

Designing Wind Farms as a Hands-on Activity for High School Students

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1. Introduction

Exposing students at an early age to science and technology activities have been considered an important factor in influencing students to select a technical career path. In the new NSF/DOE CURENT ERC (Engineering Research Center on Ultra-Wide-Area Resilient Electric Energy Transmission Networks), we plan to develop innovative power grid/electronics activities to engage K-12 students as a means to introduce them to science and technology. For most university educators, such outreach programs are a new experience and could be time consuming to establish. As a result, our group establishes a few principles that would guide us toward designing our activities, which are listed below.

1. The activity must be of high current interest to the students.
2. The activity should use realistic data to reflect real design considerations.
3. The activity should be self-contained and be completed in 1-2 hours.
4. The activity would require active participations from the students. The level of technicality would be age specific. However, more complex calculations required in a design activity should be simplified so students with appropriate age-specific mathematics skills will not be bogged down.
5. At the end of the activity, a student should feel that the time is well spent and have learned about a science-and-technology supported design process.
6. The activity can be readily adopted by other universities for similar outreach activities.¹

The Design Your Future Day ©² (DYFD) at Rensselaer Polytechnic Institute is an annual activity that brings 200 plus female high-school juniors to the RPI campus for a day of exploring science and technology as a career path. The program includes exploratory and design activities in all engineering disciplines. CURENT ERC volunteered to participate in the April 2012 event by conducting a design activity module. Adhering to our principles and because of the background of the faculty adviser (Chow), we chose wind energy as the topic and developed a module for building a wind farm in New York State and investigating the financial aspect, that is, investment, revenue, and profit-loss, of the wind farm design. Wind is a renewable resource that has attracted the attention of young people and educators. For example the Trustworthy Cyber Infrastructure for the Power Grid (TCIPG) at the University of Illinois, Urbana-Champaign, has developed hands-on activities and videos for renewable

¹ Information for obtaining the design materials and spreadsheet is given in Section 7.

² Web site is enr.rpi.edu/dyfd/

energy for K-12 schools.³ Although the dynamics of a wind turbine are quite daunting, studying the wind potential, laying out a wind farm and the transmission system, purchasing wind turbines, and estimating the annual revenue (including government tax credit) and maintenance cost can be made manageable provided such data can be presented to the student participants in an orderly manner.

The design team consists of three undergraduate power students, a graduate power student, and a power faculty member. The faculty felt that undergraduate students, who did the bulk of the research and design, would be particularly suitable for this task, as they were high school students not too long ago and could envision any potential points of confusions and design complexity. They were extremely thoughtful and worked hard to make the activity engaging and a learning experience.

The remainder of this article is organized as follows. Section 2 describes the design parameters to be used. Section 3 describes the data gathering process and Section 4 the design calculations using a Microsoft EXCEL spreadsheet. Section 5 reports on the DYFD activities with two groups of high school juniors and Section 6 provides an assessment of the activities. Finally, conclusions are given in Section 7.

2. Primary Design Parameters for Wind Farm Project

Design parameters were developed to include the pieces of the design which are most critical to the economic outcome of the wind farm project. There are many location specific challenges and costs associated with siting a wind farm. This activity had to generalize these factors to create a high level comparison for a variety of locations across the state of New York. An example case study of a wind farm project can be found in [1]. The factors which were deemed most important, and thus considered in this project, are explained below.

To focus the activity and make the results comparable between various options, a concrete design constraint was required. For this activity it was decided that this constraint would be to install one hundred turbines rated at 1.5 MW each. However, the activity could be set up with a variety of other design constraints. In a situation where more time was available a more abstract constraint could be used, such as: limit the investment to thirty million dollars (limiting the bank loan to an 80% debt ratio) or earn the highest internal rate of return possible.

2.1 Selection of Regions

Because most of the high school students engaged in our activity are from New York State, the project is thus based on New York State, which was broken up into four regions: North, West, Central, and Capitol. Each student group can select one of these regions. The first step undertaken by the students was to determine the specific location for the turbine. For example, they would have the choice of mountaintop locations, agricultural land, and for the West and Central regions, coastal areas along Lake Ontario. Each of these locations included a tradeoff which could be discussed. For example, preparation of a site in a mountainous location generally requires a higher capital investment but has a higher average wind speed. Wind generation facilities generally require large amounts of land to allow for sufficient separation between each turbine. In agricultural areas the land surrounding the turbines can still be utilized as farmland. The map in Figure 1, which depicts average wind speeds across the

³ Website is tcipg.mste.illinois.edu.

state, was provided to the students so they could evaluate which regions would be most appropriate for wind generation facilities [2].

