Assessment of Wind Energy Production Software

Hermann Reynir Hermannsson

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Joe Mahoney
Timothy Larson

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University of Washington

Abstract

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Hermann Reynir Hermannsson

Chair of the Supervisory Committee:
Professor Joe Mahoney
Professor Timothy Larson
Department of Civil and Environmental Engineering

An examination of two computer programs used for estimating wind energy, RETScreen and System Advisor Model (SAM), are examined and compared to measured data from a wind farm. Wind speed and electrical production estimated by these programs are examined and compared to the measured data. Both programs assume no losses and predict data for an ideal wind farm. Measured data on the other hand includes losses within the farm (e.g. array loss, airfoil loss and availability loss). According to results, RETScreen underestimates the electrical production by 35% and SAM overestimates it by 26%.

1 Introduction

After the oil crisis in the 1970s, the US, Denmark and Germany attempted to develop alternative sources of energy (Jain, 2011). Today these countries are some of the main producers of electricity by wind, They are also pioneers in wind turbine technology (General Electric in the USA, Vestas in Denmark and Siemens in Germany).

Development of wind energy in the U.S. is increasing and the associated generation capacity is growing. In June 2012 the US wind capacity reached 48.8 GW which is 19.2% of the worldwide capacity (WWEA, 2012). This increase, among other things, is mostly attributed to better technology in wind turbine development and changed government strategies regarding renewable energy. At this time, using as much renewable energy as possible is encouraged world-wide both due to environmental concerns and to decrease use of fossil fuels.

Position	Country	Total Capacity by June 2012 [MW]	Added Capacity first half 2012 [MW]	Total Capacity end 2011 [MW]	Added Capacity first half 2011 [MW]	Total Capacity end 2010 [MW]
1	China	67'774	5'410	62'364	8'000	44'733
2	USA	49'802	2'883	46'919	2'252	40'180
3	Germany	30'016	941	29'075	766	27'215
4	Spain	22'087	414	21'673	480	20'676
5	India	17'351	1'471	15'880	1'480	13'065
6	Italy*	7'280	490	6'787	460	5'797
7	France**	7'182	650	6'640	400	5'660
8	United Kingdom	6'840	822	6'018	504	5'203
9	Canada	5'511	246	5'265	603	4'008
10	Portugal	4'398	19	4'379	260	3'702
	Rest of the World	35'500	3'200	32'227	3'200	29'500
	Total	254'000	16'546	237'227	18'405	199'739

* till end of May 2012 ** till end of April 2012 © WWEA 2012

Figure 1. World wind turbine capacity by major country from December 2010 to June 2012 (WWEA, 2012).

A variety of feasibility analyses need to be done before applying for a wind farm construction permit including assessment of local wind direction and wind speed at the proposed project locations. It is sometimes possible to start the assessment process by use of existing, nearby data. The basic rule is this, "The annual average wind speed for a wind energy project should exceed 4m/s at a height of 10m above the ground" (Jain, 2011). If little or no data exists for a given location, one can either measure the wind directly at hub height or use computer programs that contain climate information; the computer-based analyses are typically used for early, pre-feasibility types of studies. The first option has the benefit of greater accuracy and gives good, concrete information for a certain location; however the process of gathering site specific wind data can easily take 18 to 24 months. Using computer programs doesn't take as long and is less expensive but the accuracy is lower. It is possible to use both of these methods together by starting with computer programs and, if the results are encouraging, follow up with site-specific measurements.

In this thesis two computer programs used to assess a wind farm location will be examined: RETScreen and System Advisor Model (SAM). Both of these programs contain default wind information that can be used in the absence of direct measurements. Where weather information is available it is usually measured 10m above ground surface. These programs allow the user to extrapolate directly measured surface wind information to the conditions at the turbine hub height (at top of the tower).

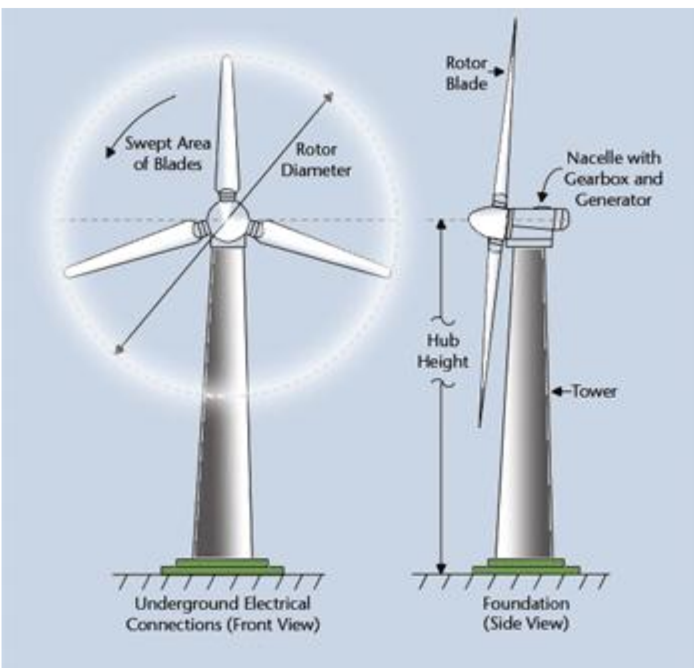


Figure 2. Drawing of a wind turbine (Commission, 2010)

The two computer programs use fundamentally different approaches to estimate wind speed and direction for any given hour at a specified location. RETScreen makes predictions anywhere on the globe, whereas SAM makes predictions only within the US. Not surprisingly, RETScreen has much coarser spatial and temporal resolution than SAM.

It is good to keep in mind the purpose of this type of software which is "to help decision makers determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects by using those computer programs" (RETScreen, 2012). In terms of accuracy each and every decision maker will have to evaluate what is good enough and how accurate those programs need to be in terms of feasibility for an energy project. It is important to look at the big picture regarding to accuracy and don't get carried away by focusing on less important results since the predictions from the programs only imply what might be feasible.

In this paper following question will be addressed

1. *How well do RETScreen and SAM predict on electrical production at a wind farm located in mountainous terrain?*

2 Methods

RETScreen and System Advisor Model (SAM) were used to compare wind speed and electrical production against data from an actual wind farm.

2.1 Measured data from the wind farm

Information on measured data comes from a wind farm that has been in operation since 2007 and has a little over one hundred turbines. There are a variety of wind data available. Each one of the turbines has a sensor at the hub height (67 meters) which records vector average wind speed and direction every 10 minutes. A separate metrological tower is located within the farm that measures wind speed and direction every ten minutes at the same height above ground as the turbines. The primary analyses in this thesis used the wind data from the met tower rather than from each turbine individually.

The measured wind data from the meteorological tower were from the year 2011. In contrast to wind speed measures at this single location, the electrical production of the wind farm is based on data from all of the turbines within the farm.

Because the electrical production data is reported for each single turbine, only losses within the farm, are taken into account, for example, array airfoil losses and downtime. Losses not included are the losses associated with transference of energy from the turbine to the grid.

2.1.1 Wind Farm Data Summaries

The 10 minute data were organized into two different time periods.

The one year analysis period included summaries as follows:

1. Monthly average wind speed at hub height (measured on the MET tower)
2. Monthly average electricity production
3. Average capacity factor for the wind farm

A one month period, January 2011 included analyses of the:

4. Quantity of time where the turbines are producing vs. not producing
5. Reasons why the turbines are not producing, slow/fast wind or maintenance
6. Frequency of wind speed over/during a one month period.

Data were analyzed using Excel with care regarding missing data.

2.2 Computer Models

2.2.1 RETScreen

RETScreen is an “Excel-based clean energy project analysis software tool that helps decision makers determine the technical and financial viability of potential renewable energy, energy efficiency and cogeneration projects” (RETScreen, 2012). The software was developed largely in Canada and it is provided free of charge online. The first version was released in April 1998 and the version used in this research is dated September 2011. It is supported and developed with the contribution of numerous government, industry and academia groups.

In this thesis only the wind energy part of this computer program is used and the wind data was analyzed by entering monthly average wind speeds (method 3).

2.2.1.1 RETScreen´s wind data

The RETScreen climate database for wind is provided from two resources, from ground monitoring stations and from model predictions based on NASA´s global satellite data. The NASA climate data base has 6,700 ground stations around the world and has incorporated the improved NASA Surface Meteorology Dataset for populated areas as shown in Figure 3. The measured surface data from ground stations are compiled from over 20 different sources from 1961 to 1990.

If climate data is not available from a specific ground monitoring station, data is then provided from NASA´s satellite data. It is also an option to overwrite the climate database if the user prefers to use other data and manually enter values into the cells.

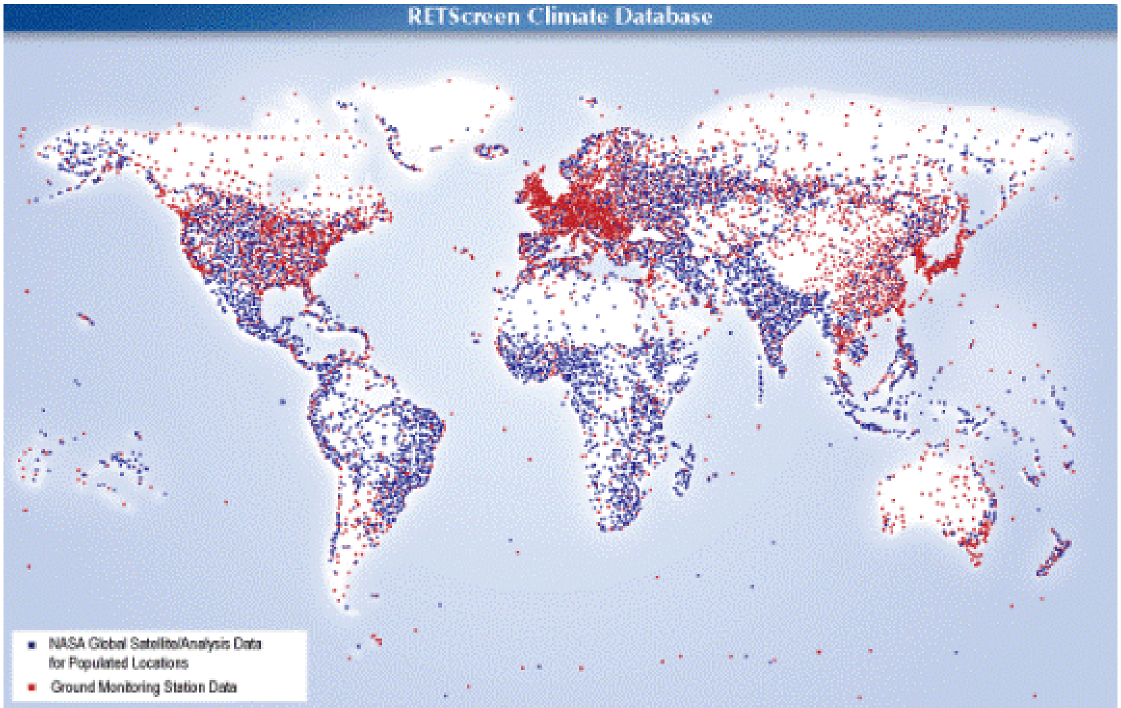
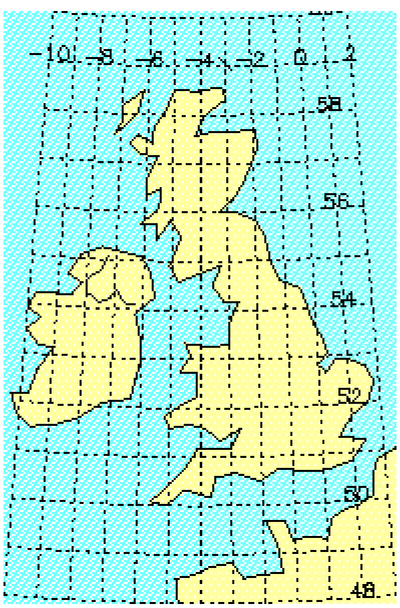


Figure 3. RETScreen climate database map. The red dots represent ground monitoring station data locations and the blue dots represent the NASA global satellite data locations for populated areas (RETScreen, 2012).



NASA´s satellite-derived meteorological data is available for any location on the earth's surface. The current NASA data set is formulated from data gathered for a 20-year period starting in July 1983, using a 1-degree cell. At mid-latitudes (45°), the cell size is approximately 80x110 km (RETScreen, 2012).

Figure 4. Example of the grid covering the UK and Ireland, used by NASA (Center, 2008)

2.2.1.2 Wind speed input

The wind speed input for RETScreen is monthly and can be obtained from the program's climate database or manually entered. To convert the monthly average wind speed to a distribution of hourly values, the Weibull distribution is used. It is possible to adjust the shape factor which is a characteristic of the Weibull distribution. With regard to shape factor, low numbers indicate a relatively wide distribution of wind speeds around the average while higher shape factors indicate a relatively narrow distribution of wind speeds around the average (RETScreen, 2012). It is possible to choose shape factor from 1 to 3 and in this research the average shape factor of two, the default value, was used.

2.2.1.3 Turbine selection

A large database of information from all turbine producers exists for RETScreen. The information that comes with each turbine is: Capacity, Hub height, Rotor diameter and Swept area which are perpendicular to the wind direction that the rotor will cover during one complete rotation (RETScreen, 2012). Most of the turbines also have power curve data which is necessary to find the production. The one selected for the research is VESTAS V80 1.8 MW turbine and as shown in Figure 5 all information needed is available.

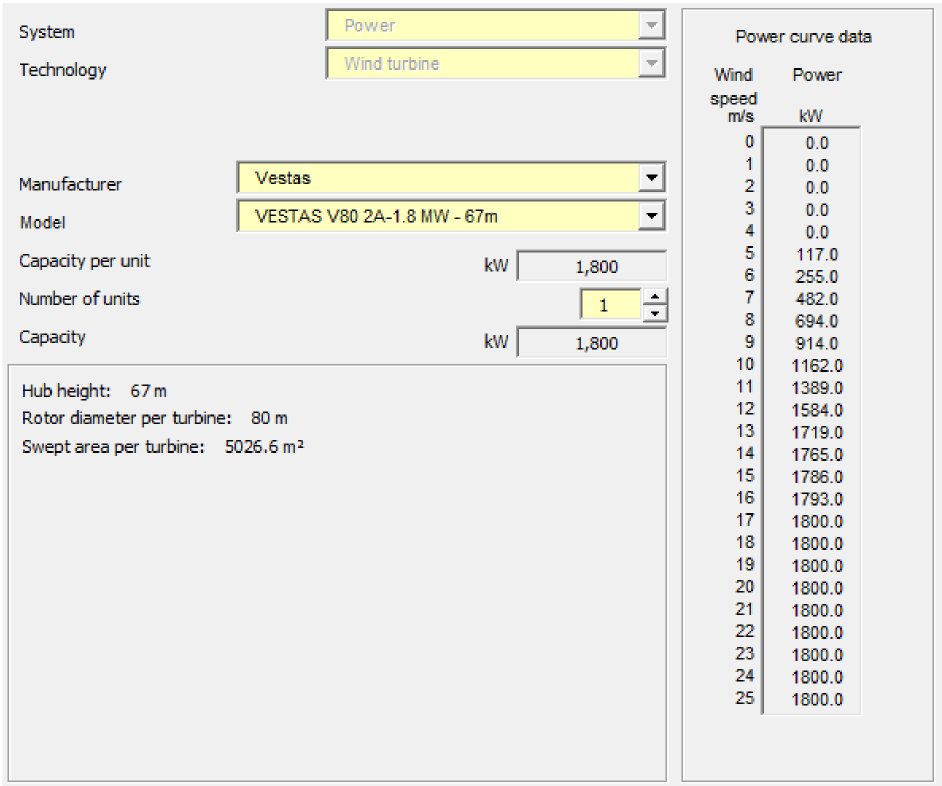


Figure 5. Power curve data from RETScreen. (RETScreen, 2012)

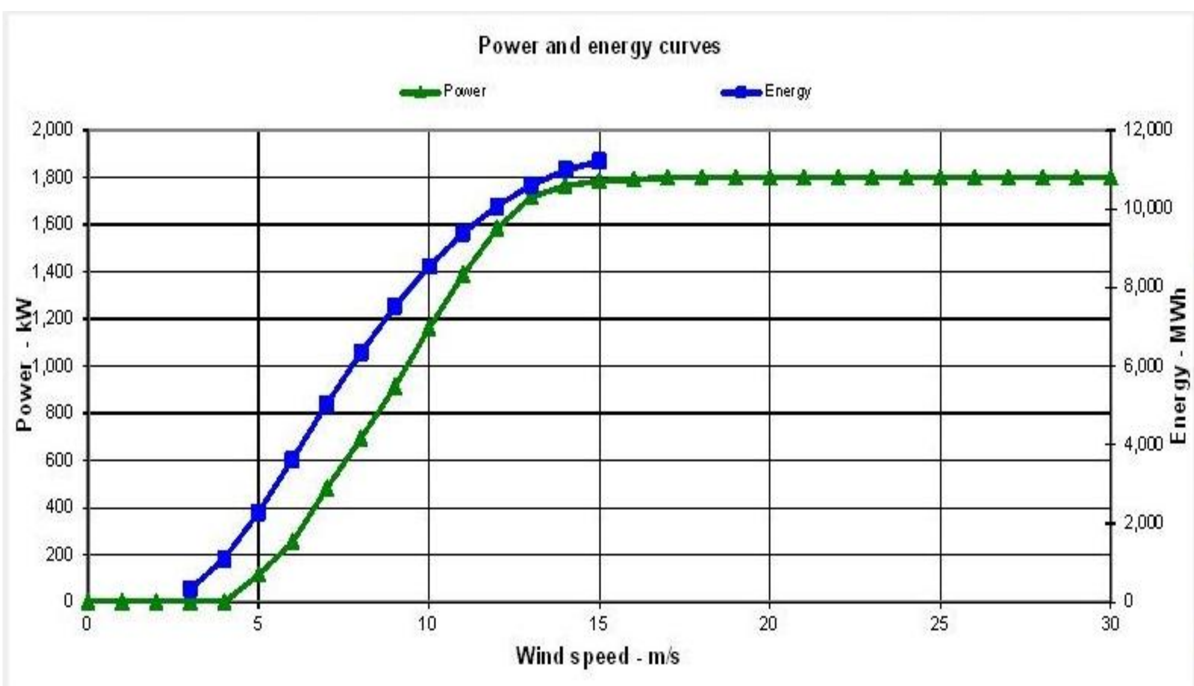


Figure 6. Power and energy curves for selected turbine in RETScreen (RETScreen, 2012).

