Wind Harvesting at Penn State

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The Pennsylvania State University at University Park

EDSGN 100 Section 20

Team Anemos


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Pennsylvania State University at University Park currently uses no renewable energy sources, including no wind energy. Team Anemos believes that Penn State UP can harvest wind energy. The solution comprises of establishing 27 Siemens SWT-2.3-101 wind turbines on the Tussey Mountain ridge, fully substituting 20% of Penn State daily energy consumption. Surveys show positive support from the community in harvesting wind energy. Initial investment was projected to be $70.63 million, with break-even point by the 68$^{th}$ month. Return will be faster if Penn State can secure lower capital price, states-supported loans, and/or estimated lower monthly maintenance price.

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## C. Introduction

Penn State UP consumes 800 million kWh/year[1]. That means 2.2 million kWh/day, which equals 57,000 average US households energy consumption[2]. Such energy consumption with zero contribution from renewable energy sources indicates that there is room for Penn State UP to begin using renewable energy sources. Constantly using non-renewable energy sources will diminish the supply over time, inducing an increase in price for energy. State College, in particular, has average wind speed compared to United States' (17.44 mph compared to 16.93 mph)[3], but being located in a valley means diminished wind speeds compared to the ridge tops around Happy Valley. Team Anemos believes that harvesting wind energy can supply Penn State a significant portion of its yearly energy needs while in the same time decrease the amount of $CO_2$ emitted by Penn State UP. Our target is to have a sustainable supply for 20% of Penn State UP's energy consumption, which is 440,000 kWh/day (see Appendix 1).

Team Anemos' definition of sustainability for this project is simple. Sustainability is the state where an individual or institution is capable of maintaining the consistent production of energy according to its specific or desired needs. Sustainability, in this particular case, refers to the capability of acquiring the desired 440,000 kWh/day in any situation throughout the year, solely from the wind-power system that will be installed.

First of all, establishing wind turbines to service Penn State have three key issues; acceptance, location, and cost. Acceptance refers to how the local community views this change. Therefore, we generated a survey and filtered the respondents to only 71 respondents from Centre County area. Figure 1 below shows that 76.8% of the respondents agree that Penn State UP should harvest the wind energy around them. In trying to pin point the location for

wind turbines, the team initially selected the Arboretum because of it's relatively high location in the valley, yet located closely to Penn State UP, so there is less power loss due to transporting the energy. But, the survey in Figure 2 shows dicotomy, which means respondents are roughly split on the Arboretum location (27 disagree with 31 agree). Therefore, we decided that Arboretum should not be the location to establish our wind turbines. Mount Tussey or Moshannon were our next possible options, with ridge-top locations and located away from populated areas to address concerns about noise and aesthetics.

1. Do you believe that Penn State University Park will be better-off if we harvest wind energy around us? Create Chart Download

| | Response Percent | Response Count |
|---|---|---|
| **Disagree** | 1.4% | 1 |
| **Somewhat Disagree** | 4.3% | 3 |
| **Neutral** | 17.4% | 12 |
| **Somewhat Agree** | **39.1%** | **27** |
| **Agree** | 37.7% | 26 |

Figure 1. Survey asking how respondents feel about wind energy harvesting, 2 respondents skipped this question

2. Do you agree that the Arboretum is an ideal place to put wind turbines? Create Chart Download

| | Response Percent | Response Count |
|---|---|---|
| **Disagree** | 20.0% | 14 |
| **Somewhat Disagree** | 18.6% | 13 |
| **Neutral** | 17.1% | 12 |
| **Somewhat Agree** | **28.6%** | **20** |
| **Agree** | 15.7% | 11 |

Figure 2. Survey of having wind turbine in Arboretum, 1 respondent skipped this question

## D. Concept Development

Table 1. Analytical Hierarchy Priority (AHP) Matrix of wind turbine

Anemos AHP

| | Cost | Durability | Public Acceptance | Ease of Installation | Maintenance Cost | Pollution | Aesthetic | Distance from PSU | Subtotal | Weight |
|---|---|---|---|---|---|---|---|---|---|---|
| Cost | | 0.5 | 3 | 1.5 | 1 | 2 | 4 | 2 | 12 | 19.72% |
| Durability | 2 | | 2 | 2 | 1.5 | 1.5 | 3 | 2 | 12 | 19.72% |
| Public acceptance | 0.33 | 0.5 | | 1 | 0.66 | 1 | 1.5 | 0.66 | 4.99 | 8.20% |
| Ease of installation | 0.66 | 0.5 | 1 | | 0.66 | 1 | 1.5 | 1 | 5.32 | 8.74% |
| Maintenance Cost | 1 | 0.66 | 1.5 | 1.5 | | 3 | 3 | 1.5 | 10.66 | 17.52% |
| Pollution | 0.5 | 0.66 | 1 | 1 | 0.33 | | 1 | 0.5 | 4.49 | 7.38% |
| Aesthetic | 0.25 | 0.33 | 0.66 | 0.66 | 0.33 | 1 | | 0.5 | 3.23 | 5.31% |
| Distance from PSU | 0.5 | 0.5 | 1.5 | 1 | 0.66 | 2 | 2 | | 8.16 | 13.41% |
| | | | | | | | | Total | 60.85 | |

Team Anemos used an Analytical Hierarchy Process (AHP) matrix in Table 1 to define the relative priorities of features of the wind turbine design. From Table 1, initial investment costs of this project and the regular maintenance costs had the highest weights. Also, distance of wind turbines from Penn State UP as important because we are concerned with the energy loss that happens during transporting the energy.