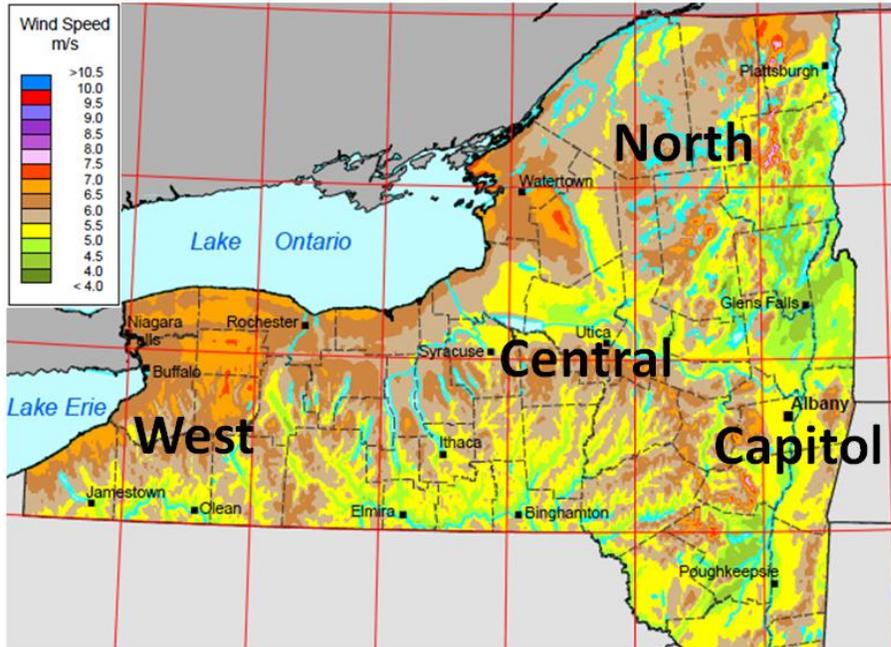


Figure 1 - Wind speed map [2] provided to students, also showing the four regions considered. New York City was not considered in this activity.

2.2 Turbine Layout

The physical arrangement of the turbines within the facility was explored. The exact arrangement of each turbine in a wind generation facility is location specific, depending on factors such as wind patterns and gradient of the land. A general rule of thumb that each column of turbines (spaced perpendicular to the dominant wind direction) should be separated by three rotor diameters while each row of turbines (spaced parallel to the dominant wind direction) should be separated by ten rotor diameters was adopted for this activity (Figure 2). The students chose the rotor diameter, based on the average wind speed, and thus found the separation between each turbine. From this spacing, the total area required for the project was calculated in acres, which was the unit the students were assumed to be most familiar with.

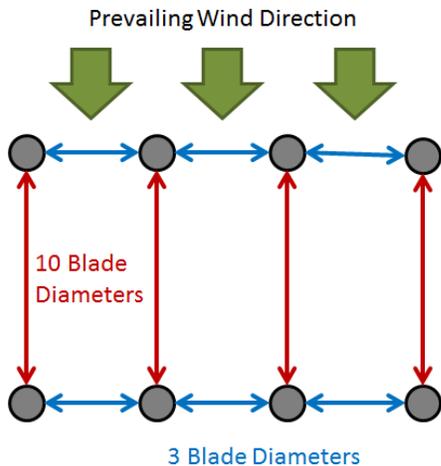


Figure 2 - Wind turbine layout guideline.

2.3 Transmission Line and Substation Costs

Transmission lines, collector substation, and other substation costs were also taken into account in the design project. Students were encouraged to calculate how many miles of transmission lines were needed to reach the collector substation at the wind farm from either an already existing substation, or connecting to already existing transmission lines. These design parameters were the most directly related to costs because there was not a lot of transmission system design experience at a high school level of education. For example, all transmission lines were rated to be 115 kV for this project based on the scope of the wind farm output. Thus, students would refer to the New York transmission line map, and directly calculate how many miles were needed from their chosen location to the nearest place they were able to connect to the grid.

In this way, students were able to immediately understand how much the cost was by multiplying the number of miles of transmission lines needed by the average cost of a 115 kV transmission line per mile. The substation costs had a little bit more variability in choice for the students. Students could either choose to T-bone transmission lines to another transmission line, if the closest transmission line were also 115 kV. They could choose to add onto or upgrade to an already existing substation, or they could calculate the cost of building a new substation connecting already existing lines as well as transmission lines from their wind farm. These parameters were categorized into three different options that the students could choose from, with chosen prices that were averaged from recent collector substation designs.

2.4 Other costs

Some other factors were important to designing the project and obtaining accurate results, but did not require direct input from the students in completing the design. For example, the cost of financing the project was included in the analysis as it is an important factor affecting the viability and cost structure of such projects. However, the goal of this project was not to educate the students on engineering economics, and it was not desired to spend time explaining how this function operated. Rather, the parallel to a home mortgage was used to explain that equal payments are made on borrowed money. With more time, this dimension of the project could be explored more fully.