2.2.2 SAM

SAM was originally called the “Solar Advisor Model” and was developed by the National Renewable Energy Laboratory (NREL) in collaboration with Sandia National Laboratories in 2005. It was first used by the U.S. Department of Energy’s Solar Energy Technologies Program for systems based analysis of solar technology. The first public version was released in August 2007. Since 2007 two versions have been released and in 2010 the name changed to “System Advisor Model” to reflect the addition of non-solar technologies.

The current version of SAM (early 2012) is a performance and financial model designed to facilitate decision making for people involved in the renewable energy industry. It makes performance predictions and cost of energy estimates for grid-connected power projects based on installation and operating costs and system design parameters specified as inputs to the model (SAM, 2012).

The program consists of a user interface, calculation engine, and programming interface. The user interface provides access to input variables and simulation controls and displays tables and graphs of the results. The calculation engine performs a time-step-by-time-step simulation of a power system’s performance (SAM, 2012).

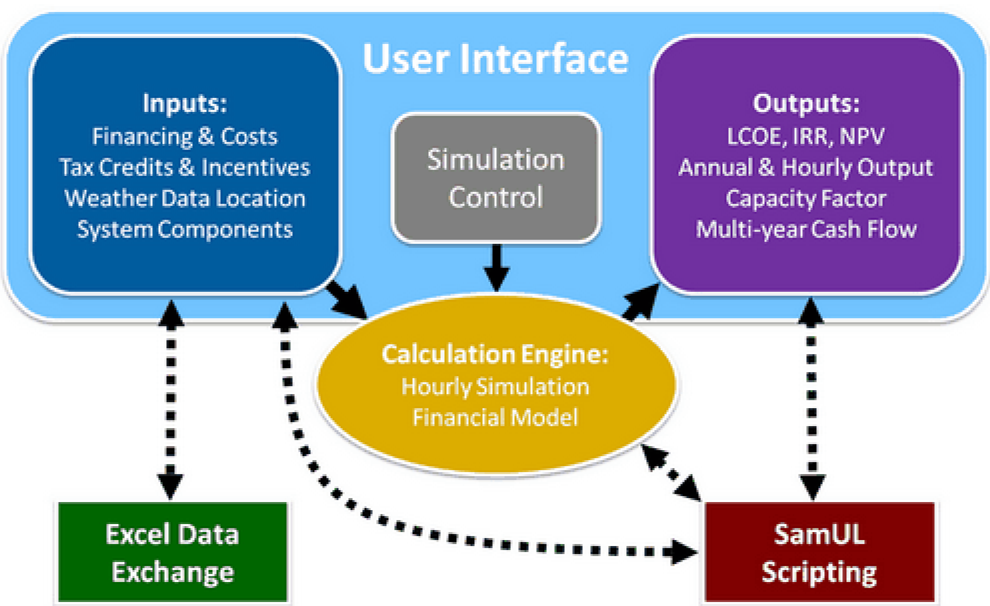


Figure 7. User interface in SAM. (SAM, 2012)

2.2.2.1 SAM´s wind data

The weather data SAM uses depends on what kind of energy resource being analyzed. The wind resource data is from NREL's Western Wind Dataset, which covers the western United States:

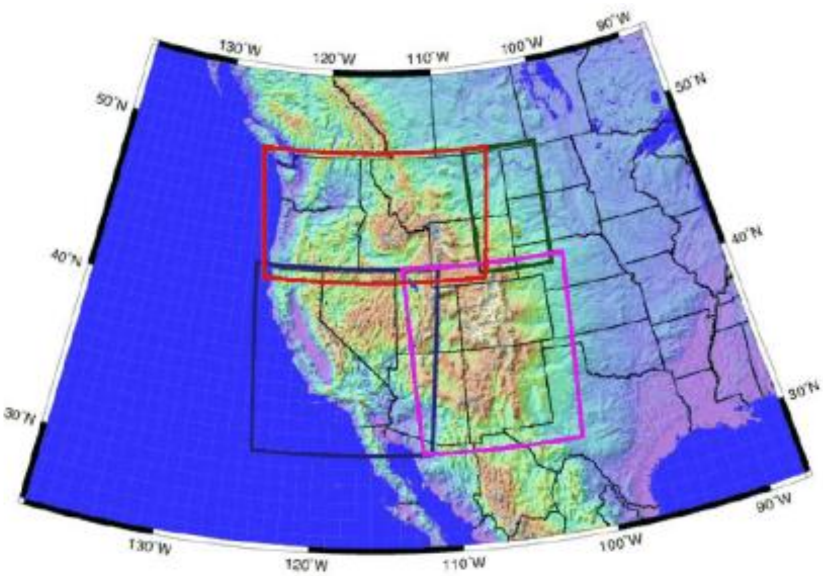


Figure 8. Map of available wind resource data from NREL in SAM. (SAM, 2012)

The company 3TIER created the Western Dataset in cooperation with NREL. "Numerical Weather Prediction (NWP) models were used to essentially recreate the historical weather for the western U.S. for 2004, 2005, and 2006. The modeled data was temporally sampled every 10 minutes and spatially sampled every arc-minute (~2 kilometers)" (NREL, 2012).

"In conjunction with NREL, the 1.2 million grid points were screened to eliminate recreational and other non-developable areas. Further sites were chosen from the remaining sites using an iterative selection algorithm. First, promising sites were selected based on proximity to planned transmission projects and energy zones and based on wind energy density. The next selection phase chose a number of sites in each state (determined by the relative importance of the state in the study) based on the correlation of the wind's diurnal cycle matched with the load profile in the study (with a mean wind energy density of at least 300 W/sqm).

The final selection phase chose a number of sites in each state (determined by the relative importance of the state in the study) based on the highest wind energy density. In total, 32,043 locations were selected" (3TIER, 2010).

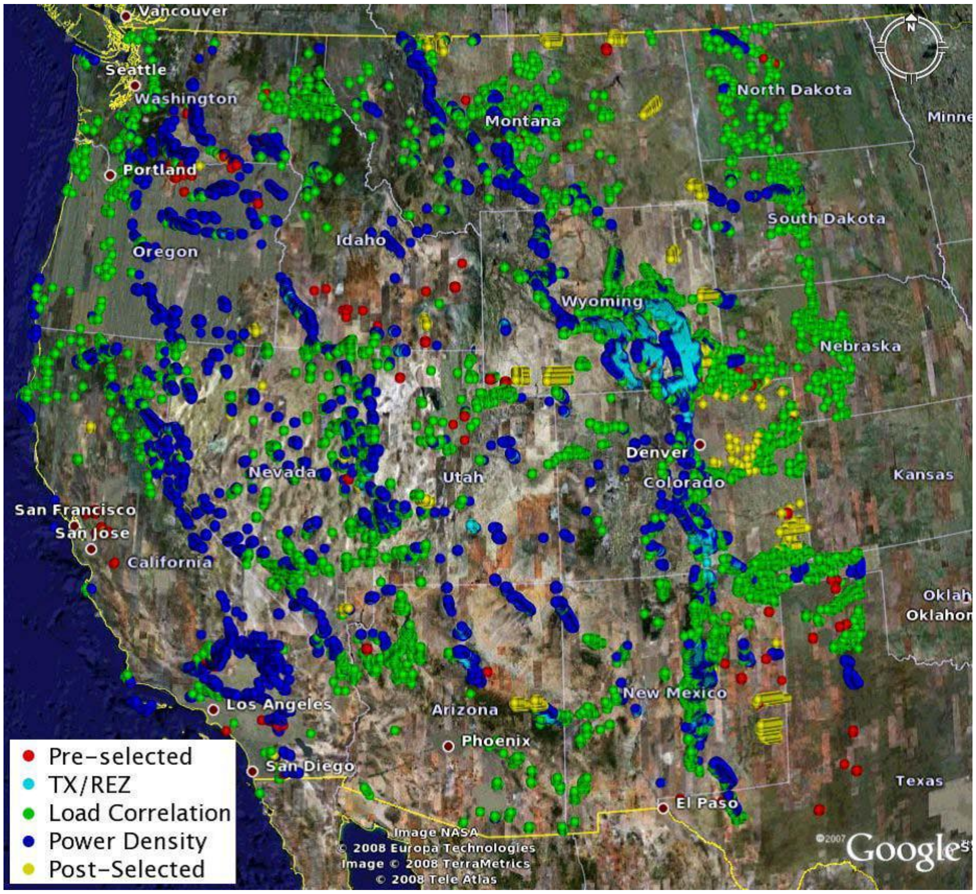


Figure 9. Map of the selected sites with the colored point matching selection techniques (3TIER, 2010).

To gain the most accuracy from the Western Dataset, the model results are compared to actual measured wind speed. 3TIER has compared the model to 28 public wind measurement towers and also some proprietary towers. "The model tends to be more accurate in non-complex terrain (no sharp features, flat or rolling terrain) and less accurate in complex terrain (canyons, mountains, terrain with sharp features)" (NREL, 2012). The model seems to work well east of the Rocky Mountains even though it underestimates some resources during the warm season. With regard to the region west of the Rocky Mountains, the model may overestimate wind on downslope acceleration areas. "In thermally driven areas (Altamont, Solano, Columbia Gorge, Stateline/Vansycle, Ellensburg/Columbia River), the model may underestimate winds, especially in the summer. To accurately model complex terrain, the model must be specifically tuned to that location, ideally using on-site data" (NREL, 2012).

2.2.2.2 Wind speed input

The wind power model uses wind resource data from files in the swrf format, which is a tab-delimited text format. Most database and spreadsheet programs are able to read or save in a delimited format, for example Excel. “A, swrf file stores one year´s worth of hourly wind speed, direction, and temperature resource data at four heights above the ground: 10, 20, 50, and 100 meters. It also includes geographic coordinates and elevation above the ground. To find specific location, coordinates or an address is needed” (SAM, 2012). Since the model absorbs the wind speed hourly, there is no need for a probability density function.

2.2.2.3 Turbine selection

The turbine selection available in SAM is a list of wind turbines with a variety of capacities. In addition to the turbine’s nameplate capacity, SAM includes information on rotor diameter, cut-in wind speed, hub height and the turbine power curve. The one picked for this research is a V80-1.8 MW as shown in Figure 10.

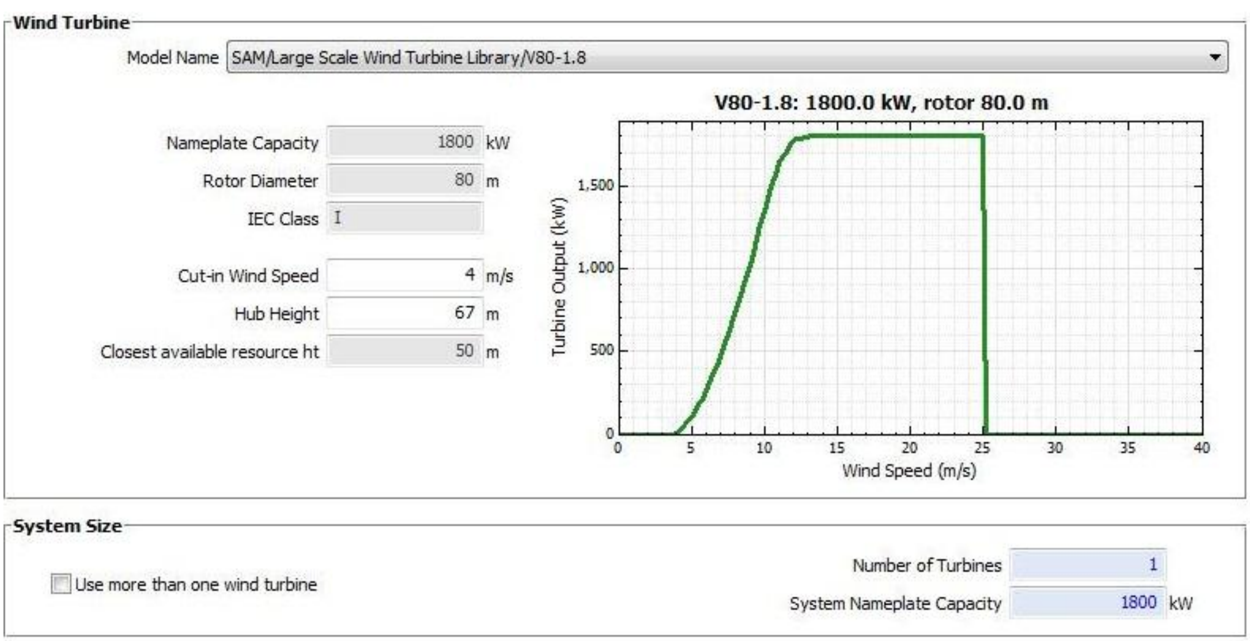


Figure 10. SAM´s wind turbine selection (SAM, 2012).

2.2.3 Model comparison

The following inputs were kept the same for both RETScreen and SAM.

1. Wind data location: one at the wind farm and one at a nearby airport (see Table 1)
2. The type of turbine
3. Turbine Power Losses: all losses are ignored for simplicity
4. Wind shear exponent (set at 0.25)

In addition, wind data from a nearby airport location was available in RETScreen and used in supplemental comparisons summarized in appendix. Table 1 shows the elevation and terrain differences between the two locations. The wind farm location is in mountainous terrain whereas the other is at a nearby airport.

Table 1. Information on compared locations

	Distance from actual wind farm		**Elevation**		**Terrain**
	Miles	Km	Feet	Meters	
Wind farm	0	0	3,495	1,065	Mountain ridge
Airfield	14.5	23.3	1,730	527	Airfield

2.2.3.1 Choice of wind shear exponent

The wind speed data available in the software is either measured at airports at a height of 10 meters or predicted from a meteorological interpolation model at elevations much greater than 10 meters. Therefore conversion of the wind speed to the turbine hub height (67 meters) is needed. A common method to describe the relationship of wind speed and height is the "power law".

$$\frac{\upsilon_2}{\upsilon_1} = \left(\frac{h_2}{h_1}\right)^{\gamma}$$

The variables υ_1 and υ_2 are wind speeds at heights h_1 and h_2, and exponent γ is termed the wind shear exponent. υ_1 indicates the known wind speed at known height (h_1) and υ_2 indicates the unknown wind speed at desired height (h_2).

”Wind shear exponent” expresses the rate at which wind speed varies with the height above the ground (RETScreen, 2012), This exponent can vary between locations, terrain and time. Following table provides descriptions for various shear exponents:

Description	Roughness Class	Roughness Length, m	Shear
Open sea	0	0.0001–0.003	0.08
Open terrain with a smooth surface, like concrete runway, mowed grass	0.5	0.0024	0.11
Open agricultural area without fences and hedgerows and very scattered buildings. Only softly rounded hills	1	0.03	0.15
Agricultural land with some houses and 8-m-tall sheltering hedgerows with a distance of approx. 1250 m	1.5	0.055	0.17
Agricultural land with some houses and 8-m-tall sheltering hedgerows with a distance of approx. 500 m	2	0.1	0.19
Agricultural land with many houses, shrubs and plants, or 8-m tall sheltering hedgerows with a distance of approx. 250 m	2.5	0.2	0.21
Villages, small towns, agricultural land with many or tall sheltering hedgerows, forests, and very rough and uneven terrain	3	0.4	0.25
Larger cities with tall buildings	3.5	0.8	0.31
Very large cities with tall buildings and skyscrapers	4	1.6	0.39

Figure 11. Description of roughness classes, roughness length, and wind shear (Jain, 2011)

The wind shear exponent used for both locations is 0.25. It is assumed that this number describes the effect of terrain at the actual site which is a mountain ridge.

