Advanced Wind Technology

Elevated Opportunities for the South

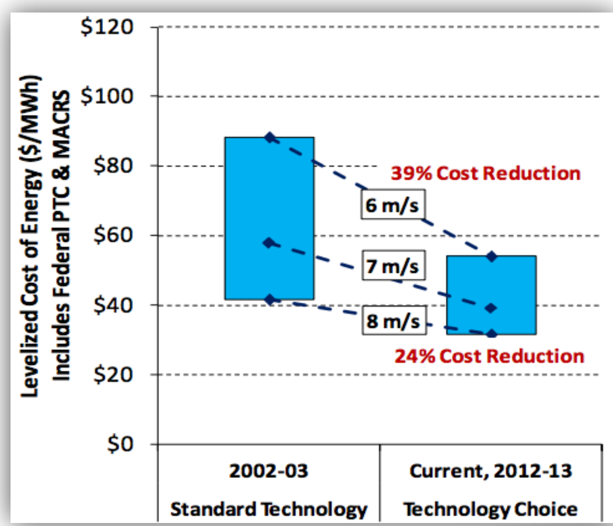
The South is a new frontier for the wind industry. Advanced wind turbine technology and reduced costs have expanded the resource potential and have made wind energy economically feasible in more places in the Southern United States.

Improved Turbines

The biggest changes in wind turbine technology over the past five years include taller turbines and longer blades. Just five years ago, wind turbines with a hub height of 80 meters (about 260 feet) and blade lengths of 40 meters (about 130 feet) were fairly standard. Taller turbines reach stronger, more consistent wind speeds. Hub heights of up to 140 meters (460 feet) are now available for wind farm developers. Longer blades are capable of capturing more wind, thus harnessing slower wind speeds. Blades are now available over 55 meters (180 feet) in length.

Reduced Costs

Wind energy is now one of the least expensive sources of new power generation in the country. Costs have declined by 39% over the past decade for wind speed areas averaging 6 meters per second. This reduced cost particularly applies to the Southeast, a region with typically lower wind speeds. Costs will continue to drop as technology improves.

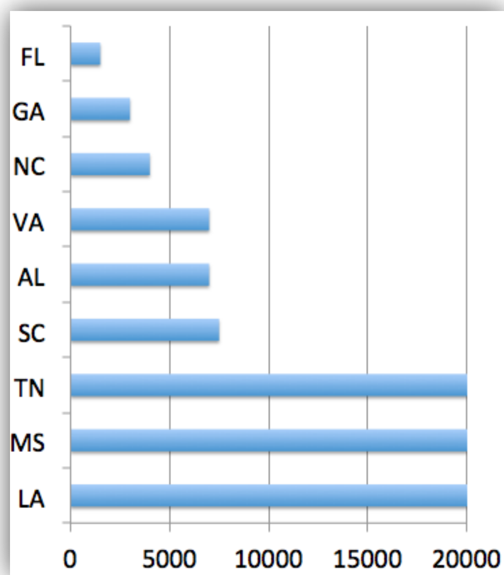


Source: National Renewable Energy Lab 2013

Expanded Potential

With improved turbines and reduced costs, wind farms now make economic sense in all states across the South. **Using currently available wind turbine technology, over 134,000 megawatts (MW) of wind potential exists within the region - about half as much of the total installed electric utility capacity.**

Megawatts of Onshore Wind Potential



Source: Adapted from National Renewable Energy Lab 2013

As can be seen in the chart above, all states in the South now contain substantial onshore wind energy resource potential. The megawatt figure for each state is based on wind energy resources that could achieve 40% annual capacity factors. **Louisiana, Mississippi and Tennessee each contain more than 25,000 megawatts of wind energy potential.** This expanded potential demonstrates a **strong need for updated resource assessments** that accurately reflect wind energy opportunities in the South.

Source

Joseph Owen Roberts (September 2013). Presentation, Land-Based Wind Potential Changes in the Southeastern US, National Renewable Energy Laboratory.

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Low Wind Speed Case Study

Arkansas Wind Energy Resource

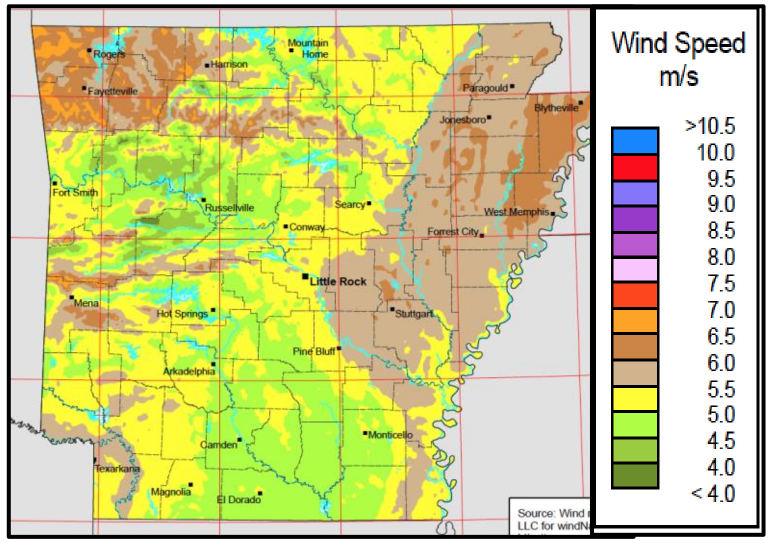
While Arkansas does not currently contain large-scale wind turbines, the state's wind resource potential has been studied. In 2011, AWS Truepower, LLC performed such a study for the Arkansas Economic Development Commission. The year-long study concluded: **"The long-term projected speeds at height of 80 m[eters] and above suggest that commercial wind development in these areas of the State is feasible, in part due to technological advancements in the industry."**

However, the success of a potential wind farm in Arkansas is contrary to the National Renewable Energy Lab's (NREL) popular 80-meter map, which fails to incorporate new turbine technology benefits for low wind speeds areas. This case study compares estimated wind speeds from available wind speed maps, and highlights Arkansas potential to develop wind energy with modern turbine technology.