Other ongoing pricing factors were also included, such as insurance, administrative costs, and electricity from the grid (when the turbines are not operating). Based on time constraints these values may be given as constants as was done in our activity, or may be found based on some function which takes into account economies of scale in situations where variable sized wind farms are to be considered.

2.5 Revenue

The revenue generated from the sale of electricity was found from the installed nameplate capacity (150 MW), the capacity factor, and an average export rate, which was provided based on the region. Not included in the calculation is the “green” energy surcharge that customers may volunteer to pay, which may have a significant impact on the financial viability of a wind farm as shown in the example calculations in Section 5.

3. Data Gathering

One of the major goals of this activity was to make it have real world meaning. As such, it was important to develop a cost model which was sufficiently accurate and reflective of real world conditions. All data on the costs of wind turbines and their associated installation, operating and maintenance costs was found from publically available sources.

3.1 Wind Data

Wind speed data was obtained by the National Renewable Energy Laboratory (NREL) (Figure 1) [2]. Table 1 shows the wind-turbine capacitor factors (*CF*) in various regions. The nameplate capacities per region were provided by NYISO Goldbook Data [3]. The data provides the average recorded nameplate capacities for the existing wind farms in NY over the last four years. In this data, there were 16 wind farms for which 14 had four years of average nameplate capacities. The nameplate capacities shown below, and used in this activity were derived by averaging the average nameplate capacity per year per farm. These averaged nameplate capacities were then averaged into the other similar values from farms in that same region and land type. Thus, some nameplate capacities are more accurate than others. For example, the agricultural area in the West region of NY has more wind farms than the coastal region in the North. Thus, there was more statistical data for this area. However, the areas which had the most data tended to be the areas with the highest wind speeds on average, and thus students chose these areas in general. In summary, only realistic recorded nameplate capacities for existing wind farms were used.

Table 1 – Capacity factors in various New York regions

| | Agricultural | Mountain | Coastal |
|---------|--------------|----------|---------|
| North | 0.26 | 0.244 | 0.283 |
| West | 0.348 | 0.264 | 0.326 |
| Central | 0.243 | 0.240 | 0.295 |
| Capitol | 0.273 | 0.251 | N/A |

The yearly energy produced is calculated as

$$\text{Yearly Energy Production (MWh)} = CF * \text{Nameplate Rating (MW)} * 8760 \text{ hrs/year} \quad (1)$$

As discussed, the nameplate rating for this activity was constrained to be one hundred 1.5 MW turbines, or 150 MW.

3.2 Land and transmission system costs

Land preparation costs were provided in [4] as a percentage of total installed project cost. An average installed cost was found, and, by working backwards, average land preparation costs were found. There are numerous factors that impact the costs associated with site development including local governmental regulations, willingness of land owners to negotiate, and area required. Data for each region and geographic location was not available, so existing wind generation projects were examined to obtain a generalized method for estimating the costs associated with land acquisition (Tables 3 and 4) [4].

Table 2 - Estimated land lease cost

| Annual Land Lease Cost | | | |
|------------------------|--------------|--------------|--------------|
| Capitol | Central | North | West |
| \$700 / Acre | \$600 / Acre | \$600 / Acre | \$750 / Acre |

Table 3 - Estimated land preparation cost.

| Initial Land Clearing and Preparation Cost | | |
|--|--------------|--------------|
| Coastal | Farmland | Mountain |
| \$750 / Acre | \$650 / Acre | \$950 / Acre |

Land area required for the wind farm was assumed to be a rectangle (refer to figure 2). With no buffer area around the turbines, the area required can be calculated as:

$$\text{Length (ft)} = (\# \text{ of turbines in row} - 1) * 3 * \text{blade diameter (ft)} \quad (2)$$

$$\text{Width (ft)} = (\# \text{ row of turbines} - 1) * 10 * \text{blade diameter (ft)} \quad (3)$$

$$\text{Area Required (Acres)} = \frac{\text{Length (ft)} * \text{Width (ft)}}{43,560 \text{ ft}^2 / \text{Acre}} \quad (4)$$

The transmission line costs were taken from both the Ernest Orlando Lawrence Berkeley National Laboratory from the Environmental Energies Technology Division [5], as well as other individual projects, most of which were also later found to be included in the statistics of the first reference. This comprehensive report attempted to analyze the current costs of transmission line and substations in various areas as well as the costs for areas with potential for wind farms and other methods of

sustainable energy. There were many existing project costs in the report [5]. The associated costs below averaged together based on regions and types of substations relevant to wind farm projects.

