An Independent Evaluation of Wild Horse Wind Farm in Washington State

By

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Introduction

Wind energy has recently become a much more valuable natural asset for the United States with the passing of the $787 billion stimulus package on February 19, 2009. Of that amount, $45 billion has been allocated to energy. The wind energy sector is specifically receiving clean power grants for up to 30 percent of the cost of projects for the next two years, an extension for Renewable Energy Tax Credits to 2012, up to $2 billion new tax credit for the production of Renewable Energy Manufacturing facilities, and a distributed portion of the $872 million of tax credit for distributed clean energy production over the next 10 years. The Pacific Northwest grid infrastructure, in particular the Bonneville Power Administration and the Western Area Power Administration, is planned to be (re)-developed with $2 billion for transmission grid improvements and $6.5 billion in low-interest loans, which places the clean energy revolution in Washington State [7].

Wild Horse Wind Farm is a clean energy project in Central Washington that was commissioned by Puget Sound Electric (PSE) in 2006 [5]. Wild Horse is one of about half a dozen major wind generation facilities in Washington State [8]. The wind farm currently has 127 Vestas V80-1.8 megawatt (MW) wind turbines operating which gives the project a 229 MW nameplate rated capacity [5]. PSE has proposed to expand Wild Horse by adding approximately 25 more units which will boost the generating capacity of the wind farm by 45 to 50 MW [5]. Wild Horse is an illustration of how wind power technology can produce a significant amount of electricity and it is an example of how Washington State is trying to fulfill the Renewable Portfolio Standard state policy of 15% by 2020 [9].

This independent evaluation of Wild Horse Wind Farm examines the considerations that must be taken into account when choosing a successful wind farm location, the development of a wind farm and the locations' characteristics, the wind data, the wind speed frequency distribution, the wind turbine power curve, and finally, the theoretical energy yield.

Wind Farm Site Selection Considerations

Wind farm sites are located based on a multitude of considerations. Most importantly, the wind conditions in the area have to be favorable in order to produce the maximum amount of energy. Geographic features of the landscape, like hills, forests and buildings, can influence the wind characteristics significantly [1]. For instance, wind speeds increase as the wind flows up gradual slopes, hillsides and mountains [11]. Conversely, terrain with much vegetation can increase the surface roughness, which increases the drag on the earth surface and reduces the mean wind speed and the attractiveness of a wind farm location [2].

Wild Horse Wind Farm, which is located on Whiskey Dick Mountain in Kittitas County near Ellensburg, Washington, is at an elevation of 3500 feet [5] and the historical temperature range (1971-2000) of nearby Yakima, Washington (48 miles away) is 33 to 74 degrees Fahrenheit [10]. The historical temperature record was not available from the source. As shown in Figure 1 and Figure 2, Wild Horse has terrain that is mountainous and hilly with few obstacles in the way that could obstruct wind flow.

Figure 1 Aerial photo of Wild Horse [5]

Figure 2 Wind Turbines at Wild Horse [5]

The location of the grid in relation to the wind farm plays a major role in the economic viability of a wind farm project [2]. Sometimes locations with the highest amount of wind power generation potential are not near transmission lines that carry the electricity to users. The infrastructure of the grid (i.e., substations, transmission lines, distribution lines) would need to be developed to allow for a wind farm project to proceed. Even if the grid is close enough to the potential wind farm, the capacity of the transmission lines needs to be considered to see if additional energy can be transmitted through the lines.

Logistical considerations are important in the creation of wind farms as well. All of the parts of the wind turbine have to be transported to the wind farm location. This includes the tower, usually two or three segments, the nacelle (with gearbox and generator), the blades and the materials for the foundations. The turbines need to be maintained during operation, so access roads are required. In remote locations, transportation routes need to be developed to allow for the wind turbines and all the necessary construction equipment to reach the wind farm site.

Additionally, local acceptance, land acquisition, proximity to airports, military bases and natural conservation areas, neighbors and permission of the authorities are more issues wind farm developers must take into account when planning a wind farm project [2].

