Wind farm: feasibility and environmental impacts

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Abstract

The renewable energy currently available at Brookhaven National Laboratory (BNL) is not adequate. I believe that with the installation of a wind turbine on site, BNL will be at the forefront of energy research and development as well as offsetting some daily energy use. I have taken a statistical approach to figuring out the feasibility of installing a wind turbine on site for energy production and research. I used wind speed data recorded over the last 20 years at the met field, a parcel of land located next to the BNL firehouse. The data sets for each year were very large, due to the fact that they had data for every minute of the year. I analyzed this data using the graphing and analysis capabilities of Excel and Minitab. Next, I was able to find the potential power production of a wind turbine using a well known formula and the average daily wind speeds in a given year, taking into account the 42% efficiency of wind turbines. Knowing the efficiency and conversion formula, I converted wind speed to power. These results showed me that the power potential of the windiest day is only slightly more than half a megawatt. The lowest power production potential is 441.30 kW/day, and the highest power production potential is 661.67 kW/day, similar to the output of the solar research array. From these results I realized that the installation of a wind turbine on site would provide a great tool for research by exploring mechanical improvements to the turbine hub and for analyzing the power produced. As a result of my work so far this summer, I have gained a much better appreciation for the differences between different types of renewable resources as well as gaining incredible knowledge on the use of statistical programs.

Background

The scope of the energy infrastructure is changing. The new wave of energy innovation is heavily focused on the use of renewable energy systems. Wind power is growing steadily in the United States as well as around the world. In 2008 only 79 countries had renewable energy and CO_2 emission reduction targets and as of 2013 there were 144 countries with similar targets. [1] Also, the global production of renewable energy in 2012 was 13.2% but in 2013 it rose to 22% a 5% increase in just one year. [2] Globally the installed wind power was 282,482 MW at the end of 2012. [2] New York State has set an ambitious goal of 80% Carbon Dioxide emission reduction by 2050. [3] When Governor Andrew Cuomo was elected in 2010 the total renewable energy production was 22% and by 2014 it was at 23%. [3] Although, the installed wind power production was increased significantly from 1275 MW to 1875 MW from 2010 to 2014. [3] To reach these goals the use of solar power and wind power has to continue on a steady upward trajectory each year. If New York could achieve a 30% growth rate of renewables or better and sustain it each year, there will be no problem reaching the renewable power production goals and carbon dioxide reduction goals by 2050 or sooner. Brookhaven National Laboratory (BNL) currently produces less than 1 MW per day from the solar research array on site, not even producing 1/80th of its daily power consumption from renewable energy sources as seen in Figure 6B. I will show that the installation of another type of renewable energy onsite will be worth while and explore the feasibility of installing a wind turbine and wind farm onsite at BNL. Globally there has been an increase of 383,000 GWH of renewable energy production from 1980 to 2006. [4] Even though there was an increase in non renewables and global energy usage. [4] The demand for energy increases every year and only a limited amount of renewable energy systems can be installed each year. However, as long as the demand for clean and renewable energy stays steady, a clean energy future is within our reach.