In 2010, NREL published maps showing state-by-state average annual wind at a height of 80 meters. The image on the right (**Figure 1**) is adapted from NREL's map for Arkansas.

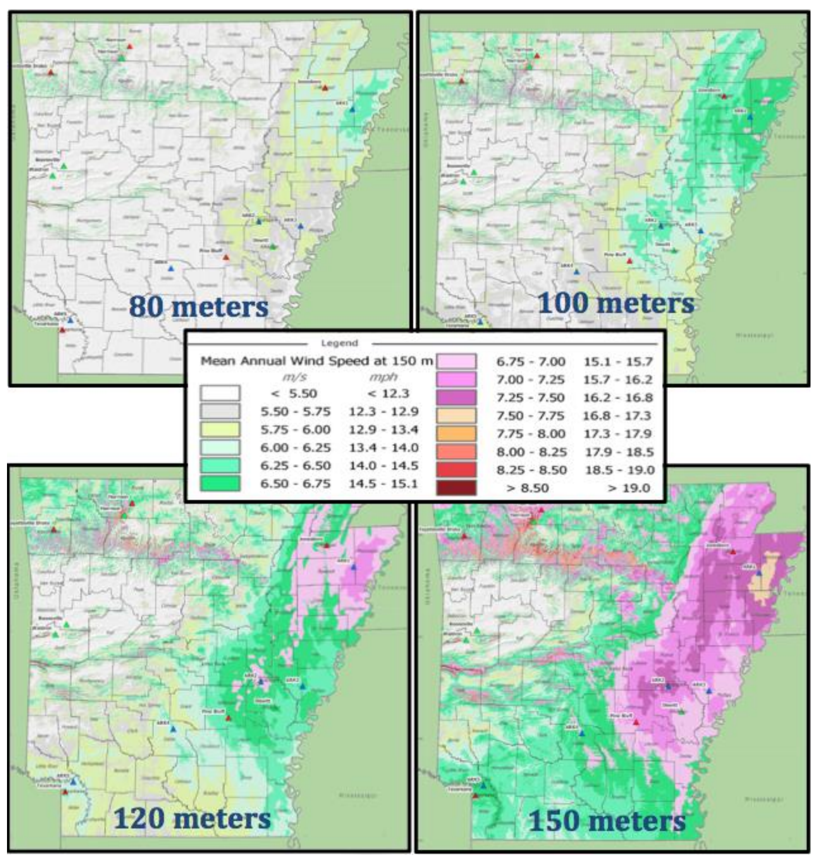
AWS Truepower, LLC identified 5 locations and summarized wind speeds at the end of each month. The information identified from these locations was presented in a final assessment and used to update resource assessment maps in the state (**Figure 2**). According to the study, the long-term wind speeds at 80 meters ranged from 5.25-6.46 meters per second (m/s), similar to wind speeds displayed in the NREL 80 meter map. **At 150 meters, the wind speeds were between 6.56-7.68 m/s, a much higher estimated wind speed compared to NREL's resource map.** As demonstrated, wind speed maps alone cannot predetermine the viability of a wind farm, and specific on-site analysis that factors in modern turbine heights is key to identifying wind energy potential.

Figure 1. Arkansas Average Annual Wind Speeds (80 Meters)



Source: National Renewable Energy Lab 2010

Figure 2. Arkansas Average Annual Wind Speeds at Multiple Heights (80 m, 100 m, 120 m, and 150 m)



Source: AWS Truepower 2012

Low Wind Speed Case Study

Arkansas Wind Energy Resource

Arkansas is traditionally viewed as having a low wind resource, as displayed in the NREL 80 meter map (**Figure 1**). However, newer, taller turbines are opening access to faster and more stable winds higher off the ground. Modern turbines, reaching up to 500 feet (150 meters) make wind energy a viable option in Arkansas. Taller turbines provide higher capacity factors for wind turbines, which increase electricity output and produce lower electricity prices for wind energy.

Figure 3, from the AWS Truepower study, demonstrates the benefits of modern turbine technology. For example, site ARK1, located in northeastern Arkansas, has a projected average wind speed of 6.46 m/s at 80 meters. The NREL 80-meter map (**Figure 1**) suggests a similar average of 6.0-6.5 m/s. Yet, at the same site (ARK1), **taller heights can produce wind speeds of 6.68 m/s at 100 meters, 7.22 m/s at 120 meters, and 7.68 m/s at 150 meters.**

Figure 3. Extrapolation of Climate-Adjusted Speeds to Different Heights

Table 6. Extrapolation of Climate-Adjusted Speeds to Different Heights

Tower Number	Monitoring Height (m)	Climate-Adjusted Speed (m/s)	Effective Wind Shear	Projected 80-m Speed (m/s)	Projected 100-m Speed (m/s)	Projected 120-m Speed (m/s)	Projected 150-m Speed (m/s)
ARK1	76.3	6.31	0.274	6.46	6.87	7.22	7.68
ARK2	70.8	5.67	0.416+/0.374++	5.97	6.55	7.01	7.62
ARK3	96.1	5.76	0.396*/0.357**	5.36	5.84	6.24	6.75
ARK4	96.4	6.05	0.437*/0.393**	5.58	6.14	6.60	7.20
ARK5	86.3	5.39	0.356	5.25	5.68	6.06	6.56

+Shear applied for 80 m and 100 m hub height wind speed estimates

++Shear reduced by 10% and used to estimate wind speeds at the 120 m and 150 m heights

*Shear applied for 80 m hub height wind speed estimate.