Research showed that a fewer high power wind turbines is a better initial investment approach than a higher number of medium power wind turbines. The wind turbines should also be in proximity to Penn State UP campus (with a goal radius of 15 miles or less) in order to not disturb the local Penn State and State College community, but still in the threshold of minimum power loss. The choice then was narrowed down to a minimum 100 kW wind turbines that will be located on either Mount Tussey Ridge (south of Penn State) or Moshannon Ridge (north of Penn State).

Environmental impact studies will need to be conducted and permits obtained for wind turbines at either Tussey Ridge or Moshannon Ridge. The contrast of both locations are as follows; wind turbines at Mount Tussey Ridge will not disturb the ecosystem tremendously because of less infrastructures such as recreation parks, inns, and lodges. Mount Tussey is in

closer proximity to Penn State UP compared to Mount Moshannon (4 miles vs. 11 miles, refer to Figure 3 and 4) which will provide us less energy loss. Mount Moshannon, though, has more elevation (2316 vs. 2119 feet, refer to Figure 3 and 4) which will allow us to acquire more wind speed which is proportionally related with energy harnessed.

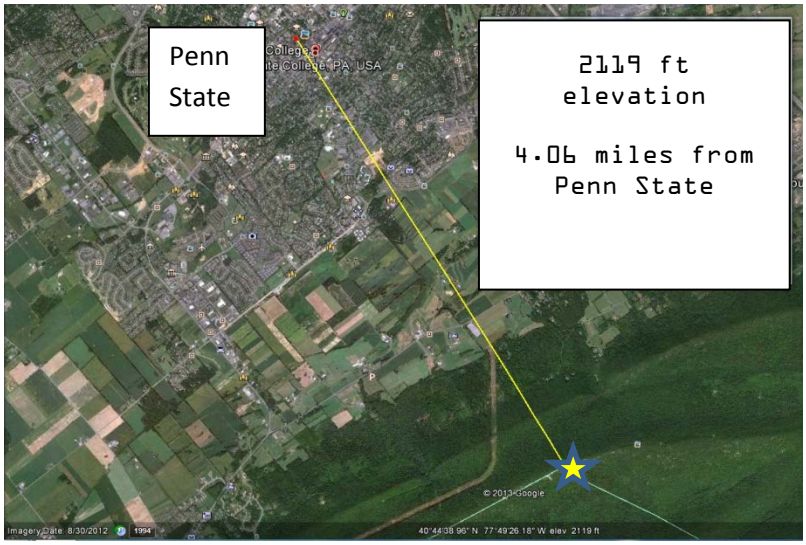


Figure 3. Mount Tussey has 2119 feet elevation above sea level and 4.06 miles distance from PSU

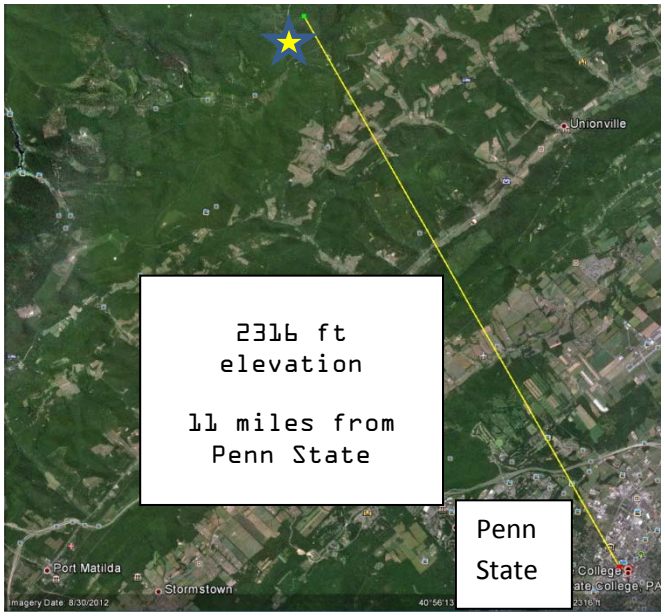


Figure 4. Mount Moshannon has 2316 feet elevation above sea level and 11 miles distance from PSU

Both mountain ridges are leptosols[4] which consist of hard rocks and highly calcareous material, indicating that these lands are better off to be covered with vegetation or infrastructures. Both mountains have an wind speed of up to 23 mph/day[3]. Considering all these factors, Team Anemos determined that establishing wind turbines at Mount Tussey Ridge will be superior compared to establishing them at Mount Moshannon Ridge. The distance from Mount Moshannon to Penn State was almost triple compared to the distance from Mount Tussey to Penn State, though Mount Moshannon has around 200 feet more elevation in comparison to Mount Tussey, the additional amount of wind that was to be harnessed was predicted to be insufficient in covering the amount of energy loss in transporting the energy.