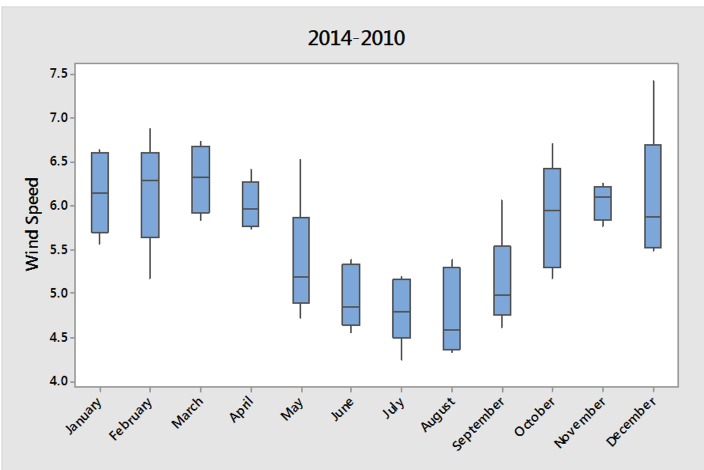
Methods

The research I am conducting is done in order to find the feasibility of installing wind turbines on the BNL site. In order to do this I needed information on the wind that is here at BNL. This information was given to me by Dr. John Heiser an employee of the Biological, Environmental and Climate Sciences Department. The data included relative humidity, temperature, barometric pressure, wind speed, wind direction, and wind gusts, at 10, 50,and 85 meters as well as the year, month, day, minute, and second. The information I focused on was the wind speeds for each minute at the 85 meter height. I did this because this is the height at which there would be the strongest winds and would provide the most power. For comparative measures I analyzed the wind speeds at 10 meters for 2014 and 2002, which are the lowest and highest levels of recorded wind speeds respectively. When I analyzed the data I used a program called Minitab. This allowed me to import the data which was stacked in a row of 525,600 points in Excel and Minitab would take those points and organize them into rows and columns. These where separated by the 1440 minutes each day and 365 days in each year as seen in Figure 5. Once I had this data organized for each of the 21 years from 1994 – 2014 I found the average of the days, months and years. Also, by going down the column I was able to find the minute averages. These minute averages were used in many of my future analyses. The reason I found this average to be so important was because it gave you an absolute average day of wind, which can give a much more accurate future prediction. I used this information to find the power production potential. I assumed the wind turbine has a blade diameter of 10 feet, about 3 meters, and a swept area of 80 square feet or exactly 7.4322432 square meters. [5] This formed my power conversion equation (in Watts), W = 0.625 *(7.4322432)*6^3. [5] Using the formula I converted all my average wind speed measurements to watts and then to kilowatts and megawatts. Although, I realized something was wrong and after a few weeks, I found out that my assumed efficiency of a turbine was 100%, when in actuality the efficiency is only 42%. As I wanted the most accurate results I multiplied all my power production potential values by .42. To put the data in perspective the most power that I found a wind turbine could create is 661.67 kW/day and the least is 441.30 kW/day. So using this data I found a wind turbine that had cut-in speeds within reasonably expected wind speeds and found a type of wind turbine that would best suit the wind speeds at BNL. Using this I could calculate the cost of installing the wind turbine and the payback period. Working with the Environmental Health and Safety department at BNL it was important that I research the impact of the wind turbines on the fragile bird and bat species. All aspects of installing a wind turbine need to be considered first as to make the best decision for BNL.

Data and Results

A. Bird and bat effects

The research and analysis I did gave me some very interesting results. The location of BNL is along the Atlantic Flyway which stretches from Canada along the east coast and down into the Caribbean islands. [6] This causes trouble for migratory birds and given the height of 100 meters at the highest or about 328 feet the birds will be impacted. Although, I have learned that birds tend to fly well above 328 feet and on very rare occasions will fly at 328 feet or below. While this will not cause a significant impact on the bird or bat population, as there are only a small amount of animals that are killed by wind turbines each year, there are alternative less fatal wind turbines available. There was a recent installation of a wind farm in Texas which was installed in the direct path of a major bird migratory path and they used avian radar technology developed and used by NASA and US air force that could sense the approaching birds as far out as four miles. [7] When this happened the turbine would lock the turbines and allow the birds to pass. [7] Once these birds passed the turbine would unlock itself and resume normal operation. [7] If upon further research it is found that BNL is in a major hotspot for bird activity then a type of wind turbine with avian radar could be considered. Another possible factor in the bird fatality rate is the fact that on average the wind speeds are stronger from fall to spring as seen in the box plot below.



This Box Plot shows the average wind speeds for 5 years from 2010-2014 for each month of the year.

I found the time of the day when there is the least wind is late afternoon with the highest peak at night. This is good for the bird population but not good for the fragile bat population. Since the wind is usually the weakest during daylight hours and strongest at night the bird activity will be less affected during their most active times of the day. Although at night when the bats are most active so are the wind turbines, but with the bats echolocation the reported impact on bats has been significantly lower than that of birds. The one risk that has been reported with many wind turbines has been the current it creates which can pull bats into the turbine and kill them. The chance of death of bats and birds are very rare and only a small amount of fatalities occur each year, which is not enough to wipe out a species.