**Shear reduced by 10% and used to estimate wind speeds at heights above top monitoring level.

Source: AWS Truepower 2012

How important is wind speed?

Electricity generation from a wind turbine is not linear; in other words, a doubling of wind speed does not double electricity generation. A 1 m/s increase in average wind speed has a greater effect on electricity generation between a wind turbine's "cut-in" wind speed (when the turbine begins to spin) and its "nominal" wind speed (when it reaches maximum production). **A 1 m/s increase in average wind speed can substantially increase electricity generation at a wind farm.**

Two monitoring towers in Arkansas used to collect data on wind speeds. Credit: AWS Truepower, LLC

Conclusions

Wind turbine technology has rapidly evolved over the past five years. New turbine technology is better able to capture low-wind energy resources.

The resource assessment maps, like NREL's 80-meter maps, are often used to initially assess a site for wind farm development. However, these maps alone are not adequate for determining the success of a wind farm, and may underestimate wind speeds in places like Arkansas. Other areas that could be characterized as "low wind speed," according to the resource assessment maps, may have similar pockets of good wind speed that may be ideal for consideration of wind power development, especially as newer wind turbine technology achieves greater efficiency.

Sources

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Low Wind Speed Case Study

Buffalo Mountain Wind Farm

The Buffalo Mountain Wind Farm is the Southeast's first and currently only wind farm. Located near Oak Ridge, Tennessee, the Tennessee Valley Authority (TVA) began this project in 2000 with three turbines. In 2004, wind farm development company Invenergy expanded the project to include fifteen additional turbines. The electricity from the 27-megawatt (MW) project belongs to TVA. **The Buffalo Mountain Wind Farm has been successful, producing enough energy to power 3,400 homes a year.** However, the success of this wind farm is contrary to the data that is publicly available via wind speed maps, which underestimate the onsite wind speeds. This case study compares estimated wind speeds from the National Renewable Energy Lab's (NREL) popular 80-meter wind speed maps with available information about the Buffalo Mountain Wind Farm.

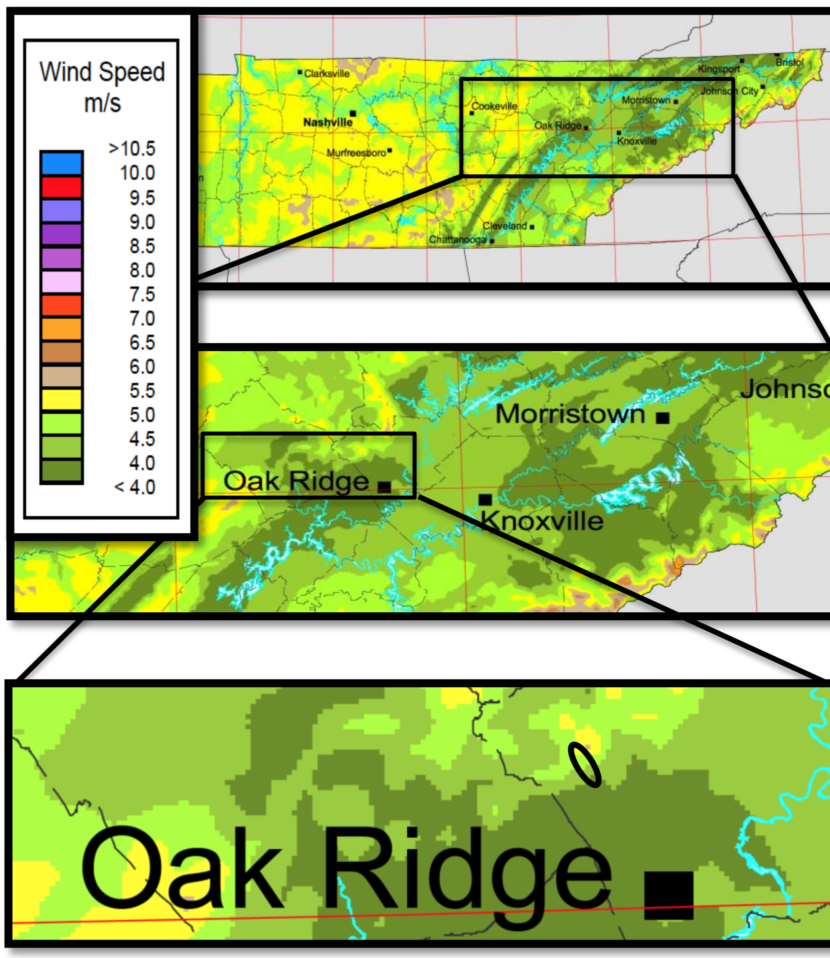
In April 2002, TVA conducted an environmental assessment for the Buffalo Mountain Wind Farm expansion that included collected wind speed data onsite. **According to TVA, average monthly wind speeds at a height of 50 meters ranged from a low of 4.4 meters per second (m/s) to a high of 7.8 m/s. That assessment may suggest average annual wind speeds of around 6 m/s at Buffalo Mountain.**

In 2010, NREL published maps showing state-by-state average annual wind at a height of 80 meters. The images on the right (**Figure 1**) are adapted from NREL's map for Tennessee. The Buffalo Mountain Wind Farm is represented by the black oval in the bottom image. **This map inaccurately represents the Buffalo Mountain Wind Farm site average annual wind speeds in the 4.0-5.0 m/s range.** While difficult to gauge, this is the most accurate prediction that can be made by this resource.