Lastly, we did cost comparison between many medium turbines vs. fewer large turbines. It turns out that the benefit of having smaller initial setup cost for a smaller number of turbines was outweighed by the cost of purchasing more transmission lines and transformers. Figure 6 and Figure 7 shows that turbine installation will actually save more money by investing on bigger windmills. The initial investment for 34 1.8 MW was $56.52 M while it was $91.8 M for 306 200 kW wind turbines (see Appendix 2). Although we do realize the proportional relationship between total cost with number of wind turbines, we believe that we need to take into account the ability of the soil on Tussey in supporting the wind turbine tower and associated infrastructure. Establishing wind turbines that are too big may result in disastreous event such as structure collapse due to the heavy wind that may exerts excessive torque.

Figure 5. Image of Altoona wind farms as an example of what has been done locally

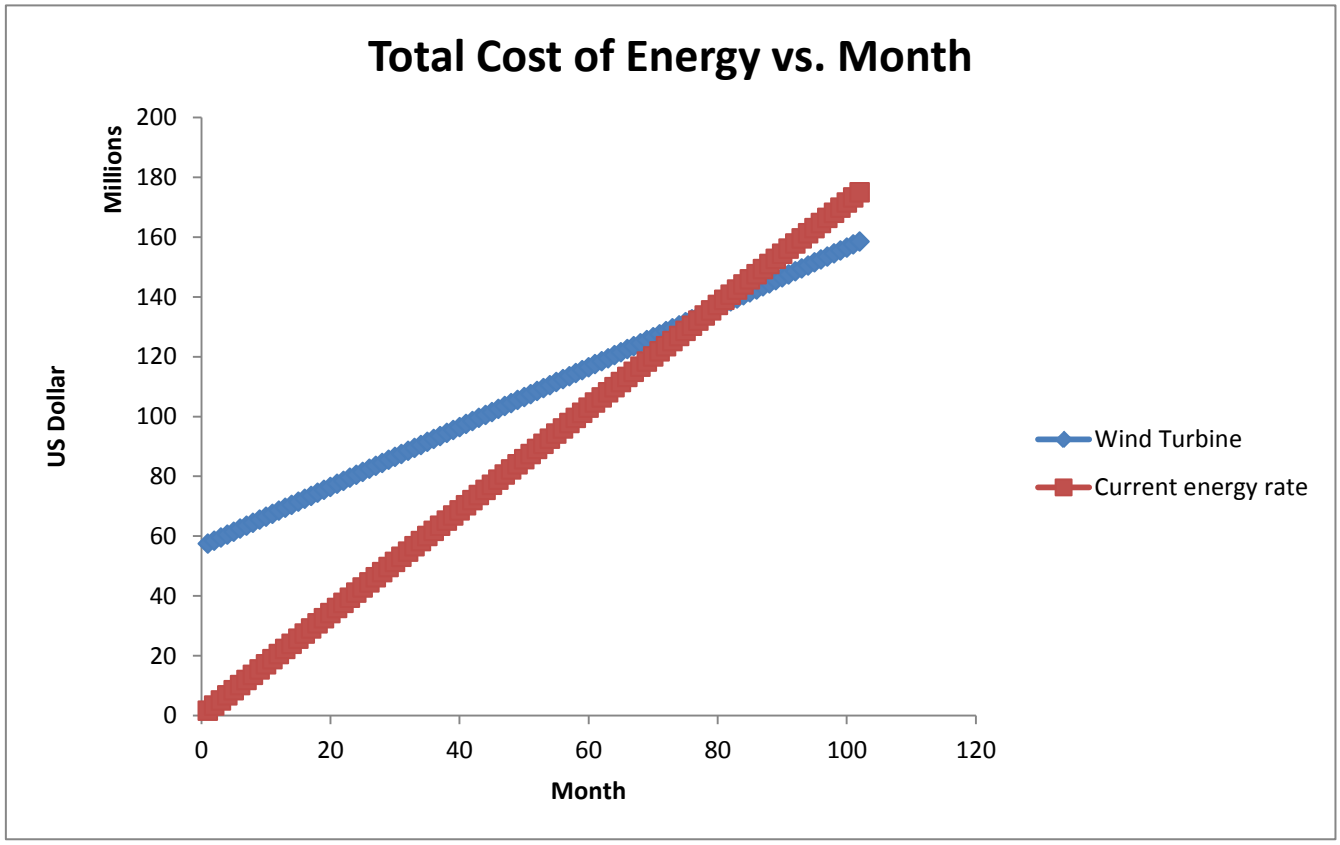


Figure 6. Total Cost comparison over time, 34 1.8 MW windmills provides break-even point on the 79th month