2.3 Analysis of wind and electrical production variation across the wind farm

This detailed analysis from January 2011 examined 10 minute data from each of the turbines within the farm on wind direction, wind speed and production as noted earlier. The wind speed was divided into the following categories: 0-4m/s, 4-5m/s, 5-7m/s, 7-9m/s, 9-11m/s, 11-13m/s, 13-15m/s, 15-20m/s, 20+m/s. A frequency distribution of hourly wind speeds across the wind farm was created. A corresponding frequency distribution of hourly electric production values was also created. Also to be examined will be how much time within this month the turbines are producing electricity vs. not producing. There are three main reasons why the turbines are not producing; too low wind speed, too fast wind speed and maintenance.

The turbines are not constantly running for several reasons. This is primarily due to low wind speed but it can also be high wind speed. Common properties for turbines are that they start producing at 4m/s, stop at 25m/s and maximum production is reached at 15m/s. Another factor is maintenance, which can be routine maintenance or unexpected damage.

3 Results

3.1 Measured wind speed vs. predicted wind speed

3.1.1 Measured wind speed

Measured wind speed was compared to estimated wind speed from both computer programs (RETScreen and SAM). Key results are shown in this chapter and related documentation (figures mostly) are contained in an appendix.

Table 2 summarizes monthly average measured wind speed at the wind farm. Feasible / minimum required 10 m wind speed of 4.0 m/s for wind farms corresponds to a value of 6.4 m/s at 67m (hub height).

Table 2. Average wind speed per month

	Measured Data (2011)
Location:	
Elevation:	**3495 ft**
Terrain:	Mountain ridge
Meter:	MET tower
	Wind speed m/s
Measured at:	67m
Jan	7.0
Feb	7.2
Mar	7.4
Apr	8.4
May	7.2
Jun	7.7
Jul	6.8
Aug	6.1
Sep	5.9
Oct	6.6
Nov	7.2
Dec	5.9
Annual	**6.9**

3.1.2 Predicted wind speed by RETscreen

The outcomes from RETScreen differ because of different locations and also different measurement methods. The locations are chosen with the wind farm locations as a guide to have the outcome as accurate as possible. The percentages shown in Table 3 are the differences between the wind speed predicted by RETScreen and the observed wind farm wind speed (from the met tower).

Table 3. 67 m wind speed predicted by RETScreen vs. observed wind farm wind speed (percent difference)

	RETScreen predicitons at wind farm location (NASA)	RETScreen predictions at airport (NASA)
Jan	6%	24%
Feb	15%	34%
Mar	27%	43%
Apr	48%	67%
May	39%	56%
Jun	44%	58%
Jul	28%	40%
Aug	11%	23%
Sep	5%	14%
Oct	13%	26%
Nov	6%	24%
Dec	6%	8%
Annual	**21%**	**35%**

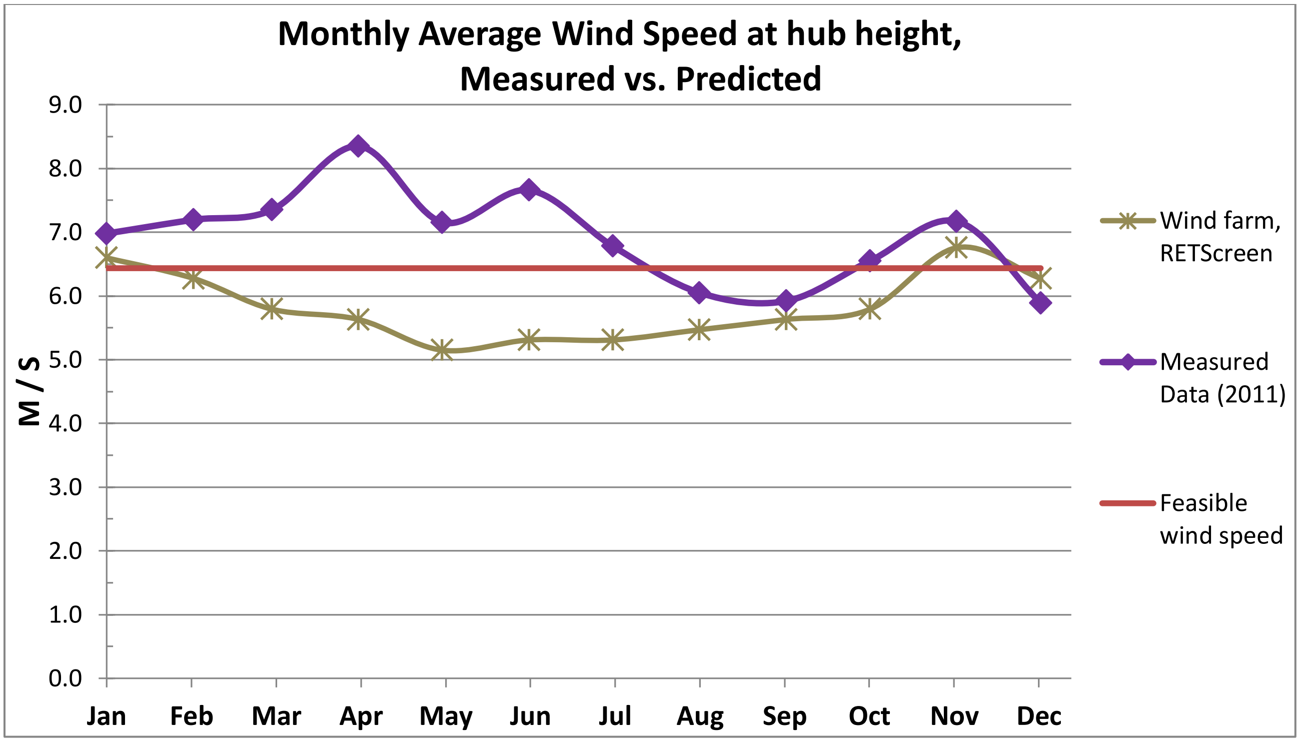


Figure 12. Monthly average wind speed at hub height (67 meters). Feasible wind speed is 6.4 m/s at hub height.

3.1.3 Wind speed predictions from SAM

The percentage shown in Table 4 is the difference between measured wind farm data compared to the two locations and available wind data in SAM. For the wind farms location, three years of wind data were available (2004, 2005, 2006) and for the airfield location two years (2004, 2006). Those five different sources were considered adequate for the comparison.

Table 4. Comparison on wind speed, SAM vs. measured data

	SAM Comparison of wind speed predicted by SAM vs. measured data at the wind farm (% difference)				
	Predictions from SAM at wind farm (2004)	**Predictions from SAM at wind farm (2005)**	**Predictions from SAM at wind farm (2006)**	**Predictions from SAM at airfield (2004)**	**Predictions from SAM at airfield (2006)**
Jan	9%	4%	49%	53%	46%
Feb	18%	3%	42%	44%	34%
Mar	30%	9%	6%	29%	43%
Apr	14%	4%	19%	35%	38%
May	4%	2%	10%	14%	15%
Jun	5%	9%	2%	19%	15%
Jul	8%	7%	3%	1%	1%
Aug	17%	1%	14%	1%	8%
Sep	27%	16%	9%	6%	7%
Oct	17%	4%	33%	37%	20%
Nov	4%	14%	35%	50%	34%
Dec	13%	28%	11%	44%	39%
Annual	**14%**	**8%**	**19%**	**28%**	**25%**
		Average for 3 years =	**14%**	**Average =**	**26%**

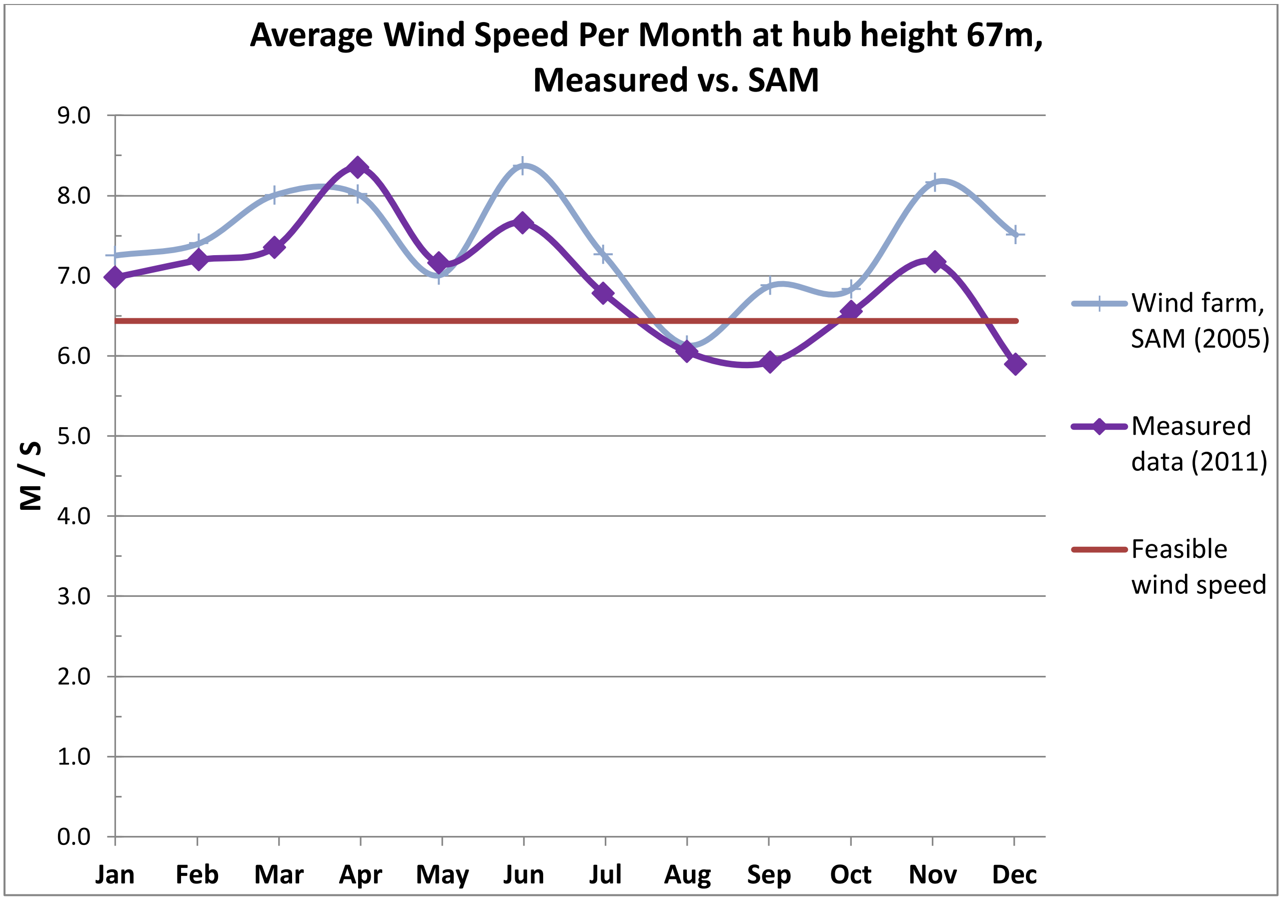


Figure 13. Average wind speed per month at hub height (67 meters). Measured vs. Wind farm (2005) in SAM.

Wind farm location uses information from the Western Wind database as addressed above in methods to gain its data. The wind speed data from the year 2005 matches the measured data quite well.

3.2 Measured electrical production vs. estimated production

3.2.1 Measured electrical production

The information below is from the years 2007-2011 of wind farm operation. It is said that the first months are insignificant due to adjustment of equipment and should therefore produce less electricity than normal (Nelson, 2011). Data from the year 2011 is used in this research and it is a little higher than the average for this 5 year period without being unusual in terms of wind speed. The capacity factor represent "the ratio of the net electricity generated, for the time considered, to the energy that could have been generated at continuous full-power operation during the same period" (U.S.NRC, 2012).

Table 5. Measured production from the wind farm per month by year

	Measured data				
	2011 MWh	**2010 MWh**	**2009 MWh**	**2008 MWh**	**2007 MWh**
Capacity factor	31.7%	26.6%	27.5%	34.1%	30.6%
Jan	59,853	26,377	58,027	57,896	46,268
Feb	47,954	15,046	30,698	58,982	36,811
Mar	51,723	46,583	63,934	59,883	61,008
Apr	75,048	75,169	57,766	69,554	48,059
May	55,317	53,161	60,833	62,610	48,639
Jun	68,251	49,428	52,017	63,021	60,992
Jul	57,032	43,286	35,067	66,150	48,299
Aug	44,416	52,841	40,758	58,144	52,559
Sep	39,571	42,987	30,661	33,447	54,682
Oct	51,882	35,680	45,117	46,831	51,187
Nov	45,587	45,267	49,505	50,834	41,988
Dec	38,941	45,993	25,790	54,746	62,360
Annual	**635,575**	**531,818**	**550,173**	**682,097**	**612,851**

3.2.2 Predicted Production from RETScreen

Table 6 shows the average production per month for each location/year along with production by manual input of measured wind speed. Normally this data reflects wind speed pattern quite well.

Table 6. Predicted average production per month for each location from RETScreen

	From measured wind speed* MWh	**From predicted wind speed at wind farm (NASA) MWh**	**From predicted wind speed at airport (NASA) MWh**
Wind shear	0.25	0.25	0.25
Capacity factor	29%	20%	15%
Shape factor	2	2	2
Losses	0	0	0
Jan	51,102	45,703	32,044
Feb	48,631	36,897	24,798
Mar	55,148	33,698	24,914
Apr	64,789	30,104	21,724
May	51,145	24,254	20,282
Jun	55,092	25,235	19,399
Jul	45,127	25,786	19,823
Aug	35,425	27,865	21,610
Sep	33,123	29,417	23,261
Oct	43,628	33,217	24,559
Nov	51,226	45,803	32,730
Dec	35,690	41,063	29,840
Annual	**570,127**	**399,042**	**294,985**

*Production estimate from RETScreen based on measured wind speed at the wind farm by month.

Table 7 shows the difference in percentage on electrical production for RETScreen vs. measured data from the wind turbines.

Table 7. Comparison on production, RETScreen vs. measured data (% difference)

Month	RETScreen prediction from measured data	Predicted by RETScreen at wind farm (NASA)	Predicted by RETScreen at airport, (NASA)
Jan	15%	24%	47%
Feb	1%	23%	48%
Mar	7%	35%	52%
Apr	14%	60%	71%
May	8%	56%	63%
Jun	19%	63%	72%
Jul	21%	55%	65%
Aug	20%	37%	51%
Sep	16%	26%	41%
Oct	16%	36%	53%
Nov	12%	1%	28%
Dec	8%	6%	23%
Annual	**13%**	**35%**	**51%**

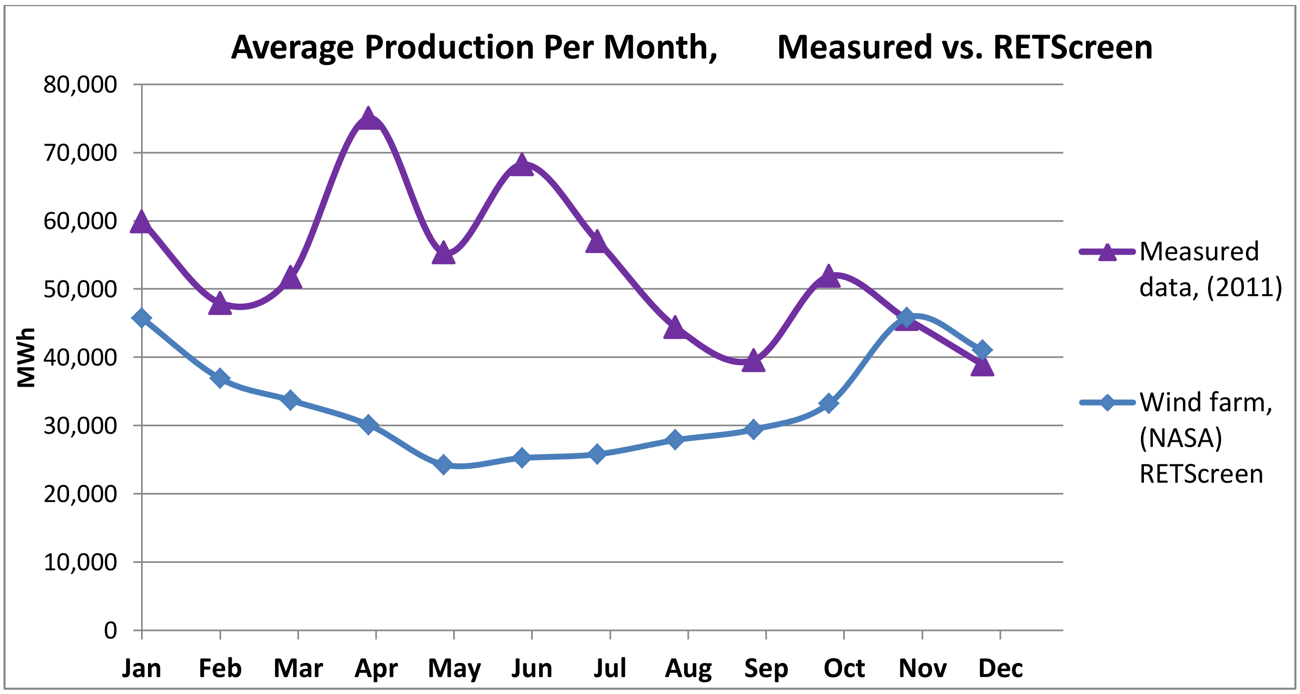


Figure 14. Average electricity production per month. Measured vs. RETScreen prediction at wind farm.