Wind Farm Site Development and Location Characteristics

A good resource to start with when locating a potential wind farm is a wind energy resource atlas [4]. The *Renewable Energy Atlas of the West* (Figure 3) gives a depiction of the renewable energy potential in the western United States. In particular, it shows that the wind energy potential in eastern Washington State is significant. As shown on Figure 3, the mean

Washington Wind Speed at 164 ft (50 m)		
	Class	Wind Speed (mph)
1		0-12.5
2		12.5-14.3
3		14.3-15.7
4		15.7-16.8
5		16.8-17.9
6		17.9-19.7
7		>19.7
Wind Power at 164 ft (50 m)		
	Class	Wind Power Density (W/m^2)
1		0-200
2		200-300
3		300-400
4		400-500
5		500-600
6		600-800
7		>800

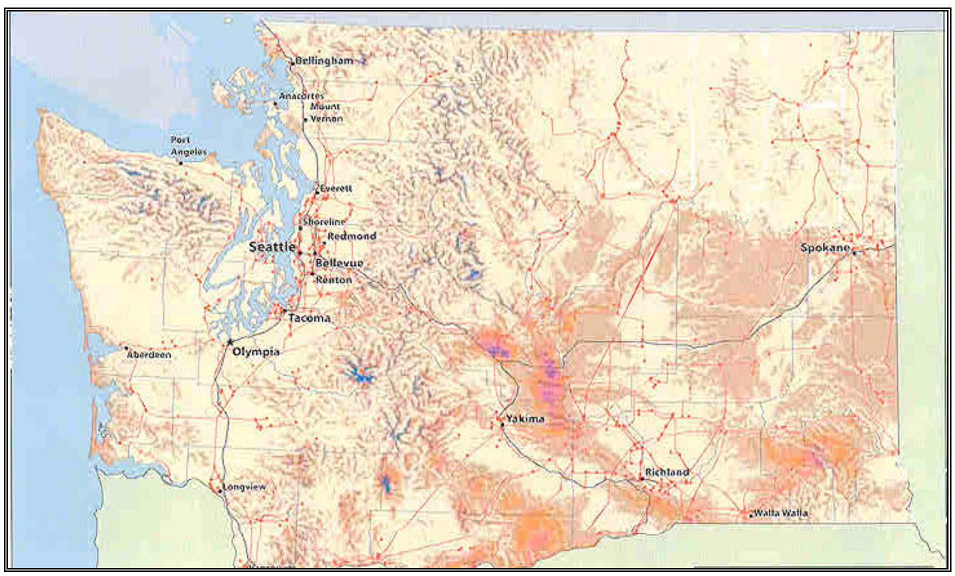

Figure 3 Washington State Wind Power Potential [6]

wind speed and wind power density at Wild Horse are in the range of 14 to 18 miles per hour (mph) and 300 to 600 watts per square meter (W/m^2), respectively.

Natural indicators (see Figure 4) of a potential wind farm landscape are observed to determine if a location has reliable evidence of a consistent, high mean wind speed. Even verbal accounts from local residents about the region's wind conditions can help in the assessment of a potential wind farm location [1].

Figure 4 Image of skewed trees due to high mean wind speed [3]

Once it is determined that the local wind conditions are suitable for a potential wind farm, meteorological data must be collected, typically using anemometers. An anemometer is a piece of equipment used to collect and record the wind speed. A wind vane is used to measure the directionality of the wind [2]. Other information, such as the temperature, humidity and pressure, can help in the forecasting of the wind farm's potential energy output.