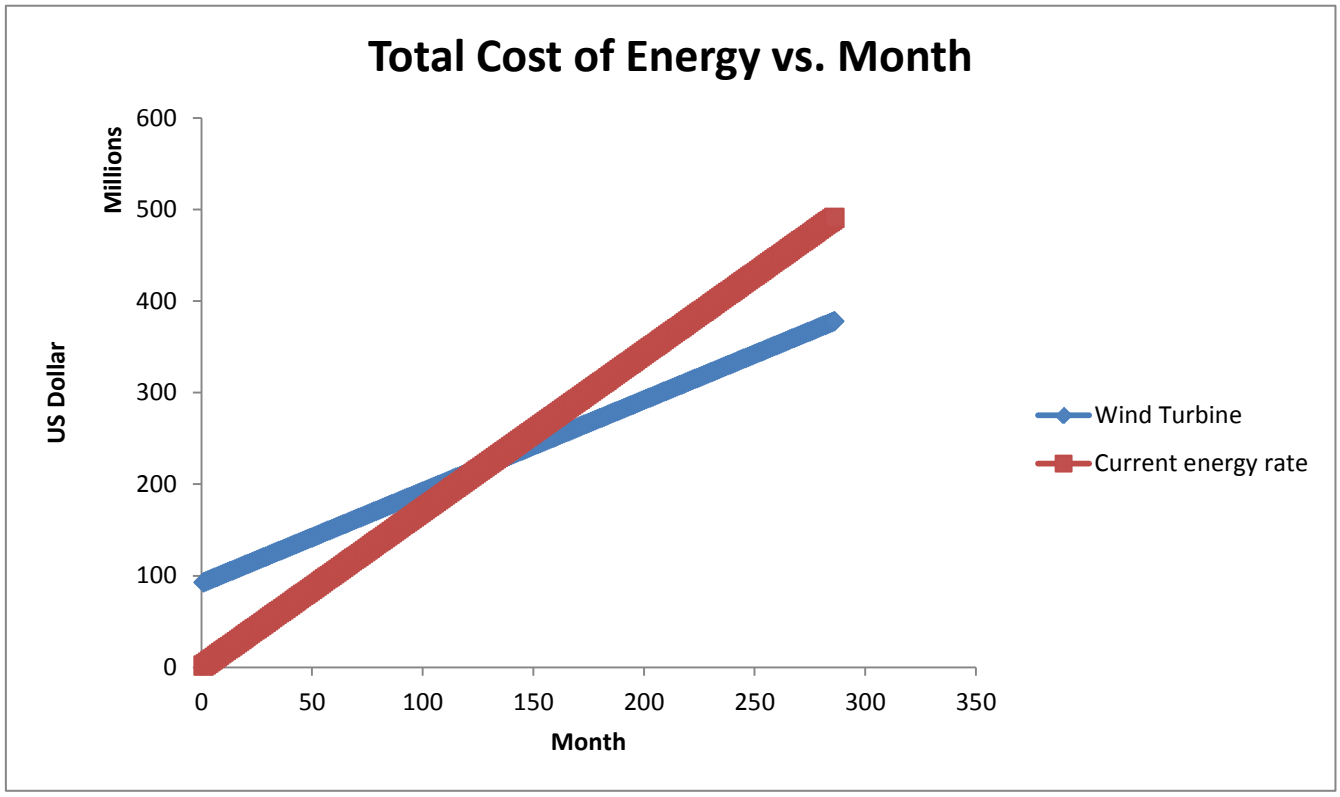


Figure 7. Total cost comparison over time, 306 200 kW windmills provides break-even point on the 128th month

## E. Detailed Concept Development

It was difficult to find detailed wind speed and wind bearing data over Tussey and Moshannon over the internet. We then contacted Penn State Department of Meteorology and were able to acquire University Park airport's wind chart. Figure 8 shows that wind in State College area travels dominantly to the west with an average of 17 mph. We then assume that this trend of dominant westward wind will be relevant and applicable to Tussey because climate does not significantly change over 8 miles (distance between airport and Tussey). We also assume that this trend will carry on throughout the year. Henceforth, using the data available and under our stated assumptions, we believe that we should orient our wind turbines to face west.

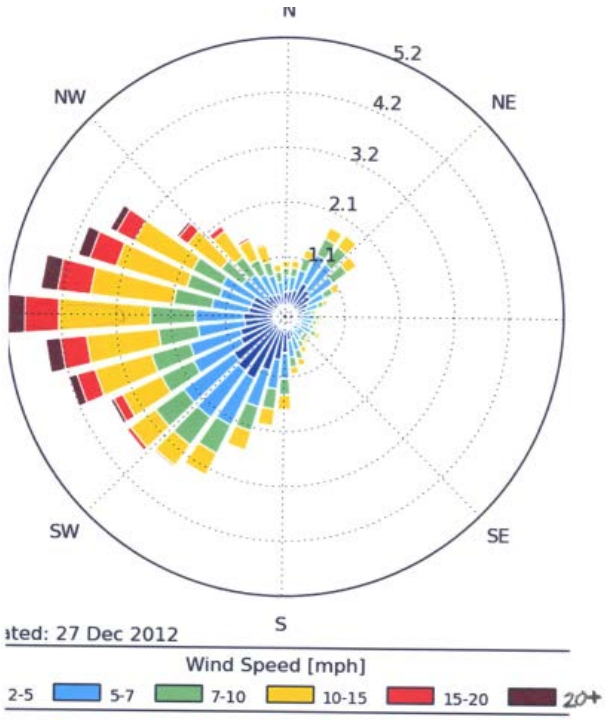


Figure 8.