RETScreen predictions at the wind farm underestimate the production by 35% on annual average.

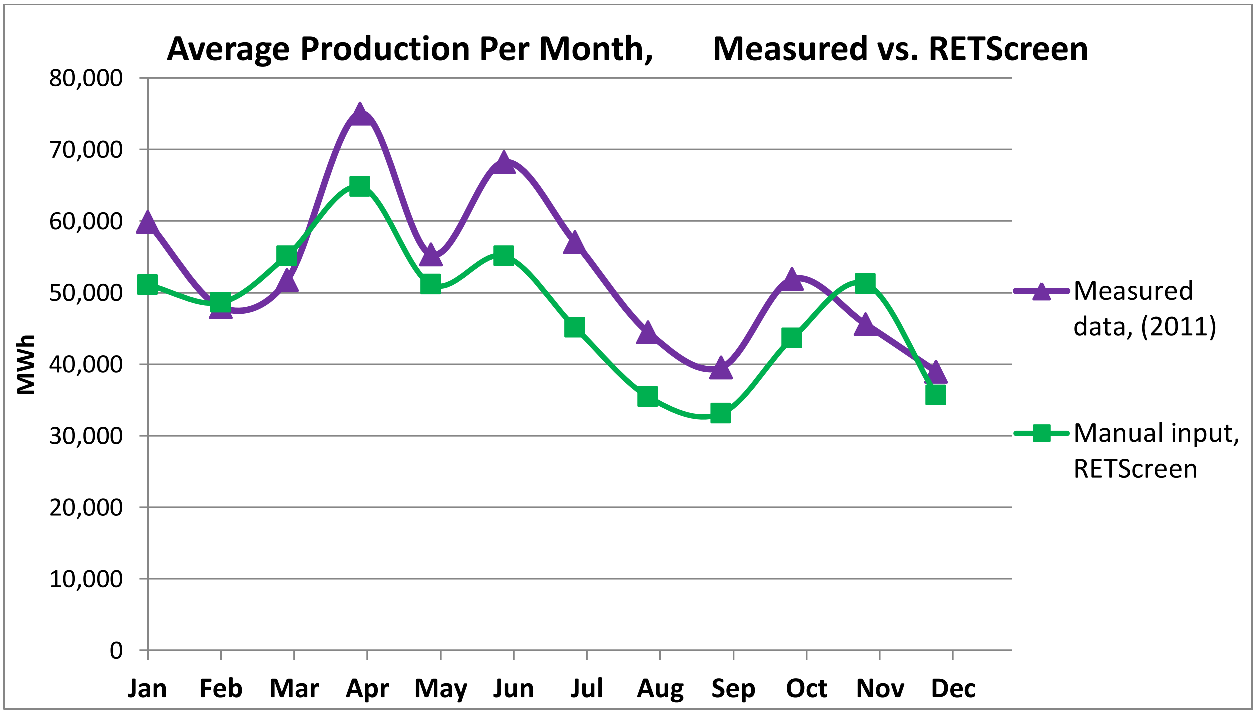


Figure 15. Average electricity production per month. Measured vs. RETScreen Predictions based on measured wind data.

Figure 15 show measured production from the wind farm and the production output from RETScreen based on measured wind data at the wind farm.

3.2.3 Production predicted by SAM

Table 8 shows average production per month for each location/annual predicted by SAM. All losses are ignored and the wind shear exponent is 0.25. The database provided data for 3 years, 2004 – 2006, except for the airfield location where the year 2005 was not available for unknown reason. Normally the production data reflects the wind data quite well though with some overestimation.

Table 8. Comparison on production, SAM vs. measured data

	SAM				
	Wind farm, SAM (2004) MWh	**Wind farm, SAM (2005) MWh**	**Wind farm, SAM (2006) MWh**	**Airfield, SAM (2004) MWh**	**Airfield, SAM (2006) MWh**
Wind shear	0.25	0.25	0.25	0.25	0.25
Capacity factor	34.5%	34.3%	38.6%	21.6%	22.6%
Shape factor	N/A	N/A	N/A	N/A	N/A
Losses	0	0	0	0	0
Jan	56,499	52,307	100,014	20,170	18,251
Feb	38,193	58,183	84,072	19,827	27,371
Mar	84,822	64,219	53,048	36,812	22,494
Apr	53,190	64,148	53,399	34,502	32,941
May	59,099	51,938	66,706	51,161	48,826
Jun	62,516	69,063	54,224	48,020	53,242
Jul	56,876	55,256	51,824	60,761	62,002
Aug	52,361	39,279	51,413	50,753	59,907
Sep	58,231	49,034	44,888	41,978	43,754
Oct	61,324	53,054	78,541	23,737	40,115
Nov	54,435	65,377	86,536	22,196	25,541
Dec	53,178	65,810	48,432	22,424	18,071
Annual	**690,723**	**687,668**	**773,098**	**432,343**	**452,514**

Table 9 shows the difference in percentage on estimated electrical production for SAM vs. measured data from the wind turbines.

Table 9. Comparison on production, SAM vs. measured data (% difference)

	Comparison on electrical production, SAM Predictions vs. Measured data at wind farm from turbines (% difference)				
	SAM Predictions at wind farm (2004)	SAM Predictions at wind farm (2005)	SAM Predictions at wind farm (2006)	SAM Predictions at airfield (2004)	SAM Predictions at airfield (2006)
Jan	6%	13%	67%	66%	70%
Feb	20%	21%	75%	59%	43%
Mar	64%	24%	3%	29%	57%
Apr	29%	15%	29%	54%	56%
May	7%	6%	21%	8%	12%
Jun	8%	1%	21%	30%	22%
Jul	0%	3%	9%	7%	9%
Aug	18%	12%	16%	14%	35%
Sep	47%	24%	13%	6%	11%
Oct	18%	2%	51%	54%	23%
Nov	19%	43%	90%	51%	44%
Dec	37%	69%	24%	42%	54%
Annual	**23%**	**19%**	**35%**	**35%**	**36%**
	26%			**36%**	
	Annual average, SAM predictions at wind farm (2004-2006)			**Annual average, SAM predictions at airfield (2004 and 2006)**	

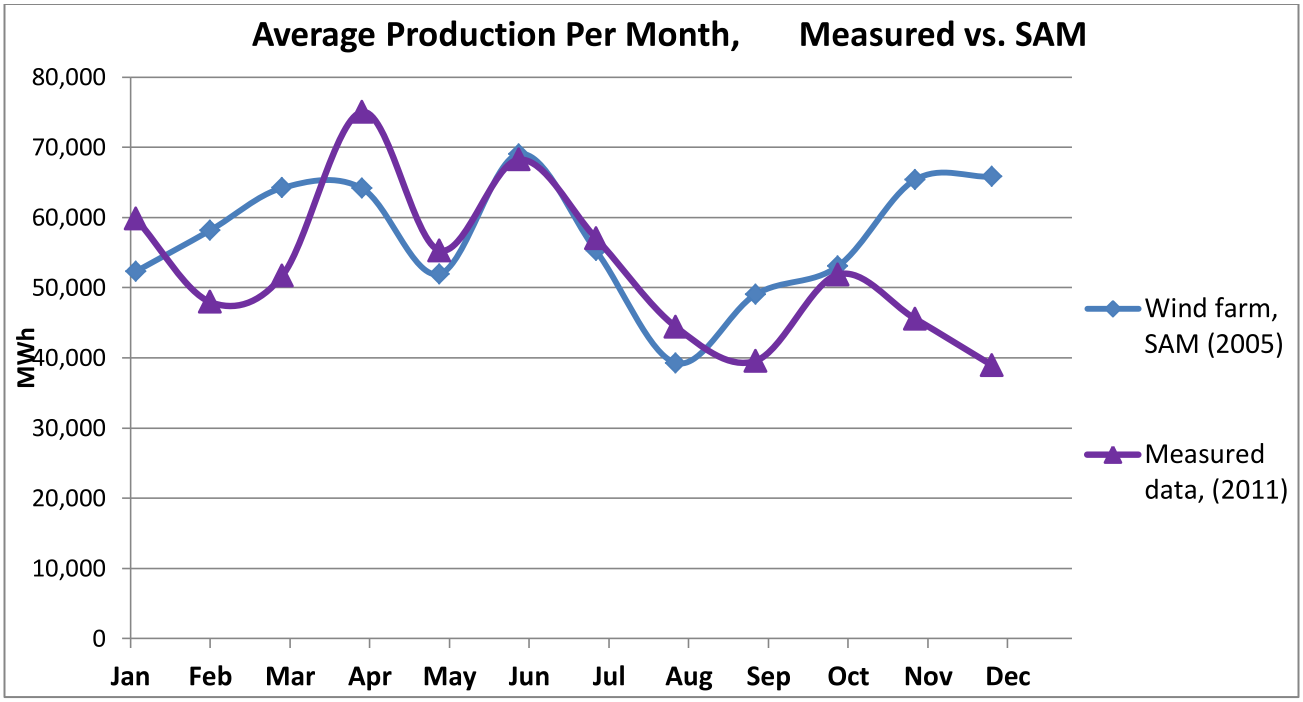


Figure 16. Average electricity production per month. Measured vs. Wind farm (2005) in SAM

3.3 Wind and production variation across the wind farm

Data from January 2011 from all turbines at the wind farm site were analyzed. The data is accumulated from each turbine every 10 minutes for wind speed and production.

Table 10. A month period divided in wind speed category

m/s	Minutes	Hours	Days	Percentage
0-4	4,840	81	3.4	10.8%
4-5	4,400	73	3.1	9.9%
5-7	7,310	122	5.1	16.4%
7-9	6,950	116	4.8	15.6%
9-11	7,130	119	5.0	16.0%
11-13	5,320	89	3.7	11.9%
13-15	3,750	63	2.6	8.4%
15-20	3,440	57	2.4	7.7%
20-25	1,240	21	0.9	2.8%
25-50	250	4	0.2	0.6%
	44,630	744	31.0	100.0%

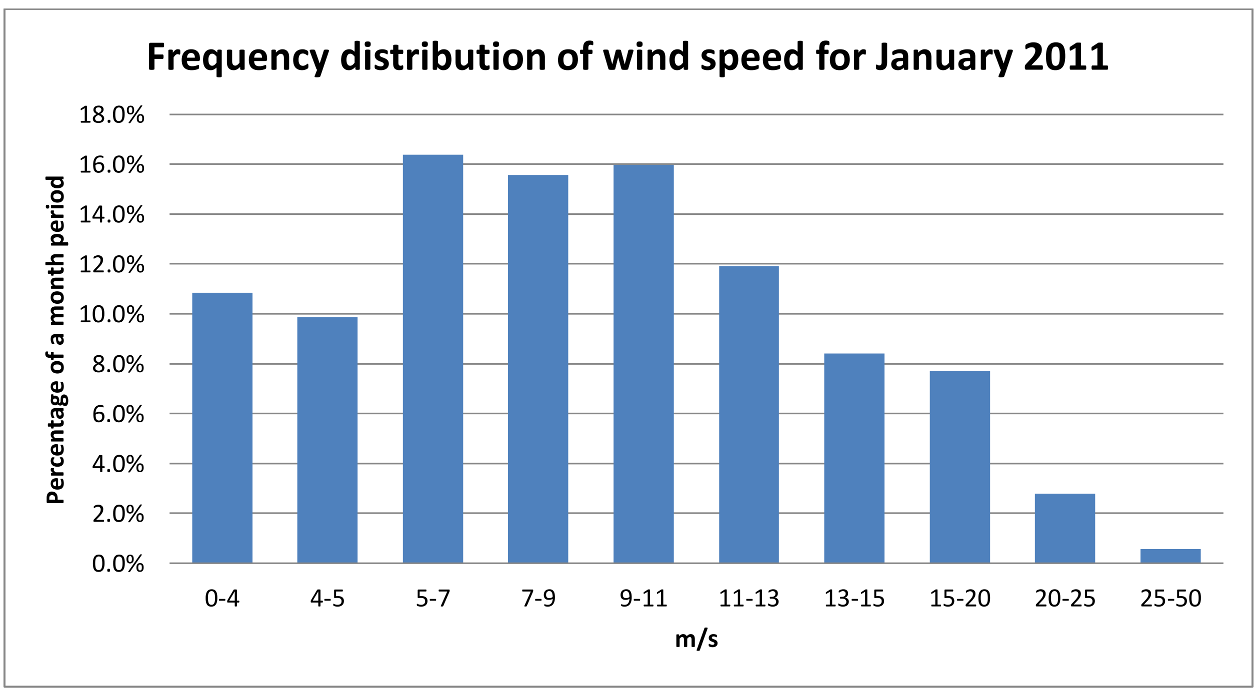


Figure 17. Frequency distribution of wind speed for January 2011

Table 11 and Figure 18 show how much electricity each wind speed category generates within a month.

Table 11. Production for each wind speed categorize over a month period

m/s	Watt hours	MWh	Percentage
0-4	0	0.0	0.0%
4-5	889,126	0.0	0.0%
5-7	20,208,289	21.1	3.7%
7-9	60,444,156	60.4	10.6%
9-11	123,018,404	123.0	21.5%
11-13	142,409,402	142.4	24.9%
13-15	108,031,183	108.0	18.9%
15-20	98,295,898	98.3	17.2%
20-25	18,067,932	18.1	3.2%
25-50	0	0.0	0.0%
	571,364,390	571.4	

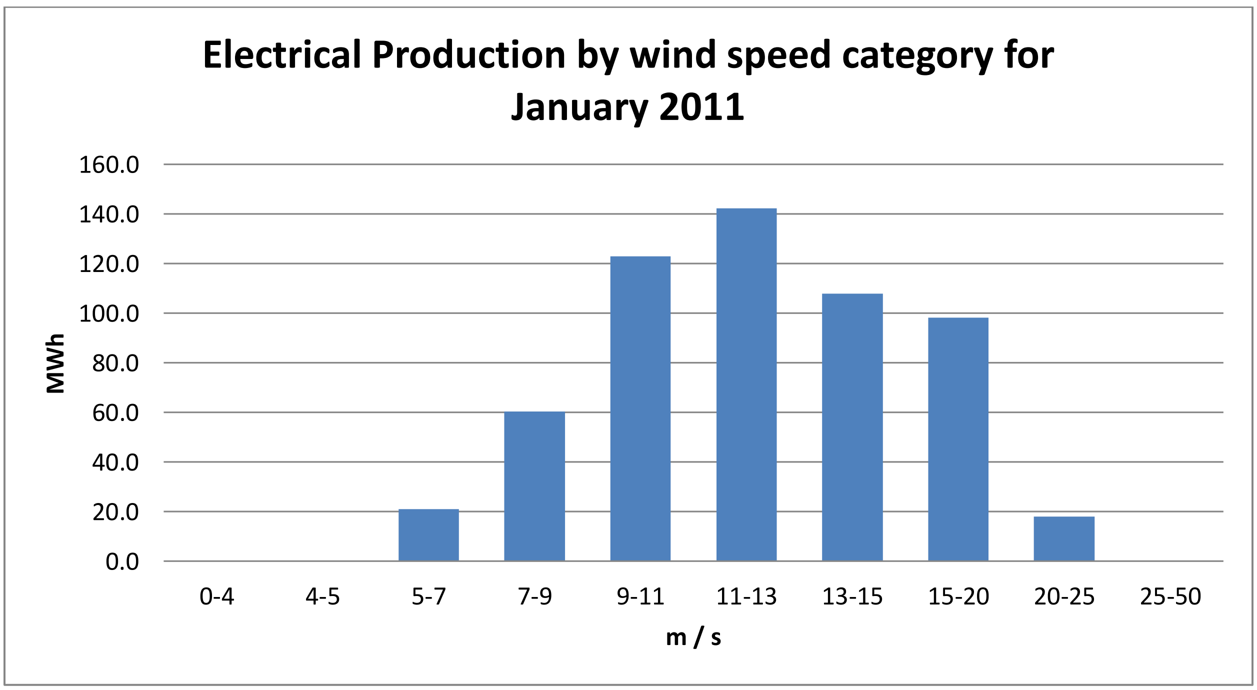


Figure 18. Production by wind speed category for January 2011

Table 12 shows the percentage of time the turbines were producing and not producing (downtime). The reason for the downtime is slow wind, fast wind or maintenance.