Wind Data

Table 1 depicts historical wind data collected by Oregon State University's Energy Resources Research Laboratory at locations close to the Wild Horse Wind Farm [4] in Kittitas County, Washington. The anemometers collect the wind speed at a defined distance from the ground, elevation, data type and period of record. As confirmed by Professor Stel N. Walker, Director of Energy Resources Research Laboratory (ERRL) at Oregon State University (OSU), most site data is sampled at one-hertz and averaged for ten-minutes. The ten-minute averages of wind speed, wind direction, standard deviation and gust wind speed are recovered in real time

Site ID	Site Name	Location	Elev (ft)	Anem Ht (ft)	Annual Speed (mph)	Data Type	Period of Record Start	End
2010	Boylesston Mtn	Ellensburg, WA	2400	20	11.6	HR	1-May-80	30-Sep-82
2030	Thorp	Ellensburg, WA	1600	30	9.2	MO	1-Oct-80	31-Oct-83
2031	Wanapum	Ellensburg, WA	520	40	11.5	HR	28-Jun-74	30-Jun-85
2036	Kittitas M/W	Ellensburg, WA	2660	110	13	HR	25-Mar-80	31-Aug-89
2045	Ellensburg Airport	Ellensburg, WA	1720	62	9.3	HR	1-Jan-35	31-Dec-38

Table 1 Annual wind speed at locations in Kittitas County [4]

and the hourly averages are composed of the ten-minute averages centered on the hour [4]. Table 2 shows the anemometer height, elevation, data type and period of record and the historical average mean annual wind speeds of wind farms close to Wild Horse [4]. Ideally,

Site ID	Site Name	Elev (ft)	Anem Ht (ft)	Period of Record Start	End	Ann Mean (mph)
GL	Goodnoe Hills, WA	2597	50	May-80	Present	11.1
GU	Goodnoe Hills, WA	2597	195	May-80	Present	14.4
KZ	Kennewick, WA	2192	86	Jun-76	Present	17.6

Table 2 Historical Average Mean Annual Wind Speeds at wind farms in Washington State [4]

attaining raw data from wind anemometers at the PSE's Wild Horse Wind Facility would be desirable, but the information is proprietary and PSE was not willing to release it for this independent performance evaluation.

The Power Law formula (see Figure 5) is used to model the vertical profile of the wind speed. It transforms the wind speed taken at a reference height to a desired height, usually for a higher elevation, to match the nacelle or hub height of the wind turbine [1]. An α value of 0.19 was chosen as the empirical wind shear exponent based on the local terrain of Wild Horse [1].

$$\underline{v}_H = v^*(H/H^*)^{\underline{\alpha}}$$

$\underline{v}_H$ =	mean wind speed at elevation H
H^* =	reference elevation
v^* =	reference wind speed at a reference elevation
$\underline{\alpha}$ =	empirical wind shear exponent

Figure 5 Power Law Formula for the height correction of wind shear speed [1]

Additionally, the Goodnoe Hills, Washington Wind Farm site has two anemometers. The lower anemometer is located at a height of 50-feet and recorded an annual wind speed of 11.1 mph. The upper anemometer is located at a height of 195-feet and recorded an annual wind speed of 14.4 mph. Using an $\underline{\alpha}$ value of 0.19 gives the same corrected wind speed of 14.7 mph (see Table 3) at the hub height of the 221-feet for the Vestas V80-1.8MW wind turbines located at Wild Horse.

Table 3 shows a range for the corrected average mean annual wind speed at the wind turbine hub height between 11.8 mph (minimum) and 21.1 mph (maximum). The average

Site Name	Elev (ft)	Anem Ht (ft)	Annual Speed (mph)	Corrected wind speed (mph) =
Boyleston Mtn	2400	20	11.6	**18.3**
Thorp	1600	30	9.2	**13.4**
Wanapum	520	40	11.5	**15.9**
Kittitas M/W	2660	110	13	**14.8**
Ellensburg Airport	1720	62	9.3	**11.8**
Goodnoe Hills, WA	2597	50	11.1	**14.7**
Goodnoe Hills, WA	2597	195	14.4	**14.7**
Kennewick, WA	2192	86	17.6	**21.1**

Table 3 Annual wind speed at locations in Kittitas County [4]

of the corrected wind speeds is equal to 15.6 mph. In comparison to the wind speeds from the *Renewable Energy Atlas of the West* (see Figure 3), the wind speed range for Whiskey Dick Mountain is from 14 to 18 mph. The minimum, maximum and average values of the corrected annual wind speed are used to determine the wind speed frequency distribution using the Weibull statistical function.