Wind Chart of University Park Airport, dated 27 Dec 2012

Two design selection matrices were then generated to choose what type of wind turbine that should be used in this project. One matrix was used to select the wind turbine's series , and another matrix to select the wind turbine's model from that particular series. Table 2 on the next page discusses the grading of the wind turbine's series. The best choice is a 2.3 MW wind turbine that balances trade-offs. Grading on the left column shows a direct grading with scale 1-10, while grading on the right column multiplies the direct grading derived from the left column with the weight of criteria (design feature) in Table 1 (p.5). Furthermore, we decided to use 2.3 MW wind turbine series that Siemens produced, the SWT-2.3 series[5].

Table 2. Design Selection Matrix of wind turbines

| Design Selection Matrix Anemos<br>Scale, 1-10 | 200 kW | | 1.8 MW | | 2.3 MW | | 3 MW | | 3.6 MW | | 6 MW | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cost | 6 | 1.1832 | 7 | 1.3804 | 9 | 1.7748 | 8 | 1.5776 | 8 | 1.5776 | 4 | 0.7888 |
| Durability | 5 | 0.986 | 6 | 1.1832 | 9 | 1.7748 | 7 | 1.3804 | 7 | 1.3804 | 5 | 0.986 |
| Public acceptance | 6 | 0.492 | 6 | 0.492 | 5 | 0.41 | 3 | 0.246 | 2 | 0.164 | 1 | 0.082 |
| Ease of installation | 8 | 0.6992 | 8 | 0.6992 | 7 | 0.6118 | 5 | 0.437 | 5 | 0.437 | 3 | 0.2622 |
| Maintenance Cost | 3 | 0.5256 | 3 | 0.5256 | 6 | 1.0512 | 5 | 0.876 | 5 | 0.876 | 4 | 0.7008 |
| Pollution | 6 | 0.4428 | 6 | 0.4428 | 5 | 0.369 | 4 | 0.2952 | 3 | 0.2214 | 2 | 0.1476 |
| Aesthetic | 4 | 0.2124 | 4 | 0.2124 | 4 | 0.2124 | 2 | 0.1062 | 2 | 0.1062 | 1 | 0.0531 |
| Distance from PSU | 10 | 1.341 | 10 | 1.341 | 10 | 1.341 | 10 | 1.341 | 10 | 1.341 | 10 | 1.341 |
| Total : | **48** | *5.8822* | **50** | *6.2766* | **55** | *7.545* | **44** | *6.2594* | **42** | *6.1036* | **30** | *4.3615* |

Table 3. Model Selection Matrix of wind turbines

| Model Selection Matrix Anemos<br>Scale, 1-10 | SWT-2.3-82-VS | | SWT-2.3-93 | | SWT-2.3-101 | | SWT-2.3-108 | | SWT-2.3-113 | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cost | 6 | 1.1832 | 7 | 1.3804 | 7 | 1.3804 | 7 | 1.3804 | 7 | 1.3804 |
| Durability | 6 | 1.1832 | 8 | 1.5776 | 8 | 1.5776 | 8 | 1.5776 | 8 | 1.5776 |
| Public acceptance | 8 | 0.656 | 7 | 0.574 | 6 | 0.492 | 6 | 0.492 | 6 | 0.492 |
| Ease of installation | 7 | 0.6118 | 8 | 0.6992 | 8 | 0.6992 | 7 | 0.6118 | 7 | 0.6118 |
| Maintenance Cost | 5 | 0.876 | 6 | 1.0512 | 7 | 1.2264 | 7 | 1.2264 | 7 | 1.2264 |
| Pollution | 8 | 0.5904 | 6 | 0.4428 | 6 | 0.4428 | 6 | 0.4428 | 6 | 0.4428 |
| Aesthetic | 8 | 0.4248 | 6 | 0.3186 | 6 | 0.3186 | 6 | 0.3186 | 6 | 0.3186 |
| Distance from PSU | 10 | 1.341 | 10 | 1.341 | 10 | 1.341 | 10 | 1.341 | 10 | 1.341 |
| Total : | **58** | *6.8664* | **58** | *7.3848* | **58** | *7.478* | **57** | *7.3906* | **57** | *7.3906* |

Table 3 discusses the selection process for Siemens SWT-2.3 series. It is noticeable that all the direct gradings are equal amongst one another as they came from the same series, while on the same time the weighted gradings differ from one another, indicating that each model excels in its own particular aspects due to the product differentiation. The last combination of digits (82, 93, 101, 108, and 113) shows the diameter of the wind turbine. As the number gets bigger, the diameter also gets bigger. We assume that public acceptance and ease of installation will drop as the wind turbines get bigger while the maintenance cost will slightly drop as we will need less wind turbines. It is noteworthy that SWT 2.3-82-VS model provides us with noise reduction features, giving it the same direct total points with the 93 and 101 model, but as we

consider noise pollution and aesthetic to be less important compared with cost and durability, the weighted grading fails to match the 93 and 101 model. If we were to consider pollution and aesthetic to be 20% more important then cost and durability, 82-VS will serve as the best option. Nevertheless, returning back to the original AHP, the model selection matrix shows that Siemens SWT 2.3-101 model will provide Penn State with the most benefit.