B. Power production potential and pay back period

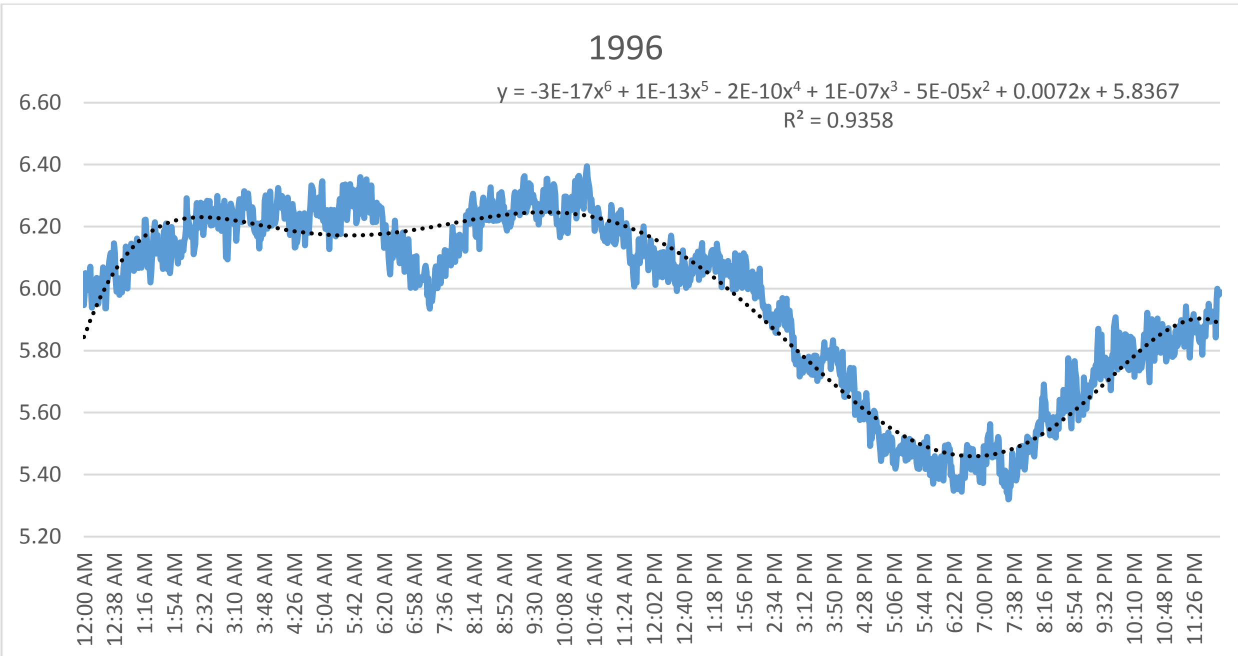
There is readily available wind for the wind turbines to function and produce power. The only viable source of wind here at BNL is at 85 meters or higher. During my analysis of the wind data I was given I used primarily the data of the wind speeds at 85 meters. The data was recorded at the met field, a parcel of land located next to the BNL firehouse. Upon analyzing this data I found that the windiest year on record was 2002 and the least windy year was 2014, as shown in Figure 3 and 2 respectively. To analyze the data I had to find a wind turbine to use. This is because every turbine has different cut-in, rated, and cut-off speeds. Cut-in speed refers to the minimum speed needed to start turning the turbines and producing limited power. Rated speed is the speed needed to produce the amount of power the turbine is capable of producing. Cut-out Speed is the speed that when maintained for 10 minutes will cause the turbine to lock up and stop producing energy. I found the Enercon E53 500 KW wind turbine and used this for further analysis. The cut-in speed starts at 2.5 m/s which even on the least windy of days we are able to achieve. The rated speed starts at 10 m/s which can be achieved, and the cut-out speed is 25 m/s which in the 21 years of data was never reached. This means we would on average make between 200 kW and 500kW. Although the amount of power is relatively small the location is very important. The locations I was given as a possible location for installation were the former landfill, the met field, and when the smoke stack is taken down installation in its place. I found that the former landfill does not have the size needed to fit a wind turbine. The location of the smokestack and the met field are two reasonable locations. The area allotted has to allow for a 300 foot buffer zone in all directions around the turbine. Also, I used a boxplot to analyze the daily average wind speeds for all 21 years and a scatter plot to compare 5 years of potential power production per minute, as shown in Figures 1 and 4 respectively. Due to the fact that the Enercon E53 500 kW, which has a hub height of 73 meters and blade length of 27 meters and produces maximum power at up to 10 m/s I calculated how many continuous days in a year the turbine could produce maximum power given wind speeds at BNL. The results showed that the best year was 1996 with 32.68 days and the worst year was 2013 with 15.97 days and the average was 24.14 days. Finally, I was able to calculate the amount of time it would take for BNL to payback the installation of a wind turbine considering rebates and incentives. This cost of installing one wind turbine I found to be $627,500. Then using the Enercon E53 500 kW model, the return on investment each year is 18.8% which would allow for the system to be paid for in 5-7 years. Also there is an incentive that can be applied by the New York State Energy Research and Development Authority (NYSERDA), which for our specific installation would give us about $174,000. With this Incentive the wind turbine would be paid for in as little as 3-5 years.

