008	3.9	4.4	4.9
2008-2009	4.0	4.5	4.9
2009-2010	4.0	4.4	4.8
Cubic Average Wind Speed [mph]	**30 m**	**40 m**	**50 m**
2007-2008	10.5	11.5	12.7
2008-2009	10.8	11.8	12.8
2009-2010	10.9	11.7	12.6
Prevailing Wind Direction	**40 m**		**50 m**
2007-2008	SSW		SW
2008-2009	SSW		SSW
2009-2010	WSW		WSW
Turbulent Intensity [std dev / mph]	**30 m**	**40 m**	**50 m**
2007-2008	0.24	0.21	0.19
2008-2009	0.23	0.20	0.18
2009-2010	0.21	0.19	0.18
Wind Power Density [W/m^2]	**30 m**	**40 m**	**50 m**
2007-2008	69.4	88.7	119.2
2008-2009	74.9	96.0	123.4
2009-2010	74.8	90.7	113.1
Wind Shear Exponent	**30 m to 40 m**		**40 m to 50 m**
2007-2008	0.4684		0.5143
2008-2009	0.3772		0.4374
2009-2010	0.3289		0.4041

Results of a comparison with a historical reference site indicate that during the 2007-2008 and 2008-2009 monitoring periods, Plum Brook experienced slightly higher wind speeds than the 20-year historical average (the normalized 50 m wind speed was calculated to be 4.8 m/s (10.8 mph) for both time periods). For the monitoring period 2009-2010 Plum Brook showed slightly lower wind speeds than the 20-year historical average (the normalized 50 m wind speed was calculated to be 5.0 m/s (11.1 mph)). Extrapolating the 3-year average normalized 50 meter wind speed of 4.9 m/s to a height of 80 meters, using the 3-year average measured wind shear of 0.4519 yields an average wind speed of 6.1 m/s. The above wind speed map shows that the area near the Plum Brook monitoring site is estimated to be in the range of 6.0 – 6.5 m/s.

4. Wind Speed Data from GEO's Monitoring Site at Bowling Green

Green Energy Ohio conducted a wind monitoring study in cooperation with the Bowling Green Municipal Utility from the period September 1999 to November 2000. The purpose of the study was to gather wind data that could be used to evaluate the feasibility of using wind turbines to generate electrical power for the Bowling Green utility. The location chosen for this study was at the NW corner of Poe and Green Roads, northwest of downtown Bowling Green. Meteorological data, including wind speed at heights of 49.6 m, 48.7 m, 39.8 m, and 30.1 m, wind direction at heights of 49.4 m and 30.1 m, and temperature, were collected for the period November 1999 through October 2000, comprising one complete year. Historical wind data from Dayton and Toledo were used as a comparison. Overall, the site was found to be a Class 2 wind site when the historical data were considered.

Figure 15: Aerial Image of the Bowling Green Test Site

Table 6: Bowling Green Site Summary Statistics

Bowling Green Summary Statistics (11/1/99 – 10/31/00)			
	30 m	**40 m**	**50 m**
Average Wind Speed [mph]	N/A*	N/A*	13.0
Average Wind Speed [m/s]	N/A*	N/A*	5.8
Cubic Average Wind Speed [mph]	N/A*	N/A*	15.0
Cubic Average Wind Speed [m/s]	N/A*	N/A*	6.7
Prevailing Wind Direction	SSW	N/A	SSW
Turbulent Intensity [std dev / m/s]	N/A*	N/A*	N/A
Wind Power Density [W/m^2]	N/A*	N/A*	197
	30 m to 40 m	**40 m to 50 m**	
Wind Shear Exponent	0.32	0.65	

Annual average statistic data from the 30 meter and 40 meter heights were not compiled for the Bowling Green final report.

The wind speed maps above show the Bowling Green monitoring site to be in the range of 6.0 – 6.5 m/s at a height of 80 meters. Extrapolating the Bowling Green 50 meter wind speed to 80 meters using the more conservative wind shear of 0.32 yields a wind speed average of 6.7 m/s, slightly higher than the wind speed map estimated range.