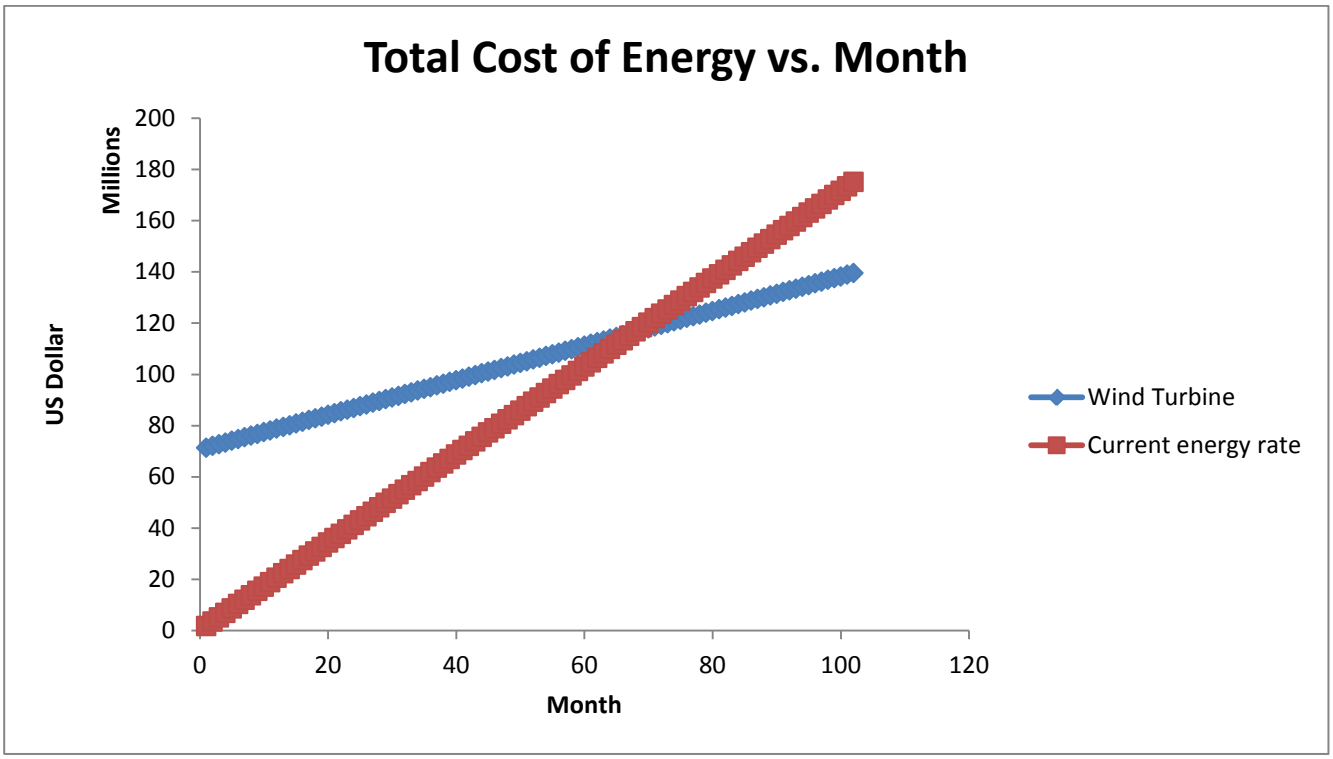


Figure 9. Total Cost comparison over time, 27 SWT-2.3-101 provides break-even point on the 68th month

In using Siemens SWT-2.3-101, we intentionally decreases our monthly maintenance cost used in generating Figure 9 (see Appendix 2). We are confident that this particular technology provided by Siemens gives us better durability, reducing the amount of money needed to maintain its operation, decreasing our expenditure over the long term. In conclusion, installation of 27 SWT -2.3-101 wind turbines will require an initial investment of $70.63 M with total monthly occuring maintenance cost of $650,000.

Figure 10. Visual sketch of wind turbines over Mount Tussey facing west, credits to Matthew Planzos

## F. Conclusion

A 2.3 MW windmill provides the best trade-off for the design features that we require a windmill to have. A 2.3 MW windmill provides us with cheaper prices from a smaller wind turbine as a whole, having less in numbers resulted in less maintenance cost as we will have less capitals (transmission lines, transformers, the wind turbine itself, etc.) that need to be regularly checked. Its relatively smaller size compared to a 3 MW or bigger windmill reduces the amount of time needed to install over Mount Tussey, decreasing labor costs and possible aesthetic issues that may arise in the local community.