As demonstrated, wind speed maps alone cannot predetermine the viability of a wind farm.

Credit: NREL (Buffalo Mountain Wind Project, Tennessee)

Figure 1. Tennessee Average Annual Wind Speeds (80 Meters)



Source: National Renewable Energy Lab 2010

Low Wind Speed Case Study

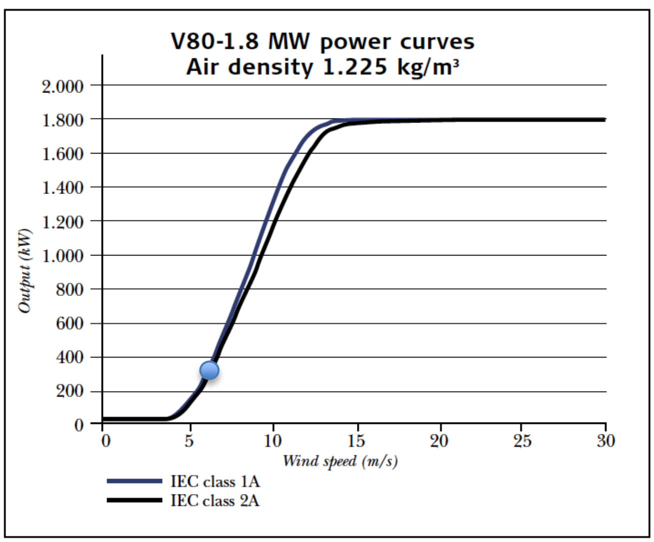
Buffalo Mountain Wind Farm

With conflicting average wind speed estimates from the NREL map and the TVA environmental assessment, additional information is necessary. Fortunately, data exists from the Buffalo Mountain Wind Farm and the specific turbine model used on site. Actual wind speeds can be deduced using these two data sources.

In 2012, the Buffalo Mountain Wind Farm generated approximately 48,000 megawatt hours of electricity from the fifteen turbines constructed by Invenergy. Each turbine is rated for a maximum output of 1.8 megawatts per hour, indicating that the wind farm achieved a 20% capacity factor. Therefore, each wind turbine's average hourly output was approximately 360 kilowatts (20% of 1.8 megawatts).

Wind turbine manufacturers provide estimates of energy output based on various wind speeds in a graph known as a power curve. In 2004, fifteen V80-1.8 wind turbines (manufactured by Vestas) expanded the Buffalo Mountain Wind Farm. **Based on the V80-1.8 power curve, the Buffalo Mountain Wind Farm site may achieve 6 m/s average wind speeds (see Figure 2).**

Figure 2. Vestas V80-1.8 Power Curve



Source: Vestas V80-1.8 Factsheet

How important is wind speed?

Electricity generation from a wind turbine is not linear; in other words, a doubling of wind speed does not double electricity generation. A 1 m/s increase in average wind speed has a greater effect on electricity generation between a wind turbine's "cut-in" wind speed (when the turbine begins to spin) and its "nominal" wind speed (when it reaches maximum production). **A 1 m/s increase in average wind speed can substantially increase electricity generation at a wind farm.**

Using the NREL estimate of 4.0-5.0 m/s, the Buffalo Mountain Wind Farm should only achieve a capacity factor of approximately 5-10%. **Actual output at the Buffalo Mountain Wind Farm is at least double what would be expected using the NREL map with the estimated wind speed.**

Conclusions

The NREL resource assessment maps are often used to initially assess a site for wind farm development. However, these maps alone are not adequate for determining wind farm success and may underestimate wind speeds in places like the Southeastern United States. The Buffalo Mountain Wind Farm achieves a greater energy output than can be estimated by the NREL resource assessment map, since it assesses such a large area. Other areas that could be characterized as "low wind speed," according to the resource assessment maps, may have similar pockets of good wind speed that may be ideal for consideration of wind power development, especially as newer wind turbine technology achieves greater efficiency.

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Vestas. V80-1.8 Factsheet.

Low Wind Speed Case Study

University of Delaware Wind Turbine

Credit: Evan Krape, UDaily News

The University of Delaware (UD) installed a 2 megawatt Gamesa wind turbine on the Hugh R. Sharp Campus in Lewes, Delaware in June 2010. **UD's turbine has been a success, powering the Lewes campus with a surplus of 1.3 million kilowatt-hours.** However, the success of this wind turbine is contrary to data that is publicly available via wind speed maps, which underestimate the onsite wind speeds. This case study compares estimated wind speeds from the National Renewable Energy Lab's (NREL) popular 80-meter wind speed maps with available information about the UD turbine.