Table 4 – Transmission system costs.

| Substation and Transmission Line Costs | | |
|--|----------------------------|-----------------|
| Transmission Line | | \$300,000 / mi. |
| Collector Substation | | \$1,150,000 |
| Connection to Existing T-Line | T-Bone (110 kV line) | \$100,000 |
| | Expand Existing Substation | \$500,000 |
| | New Substation | \$1,200,000 |

Transmission and substation costs are thus

$$\text{Miles of new line} * \$300,000 + \$1,150,000 + \text{connection cost to existing T – line} \quad (5)$$

3.3 Maintenance costs

The maintenance costs of wind turbines were an interesting challenge to model because the true costs are not known. Today’s wind turbines are rated to last for 20 years. However, there are very few megawatt scale turbines which have been operating for twenty years. With constantly improving technology, and as manufacturers learn from experience, the cost of maintaining turbines is falling. Based on predictions provided in [6], a model was created which accounts for the escalating costs of maintenance over time

$$\text{Maintenance Cost}(\text{year of operation}) = -0.0002y^3 + 0.0084y^2 - 0.0081y + 0.514 \text{ cents/kwh}$$

$$\text{valid for } 0 \leq y \leq 20 \quad (6)$$

This function was confirmed with observations from [7] and [8].

3.4 Energy prices

Wholesale energy prices vary significantly throughout the day, from day to day, and from season to season, as well as with location. Energy prices are higher when demand is greater. In general, weekday summer afternoons have the highest demand and energy prices, while cool nights have low energy demand, and thus low prices.

Wind speeds also have patterns, blowing stronger at night and in the winter and spring. The power generated by a wind turbine is a cubic function of the wind speed, so these changes in average wind speed have a dramatic effect on the amount of energy generated by wind turbines.

The pricing model was developed to take into account the time value of energy prices and the availability of wind energy without burdening the students with these computational complexities. Energy pricing data for the state of New York was collected from the New York Independent System Operator (NYISO). To simplify the process of sorting this data, four representative weeks were selected, one for each season. Locational marginal prices were recorded for five regions representing much of the state; North, West, Central, Capitol, and NYC. The pricing data from NYISO was sorted to include

only the price point at the top of every hour. These prices were averaged into four, six-hour blocks (morning, day, evening, and night) for each of the four seasons. Each of these sixteen blocks (four seasons x four time blocks) then had a multiplier for the availability of wind energy during each of the respective periods. The resultant “corrected” price was a levelized, average export rate for each region (Table 5).

Table 5 – Example of corrected energy pricing for the summer season

| | Capitol | Central | NYC | North | West |
|---------|---------|---------|--------|--------|--------|
| Morning | 39.88 | 37.55 | 51.16 | 35.85 | 35.06 |
| Day | 144.15 | 131.13 | 167.33 | 122.15 | 122.08 |
| Evening | 90.19 | 84.47 | 120.20 | 79.46 | 76.11 |
| Night | 78.1 | 72.57 | 101.75 | 69.85 | 67.83 |

From these corrected prices, and the yearly energy output, the yearly income can be calculated

$$\text{Average Export Rate} = \frac{\sum \text{Corrected price for each time of day (4) and each season (4)}}{16} \quad (7)$$

$$\text{Income (\$)} = \text{Average Export Rate} \left(\frac{\$}{\text{MWh}} \right) * \text{Annual Energy Production (MWh)} \quad (8)$$

In situations where the activity is pressed for time these corrected energy prices may be presented with a quick mention of the complexities that went into creating them. In an activity for which more time is available, the students may dig as far backward through the energy pricing analysis as desired to understand these time value factors.

3.4 Production tax credit

The Production Tax Credit (PTC) is a federal subsidy to commercial-scale renewable energy projects which, for 2012, provides 2.2 cents per kWh for the first 10 years of a projects operation

$$\text{PTC Income (\$)} = \text{Yearly Energy Production (MWh)} * 1000 \left(\frac{\text{kWh}}{\text{MWh}} \right) * 0.022 \left(\frac{\$}{\text{kWh}} \right) \quad (9)$$

This value is corrected yearly for inflation; however, for simplicity, inflation has been neglected from this analysis, and a reduced financing rate of 4% is used to correct for this factor [9]. This tax credit was automatically included, but could easily be removed to demonstrate the importance of this federal subsidy to the current viability of wind projects.

4 Computation Template

A pencil-and-paper worksheet was prepared for the students to select the design parameters used for the generation of the cost values that were included in the analysis. The worksheet focused the students on working through the process one step at a time without overloading them with information.

In addition, it allowed greater involvement as each student was provided with a worksheet, while only one computer was available per group.

An Excel spreadsheet was developed to help expedite the analysis, rather than have the students bogged down in arithmetic. Once all costs were calculated on the activity worksheet, the students entered these values into the spreadsheet, which provided the analysis of the project over the 20 years. The spreadsheet also allowed for a graphical representation of the cost analysis, which was invaluable in understanding the trends over time. Results included the yearly net income/loss, cumulative income, and the internal rate of return for the project.