5. Wind Speed Data from GEO's Monitoring Site at Lorain

On May 19, 2009, GEO completed successful wind monitoring instrumentation on a 104-meter (342-foot) communication tower at the FirstEnergy Power Plant at 7017 West Erie Ave. The goals of the study were to evaluate the near-shore wind resource, compare the resource to data taken offshore at the Cleveland Water Intake Crib, and to help spur in-lake or near-lakeshore wind development near the monitoring site. The project was a part of The Great Lakes Tall Tower Wind Monitoring Project and was funded by a U.S. Department of Energy (DOE) grant channeled through the State of Wisconsin[2]. The project involved collecting 12 months of wind data from an existing tall tower (at least 100 meters in height), within 0.5 miles of Lake Erie. The monitoring site is located in a wooded area just southeast of the FirstEnergy West Lorain Plant. The tower is about 0.5 mile directly south of Lake Erie. Twelve months of wind speed, directional and temperature data were collected at the site at heights of 51 m, 73 m and 93 m (168, 238 and 305 feet, respectively). The study officially ended on May 31, 2010.

[2] GEO was awarded a grant from the Ohio Lake Erie Commission as part of their Lake Erie Protection Fund. Without this grant to supplement the DOE grant budget, the project would not have been feasible.

Figure 16: Aerial Image of the Lorain Test Site

In summary, the Lorain site was found to be a class 1 wind site based on a 51 m measured yearly wind speed average of 4.8 m/s (10.7 mph) and a wind power density of 109.9 Watts per square meter (W/m^2). Results of a historical comparison of the data to a long term reference site showed that the period of monitoring (6/1/09-5/31/10) was a low wind speed period. The historical analysis yielded a normalized 51 m annual average wind speed of 5.3 m/s (11.8 mph), which still classifies the site as a class 1 wind site.

Table 7: Lorain Site Summary Statistics

Lorain Summary Statistics (6/1/09-5/31/10)			
	51 m	**73 m**	**93 m**
Average Wind Speed [mph]	10.7	12.4	13.8
Average Wind Speed [m/s]	4.8	5.5	6.2
Cubic Average Wind Speed [mph]	12.5	14.5	16.1
Cubic Average Wind Speed [m/s]	5.6	6.5	7.2
Prevailing Wind Direction	WSW	WSW	SW
Turbulent Intensity [std dev / m/s]	0.21	0.17	0.14
Wind Power Density [W/m^2]	109.9	172.8	235.3
	51 m to 73 m	**73 m to 93 m**	
Wind Shear Exponent	0.4575	0.4389	

High wind shears and moderate turbulent intensities measured at the site indicate that the site is surrounded by surface roughness that is impeding the wind flow and creating excess turbulence. Higher turbulent intensity results in more stress on turbine components and less efficient energy conversion. Though a high wind shear means the wind speed is increasing more rapidly with height, it is also indicative of obstruction to the wind flow.

Beyond the high wind shears and moderate turbulent intensity values, the wind speeds measured at the site were found to be lower than those predicted by the wind speed maps above, which predict the area to be in the range of 6.0 – 7.0 m/s at 80 meters. Extrapolating the 73 meter and 93 meter measured wind speeds to 80 meters, using the measured wind shear of 0.4389, yields wind speeds of 5.7 and 5.8 m/s, respectively. Adjusting the extrapolated 80 meter wind speed using the percent difference (~ 10%) determined from the historical normalization discussed earlier, yields a normalized extrapolated wind speed of 6.3 and 6.4 m/s, which falls in the range predicted by the wind speed maps. The wooded areas surrounding the tower, the abandoned Ford plant facility to the west and southwest, and the various microwave dishes occupying the tower, appear to be impeding the wind flow and are causing lower wind speed values than expected, high wind shear values, and moderate turbulent intensity values.

GEO investigated other near-shore towers throughout the state to use for this project. However, these towers were eliminated because they were located beyond 0.5 mile of Lake Erie (U.S. DOE grant requirement), were too short, and/or the tower owner would not provide access for GEO's wind monitoring equipment for the duration of the study. The tower used for this study was not ideal but met the U.S. DOE grant requirements and also represented a part of Ohio from which very little to no wind data existed at wind turbine hub heights.

Figure 17: View of FirstEnergy Tower and Microwave Dishes during installation activities at Lorain

6. Wind Speed Data from GEO's Monitoring Site at Sullivan

On December 23, 2005, GEO completed successful wind monitoring instrumentation on a 400 ft communications tower owned by Verizon Wireless and located 0.25 miles southeast of the intersection of U.S. Highway 224 and State Route (SR) 58 in Sullivan, Ohio. The City of Sullivan and Verizon Wireless partnered with GEO on the project, which ran through October 31, 2007. In all, 22 months of wind speed, directional and temperature data were collected at the site at heights of 40 m, 80 m and 106 m.