Siemens SWT-2.3-101 excels in our model selection matrix under the notion of cost efficient. Understanding that the noise reduction feature in SWT-2.3-82-VS results in higher appraisal to pollution and aesthetic issues, it is unfortunate that having an extra feature also results in higher maintenance cost and initial investment. Henceforth, 27 SWT-2.3-101 wind turbines requires an initial investment of $70.63 M with $650,000 monthly maintenance cost. Break even point was projected to be in the 68$^{th}$ month, under the assumption that energy rate stays the same the whole year and the performance of all capitals do not deteriorate significantly over time. By the 72$^{nd}$ month (6$^{th}$ year after installation), it was projected that the client (Penn State UP) will obtain a monetary benefit of $4.3 M. Indirectly, we may say that client will obtain a monetary benefit of $29.3 M by the 96$^{th}$ month (8$^{th}$ year after installation).

We are optimistic that Penn State will adopt our design solution, by adopting our design solution, Penn State will benefit in having to spend less money on energy. Having renewable energy at disposal would establish a positive image towards the community, and moreover, the world. Initiating the action of renewable energy system will also make Penn State take the forefront position of applying alternative energy for sustainability in collegiate level, distinguishing itself from other universities as what Figure 7 on the next page suggests.

5. What do you think will the biggest advantage of having the wind turbine in Penn State?

Create Chart Download

| | Response Percent | Response Count |
|---|---|---|
| **Alternative Energy solution** | **80.0%** | **56** |
| **Statement of Go Green to community** | 65.7% | 46 |
| **A field of research for Penn State students** | 54.3% | 38 |
| **Aesthetically pleasing** | 5.7% | 4 |
| **Cheaper Energy Cost** | 37.1% | 26 |
| **Opening up job field** | 28.6% | 20 |

Figure 11. Survey asking the effect of having wind energy system in Penn State

Team Anemos learned that Penn State consumes massive amount of energy. Through this research, we found that it is close to impossible to replace Penn State UP's current energy consumption by only relying on one type of renewable energy source. It requires a collaborative effort from all aspects of Penn State UP's services to fully substitute their energy consumption. We also found that in order for Penn State UP to be sustainable, actions should be broken down to a combination of small projects over the long run. This will help decrease the amount of money Penn State UP would have to pay upfront.

## G. References


1. Penn State UP energy consumption

   Catanach, W. *PSU_calculations_Sp13*. PowerPoint. April 2013.

2. US household energy consumption

   U.S. Energy Information Administration. http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3. Web. March 2013.

3. Wind Speed

   Intellicast. http://www.intellicast.com/Local/Weather.aspx?location=USPA1575. Web. April 2013.

4. Geography of State College

   United Nations Cartographic Section. http://www.un.org/Depts/Cartographic/english/htmain.htm. Web. April 2013.

5. Siemens wind turbines

   Siemens. http://www.energy.siemens.com/hq/en/renewable-energy/wind-power/wind-turbines/. Web. April 2013.

## H. Appendix

1. Energy usage of the Pennsylvania State University at University Park

   a. Penn State consumes 2.2 million kWh/day. We aim to substitute 20% of it, therefore we multiply total energy consumption per day by .2

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| UP has 80 acres of roof, assume we use all 80 acres to produce electricity from PV | | | | | | | | | | | | | |
| 340899524 | kwh | total electricity, UP per year | | | | | | 340899524 | | | | | |
| 295653 | mcf | natural gas, U | 1 | mcf | = | 301 | kWh | 88991553 | kWh, gas | | | | |
| 1065604 | klb | steam, UP/year | | | | | | | 1065604310 | lbs, steam, UP per year | | | |
| | | | | | | | | | 1194 | Btu/lbs | conversion | | |
| | | | | | | | | | 1.27233E+12 | Btu | Enthalapy of steam @ 130 psi | | |
| | | | | | | | | | 3.412 | btu/wh | = lbs*Btu/lbs | | |
| | | | | | | | | | 372899046348 | wh | =Btu*Btu/wh | | |
| | | | | | | | | 372899046 | kwh | from steam | | | |
| | | | | | | | | 802790123 | kWh, UP per year | | | | |
| | | | | | | | | 2199425 | kWh, UP per day | | | | |

2. Cost Report equations and assumptions

   a. We assume 30% efficiency from wind turbines

   b. 1 month = 30 days

   c. 440,000 kWh/day*30 days = 13,200,000 kWh/month

   d. Penn State currently spends 13 cents to produce 1 kWh[1], that means $1,716,000 per month, red line equation → y = 1.716 M*(x)

   e. In installing wind turbines, we say that labor rate = $60/hour

   f. We find the amount of power that needs to be generated per day. (440,000 kWh/day) / (1000 W) / (24 h) = 18.33 MW/day

   g. (18.33 MW/day) * (3.33 efficiency rate) / (nominal power) = the amount of windmills needed

| Windmill needed | Type | Windmill cost | Additional Capital Cost | Labor Cost |
|---|---|---|---|---|
| 306 | 200 kW | $ 42,840,000 | $ 15,300,000 | $ 18,360,000 |
| 34 | 1.8 MW | $ 25,500,000 | $ 17,000,000 | $ 4,590,000 |
| 27 | SWT-2.3-101 | $ 54,000,000 | Windmill cost includes additional capital | $ 4,860,000 |