The spreadsheet was organized into four categories: Basic Information, Capital Costs, Ongoing Costs, and Production Data. Basic Information included the choice of locations, wind speed and capacity factor at that location. Capital Costs included the cost of the wind turbine itself, installation of transmission lines and substations, and land clearing and preparation costs

$$\text{Capital Costs} = \text{Turbine Cost} + \text{Land Preparation} + \text{Transmission Lines} + \text{Substation} \quad (10)$$

Ongoing Costs, assumed to be paid on a yearly basis, included the payment on borrowed capital, maintenance costs, leased land, and miscellaneous costs such as administration, insurance, and electricity from the grid when the turbines are not operating

$$\text{Annual Costs} = \text{Maintenance} + \text{Land Lease} + \text{Debt Payment} + \text{Misc. Operating Costs} \quad (11)$$

Production Data included the yearly energy the wind farm generated, from which the production tax credit value can be calculated, and the income from the sale of electricity to the wholesale market.

Some factors included in the spreadsheet were not included in the students' calculations due to time constraints. For example, ongoing insurance and administrative costs were set values factored into the spreadsheet, but not calculated by the students. In addition, as this was not meant to be an activity on finance, the debt ratio and interest rate were not considered; the function to calculate annual payments was built into the spreadsheet, requiring no contribution from the students.

The production tax credit was calculated from the nameplate capacity of the wind farm (which was specified as a design constraint) and the capacity factor by the spreadsheet. With more time the calculation of capacity factor could be looked at, and the total energy produced could be calculated from the capacity factor by the students. This would be a good way to transform capacity factor, which was an abstract number, into a concrete understanding of how it is calculated. The calculation of capacity factor from an average wind speed, assuming some wind speed distribution, is likely beyond the capabilities of the high school students this activity was designed for.

Multipliers were built into the spreadsheet for a variety of factors such as turbine capital costs and maintenance costs. These allowed the students to look at the sensitivity of these factors on the profitability of their proposed projects.

With all values entered in the spreadsheet, yearly income and costs were calculated in tabular form. These included separate columns for the production tax credit, maintenance, yearly costs, and yearly income. Net yearly income or loss and cumulative income/loss were then calculated and represented in both tabular and graphical form. These graphical representations of the project's cash flow proved very valuable for the students in visualizing how costs were changing over the life of the project and sparked many good questions about why a trend appeared or how the graph would change if a particular input was changed. The spreadsheet was designed for just this sort of curiosity; a value under question could be changed, and the results instantly seen in the plots.

The internal rate of return, effectively the financial return that the owner earns by investing in this project, was also calculated by the spreadsheet. This is not a metric that most high school students are familiar with. However, by making the connection to the interest rate the students earned on their personal bank accounts, the students seemed to have a good understanding of the importance of this value. With more time, the calculation of this measure, and its importance in decision making could be discussed more fully. Another decision making tool which was discussed as time permitted was the simple payback period, which can be read directly off the cumulative income chart.

The results of using these cost data for wind farm design are shown in the next section.

5 *Workshop*

This activity was first presented at Rensselaer Polytechnic Institute's "Design Your Future Day," a day of activities developed to encourage female high school students to pursue education and careers in STEM fields. In addition to panel discussions and a keynote speaker, the young women participate in two, one hour long sessions on specific topics. This project, entitled "Harness the Wind & Generate Electricity!" was presented in two sessions to groups of 9 and 12 high school students, respectively.

The session started with a brief presentation on wind energy. In less than 15 minutes it stepped through the history of wind farms, attempted to put the scale of these machine into perspective, explain the design activity, and introduce the factors that the students would need to look at to complete the activity. The goal of the presentation was to help the students' transition from thinking of wind turbines as those big shapes on the horizon to a real and complete project for which they could analyze the major factors.

The students were then broken into teams of three or four, and each team was led by an undergraduate student. The small team size allowed the students to easily work together as a team as they discussed options and completed the worksheet. There was enough information presented and available in the worksheet such that the students should have been able to complete the activity without help. However, they would not have developed as strong an understanding of the design variables as they did, without a leader there to answer questions and guide the discussion. For example, in each group there was much discussion about where to site the wind farm, which had to be decided early on in the analysis.



Figure 3 – Students working on the parameter selection phase of the design activity.

Thus, the students could efficiently see how their location required more or less miles of transmission lines, whether a new substation needed to be built, or if they could save money by adding onto already existing substations. In both workshops, at least one group found that the optimum location within their region for a wind farm required hundreds of miles of new transmission lines, resulting in millions of dollars of added initial investment. By scaling the unit price of transmission line per mile, the impacts of such decision making processes became very realistic and allowed them to see the advantages and disadvantages that come with choosing one location over another, outside of just choosing a location with the optimum wind speed.

For example, students designing in the Western New York region found high wind speeds both on the coastal region of Lake Ontario, as well as in fields far from the coast. However, students chose locations closer to the coast because the coast was more developed with already existing power plants and thus a power grid system, allowing them to save money on both transmissions lines and substation coasts.