Figure 18: Aerial Image of the Sullivan Test Site

In summary, the Sullivan monitoring site was found to be a class 1 wind site based on an extrapolated 50 m annual wind speed average of 5.3 m/s. However, a historical data comparison showed a normalized 50 m extrapolated wind speed of 5.7 m/s, which classifies the site as class 2.

Table 8: Sullivan Site Summary Statistics

Sullivan Summary Statistics (9/1/06-8/31/07)			
	40 m	**80 m**	**106 m**
Average Wind Speed [mph]	10.7	13.4	14.5
Average Wind Speed [m/s]	4.8	6.0	6.5
Cubic Average Wind Speed [mph]	12.5	15.7	17.0
Cubic Average Wind Speed [m/s]	5.6	7.0	7.6
Prevailing Wind Direction	W	W	W
Turbulent Intensity [std dev / m/s]	0.19	0.15	0.13
Wind Power Density [W/m^2]	114.7	213.8	275.9
	40 m to 80 m	**80 m to 106 m**	
Wind Shear Exponent	0.3435	0.2812	

The wind speed maps above estimate the annual wind speed average near the Sullivan site to be in the range of 6.0 – 6.5 m/s. The 80 meter measured wind speed at the site was 6.0 m/s; on the low end of the estimation, but again, the monitoring period was found to be a low wind speed period.

Installed Wind Energy System Production Estimates

Production estimates were reviewed from installed wind energy systems in the district. Following is a table of annual production estimates for two example solar energy systems installed in the district. The data were gathered from applications for eligible Ohio renewable energy resource generating facilities, filed with the Public Utilities Commission of Ohio (PUCO).

Table 9: Annual Production Estimates of Two Example Wind Energy Systems

City	County	Generating Capacity (kW)	Manufacturer	Estimated Production (kWh)	Estimated Capacity Factor (%)	PUCO Case Number
Swanton	Lucas	10	Merrick Machine	13,456	15.36	11-0990
Marblehead	Ottawa	400	TurboWind	550,000	15.70	10-0470

Solar Resource

The amount of solar radiation that any given point on the earth's surface receives is dependent on the season, the location's latitude, and the composition of the atmosphere that acts to reflect, absorb, or transmit the radiation. As latitude increases (moving from south to north), the solar radiation reaching the earth decreases. This is a result of the radiation from the sun becoming more diffuse at higher latitudes. The composition of the atmosphere also affects the amount of solar radiation that reaches the surface; atmospheric water vapor, trace gases, aerosols and cloud cover act to either transmit the radiation to the surface, absorb it, or reflect it back into space.

Solar Resource Maps from the National Renewable Energy Laboratory

The National Renewable Energy Lab (NREL) maintains several resources for solar radiation data and maps. The most useful data and maps, for the purposes of this report, are the annual photovoltaic solar radiation, at a resolution of 10km. The map provides annual average daily total solar resource averaged over surface cells of 0.1 degrees in both latitude and longitude, or about 10 km in size. Maps of monthly averages are also available from NREL (http://www.nrel.gov/gis/solar.html). The insolation (measure of solar radiation received on a given surface) values represent the resource available to a fixed flat plate system tilted towards the equator at an angle equal to the latitude of the location. The data are created using the State University of New York/Albany satellite radiation model developed by Richard Perez and collaborators at the National Renewable Energy Lab and other universities for the U.S. Department of Energy. "Specific information about this model can be found in Perez, et al. (2002). This model uses hourly radiance images from geostationary weather satellites, daily snow cover data, and monthly averages of atmospheric water vapor, trace gases, and the amount of aerosols in the atmosphere to calculate the hourly total insolation (sun and sky) falling on a horizontal surface. Atmospheric water vapor, trace gases, and aerosols, are derived from a variety of sources. The procedures for converting the collector at latitude tilt are described in Marion and Wilcox (1994). Where possible, existing ground measurement stations are used to validate the data (http://www.nrel.gov/gis/solar_map_development.html)." Figure 19 below is a national map of annual average solar resource for a south facing flat plate collector with a tilt angle equal to the site's latitude. As expected, the region of the country receiving the most solar insolation is the southwest, and the region of the county receiving the least solar insolation is the northeast. Figure 20 below depicts the solar insolation data for Ohio's 9th Congressional District. As the map shows, the solar resource is homogeneous throughout the district, and is in the range of 4.0 – 4.5 kWh/m^2/day.