Wind Speed Frequency Distribution

The wind speed frequency distribution for a specific wind farm location is determined by mathematical approximation when there is an insufficient amount of data available. However, as stated previously, having the experimental data from anemometers at Wild Horse would provide more accurate results.

A Weibull statistical function is used to approximate the relative probability density and the cumulative probability density (or distribution) for this independent evaluation on Wild Horse [1]. The mean wind speed (see Table 4) from the wind speed data attained from the ERRL at OSU [4] is used in the statistical frequency distribution. Based upon the results from

Weibull Method of Moments with fixed k = 2			
	MIN	MAX	AVG
mean [mph]	11.8	21.1	15.6
k or alpha estimate	2	2	2
w1 or beta estimate [mph]	13.4	23.8	17.6

Table 4 Weibull statistical function input parameters [11]

the references, Pinilla et al [12] and Wekken [13], the Weibull shape factor, k (or alpha), was chosen to be a value of 2. It should be noted that in the Pinilla et al [12], it was stated that the Weibull shape factors were 4 and 5 for especially high mean wind speed value months [12]. The Method of Moments [11] was then used to determine the w_1 (or beta) values by using the mean wind speed and k (or alpha) value. These variables are the input parameters of the statistical Weibull function. The range was set by the shut down (or cut-out) speed of the wind turbine, which is at a constant wind speed of 56 mph [5]. The relative probability density vs. wind speed graph (see Figure 5) shows the probability densities for different mean wind speeds. The peak of the relative probability density for the minimum mean wind speed is at a lower wind speed compared to the maximum and average means. This implies that the relative probability density is denser at wind speeds less than the mean. Since at the mean wind speed fifty percent of the probability density would be accumulated, the curve will continue to steepen for smaller mean values.

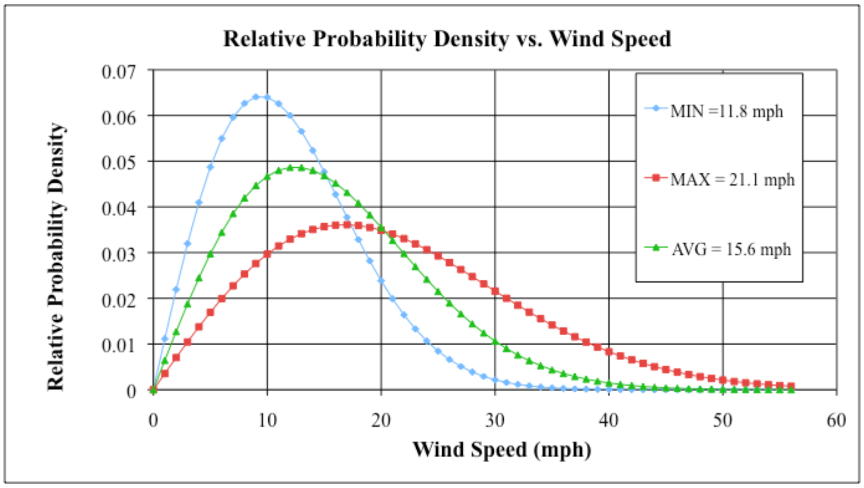

Figure 5 Relative probability density vs. wind speed using Weibull statistical function [11]

The cumulative probability density (or distribution) vs. wind speed graphs (see Figure 6) depicts clearly that at lower mean values, the wind frequency distribution is denser in the lower wind speed range prior to the mean. The mean wind speed can be deducted from the graph by drawing a line horizontal from 0.5 (or 50% accumulation) on the cumulative probability density axis until it meets the curves. The location where the line meets the curve is the corresponding