Table 12. January 2011 plus a day analyzed for producing vs. not producing

	Hours	Days	%
Slow wind	180	7.5	23.4%
Fast wind	24	1	3.1%
Maintenance	0.35	0.01	0.05%
Producing	563.65	23.5	73.4%
Total time	**768**	**32.0**	**100.0%**

4 Discussion

4.1 Measured wind speed vs. estimated wind speed

Comparison of measured wind speed from the turbines and estimated wind speed from RETScreen and SAM are difficult to evaluate because of numerous factors. The measured data on wind speed is from a location which is 2900 – 3600 feet above sea level and the data is from the year 2011. The wind is measured every 10 minutes for an entire year and then merged into an average per month. Among influencing factors are: elevation, terrain, height on the meter, and location.

4.1.1 Predicted wind speed by RETScreen vs. measured wind speed

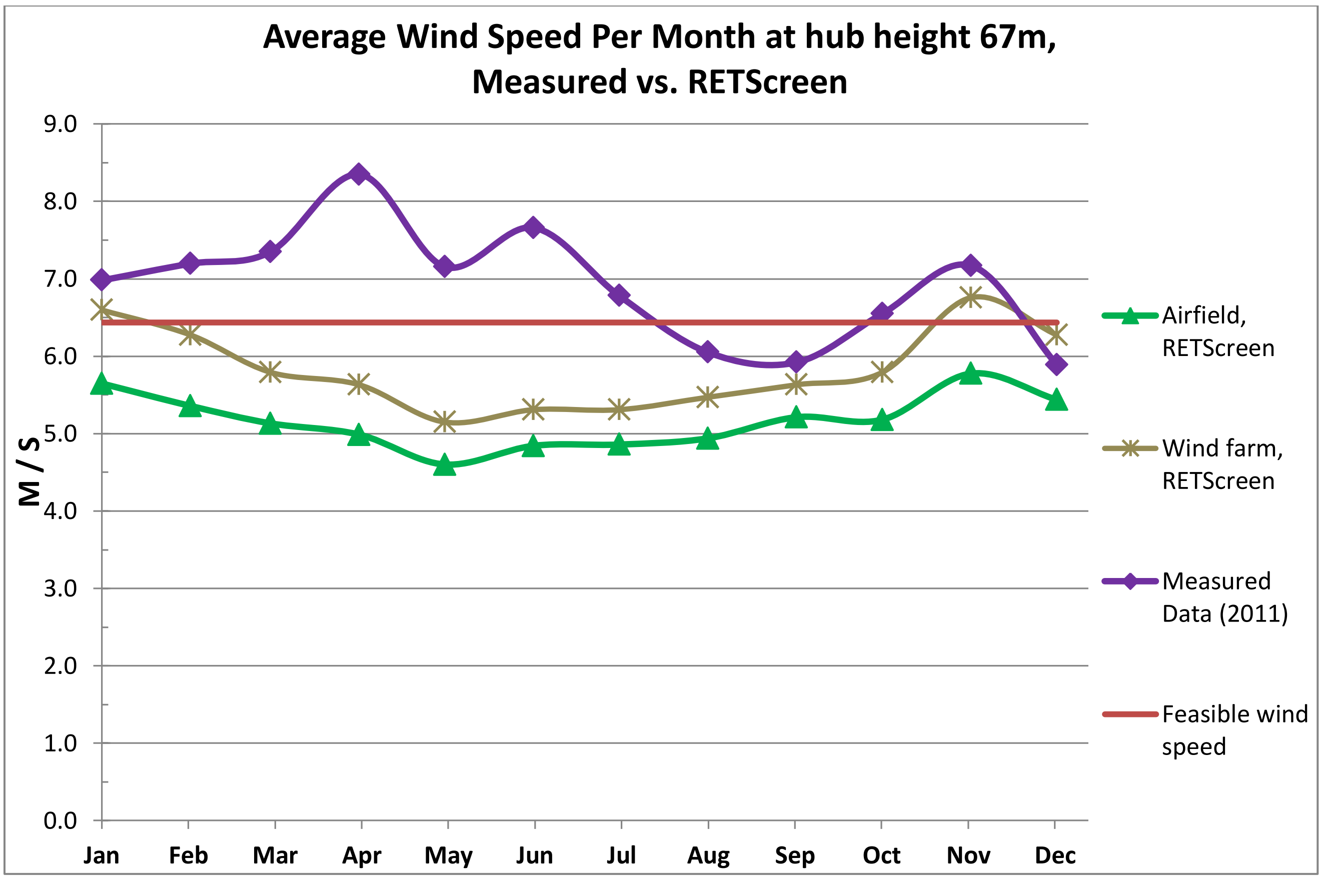


Figure 19. Average wind speed per month at hub height (67m) for both locations in RETScreen

According to Figure 19, the wind farm location and the airfield location are quite similar for the RETScreen NASA data even though the elevation and terrain is different. The reason why they are similar could be because both include climate information from NASA. The figure also shows those two lines are offset; the wind farm location is offset about a 1.0 m/s from airfield location. This 1.0 m/s could be caused by the difference in elevation. Also, because those two locations are not that far apart, the NASA information could be gathered from cells side by side. It appears that information from NASA does not take into account the terrain because wind farm location is a mountain ridge and the other location is on an airfield.

The minimum required wind speed is the minimum wind strength needed for developing a potential wind farm. In Figure 19, either of the locations reaches the limit of feasibility on annual average. On the other hand, as addressed above, the wind farm location could partially meet those requirements, depending on periods.

4.1.2 Predicted wind speed by SAM

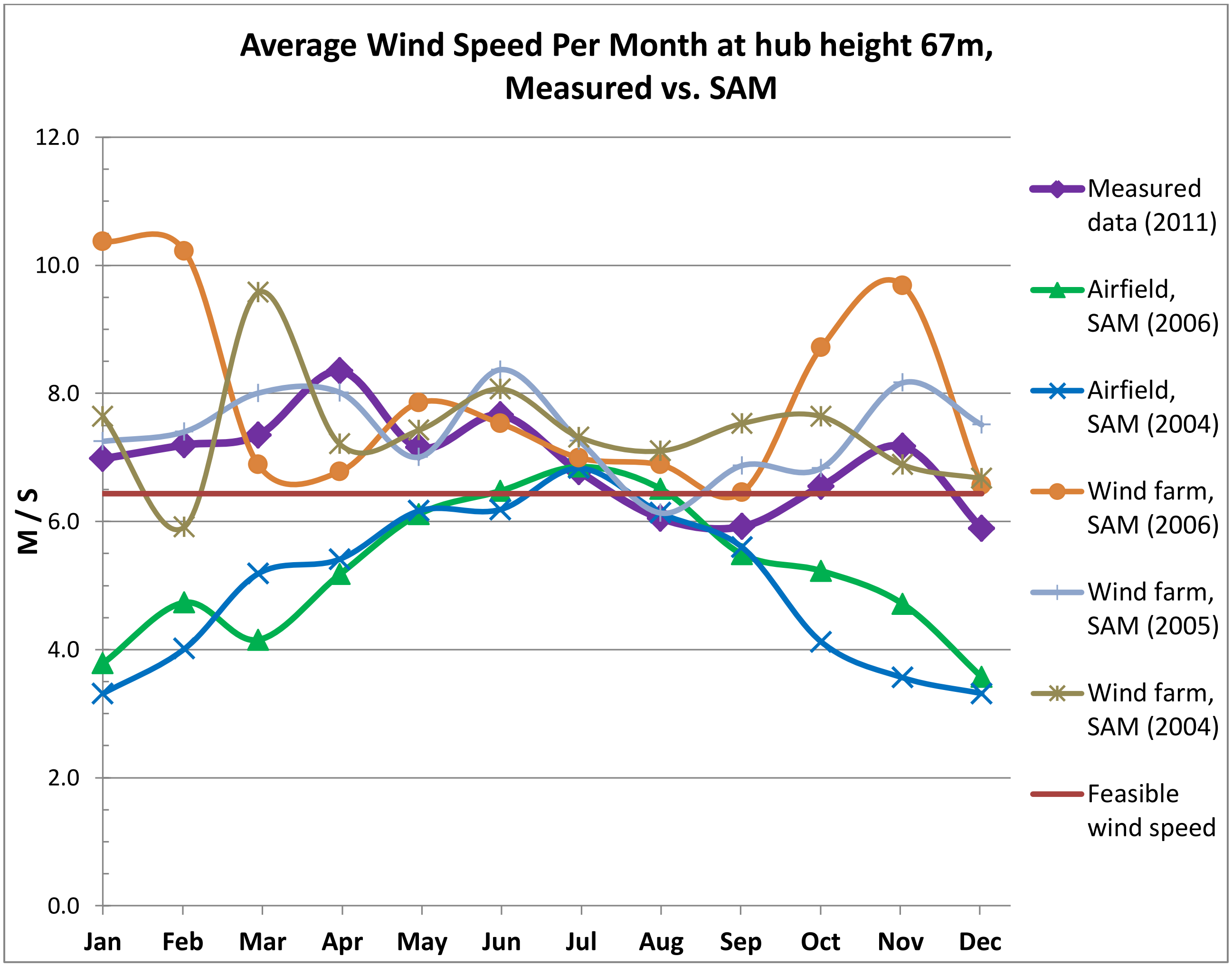


Figure 20. Average wind speed per month at hub height (67m) for all locations in SAM

As shown in Figure 20 both locations (wind farm and airfield) seem to have similar patterns between years. At both locations the spring/summer (April through October) is rather consistent regarding wind. On the other hand the fall/winter period (November through March) varies more between years. The wind farm location includes the best matching predicted wind data to the measured data, especially from the year 2005. The airfield location has a similar parabolic shape between years and is also quite consistent even though it does not have as reliable information as the wind farm location.

Predicted wind information for both locations comes from NREL's Western Wind Dataset (see above in chapter 2, methods).

Figure 20 demonstrates that the wind farm location in SAM is quite reliable regarding measured data. The airfield location on the other hand is not quite as reliable, that could be caused by lower elevation and a different terrain. The wind farm location exceeds the feasible wind speed the largest part of the year while the airfield location only exceeds it between June-August. The accuracy for the wind farm location could be related to the good wind data NRFL possesses.

4.1.3 RETScreen vs. SAM

With regard to comparison on the two computer programs, numerous factors must be taken into consideration. The wind farm location wind speed is underestimated according to RETScreen even though for a few months (August through January) it is closer to the measured wind speed. Predicted wind data for wind farm location by SAM, follows the measured data quite well even though it fluctuates over a few months (October through February). The reason why the computer programs differ could be that NASA data set has information from locations that are far apart while SAM has information from sites (locations) closer to each other. Information from SAM comes closer to measured data than from RETScreen so that measuring technique might be more accurate.

It appears that the airfield wind speed data from SAM have a tendency for higher wind during the spring/summer months while the airfield wind speed data from RETScreen have it through the fall/winter months. Again, it could be that the data from NASA is not taking the terrain (environment) into full consideration.

4.2 Measured production vs. estimated production

The summary shown in Figure 21 and Figure 22 of estimated production in MWh from both RETScreen and SAM is compared against measured production from turbines.

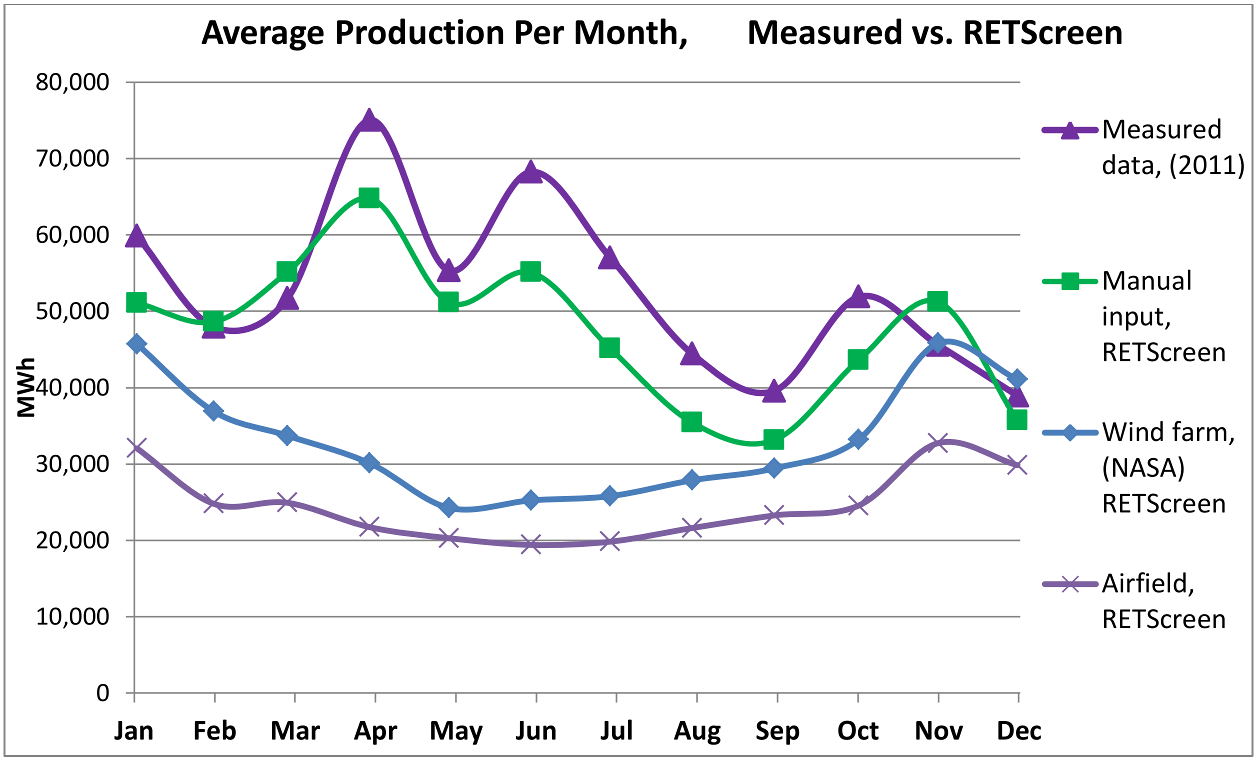


Figure 21. Average production per month for both locations in RETScreen, measured data vs. RETScreen

The electrical production results in Figure 21 shows for both locations are similar for RETScreen NASA wind data.

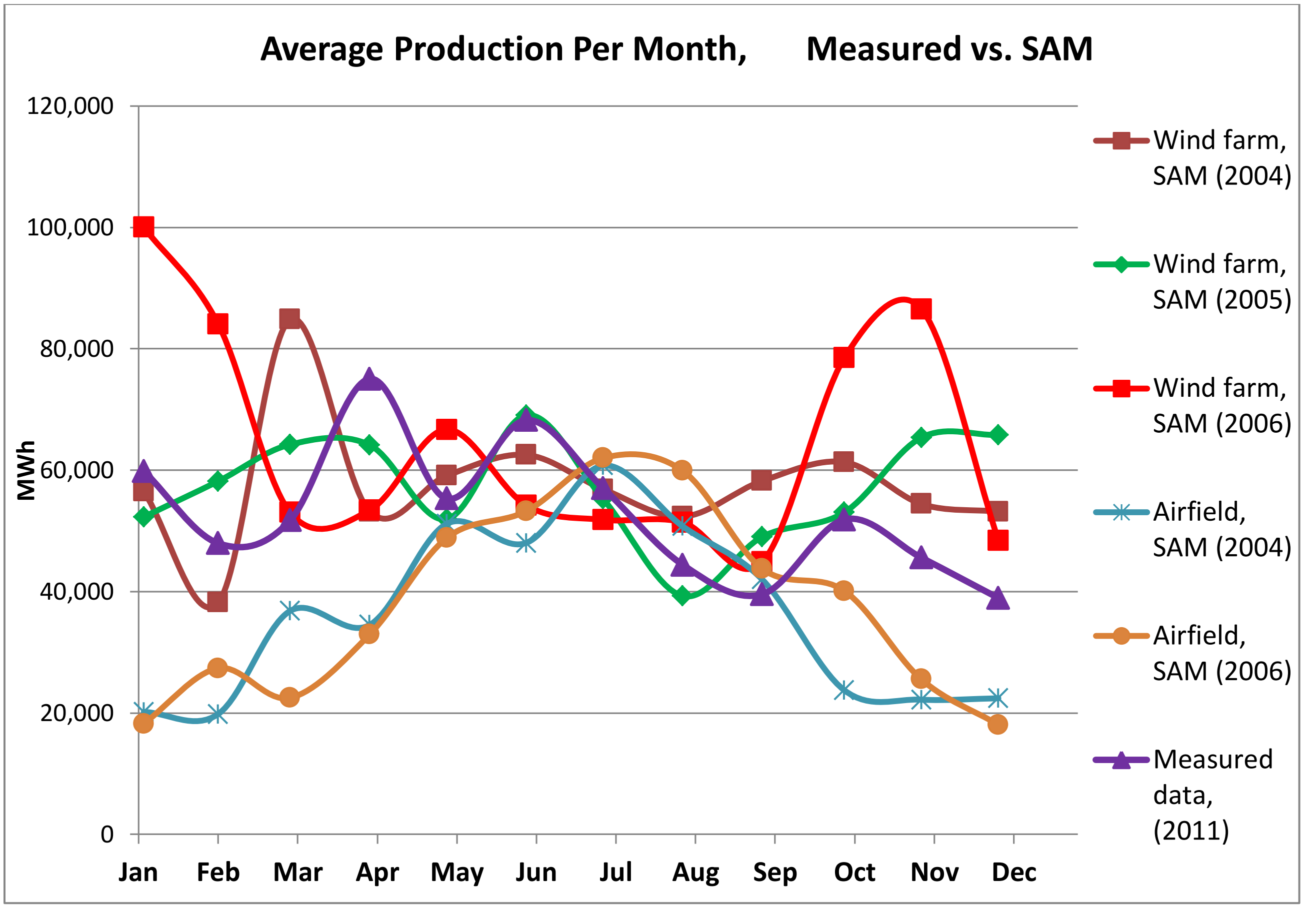


Figure 22. Average production per month for all locations in SAM, Measured vs. SAM

SAM allows the user to enter wind data by coordinates and specific information on turbine type but no other specific information such as manufacturer, losses, etc. The climate database consists of hourly wind speed data and therefor no need for Weibull distribution to estimate wind speed within the month.