Once the worksheet was completed, the values were transferred to the Excel spreadsheet by one of the students. From here a discussion of the results was led by the group leader. This discussion was an interactive conversation about what the results mean and what factors are impacting the results. The students were encouraged to go back and experiment with values; to see how changes in the input parameters affected the results and, ultimately, the feasibility of the project.

The results of one of the students’ projects are shown below as an example. The West Region was selected and the other design parameters are shown in Table 6. Figures 3 and 4 summarize the yearly and cumulative income of the project over 20 years, the presumed life span of the project.

Table 6 – Some selected design parameters

| | | |
|--------------------|-----------|-----|
| Region | West | |
| Location | Farm Land | |
| Average wind speed | 10 | m/s |
| Capacity Factor | 0.348 | |

| | | |
|--------------------|---------|-----|
| Nameplate Capacity | 150 | MW |
| Yearly Energy | 457,272 | MWh |

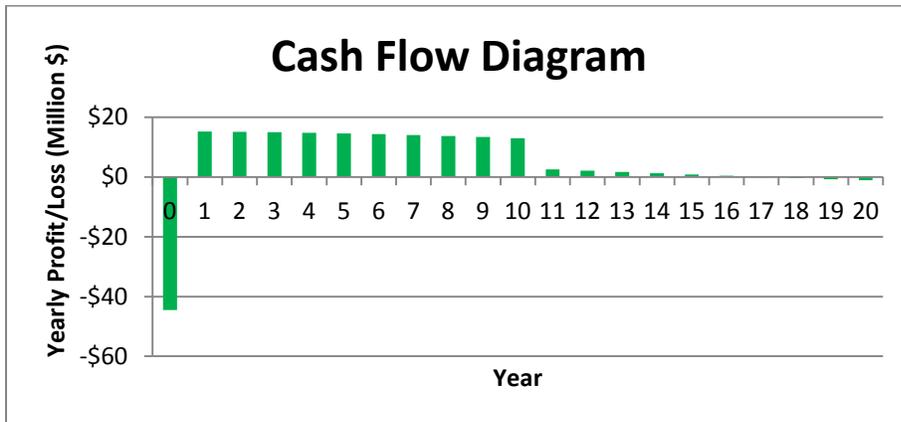


Figure 4 – Cash flow diagram (CF=0.348).

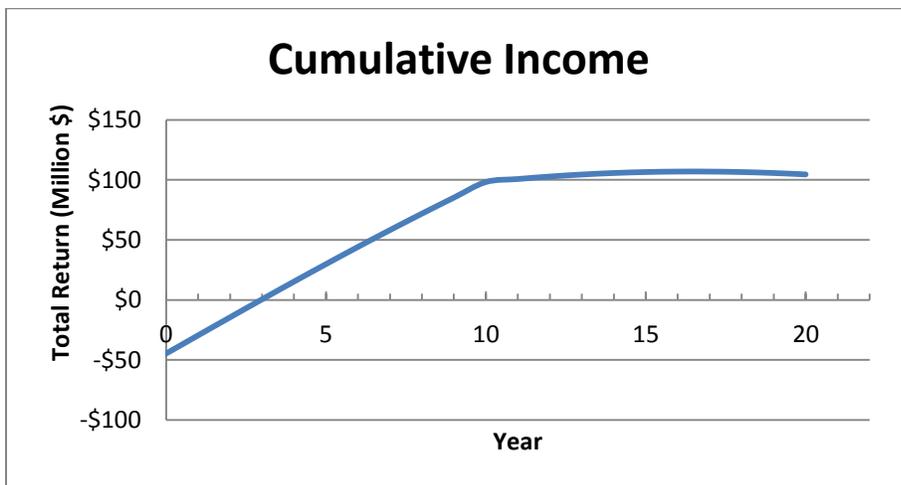


Figure 5 – Cumulative income (CF = 0.348).

The gross annual income was \$22,644,529 with an annual production of 457,272 MWh. These results were common among the results of the various groups. The students recognized immediately the significance of the tax credit, without which the wind farm would operate at a loss. Thus a voluntary green energy surcharge paid by customers may provide enough revenue for the project to have positive cash flow when the tax credit goes away. In some other student groups choosing a region with a lower capacity factor, the project was less financially successful. For the project in Table 6, if the capacity factor is decreased from 0.348 to 0.290, the results are shown in Figures 6 and 7. The main difference is that the project stops yielding revenue as soon as the tax credit expires (i.e. 10 years after the construction of the wind farm). It is also worth noting that the maximum total income for the highest capacity factor is close to one hundred million whereas it is half of that, close to fifty million, when the capacity factor is decreased to 0.290. Adjusting these factors allowed students to understand the significance of various design aspects, and the relevancy of engineering design in relation to its economic viability.