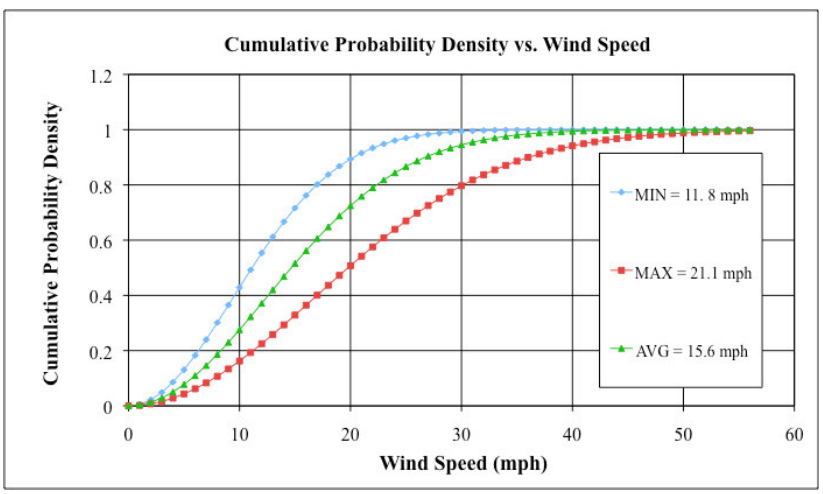

Figure 6 Cumulative probability density vs. wind speed using Weibull statistical function [11]

mean wind speed. The relative probability density and the wind turbine power curve, covered in the following section, are used to calculate the approximate theoretical energy produced at Wild Horse, which is presented in the final section of this report.

Wind Turbine Power Curve

The prevailing winds from the northwest [5] turn the 127 Vestas V80-1.8 MW wind turbines at Wild Horse Wind Farm [14]. The wind turbines reach their peak production once the wind speeds are at the rated speed (or velocity) of 31 mph. The cut-in velocity is at a low wind speed of 9 mph, which is the speed the generator can start producing energy [1 and 5]. The Vestas V80-1.8 MW wind turbine power curve (see Figure 7) shows the energy output (kW) for a corresponding wind speed (m/s). At the Wild Horse facility, IEC class 2A wind turbines (i.e., the darker line in Figure 7) are used. From the power curve figure, the whole number wind speeds, from zero to 56 mph, are scaled to determine the energy output.

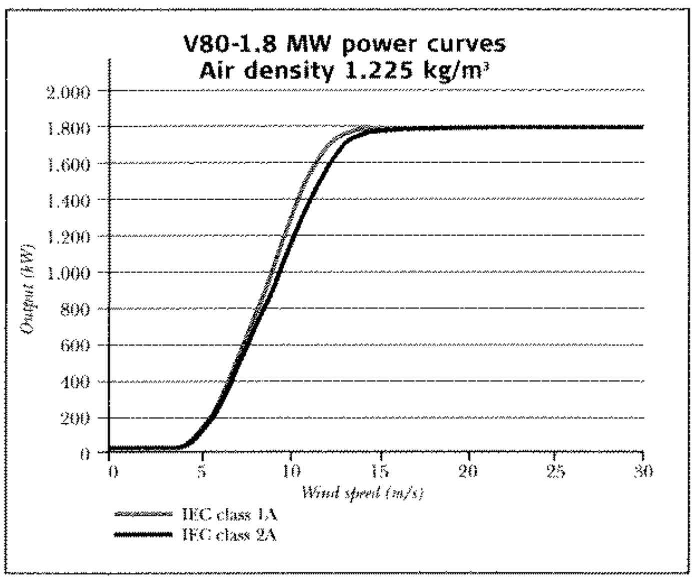

Figure 7 Power Curve for Vestas V80-1.8 MW wind turbine [5 and 14]

Most power curves are understood as net power [1], but it is uncertain if the power curve provided is for the net power. It would need to be confirmed with PSE [5] and Vestas [14]. For this study, the power curve (see Figure 7) is assumed to be for the net power. The net power is basically taking all the power losses caused by the turbine's internal combustion and subtracting them from the ideal electrical power output. The transformer usually does not need to be used in calculating the net power since the transformer is based on site conditions. Still, some wind turbine generators have transformers built internally, so the transformer loss may be included in the manufacturer's net power calculations [1]. The power curve and the relative probability density for the Weibull statistical function have to be compatible in order to sum the annual energy output. Presented next is the summation of the product of the relative probability and the power curve at certain compatible wind speeds (bins), which is the approximate theoretical energy produced at Wild Horse.