In both locations, the spring/summer (April through October) is rather consistent regarding production. On the other hand, the fall/winter period (November through March) varies more between years. According to predicted data from SAM the wind farm location is producing more electricity than measured production from turbines. Predicted data from SAM still includes the best matching results to measured data, especially for the year 2005.

4.1 Wind and production variation across the wind farm

Numerous factors affect the process on how wind is converted to electricity. Among those factors are losses as addressed earlier. The parameters of the turbine affect the conversion from wind speed to electricity, therefore it is an important decision when selecting the type of turbine. These parameters are, for example; cut-in wind speed, cut-out wind speed, and maximize wind speed. Another influencing factor is maintenance, this is a factor that is hard to predict and can affect the conversion of wind speed to electricity too.

Maintenance of a wind farm is a factor that needs to be addressed to prevent loss of wind capacity and profitability. "A single wind turbine may have more than 10,000 mechanical and electrical parts, and a typical wind project is located far from the manufacturer´s warehouse or any emergency repair services" (Nelson, 2011). A standard wind product warranty has increased from two up to 5 years since 2008. Companies operating a wind farm tend to purchase extended warranties, typically for up to five years beyond the standard warranty (Nelson, 2011).

As shown on Table 12 (Chapter 3) only 0.05% of the total time, no electricity was produced due to maintenance. This is a low number and it is possible to attribute the reasons to the fact that the results are only based on data from one month (January 2011). This month is usually windy and cold and therefore it could be assumed that all routine maintenance (for example oil-change) is executed on different, less windy times of the year. Cut-in and cut-out wind speed can be different between types of turbine.

The difference between a turbine that starts producing at 4m/s vs. 5m/s was examined earlier in the paper. According to Table 11 it shows how little production is lost even though about 10% of the month the wind is between 4-5m/s.

4.2 Wind vs. Production

As addressed above, the wind farm location comes closest to measured data both regarding wind speed and production and airfield location follows. This makes sense because the wind farm location is closest to the actual wind farm and at a similar elevation. The airfield location follows and is quite far away, at a lower elevation and different terrain,it does not deliver as reliable information as shown in Table 1.

According to Table 13 the percentage numbers are first representing the difference between measured data and predicted data from RETScreen. It appears that the more variation between estimated vs. measured wind speed the more variation occurs between estimated vs. measured production.

Table 13. Result: Average annual numbers for RETScreen vs. measured data

Average annual numbers for RETScreen	Wind farm, (NASA) RETScreen	Airfield, (NASA) RETScreen
RETScreen, wind speed	-21%	-35%
RETScreen, production	-35%	-51%
Difference on wind speed vs. production	**41%**	**32%**

According to Table 14 from SAM, it also appears that the more it varies between estimated vs. measured wind speed the more it varies between estimated vs. measured production like from RETScreen above.

Table 14. Result: Average annual numbers for SAM vs. measured data

Average annual numbers for SAM	Wind farm, SAM (2004)	Wind farm, SAM (2005)	Wind farm, SAM (2006)	Wind farm, SAM (2004)	Wind farm, SAM (2006)
Wind speed	14%	8%	19%	-28%	-25%
Production	23%	20%	35%	-35%	-36%
Difference on Wind speed vs. prod.	**39%**	**57%**	**44%**	**21%**	**30%**

4.3 Final results

Final results from both programs on wind speed and electrical production vs. measured data in percentages. Both programs assume no losses even though measured data includes losses within the farm. By taking losses into account estimated production would be reduced and result would be closer to measured data. Therefore by overestimating, programs deliver more reliable data.

Results from SAM are the average from 3 years period (2004-2006) that was available in the climate database. Only SAM delivered overestimated results on electrical production compared to measured data. Table 16 shows the production results and if the programs would take losses into account SAM would deliver more accurate data and RETScreen less accurate.

Table 15. Wind speed results

	Wind speed results	
	Wind farm location	**Airfield location**
RETScreen	-21%	-35%
SAM	14%	-26%

Table 16. Production results

	Production results	
	Wind farm location	**Airfield location**
RETScreen	-35%	-51%
SAM	26%	-36%

4.4 Other similar research

No general research was found on the thesis topic; however, two examples were found in the RETScreen textbook. “First, predictions of the RETScreen Wind Energy Project Model are compared to results from an hourly simulation program. Then, model predictions are compared to yearly data measured at a real wind energy project site” (Canada, 2004). The actual data is from a small scale wind farm in Kotzebue in Alaska with 10 turbines (hub height 24m) that have a combined rated capacity of 500 kW. The hourly simulation program is HOMER from the USA which is a similar to RETScreen. It is only used as a simulation tool and the input data of the wind speed it requires is monthly values and stochastically estimates hourly values from these. The results on RETScreen vs. HOMER, in other words monthly estimated data vs. hourly simulated data, are as follows:

Table 17. Comparison of predicted annual energy production – small wind farm (Canada, 2004).

RETScreen Unadjusted Energy Production (MWh)	HOMER Total Energy Production (MWh)	Difference
1,532	1,515	**+1.12%**

Table 18. Comparison of predicted annual energy production – Large wind farm (Canada, 2004).

RETScreen Unadjusted Energy Production (GWh)	HOMER Total Energy Production (GWh)	Difference
258.2	265.2	**-2.64%**

The result on model predictions from RETScreen vs. yearly data measured at a real wind energy project site is as follows:

Table 19. Comparison of RETScreen predictions vs. actual data for Kotzebue, AK (Canada, 2004).

Period	Turbines	Average Wind Speed (m/s)	RETScreen Prediction (MWh)	Actual Electricity Production (MWh)	Difference
1998*	1-3	4.9	250	270.9	-8%
1999*	1-3	5.4	317	208.6	+52%
July 1999-June 2000*	4-10	5.1	646	546.9	+18%
1999-2000**	1-10	5.4	1,057	≈1,170	-10%

* From CADDET (2001). ** From Bergey (2000).

These results suggest that RETScreen is reasonable for preparation of pre-feasibility studies. By looking at the purpose of those computer programs it has to be considered that they should only predict the feasibility and potential profitability for a wind farm location. Each and every person then has to evaluate how accurate the data has to be to decide on further investigation/measures.

5 Conclusions

According to results on electrical production SAM will be better than RETScreen given that SAM includes a much more detailed topography and a much finer scale wind field.

RETScreen is straightforward and convenient to use. It offers a variety of options such as losses and turbine parameters. RETScreen accesses wind data from ground stations and NASA, the ground stations are located near populated areas and are often on an airfield. Those locations do not necessarily provide the best wind data for a specific, nearby location as illustrated by the assessment provided in this thesis. The data resolution is fairly coarse for the NASA database and does not work well for complex terrain.

SAM is easy and convenient to use like RETScreen. The wind data base includes fairly dense resolution and offers data from three years (2004-2006) for comparison.

The results from both programs for annual average wind speed (see Table 15) are compared to measured wind farm data. RETScreen underestimates the wind speed by 21% (wind farm location and source data from NASA) compared to measured wind speed from the wind farm. SAM on the other hand overestimates the wind speed by about 14% (wind farm location) compared to measured wind speed from the wind farm. The outcomes associated with SAM appear more accurate and the western wind database appears to predict wind quite well, although different terrain might impact this finding.

RETScreen underestimates electrical production by 35% on wind farm location compared to measured production from turbines while SAM overestimates it by 26%. SAM is more accurate in estimating electrical production for a potential wind farm. Based on this comparison SAM contains more accurate wind data to compare with measured data and could be used in the future to develop a wind farm. By adding information on array loss, airfoil loss and availability loss to the programs like addressed in the paper, they could deliver more accurate results on production. This would deliver more accurate results on production for SAM while less accurate for RETScreen.

By looking at the purpose of those computer programs it has to be considered that they should only predict the feasibility and potential profitability for a wind farm location. Each and every one then has to evaluate how accurate the data has to be to decide on further investigation/measures.

Suggestions for further research on measured data: It would be interesting to examine more locations and compare readily available wind data to actual wind farm data to gain a better perspective on this issue. It could also be examined how the development on the wind speed would fit to the Weibull distribution for this location. An assessment of the shear exponent could also be examined for that specific terrain.

Regarding to predicted data there is uncertainty about several variables and it would be interesting to do sensitivity analyses by examining; wind shear exponent, Weibull distribution shape factor and year (year for SAM only).

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Appendix A – Wind speed

Table A - 1. Average wind speed per month for both locations in RETScreen

	RETScreen			
Location:	**Wind farm**		**Airefield**	
Elevation:	**2260 ft**		**1729 ft**	
Wind shear:	0.25		0.25	
Terrain:	Mountain ridge		Airfield	
Meter:	NASA		NASA	
	Wind speed m/s		**Wind speed m/s**	
Measured at:	10m	67m	10m	67m
Jan	4.1	6.60	3.51	5.65
Feb	3.9	6.27	3.33	5.36
Mar	3.6	5.79	3.19	5.13
Apr	3.5	5.63	3.10	4.99
May	3.2	5.15	2.86	4.60
Jun	3.3	5.31	3.01	4.84
Jul	3.3	5.31	3.02	4.86
Aug	3.4	5.47	3.07	4.94
Sep	3.5	5.63	3.24	5.21
Oct	3.6	5.79	3.22	5.18
Nov	4.2	6.76	3.59	5.78
Dec	3.9	6.27	3.38	5.44
Annual	**3.6**	**5.8**	**3.21**	**5.16**

Table A - 1 shows predicted average wind speed from RETScreen for each location and converts the wind from 10m to 67m (hub height).

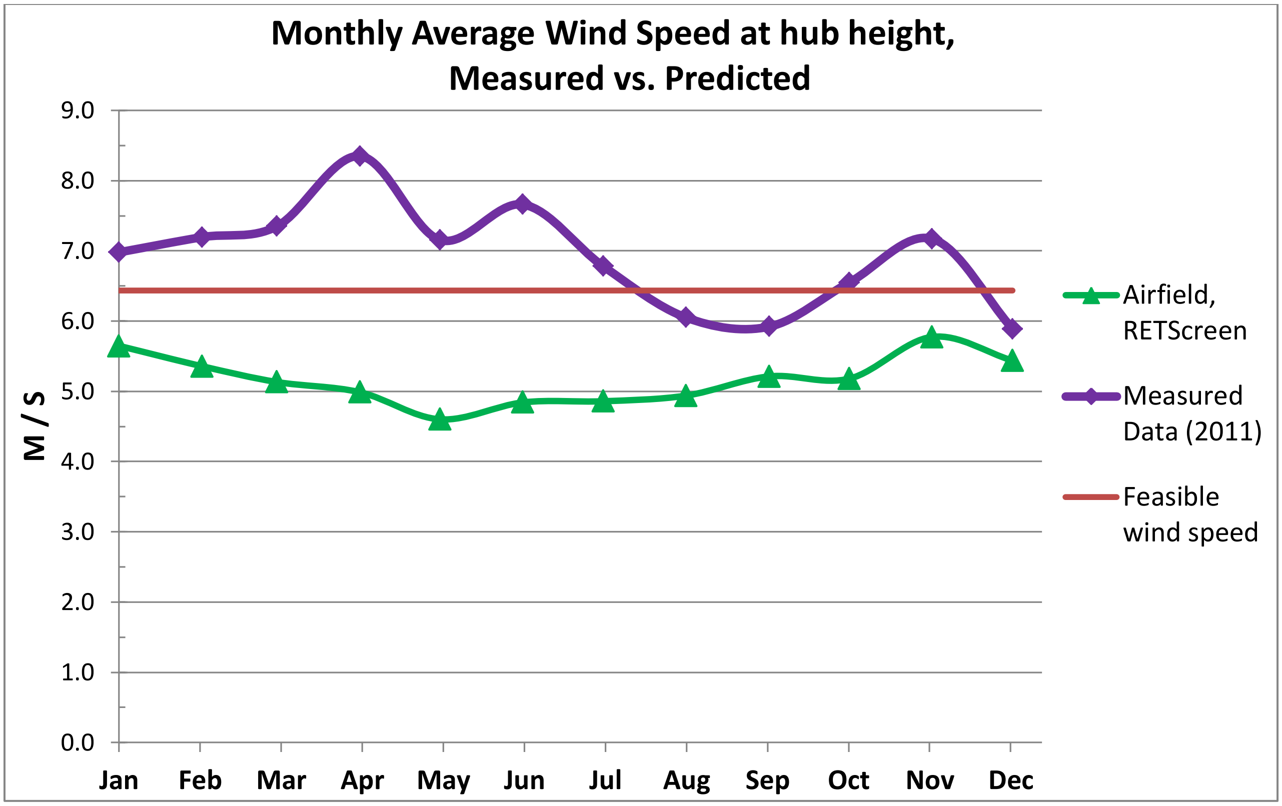

Figure A - 1. Monthly average wind speed at hub height (67 meters).

Table A - 2. Average wind speed per month for each location in SAM

	SAM									
Location:	**Wind farm location, SAM (2004)**		**Wind farm location, SAM (2005)**		**Wind farm location, SAM (2006)**		**Airfield location, SAM (2004)**		**Airfield location, SAM (2006)**	
Elevation:	**2460 ft**		**2460 ft**		**2460 ft**		**1560 ft**		**1560 ft**	
Wind shear:	0.25		0.25		0.25		0.25		0.25	
Terrain:	Mountain ridge		Mountain ridge		Mountain ridge		Airfield		Airfield	
	Wind speed m/s		**Wind speed m/s**		**Wind speed m/s**		**Wind speed m/s**		**Wind speed m/s**	
Measured at:	50m	67m	50m	67m	50m	67m	50m	67m	50m	67m
Jan	7.10	7.64	6.7	7.25	9.6	10.37	3.1	3.31	3.5	3.79
Feb	5.50	5.92	6.9	7.40	9.5	10.22	3.7	4.01	4.4	4.73
Mar	8.90	9.58	7.4	8.00	6.4	6.89	4.8	5.19	3.9	4.15
Apr	6.70	7.21	7.5	8.02	6.3	6.78	5.0	5.41	4.8	5.18
May	6.90	7.42	6.5	7.00	7.3	7.85	5.7	6.16	5.7	6.11
Jun	7.50	8.07	7.8	8.37	7.0	7.53	5.8	6.19	6.0	6.48
Jul	6.80	7.32	6.8	7.26	6.5	6.99	6.4	6.83	6.4	6.85
Aug	6.60	7.10	5.7	6.13	6.4	6.89	5.7	6.13	6.1	6.51
Sep	7.00	7.53	6.4	6.88	6.0	6.46	5.2	5.59	5.1	5.49
Oct	7.10	7.64	6.4	6.83	8.1	8.71	3.8	4.12	4.9	5.23
Nov	6.40	6.89	7.6	8.17	9.0	9.68	3.3	3.56	4.4	4.71
Dec	6.20	6.67	7.0	7.51	6.1	6.56	3.1	3.31	3.3	3.57
Annual	**6.89**	**7.41**	**6.88**	**7.40**	**7.35**	**7.91**	**4.63**	**4.99**	**4.86**	**5.23**