In May 2009, the University of Delaware conducted a feasibility report for wind turbine development, which included an average wind speed resource assessment. **In this report, UD predicted average wind speeds at a height of 80 meters were approximately 6.74 meters per second (m/s).**

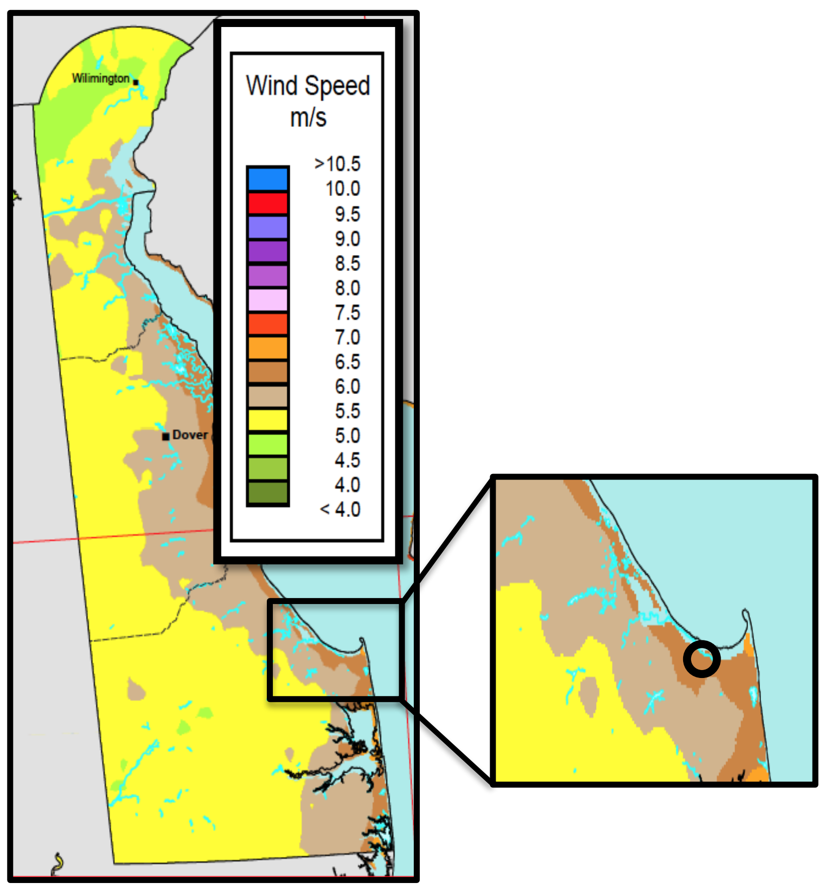
Figure 1. University of Delaware Wind Resource Assessment and Output Modeling

Potential Turbine Location	Mean Wind Speed at Hub Height	Annual Energy Output
Location 1	6.74 m/s	4,023,375 kWh

Source: UD Technical Analysis for On-Site Wind Generation 2009
*[*Note: While 5 locations were analyzed, Location 1 was the closest to the current site of the UD turbine.]*

In 2010, NREL published maps showing state-by-state average annual wind speeds at a height of 80 meters. The images on the right are adapted from NREL's map for Delaware. The UD Lewes' turbine location is represented by the black circle in the image on the far right. **This map inaccurately represents the UD wind turbine site average annual wind speed of approximately 6.0 m/s.** While difficult to gauge, this is the most accurate prediction that can be made by this resource. **As demonstrated, wind speed maps alone cannot predetermine the viability of a wind project.**

Figure 2. Delaware Average Annual Wind Speeds (80 Meters)



Source: National Renewable Energy Lab 2010

Low Wind Speed Case Study

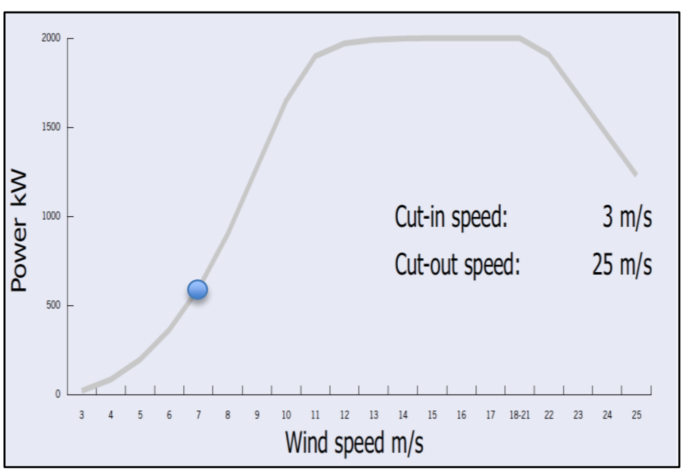
University of Delaware Wind Turbine

With conflicting average wind speed estimates from the NREL map and the UD feasibility report, additional information is necessary. Fortunately, data exists from the UD turbine and the specific turbine model used on site. Actual wind speeds can be deduced using these two data sources.

From June 2010-May 2011, the UD wind turbine produced 5,100 megawatt-hours of electricity; this figure was better than the approximately 4,023 megawatt-hours estimated. The turbine is rated for a maximum output of 2 megawatts per hour, indicating the wind turbine achieved a 29% capacity factor. Therefore, the wind turbine's average hourly output was approximately 580 kilowatts (29% of 2 megawatts).

Wind turbine manufacturers provide estimates of energy output based on various wind speeds in a graph known as a power curve. **Based on the Gamesa G90 2 megawatt power curve (Figure 3), the UD wind turbine site may achieve 7 m/s average wind speeds.** This estimate is in line with UD's previous estimate of 6.74 m/s and reflects the better-than-expected electricity generation.

Figure 3. Gamesa G90-2.0 MW Power Curve



Source: Gamesa G90-2.0 MW Brochure

How important is wind speed?