| Type | General Administra | Initial Investment | Monthly Maintenance Cost | Equation | Break Even Month |
|---|---|---|---|---|---|
| 200 kW | $ 15,300,000 | $ 91,800,000 | $ 1,000,000 | y=91.8 M + 1 M*(x) | 128 |
| 1.8 MW | $ 9,420,000 | $ 56,520,000 | $ 1,000,000 | y=56.52 M + 1 M*(x) | 79 |
| SWT-2.3-101 | $ 11,772,000 | $ 70,630,000 | $ 675,000 | y=70.63 M + 675 K*(x) | 68 |

| | | |
|---|---|---|
| 200 kW labor cost | 60$/(labor*hour) * 50 labors * 20 hours * 306 windmills = | $ 18,360,000 |
| 1.8 MW labor cost | 60$/(labor*hour) * 75 labors * 30 hours * 34 windmills = | $ 4,590,000 |
| SWT-2.3-101 labor cost | 60$/(labor*hour) * 75 labors * 40 hours * 27 windmills = | $ 4,860,000 |

## 3. SWT-2.3-101 Technical Specification[5]

### 1. Rotor

| | |
|---|---|
| **Type** | 3-bladed, horizontal axis |
| **Position** | Upwind |
| **Diameter** | 101 m |
| **Swept area** | 8,000 m² |
| **Rotor speed** | 6-16 rpm |
| **Power regulation** | Pitch regulation |
| **Rotor tilt** | 6 degrees |

### 2. Blades

| | |
|---|---|
| **Type** | Self-supporting |
| **Blade length** | 49 m |
| **Root chord** | 3.40 m |
| **Aerodynamic profile** | NACA 63.xxx, FFAxxx, SWPxxx |
| **Material** | GRE |
| **Surface gloss** | Semi-gloss, <30 / ISO2813 |
| **Surface color** | Light grey, RAL 7035 |

### 3. Aerodynamic Brake

| | |
|---|---|
| **Type** | Full span pitching |
| **Activation** | Active, hydraulic |

### 4. Load Supporting Parts

| | |
|---|---|
| **Hub** | Nodular cast iron |
| **Main bearings** | Spherical roller bearing |
| **Transmission shaft** | Alloy steel |
| **Nacelle bedplate** | Steel |

### 5. Transmission System

| | |
|---|---|
| **Coupling hub - shaft** | Flange |
| **Coupling shaft - gearbox** | Shrink disc |
| **Gearbox type** | 3-stage planetary-helical |
| **Gearbox ratio** | 1:91 |
| **Gearbox lubrication** | Splash / forced lubrication |
| **Oil volume** | Approx. 400 l |
| **Gearbox cooling** | Separate oil cooler |
| **Gearbox designation** | PEAB 4456 or EH851 |
| **Gearbox manufacturer** | Winergy AG or Hansen Transmissions |
| **Coupling gear - generator** | Double flexible coupling |

### 6. Mechanical Brake

| | |
|---|---|
| **Type** | Hydraulic disc brake |
| **Position** | High-speed shaft |
| **Number of calipers** | 2 |

### 7. Generator

| | |
|---|---|
| **Type** | Asynchronous |
| **Nominal power** | 2,300 kW |
| **Synchronous speed** | 1,500 rpm |
| **Voltage** | 690 V |
| **Frequency** | 50Hz |
| **Protection** | IP54 |
| **Cooling** | Integrated heat exchanger |
| **Insulation class** | F |
| **Generator designation** | AMA 500L4 BAYH |

### 8. Canopy

| | |
|---|---|
| **Type** | Totally enclosed |
| **Material** | Steel |

### 9. Yaw System

| | |
|---|---|
| **Type** | Active |
| **Yaw bearing** | Externally geared slew ring |
| **Yaw drive** | Eight electrical gear motors with frequency converter |
| **Yaw brake** | Passive friction brake |

### 10. Controller

| | |
|---|---|
| **Type** | Microprocessor |
| **SCADA system** | WPS via modem |
| **Controller designation** | KK WTC 3.0 |

### 11. Tower

| | |
|---|---|
| **Type** | Cylindrical or tapered tubular steel tower |
| **Hub heights** | 80 m or site-specific |
| **Corrosion protection** | Painted |
| **Surface gloss** | Semi-gloss 25-45 ISO 2813 |
| **Surface color** | Light grey, RAL 7035 |

### 12. Operational Data

| | |
|---|---|
| **Cut-in wind speed** | 4 m/s |
| **Nominal power at approx.** | 12-13 m/s |
| **Cut-out wind speed** | 25 m/s |
| **Maximum 2 s gust** | 55 m/s (standard version)<br>59.5 m/s (IEC version) |

### 13. Masses (approximate)

| | |
|---|---|
| **Rotor** | 62 t |
| **Nacelle excl. rotor** | 82 t |
| **Tower (80 m)** | 162 t |