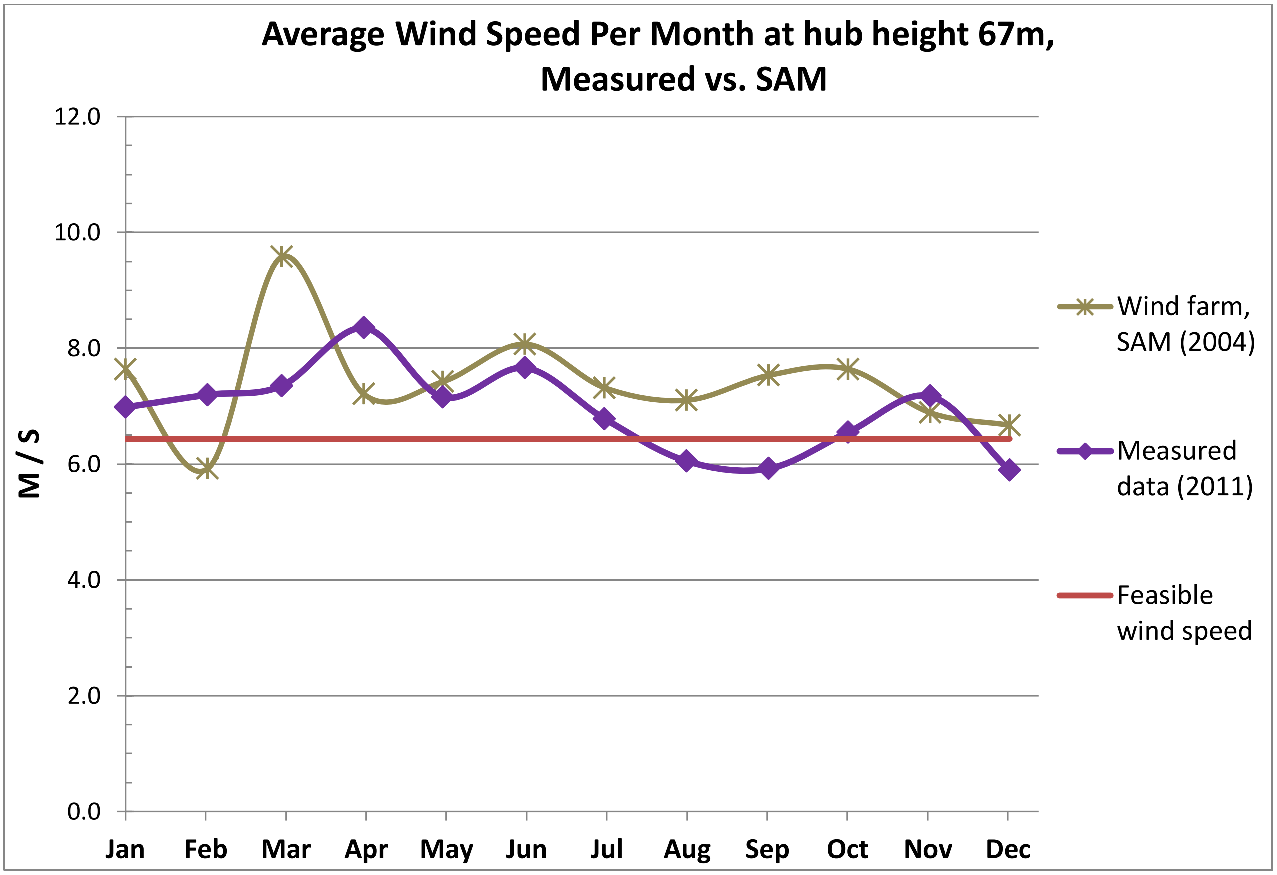

Figure A - 2. Average wind speed per month at hub height (67 meters). Measured vs. Wind farm location (2004) in SAM.

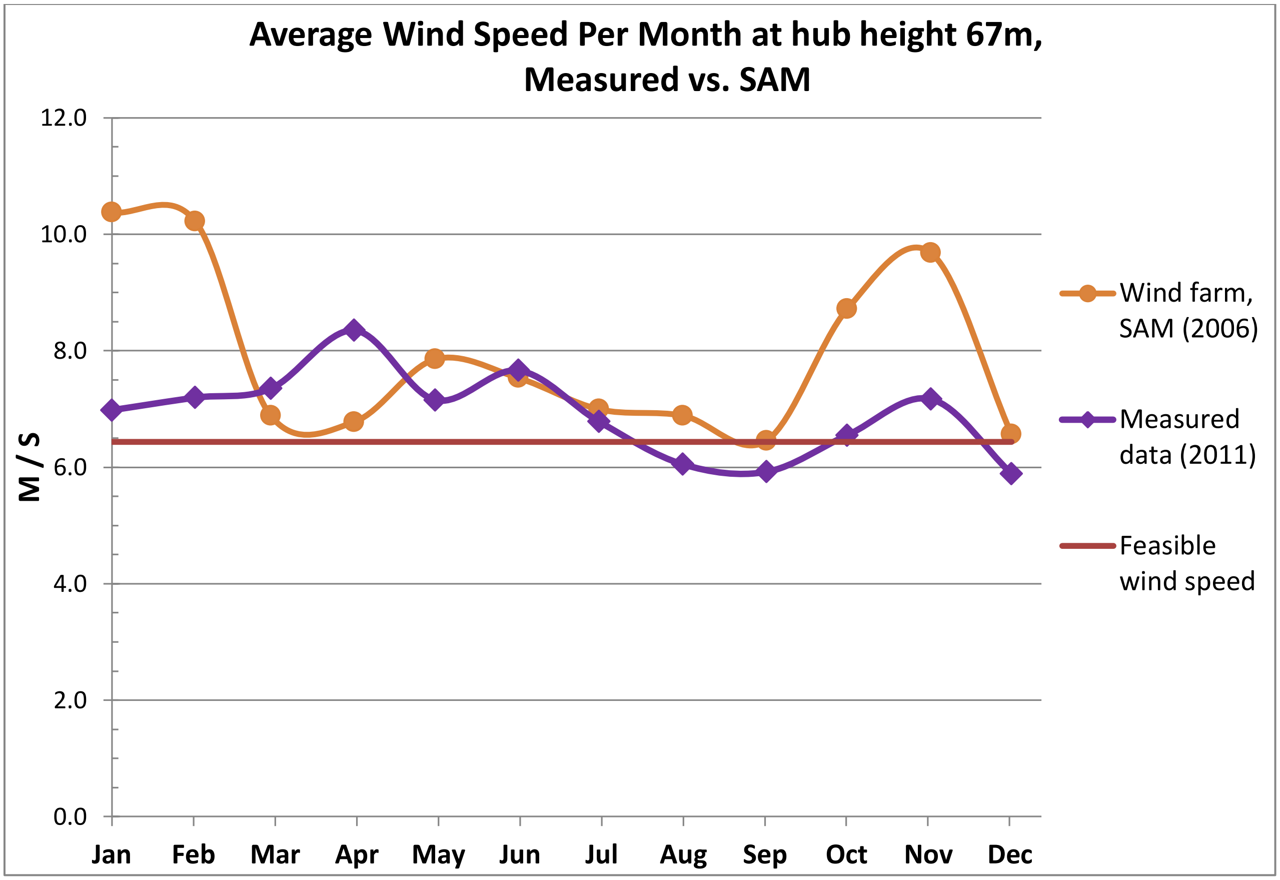

Figure A - 3. Average wind speed per month at hub height (67 meters). Measured vs. location (2006) in SAM.

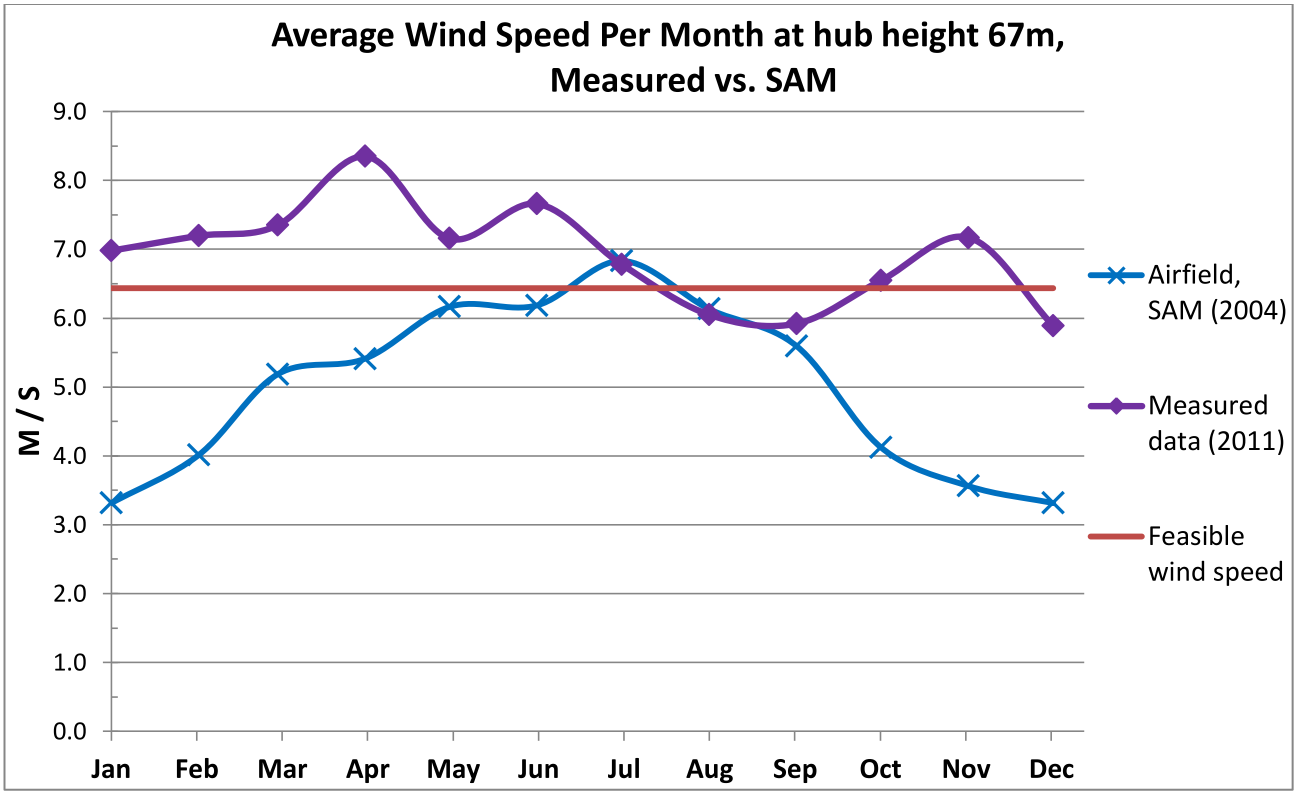

Figure A - 4. Average wind speed per month at hub height (67 meters). Measured vs. Airfield location (2004) in SAM.

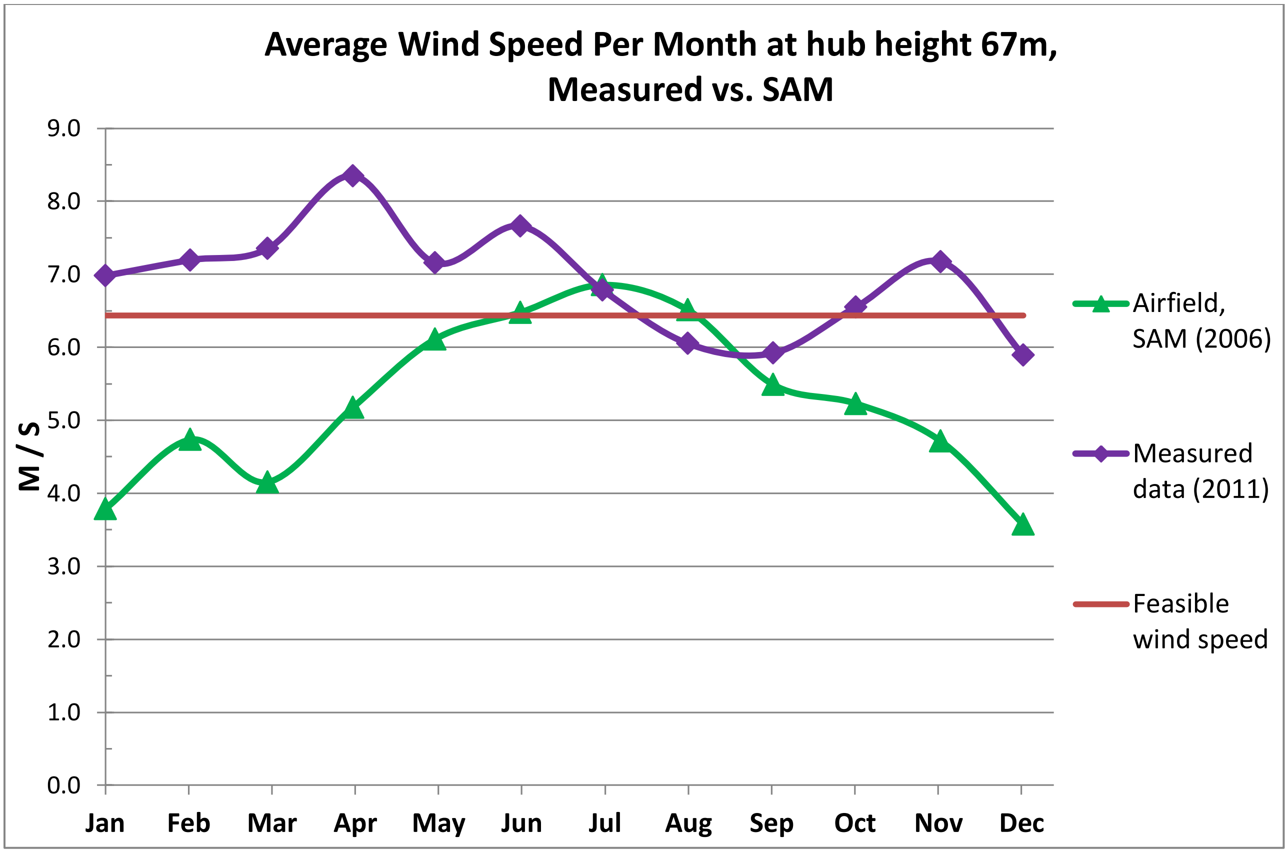

Figure A - 5. Average wind speed per month at hub height (67 meters). Measured vs. Airfield (2006) in SAM.

Appendix B - Production

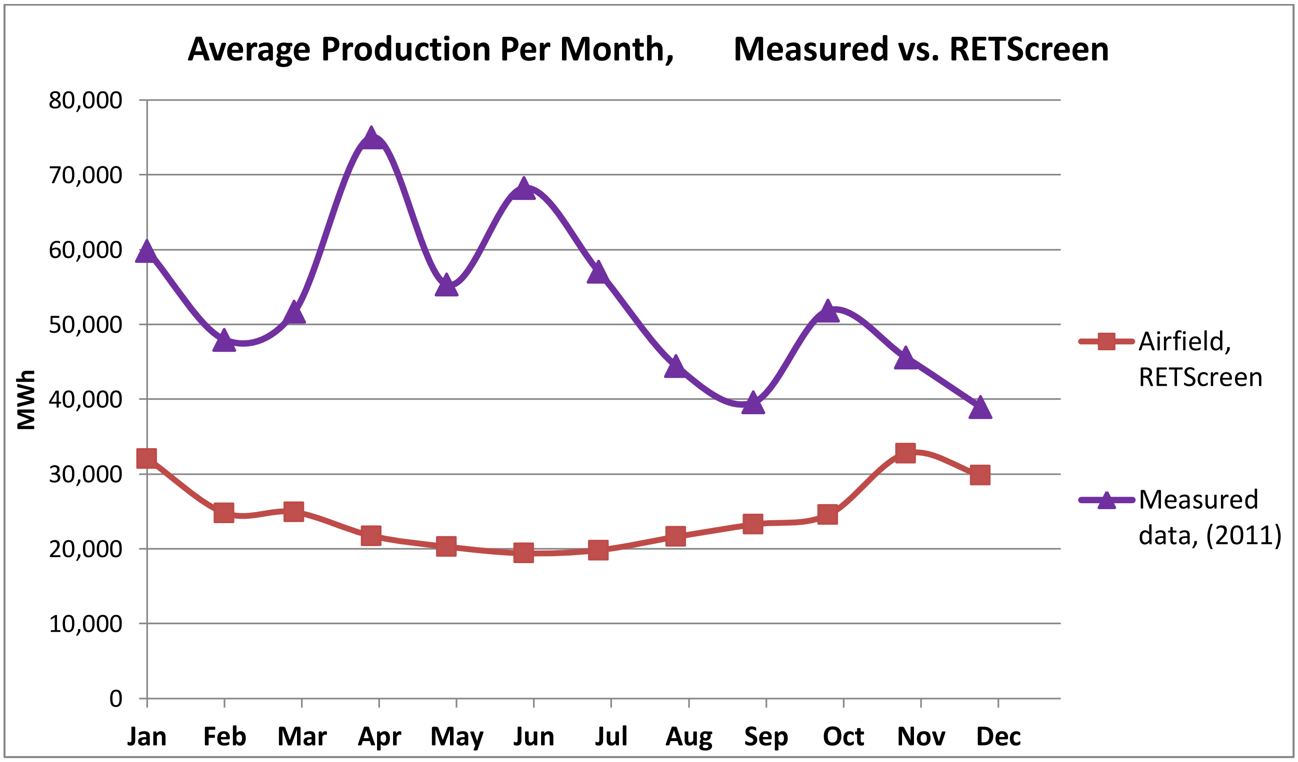

Figure B - 1. Average electricity production per month. Measured vs. Airfield in RETScreen.