C. Noise and health impacts

The implications that come with installing a wind turbine very minimally affect a person's everyday life. These include most notable shadow flicker and noise pollution. Shadow Flicker refers to the constant shadow that the turbine casts during the day time. This constant flicker of light has rarely had a substantial affect on people. Although in rare cases it has been reported to cause epileptic seizures and symptom, mental illness, and irritability. The other noticeable affect is noise and visual pollution. The noise emitted at 300 meters is 43 decibels, which is more than a refrigerator at 40 decibels and less than an air conditioner at 50 decibels. [8] When I see a wind turbine I get excited as so do others but for many the sight of a wind turbine is just visual pollution. This can sometimes make the installation of wind turbines more difficult because of the people who do not want to see it. A recent example of this was with the Cape Wind offshore wind turbine project in long island sound. There were a select few people who were upset about their view being obstructed by these wind turbines and eventually these people derailed the project from coming into fruition.

D. Wind Pattern Forecast

The use of forecasting models are important when analyzing wind turbine power production potential. This can be done by plotting all the recorded wind speeds for a day in a scatterplot and then trying to find a polynomial trend line that is most accurate. If the trend line has an r^2 value of 80 % or higher then you can accurately predict when the most wind will be available and the most power would be produced. An r^2 value is a percentage given to show the accuracy of a polynomial trend line when applied to a scatterplot. This can be especially important for the wild life that shares the air space with the wind turbine blades. For example if it is found that during the times that birds are most active the wind is lowest the turbine could be locked out, therefore reducing the bird fatalities and when the wind speeds are strongest the wind turbine will be unlocked to harness the energy. Although the forecasting of wind speeds don't just apply to individual days, forecasting models using trend lines can be used for monthly forecasts as well. They could be instrumental into deciding the feasibility of a wind turbine project. This is because you could predict the windiest months and determine to what degree it will interfere with the migrating birds. The 1996 scatterplot was found to have a 93% r^2 value when compared with a 6^{th} degree polynomial trend line as shown in the figure below. Given that the model was so accurate I was able to predict when there will be the strongest and weakest winds throughout the year on a daily basis. This model showed me that late evening until early morning the wind speeds were the strongest and at around noon time they dropped until the lowest wind speed was reached at about sunset. Assuming there were no extreme deviations in the wind speeds then you could reasonably predict when during the day the most and least wind will be available. The use of a scatterplot and trend line for forecasting in Excel is instrumental in wind energy analysis.



This scatter plot is 1996 average minute wind speeds in one day compared to the 6th degree polynomial trend line (Black).

Conclusion and Recommendations

The installation of a wind farm on BNL site would go a long way to offset carbon emissions and provide vital research opportunities as the new wave of energy production takes root. When the wind farm is installed it would be very powerful in the daily energy offset at BNL, shown in figure 6A. As there are limited places available for installation realistically only one turbine would be able to be installed. Also, the bird and bat population would need to be steady and not in decline as the inevitable fatalities of the wind turbine could damage a declining bird or bat population. Also, I used a 500 kW system to do my analysis so that the energy production could be similar to that of the solar research array that is currently used for BNL energy offset. For a steadier output though BNL could consider a smaller system. The wind speeds are the best higher up and with the Enercon E53 500 kW wind turbine its highest point reaches 100 meters, so it can be provided with the strongest wind available. I enjoy seeing wind turbines installed and running, and I hope others at BNL do to because a project with so much potential as this one has, would be a shame to see falter because of visual unattractiveness. A vast area of farm land in North Carolina is getting a wind farm installed with low wind speeds. [9] This is possible with taller wind turbines that catch more powerful wind and also the construction of larger blades that can catch stronger and weaker wind and spin the blades faster producing more energy with lower wind speeds. [9] There are a multitude of options for wind turbine installation from the use of avian radar to stop a turbine when birds or bats are flying nearby to taller turbines with bigger blades to catch more wind. The research opportunities associated with the installation of even one wind turbine are so great given such a short payback period and a useful life of 20 years, that BNL should not pass up the opportunity to be a leader in turbine hub research or wind power analysis. The wind energy and renewable energy industries are rapidly growing and BNL can be a part of it, all we have to do is make the next step.