The session ended with a brief discussion of the results from each group. This was run by the group leaders and served to share the experiences of each group with the rest of the participants. If more time had been available, it would have been valuable to have the students from each group develop a three- to five-minute presentation on the results they found. Finally, a results sheet was printed for each group member so they had something to take home, which, hopefully, would spawn further discussion of the project with family and friends.

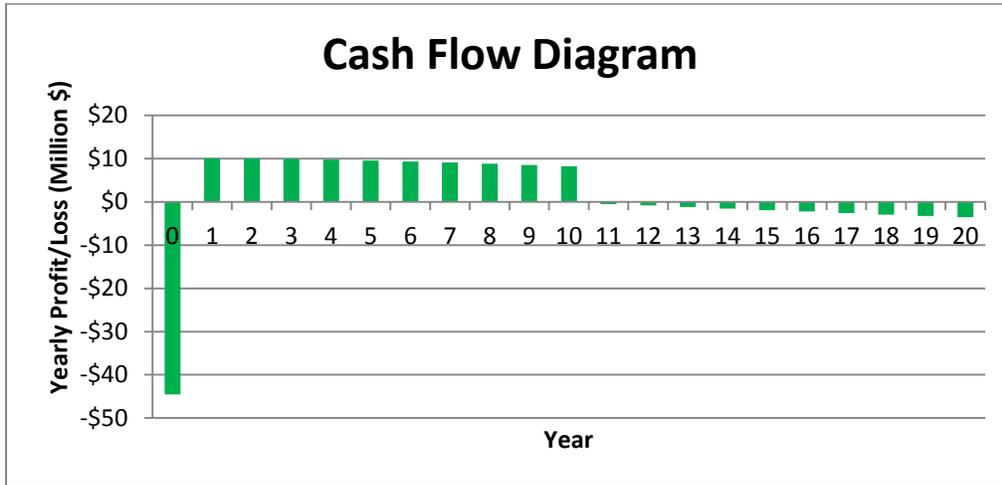


Figure 6 – Cash flow diagram with a decreased factor (CF = 0.290).

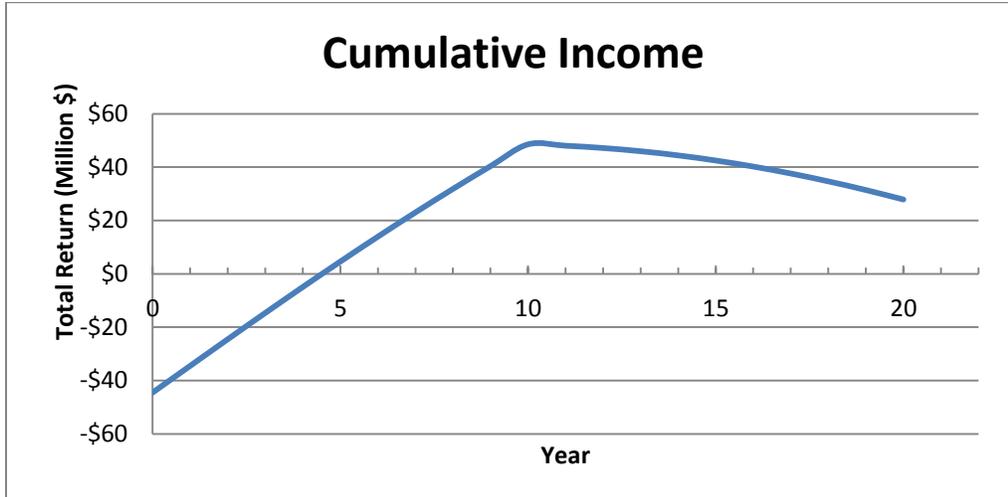


Figure 7 – Cumulative income with a decreased factor (CF = 0.290).

6 Assessment

A post-activity survey was designed to determine whether participants' levels of knowledge, interest and confidence in learning engineering have increased after this workshop. In addition, participant's opinions on the overall workshop program will be helpful in understanding the strengths

and weaknesses of the program. Among all students who responded to our survey, there were 19 girls aged between 15 and 17 (18 Caucasians and 1 Asian).

Knowledge, Interest and Confidence. Participants evaluated the extent to which this session increased their level of understanding engineering knowledge, interest in studying engineering and confidence in participating in engineering projects based on a 5-point *Likert* scale ranging from 1 (= *strongly disagree*) to 5 = (*strongly agree*).

Overall, participants’ levels of knowledge of wind farms, interest in learning engineering and confidence in participating in an engineering project were positive. As shown in Table 7, results of the survey demonstrated that this session helped students understand wind farms (*Mean* = 4.53, *SD* = 0.51), and learn something new about engineering (*Mean* = 4.53, *SD* = 0.51). In addition, this program has increased participants’ interest in studying engineering or science in college (*Mean* = 4.37, *SD* = 0.76) and confidence in their ability to participate in an engineering or science project (*Mean* = 4.42, *SD* = 0.51). Figure 8 depicts results of the knowledge, confidence and interest using a spider chart based on the average scores from the items of each aspect. Spider charts are helpful in displaying multivariate observations with a number of variables.