Figure 19: U.S. Annual Average Solar Resource Data for a Flat Plate Collector Tilted South at Latitude

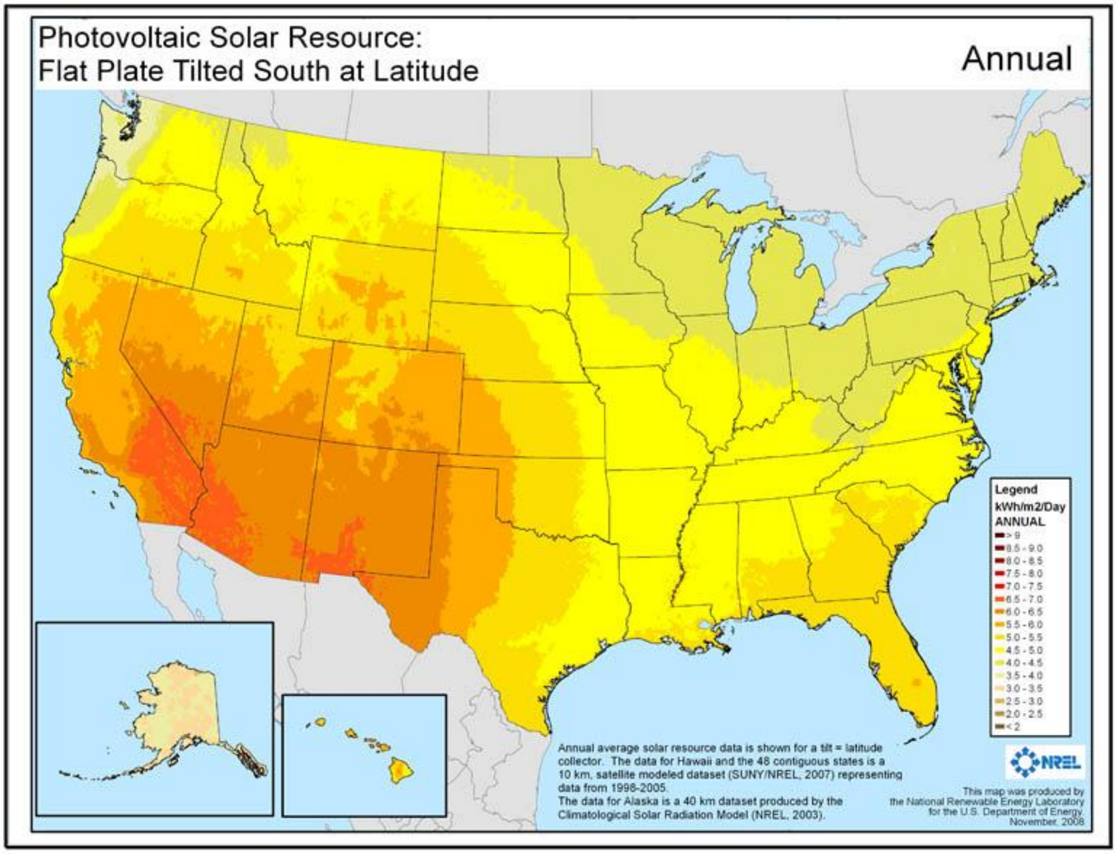
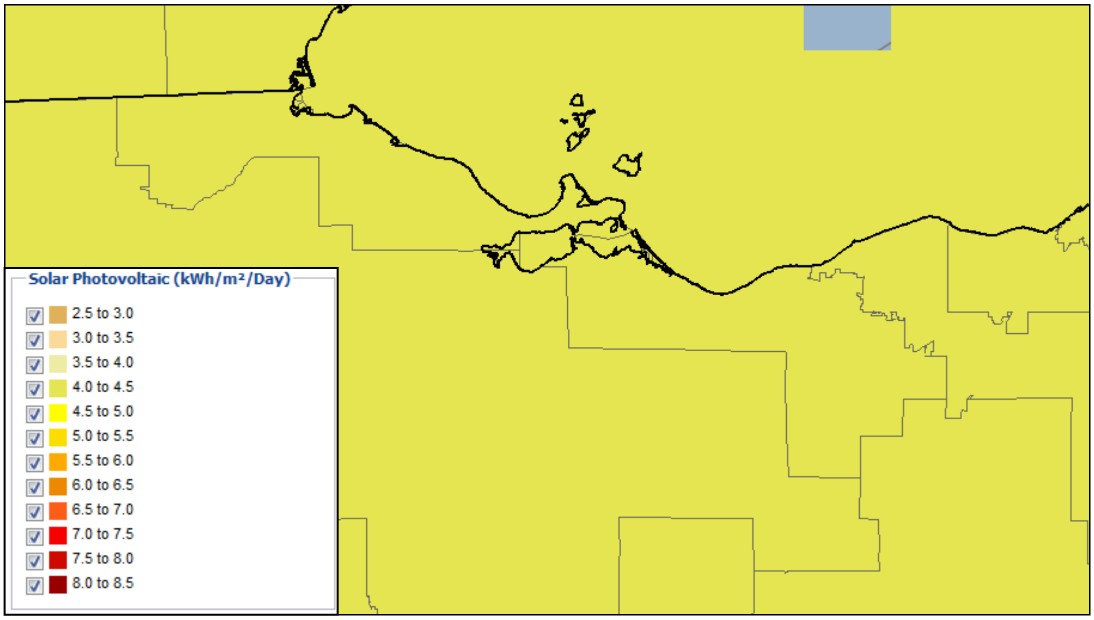