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Acknowledgements

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Appendixes

Figure 1

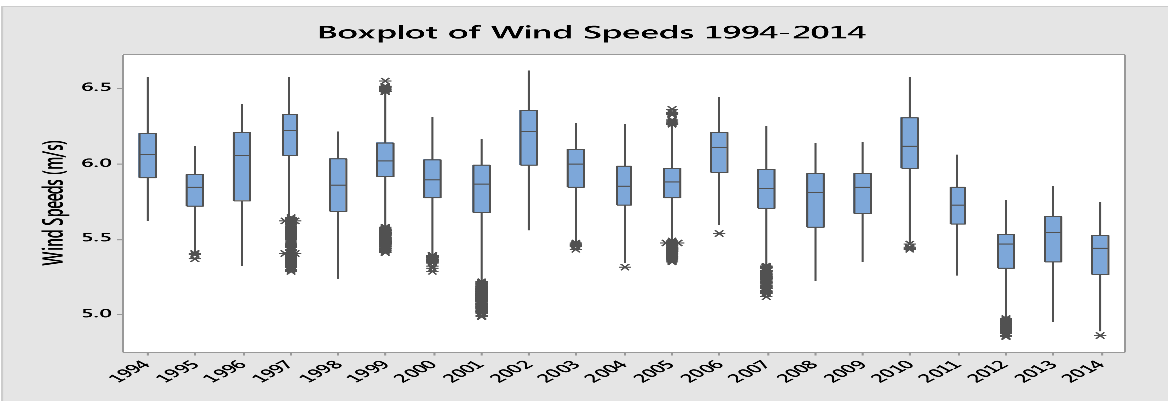

Figure 1: This box plot shows the average daily wind speeds for each of the 21 years from 1994-2014.

Figure 2

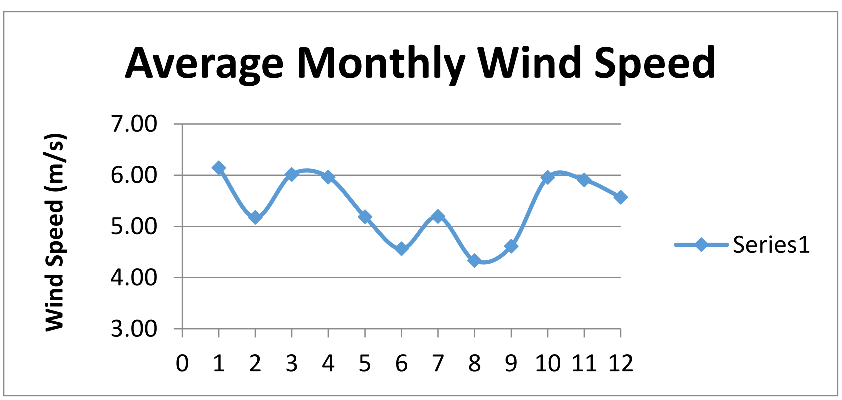

Figure 2: this line chart shows the average monthly wind speeds for 2014, the least windy year.

Figure 3

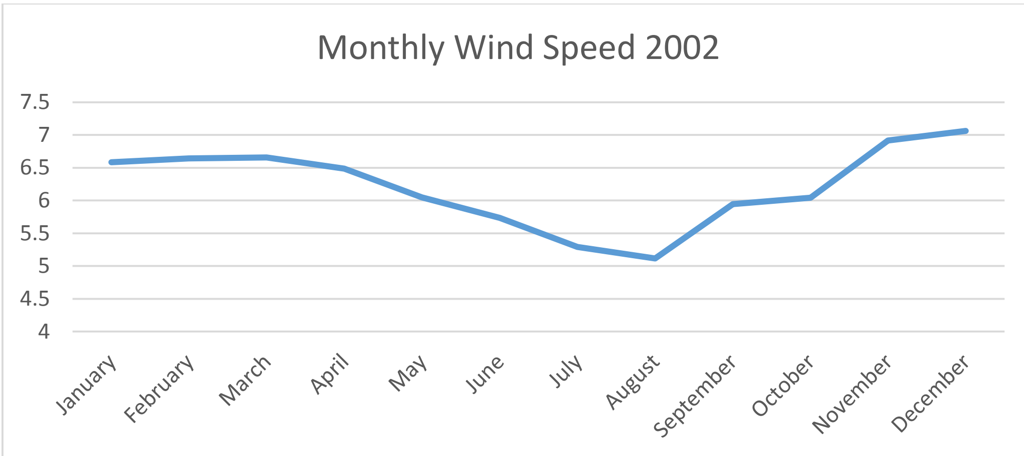

Figure 3: This line chart shows the average monthly wind speeds for 2002, the windiest year.