Overall Evaluation. Participants also evaluated the extent the session was interesting, informative and approachable (e.g., easy to ask questions) based on a 5-point *Likert* Scale. The overall evaluations were very positive in terms of interest (*Mean* = 4.53, *SD* = 0.51), informative (*Mean* = 4.63, *SD* = 0.50) and approachable (*Mean* = 4.63, *SD* = 0.50). Figure 9 shows the average scores for each question using a Spider chart.

Table 7 – Rating on Perceived Knowledge, Interest and Confidence

| Aspect | Item | Average (±Standard Deviation) |
|------------|---|-------------------------------------|
| Knowledge | Helped me understand the knowledge of wind farm better. | 4.53 ±0.51 |
| | Helped me learn something new about engineering or science. | 4.53 ±0.51 |
| | Enabled me to explain to my friends what engineers or scientists are doing in their work. | 4.16 ±0.83 |
| Interest | Inspired me to find out more information about wind farms. | 4.11 ±0.66 |
| | Increased my interest in studying engineering or science in college. | 4.37 ±0.76 |
| Confidence | Increased confidence in my ability to participate in engineering or science activities or projects. | 4.42 ±0.51 |

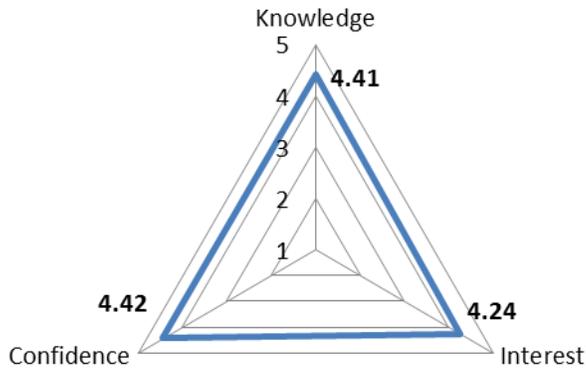


Figure 8. Participants' perceived gain after the session

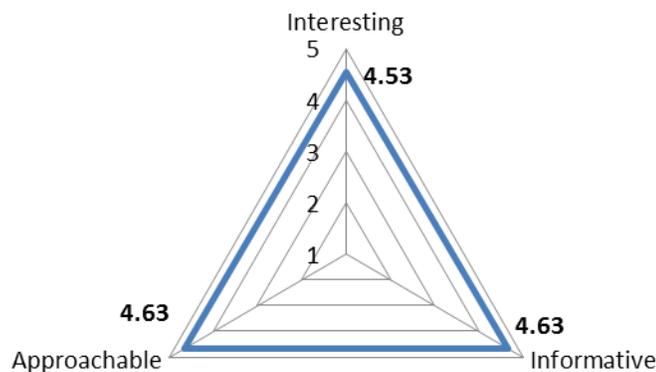


Figure 9. Overall evaluation based on a 5-point scale

Word-of-mouth recommendation. Participants were then asked if they would recommend this workshop to their friends. All of the participants answered yes. Examples of participants' responses are listed below:

"I would recommend that my friends participate in this activity because it offered a good opportunity to learn about wind farms and how it helps the environment but also how much it costs to run one."

"I really got a more clear understanding of sustainable energy which I am passionate about the realities of it."

"I believe that this activity would be useful to anyone interested in engineering or electricity. You learn how slight change in your decisions can make a big difference."

Suggestions for improvement. In the end, participants were asked how this program could be improved if the session was offered again. While some participants offered no suggestions (31.6%), a majority of participants reported that they need "more background information" (52.6%). For example, it would be helpful to explain each step of the process more clearly, discuss more details about where each number came from and provide maps.

7 Conclusions

In this paper, we have described the process of designing a wind farm design project for engineering outreach and the experience in leading student groups through the design activity. Although the data are obtained from searching the world-wide-web and thus, do not directly reflect the true parameters of a particular design project, the results seem to be reasonable and quite illuminating. From the workshop survey, it seems that the materials were presented at the right level and students were engaged. The wind farm design module will be put to use in multiple outreach programs at RPI, including a one-week summer program on "Smart Grid" and the Engineering Ambassador program in which undergraduate students visiting local schools for science and technology outreach. Also it will be used in the CURENT ERC program for University of Tennessee, Northeastern University, and Tuskegee University.

For power educators, the wind farm design materials (power point introduction, wind profile map, computation template, Excel spreadsheet) described in this paper can be downloaded from the website www.ecse.rpi.edu/~chowj. Interested users are encouraged to adopt the design materials for use to their own regions by using the appropriate wind and transmission system data.

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