Figure 20: Ohio's 9th Congressional District Annual Average Solar Resource Data for a Flat Plate Collector Tilted South at Latitude



Installed Solar Energy System Production Estimates

Production estimates were reviewed from solar energy systems in the district. Following is a table of annual production estimates for eight example solar energy systems installed in the district. The data were gathered from applications for eligible Ohio renewable energy resource generating facilities, filed with the Public Utilities Commission of Ohio (PUCO).

Table 10: Annual Production Estimates of Eight Example Solar Energy Systems

City	County	Generating Capacity (kW)	Manufacturer	Estimated Production (kWh)	Estimated Capacity Factor (%)	PUCO Case Number
Milan	Erie	4.7	Sharp	6,500	15.78	10-2418
Milan	Erie	11.232	Sharp	13,000	13.20	10-0339
Holland	Lucas	4.3	First Solar	6,000	17.0	09-0910
Maumee	Lucas	1.988	Sharp	2,186.8	13.13	11-0325
Perrysburg	Lucas	2440	First Solar	2,861,110	13.4	10-0134
Toledo	Lucas	101	First Solar	120,000	15.7	09-1964
Toledo	Lucas	248.6	SolarWorld	316,593	14.5	10-1380
Elmore	Ottawa	6.0	Sharp	3,700	7.0	10-2496

Conclusions

This report describes the results of a wind and solar resource evaluation of Ohio's 9th Congressional District.

From the wind speed maps above, the region occupying the 9th congressional district ranges in wind speed, at a height of 80 meters, from 5.2 m/s – 8.2 m/s, with the lowest wind speeds found in, and extending southwest of the city of Toledo, south-central Erie County, and mid-central and south-central Lorain County, and the highest wind speeds found on the southern edge of Marblehead, northern Catawba Island, the southern half of Kelley's Island and all of South, Middle and North Bass Islands. At a height of 30 meters, the region ranges in wind speed from 3.8 m/s – 7.2 m/s.

When comparing data collected at GEO's monitoring sites to the wind speed maps, the measured wind speed averages at the Toledo Zoo, NASA Plum Brook, and Sullivan were all in agreement with the estimates in the wind speed maps. This comparison is useful in providing validation to the wind speed maps.

Measurements at the monitoring sites at Port Clinton and Lorain, were found to be lower than those predicted by the wind resource map, while the measurements from the Bowling Green monitoring site were found to be higher than predicted. This comparison is useful in demonstrating the annual and site-specific variability from the wind speed map estimates, and the importance of choosing a good site for site specific wind speed measurements.

The solar resource maps obtained show the available solar resource to be homogonous across the 9th district at 4.0 – 4.5 kWh/m^2/day.

Works Cited

Brower, Michael. "New U.S. Wind Energy Potential Estimates; Background and Explanation of Changes from Prior Estimates." *AWS Truepower*. 17 May 2010. Web. 13 Jun. 2011. < http://www.awstruepower.com/wp-content/media/2010/09/New-US-Wind-Energy-Potential-Estimates.pdf>.

"Estimates of Windy Land Area and Wind Energy Potential, by State, for areas ≥ 30% Capacity Factor at 80m." *Wind Powering America*. U.S. Department of Energy. 4 Feb. 2010. Web. 13 Jun. 2011. <http://www.windpoweringamerica.gov/docs/wind_potential_80m_30percent.xls>.