Theoretical Energy Yield

The annual theoretical energy yield results for Wild Horse wind farm are summarized in Figure 8. The annual energy yield total for wind speeds of 11.8 mph (min), 21.1 mph (max) and 15.6 mph (average) are 368,471 megawatt-hours (MW-hrs), 1,021,764 MW-hrs, and 660,938 MW-hrs, respectively. Each one of these energy yield totals can be equated to supplying a certain number amount of homes with energy each year. The average amount of energy a home uses per year is approximated at 13 MW-hrs. The number of homes powered by the theoretical energy yield, in the same order as above, is about 29,000 homes, 79,000 homes, and 51,000 homes [5]. The ideal energy yield is for a 100% efficient wind farm that could produce energy constantly at the rated power capacity. In this case, the 127 Vestas wind turbines would have to produce 1.8 MW each for 8,760 hours per year to get an ideal energy yield of 2,002,536 MW-hrs (see Figure 8). The PSE Wild horse website claims that the average annual energy yield for Wild Horse is 642,000 MW-hrs which is enough energy to serve 50,000 households [5]. The capacity factor for PSE value is 32.1% [5].

127 - 1.8 MW Wind Turbines			
	Minimum mean wind speed = 11.8 mph	Maximum mean wind speed = 21.1 mph	Average mean wind speed = 15.6 mph
Annual Totals Energy Yield (MW-hr)	368471	1021764	660938
Ideal Energy yield (MW-hr)	2002536	2002536	2002536
Capacity Factor	18.4%	51.0%	33.0%

Figure 8 Theoretical annual energy yield for Wild Horse wind farm

The actual annual energy yield divided by the ideal annual energy yield will give the efficiency or capacity factor of the wind farm. The capacity factor, 33.0%, for the average mean wind speed of 15.6 mph gave a close approximation to the actual capacity factor of 32.1% for Wild Horse. Both of these values seem accurate because the general "rule of thumb" is to take the rated energy capacity and divide it by three to get the actual energy output.

The minimum and maximum mean wind speeds show the great variability of the actual energy output and the capacity factor with a few miles-per-hours of difference. At locations with mean wind speeds above 20 mph, the capacity factor has the possibility of being above 50%, which is considered highly efficient for almost any form of electrical generation production.

Conclusions

The wind power electricity generation potential is estimated to be 62 million MW-hrs per year [5] for the State of Washington. Wild Horse is the beginning of the successful creation of energy produced by wind power in Washington State.

With the ever-evolving research and development of more efficient wind turbines, the power curve will continue to improve. This will increase the capacity factors of wind farms, which makes wind energy more efficient and lucrative.

The development of offshore wind farms is a way to increase the Weibull shape factor because the surface roughness of the open sea is quite low. Wind turbines with 5 MW (or even 7 MW) rated energy (power) capacity are now manufactured for the production of onshore and offshore wind farms. The tremendous energy capacity of these gigantic wind turbines along with favorable wind conditions of an offshore wind farm locations can combine to make a wind farm that produces large amounts of energy with higher capacity factors.

Now that the federal, state, and local governments of the United States are interested in the value of wind energy, the time has come to restructure the way the US has traditionally produced energy. The economics of wind energy production are becoming more competitive with other forms of electricity production and the environmental benefits from wind energy bring additional momentum for the expansion of wind power production in the US. The wind energy revolution is now in bloom in the US and the State of Washington.

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