Figure 4

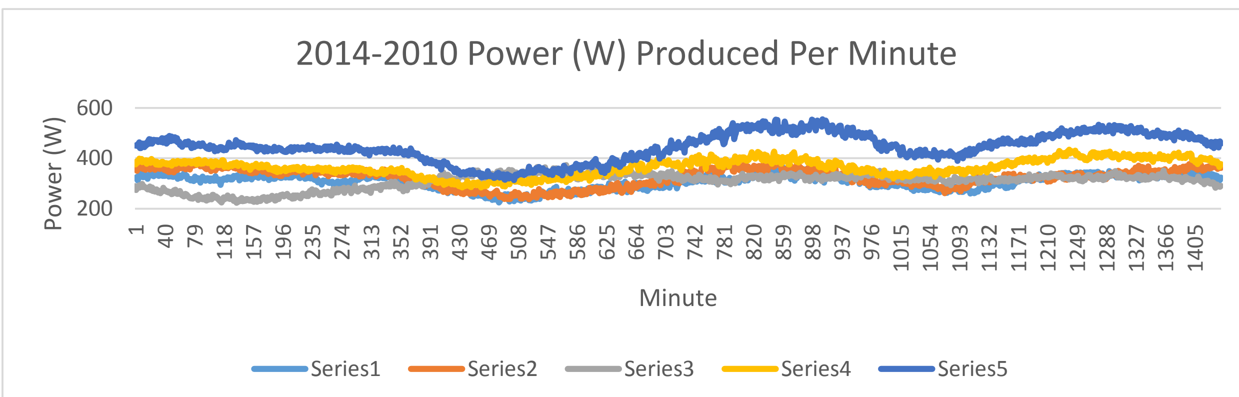

Figure 4: These scatter plots compare the average power production potential per minute in one given day for 5 years from 2014-2010. 2014 (Light Blue), 2013 (Orange), 2012 (Grey), 2011 (Yellow), 2010 (Blue)

Figure 5

Date	1/1/2010	1/2/2010	1/3/2010	1/4/2010
Number	WSM88_1	WSM88_2	WSM88_3	WSM88_4
1	2.9	6.2	11.2	9.7
2	3.1	6.8	12	10.8
3	3.1	6	10.5	11.6
4	3.3	5.8	11.2	12.6
5	3.4	6.2	12	12.2
6	3.4	6.2	12.5	10.4
7	3.4	5.5	9.3	11.9
8	3.4	5.9	9.7	11.9
9	3.4	5.3	13.2	11.2
1440	6.3	12.3	9.4	6.5

Figure 5: This picture shows the way I used Minitab and Excel to organize the wind data I was given.

Figure 6A

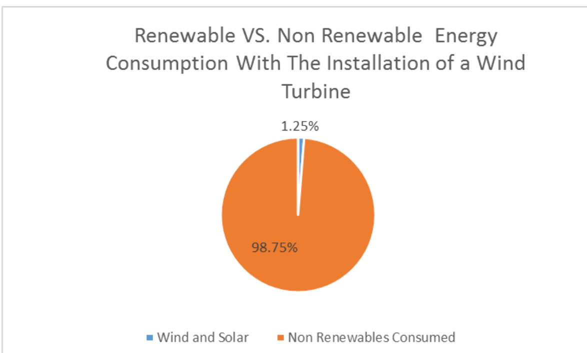

Figure 6A: This Pie chart shows the potential renewable energy production with the installation of a wind turbine on the BNL site.

Figure 6B

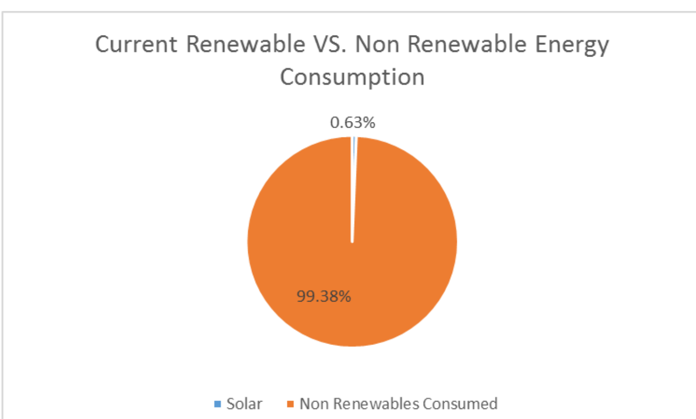

Figure 6B: This Pie chart shows the current renewable energy production on the BNL site.