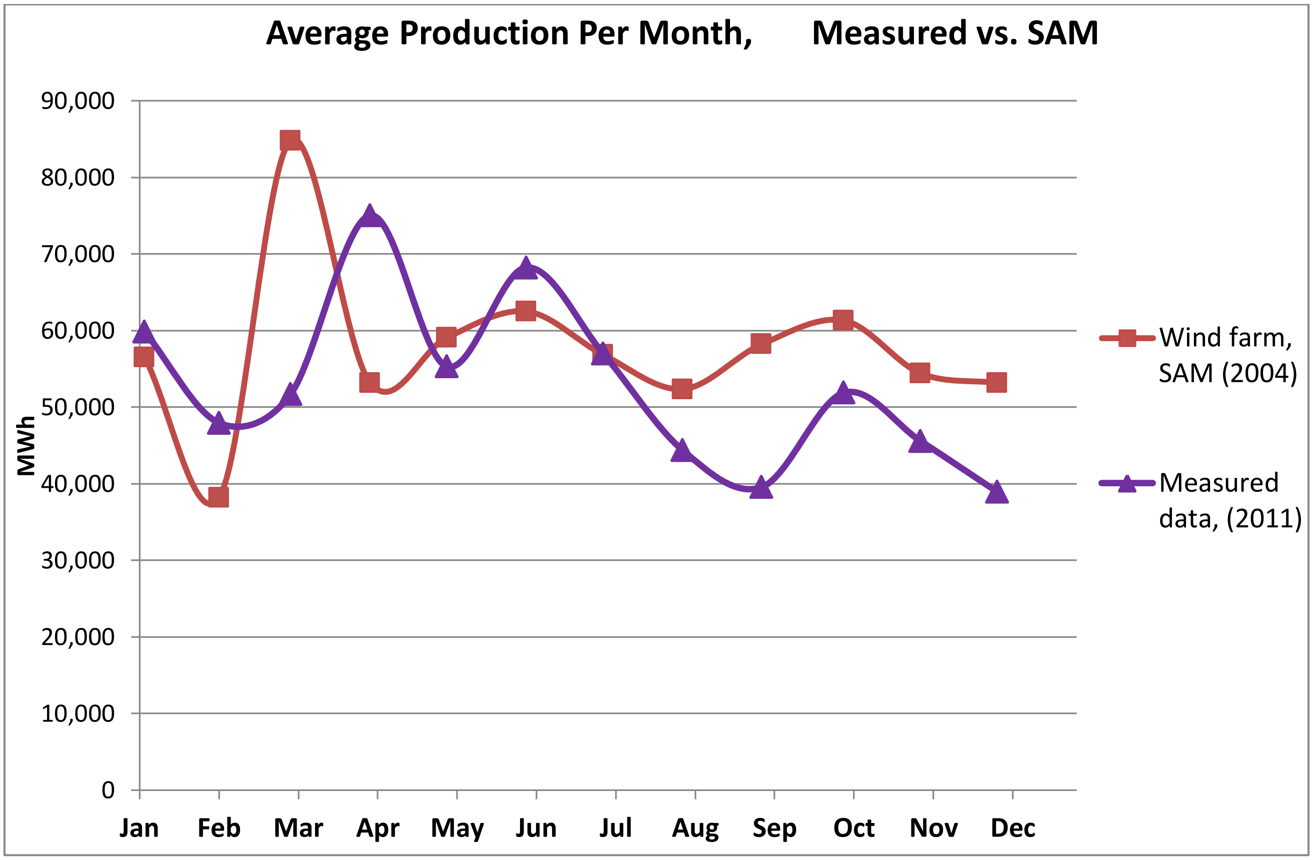

Figure B - 2. Average electricity production per month. Measured vs. Wind farm (2004) in SAM

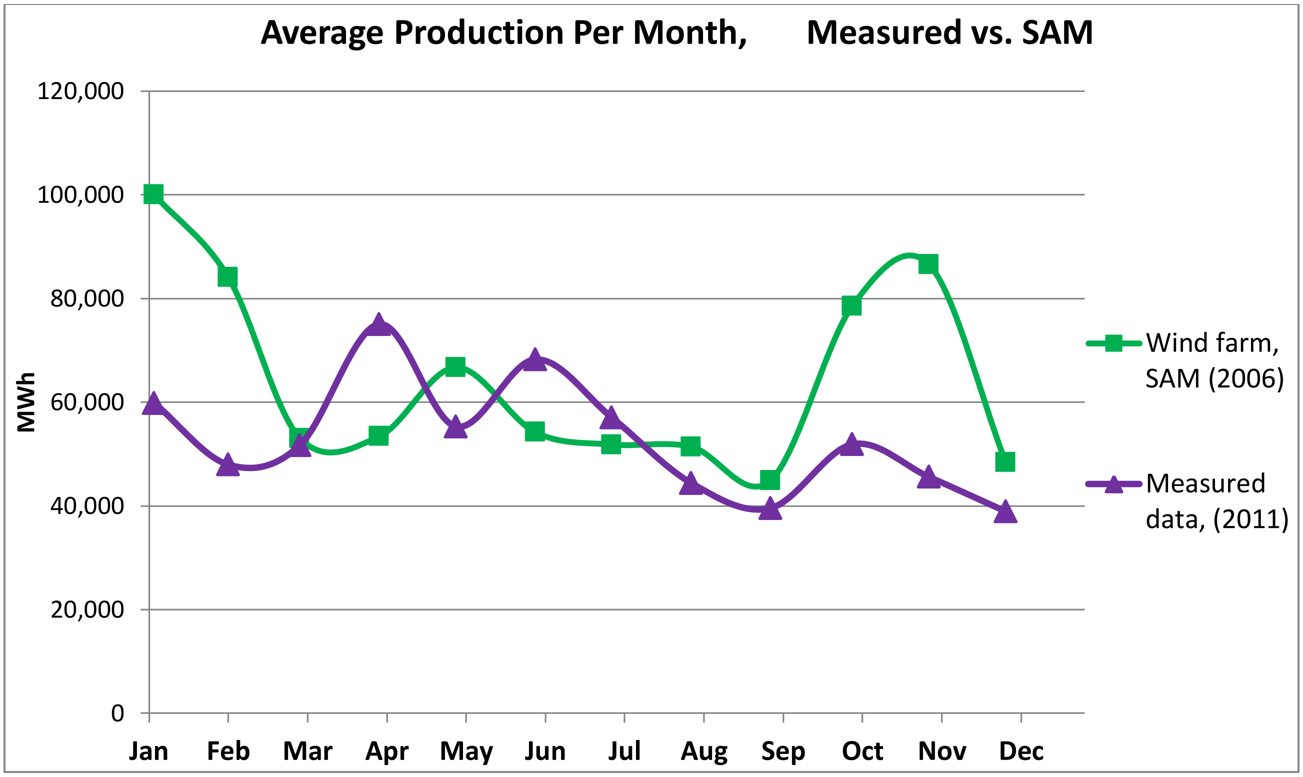

Figure B - 3. Average electricity production per month. Measured vs. Wind farm (2006) in SAM

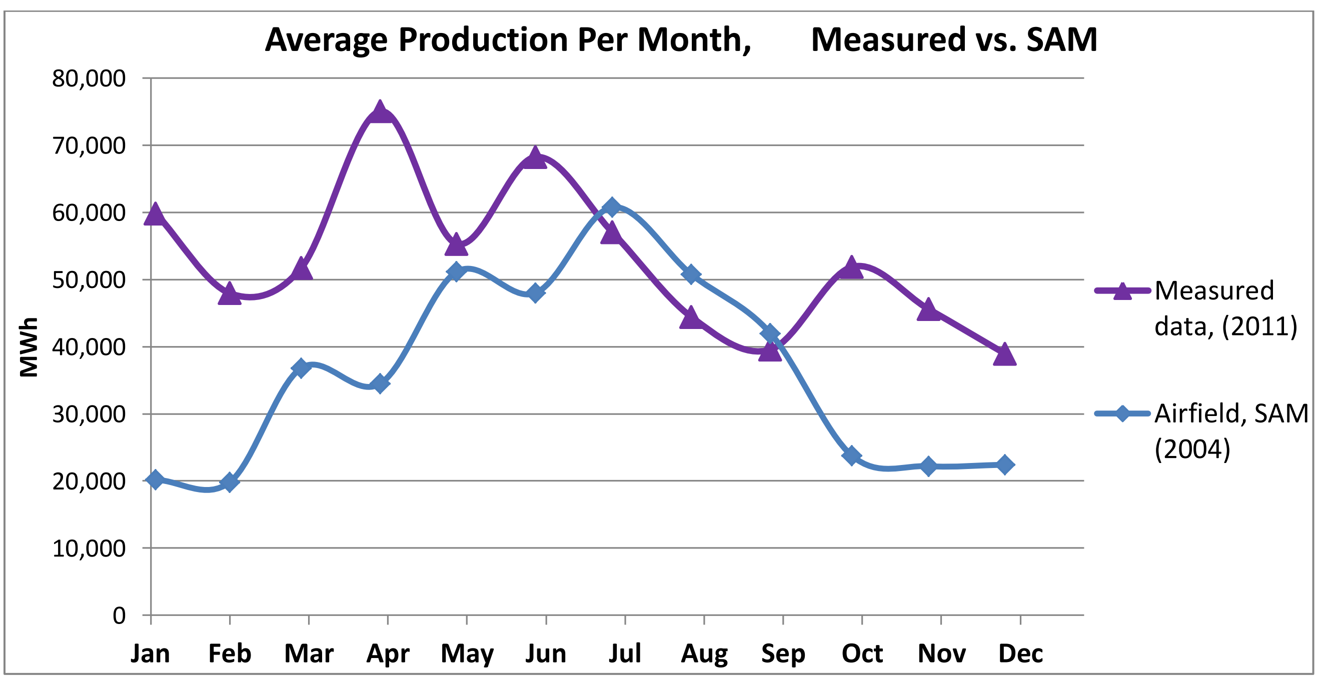

Figure B - 4. Average electricity production per month. Measured vs. Airfield (2004) in SAM

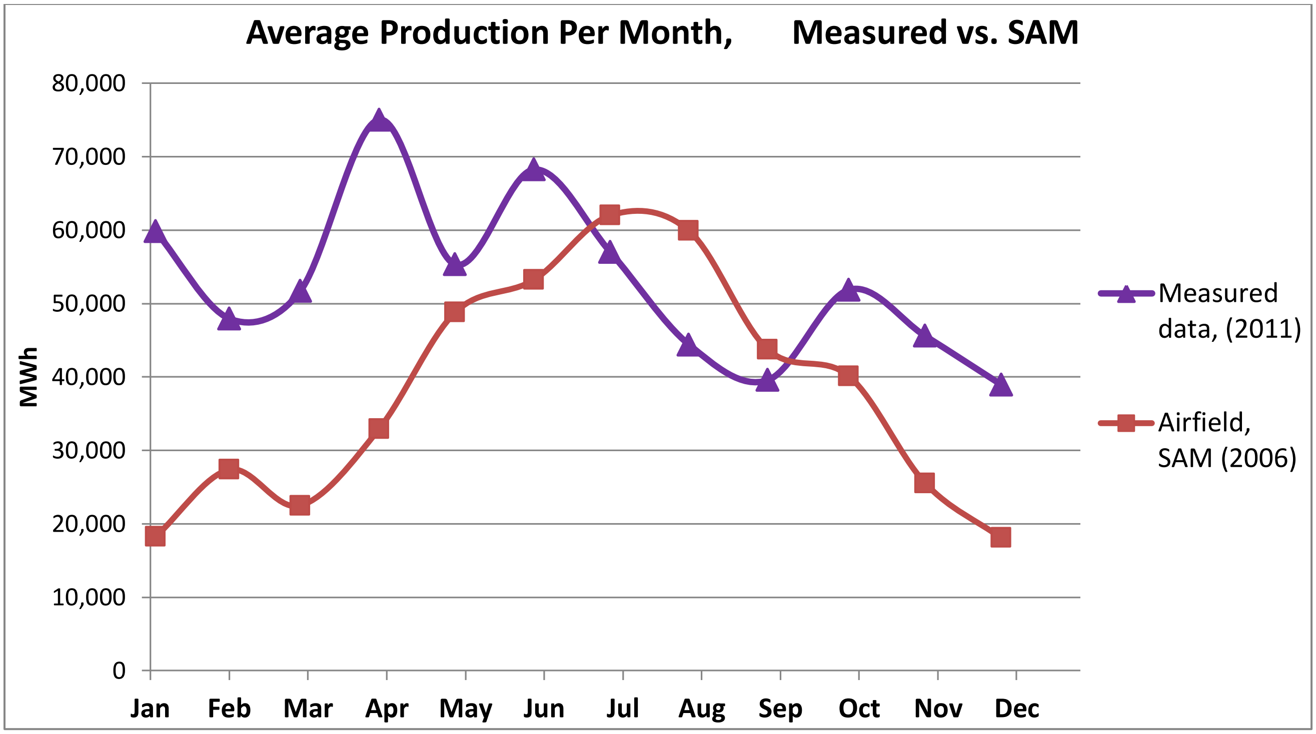

Figure B - 5. Average electricity production per month. Measured vs. Airfield (2006) in SAM

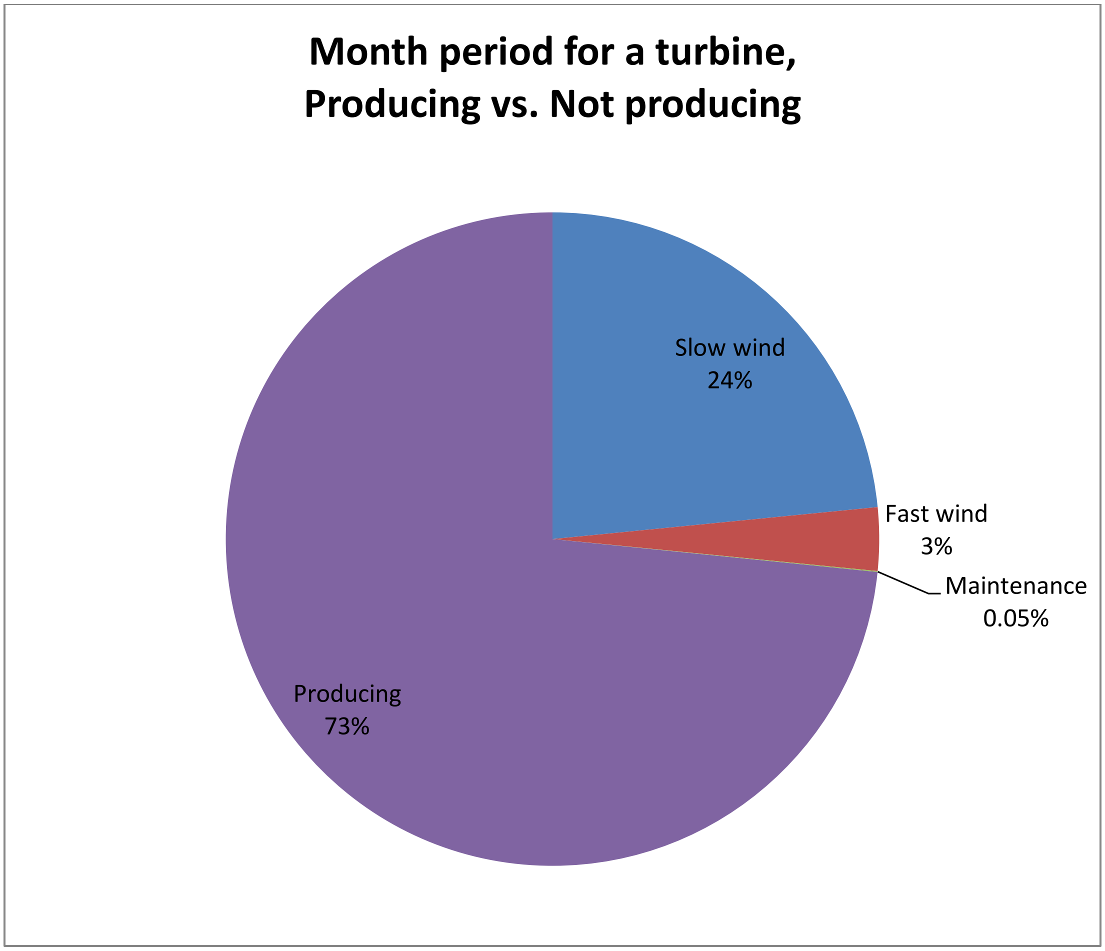

Figure B - 6 Month period for a turbine, producing vs. not producing