Electricity generation from a wind turbine is not linear; in other words, a doubling of wind speed does not double electricity generation. A 1 m/s increase in average wind speed has a greater effect on electricity generation between a wind turbine's "cut-in" wind speed (when the turbine begins to spin) and its "nominal" wind speed (when it reaches maximum production). **A 1 m/s increase in average wind speed can substantially increase electricity generation at a wind farm.**

Using the NREL estimate of 6.0 m/s (**Figure 1**), the UD wind turbine should only achieve a capacity factor of approximately 15-20%. **Actual output at the UD wind turbine site is approximately double what would be expected using the NREL map with the estimated wind speed.**

Conclusions

The NREL resource assessment maps are often used to initially assess a site for wind farm development. However, these maps alone are not adequate for determining wind farm success and may underestimate wind speeds in places like Delaware. The UD wind turbine achieves a greater energy output than can be estimated by the NREL resource assessment map.

Sources

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Gamesa. G90-2.0 MW Brochure.

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Low Wind Speed Case Study

Narragansett Bay Commission Field's Point Wind Energy Project

Three large-scale wind turbines were installed in 2012 to provide power for Narragansett Bay Commission's (NBC) Field's Point wastewater treatment plant in Providence, Rhode Island. Even though the wind turbines had a restricted capacity of 900 kilowatts (instead of the full 1.5 megawatt potential) during initial operation, the wind turbines' first year of operation was successful, **producing 6,700 megawatt hours (MWh) of electricity.** The success of this wind farm is contrary to data that is publicly available via wind speed maps, which underestimate the onsite wind speeds. This case study compares estimated wind speeds from the National Renewable Energy Lab's (NREL) popular 80-meter wind speed maps with available information about the NBC Field's Point Wind Energy Project.

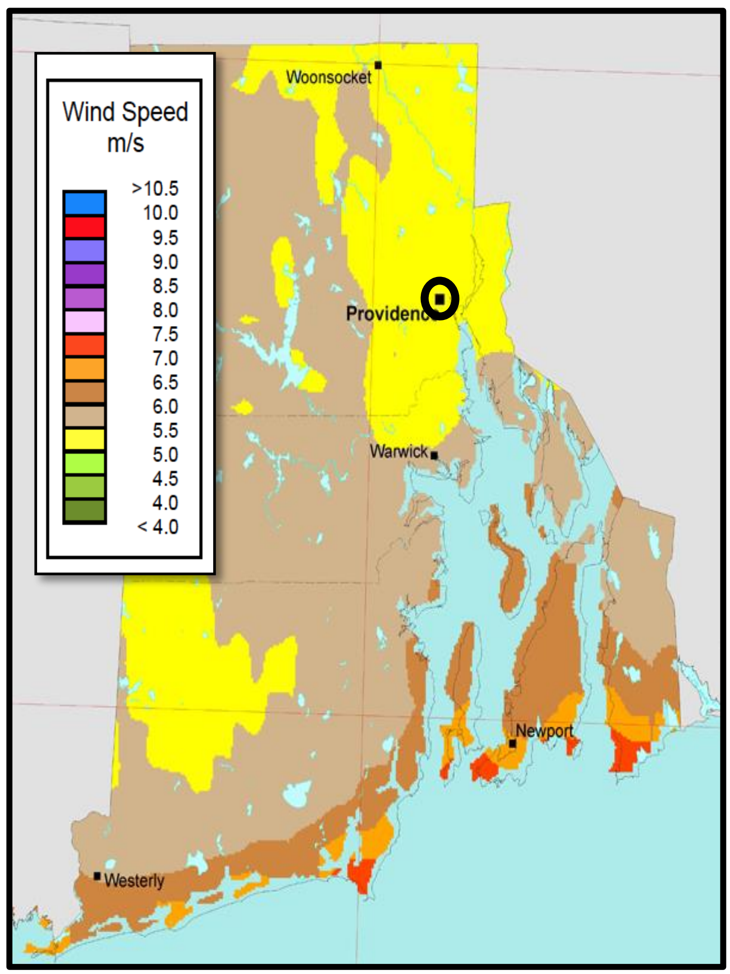
NBC began evaluating wind energy as early as 2005, commissioning Roger Williams University to conduct a 24-month Wind Energy Feasibility study. Roger Williams University installed a meteorological tower on site to assess wind speeds. **The study estimated that three 1.5 MW wind turbines could provide an estimated 7,000 MWh of electricity per year. The study would suggest the site has an average wind speed of about 6 meters per second (m/s) at a 70-meter hub height.**

In 2010, NREL published maps showing state-by-state average annual wind speeds at a height of 80 meters. The image on the right is adapted from NREL's map for Rhode Island (**Figure 1**). Field's Point wastewater treatment plant in Providence is represented by the black circle. **This map inaccurately represents the site average annual wind speeds of approximately 5.0 m/s at an 80-meter hub height.** While difficult to gauge, this is the most accurate prediction that can be made by this resource.

As demonstrated, wind speed maps alone cannot predetermine the viability of a wind farm.

Credit: Mary Murphy, The Providence Journal

Figure 1. Rhode Island Annual Wind Speeds (80 Meters)



Source: National Renewable Energy Lab 2010

Low Wind Speed Case Study

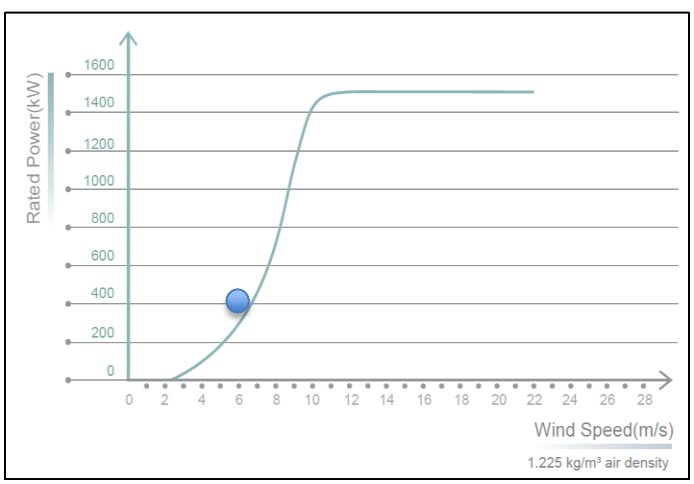
Narragansett Bay Commission Field's Point Wind Energy Project

With conflicting average wind speed estimates from the NREL map and the NBC Wind Energy Feasibility study, additional information is necessary. Fortunately, data exists from the NBC Field's Point Wind Project and the specific turbine model used on site. Actual wind speeds can be deduced using these two data sources.

After a year of operation, the NBC Field's Point Wind Project generated approximately 6,700 megawatt hours of electricity. Each turbine is rated for a maximum output of 1.5 megawatts per hour, indicating approximately a 17% capacity factor. Therefore, each wind turbine's average hourly output was approximately 255 kilowatts (17% of 1.5 megawatts). This capacity factor may be conservative because the turbines had restricted output the first year of operation due to local transmission constraints.

Wind turbine manufacturers provide estimates of energy output based on various wind speeds in a graph known as a power curve. Goldwind America manufactured the three turbines. **Based on the Goldwind GW 82/1500 power curve, the NBC Field's Point Wind Project site may achieve 6 m/s average wind speeds (see Figure 2).**

Figure 2. Goldwind America GW 82/1500 Power Curve



Source: Goldwind America 1,5 MW Product Brochure 2013

How important is wind speed?

Electricity generation from a wind turbine is not linear; in other words, a doubling of wind speed does not double electricity generation. A 1 m/s increase in average wind speed has a greater effect on electricity generation between a wind turbine's "cut-in" wind speed (when the turbine begins to spin) and its "nominal" wind speed (when it reaches maximum production). **A 1 m/s increase in average wind speed can substantially increase electricity generation at a wind farm.**

Using the NREL estimate of 5.0 m/s, the NBC Field's Point Wind Project should only achieve a capacity factor of approximately 12%. **Actual output at the NBC Field's Point Wind Farm is at least 40% better than what would be expected using the NREL map with the estimated wind speed.**

Conclusions

The NREL resource assessment maps are often used to initially assess a site for wind farm development. However, these maps alone are not adequate for determining wind farm success and may underestimate wind speeds. The NBC Field's Point Wind Project achieves a greater energy output than can be estimated by the NREL resource assessment map. During the second year of operation, and after resolving transmission constraints, the turbines are predicted to **generate 7 million kilowatt hours a year—which will power approximately 1,125 homes a year.**

Sources

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Narragansett Bay Commission Website. "NBC's Field's Point Wind Energy Project." *Narragansett Bay Commission*

National Renewable Energy Laboratory (2010). Rhode Island Average Wind Speed at 80 m.

Low Wind Speed Case Study

Puerto Rico Wind Farm Projects

With high energy costs and a need for diversified electricity sources, Puerto Rico has started to invest in wind energy. Puerto Rico contains two large-scale wind farms (totaling over 120 megawatts) and small-scale single turbines along the coasts.

Credit: Pattern Energy (Finca de Viento Santa Isabel Wind Project, Puerto Rico)

Santa Isabel Wind Farm

Finca de Viento Santa Isabel (Santa Isabel), Puerto Rico's first and currently largest wind farm, began operation in late 2012. **The wind farm is composed of 44 wind turbines (each 2.3 megawatts), with a total capacity of 101.2 megawatts.**

Punta de Lima Wind Farm

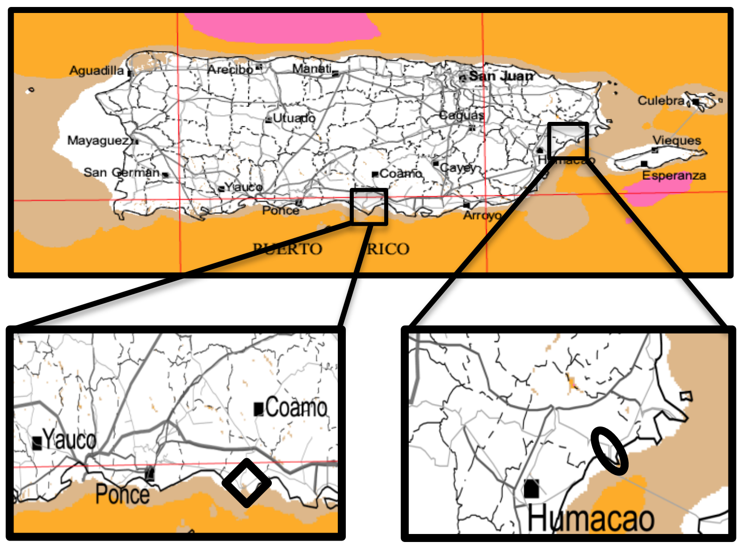
Punta de Lima Wind Farm began operation in April 2013. **The wind farm is composed of 13 Vestas 1.8 megawatt turbines, adding up to a total capacity of 23.4 megawatts.**

Both wind farms are successful and provide electricity for the island. The success of these wind farms is contrary to data that is publicly available via wind speed maps, which underestimate the onsite wind speeds. This case study compares estimated wind speeds from the National Renewable Energy Lab's (NREL) only publicly available wind speed map for Puerto Rico (a 50-meter wind speed map) with available information about the two wind farms.

In 2007, NREL published maps showing average annual wind speeds for Puerto Rico. The images on the right (**Figure 1**) are adapted from NREL's 50-meter map for Puerto Rico. The Santa Isabel wind farm, along the Southern coast, is represented by the black diamond. The Punta de Lima wind farm is located along the eastern coast of Puerto Rico in Naguabo and is represented by the black oval.

Based on actual data from wind farm developers in Puerto Rico, average annual wind speeds for the two wind farms are approximately 6-6.5 meters per second (m/s); however, the NREL map would suggest these sites are undevelopable.

Figure 1. Puerto Rico and the Virgin Islands 50-Meter Wind Resource Map



Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m ^{2}	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
1	Poor	0 - 200	0.0 - 5.9	0.0 - 13.2
2	Marginal	200 - 300	5.9 - 6.8	13.2 - 15.2
3	Fair	300 - 400	6.8 - 7.5	15.2 - 16.8
4	Good	400 - 500	7.5 - 8.0	16.8 - 17.9
5	Excellent	500 - 600	8.0 - 8.5	17.9 - 19.0

[a] Wind speeds are based on a Weibull k of 2.5 at sea level.

Source: National Renewable Energy Lab 2007

How important is the height of wind speed measurements?

A significant cause of the NREL map inaccuracy is the height at which the wind speeds were estimated. The NREL map focuses on wind speeds at 50-meter heights. Both wind projects have turbines with a hub height of 80 meters, making the NREL map an inaccurate portrayal of wind energy capability in Puerto Rico.

Low Wind Speed Case Study

Puerto Rico Wind Energy Projects

This NREL map portrayal of the sites in **Figure 1** would likely make the site unfeasible for wind energy development. Yet, sources from the two wind farms indicate that Puerto Rico has a better wind resource than the wind speed map predicted.

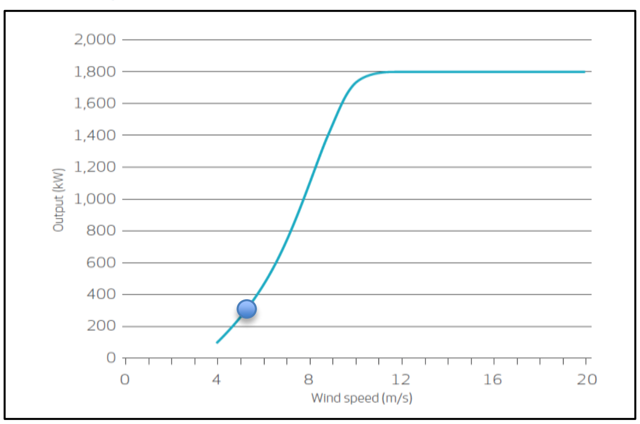
Santa Isabel Wind Farm

Pattern Energy, the developer of Santa Isabel, performed studies before the wind farm was constructed to try to identify Puerto Rico's wind resource potential. **The Santa Isabel site has been reported to have an average wind speed of 6.5 m/s.** This is substantially better than the 0.0-5.9 m/s estimated by the NREL 50-meter wind speed map.

Punta de Lima Wind Farm

According to the developer, Gestamp Wind, "this wind farm will generate 52 GWh per year…" Each turbine is rated for a maximum output of 1.8 megawatts per hour, indicating the wind farm achieves a 25% capacity factor. Therefore, each wind turbine's average hourly output is approximately 450 kilowatts (25% of 1.8 megawatts). Wind turbine manufacturers provide estimates of energy output based on various wind speeds in a graph known as a power curve. Based on the Vestas V100-1.8 power curve, the **Punta de Lima Wind Farm site may achieve 6 m/s average wind speeds (see Figure 2).**

Figure 2. Vestas V100-1.8 Power Curve



Source: Vestas V100-1.8 Brochure

U.S. Virgin Islands Wind Resource: A Comparison

There is currently little public information available regarding Puerto Rico's wind resource. Yet, NREL recently published a report that extensively evaluated wind energy potential in the U.S. Virgin Islands—a potentially comparable location to Puerto Rico. The report recognized St. Thomas, St. Johns, and the Bovoni peninsula as **"prime candidate[s] for utility-scale wind generation."** Some areas in the U.S. Virgin Islands may contain average wind speeds in the 7-7.5 m/s range – significantly higher than estimated by the 50-meter NREL maps in Puerto Rico.

Conclusions

The NREL resource assessment maps are often used to initially assess a site for wind farm development. However, these maps alone are not adequate for determining wind farm success and underestimate wind speeds throughout Puerto Rico. The Puerto Rico wind farms achieve a greater energy output than can be estimated by the NREL resource assessment map. Other areas that could be characterized as "low wind speed," according to the resource assessment maps, may have similar pockets of good wind speed that may be ideal for consideration of wind power development, especially as newer wind turbine technology achieves greater efficiency.

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Pattern Energy Projects (2014) "Santa Isabel," Pattern Energy.

Vestas V100-1.8 Brochure.