Iowa State University

Siting and Project Development Report

2019 Collegiate Wind Competition

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Table of Contents

Executive Summary

The Wind Energy Team at Iowa State University has redesigned a detailed wind farm site plan and completed a financial analysis. The team has improved upon the site plan from last year's competition by changing turbine placement to increase energy production, decrease road length, decrease transmission line length, and reduce the number of different landowners. A cost of energy and cash flow analysis was completed for the 20-year expected life of the project. In our best analysis our project could produce a lifetime profit of $39,930,700 after using the investment tax credit (ITC) from the federal government.

Brief Site Description

For the 2018 Department of Energy Collegiate Wind Competition, our team began by identifying potential wind farm sites for a 100MW wind farm within 100 miles of our school, Iowa State University, in Ames, Iowa. We identified five potential locations in Iowa for a wind farm: Fort Dodge, Jefferson, Ottumwa, Grinnell, and Boone. The five sites were ranked based on wind resource, transmission accessibility, and geography to choose the best location.

Northwest Iowa has the strongest wind resource in the state, and thus we picked three potential sites northwest of our university. Since there are already many wind farms in Iowa, these locations were avoided. Six years of wind speed and direction data for each of the potential sites were downloaded from the Iowa Environmental Mesonet [1]. After performing a wind speed analysis of the data, the Fort Dodge and Jefferson sites were found to have the strongest wind resource.

As the next step, we looked at transmission maps of the state for high voltage lines including 161 kV lines and 345 kV lines, as well as the locations of other power generation stations and substations. Between the Fort Dodge and Jefferson sites, Fort Dodge was chosen as the best site because it has an existing substation near our site which our wind farm could feed into. The Jefferson site has many transmission lines that have been recently improved, but there is a new wind farm in the same area. In consideration of these facts, an area with flat farmland was chosen as the final site in the northeast corner of Webster County, Iowa. It has an average wind speed of 7.64 m/s at 100m, with the wind being predominant in the northwest-southeast direction.

After choosing the site, we focused on selecting a suitable wind turbine. We found power curve data for three different wind turbines: Gamesa G114-2.0, Siemens 3.2-113, and Vestas V136-3.45. By using the power curve data and the local wind data, we could identify the AEP (annual energy production) for each turbine and scaled it up to represent a 100 MW wind farm. This AEP was inserted into our levelized cost of electricity (LCOE) analysis. Our LCOE model was constructed using many resources including emailing manufacturing, development, and construction companies. Our strategic advisor, Nicholas David, is a former wind turbine technician, who advised us on building an outline for calculating the costs of building a wind farm including the turbine cost, construction cost, and operation and maintenance costs. This cost analysis proved that the Vestas V136-3.45 is the most effective wind turbine for the site.

The final step was to determine the turbine locations. The Webster County Assessor's map was used to identify the property lines and owners in the area [2]. Since we wanted to have a small footprint in the county, we focused on minimizing the number of different landowners while keeping in mind wake effect and proximity to the substation. The siting was all done manually. We were successful by having the turbines a suggested distance apart, but close enough to minimize road and transmission line costs.

Design Changes

Using the 2018 site layout as reference, further refinement to the site layout was done to optimize the annual energy production while reducing both the initial cost and the annual operating cost. This process involved relocating the turbines to increase energy production, decrease the length of access roads and transmission lines, and reduce the number of land lease contracts. By reducing the number of landowners, we also have reduced the chances of landowners refusing to have a turbine on their property. Changes were made to the turbine placement with the help of DNV-GL's WindFarmer Analyst software because it will more accurately calculate energy production.

When using WindFarmer Analyst, the buildable area where turbines can be placed was first defined. Map and elevation data were downloaded from within the software for the entire wind farm. Appropriate turbine setbacks from roads, creeks, dwellings, structures, and railroads were applied to comply with the Webster County Zoning Ordinances 8.03.05 [3]. Next, 2007-2012 wind speed and direction data from the Iowa Environmental Mesonet at 100m altitude from near the site was uploaded. Using the wind data combined with the terrain data, a wind flow model was then established. The flow model calculates the approximate wind speed across the entire wind farm area based on a measurement reference point set in northwest corner of the site.

The final step in WindFarmer was to optimize the turbine locations using one of the three built-in algorithms. The symmetrical layout optimization algorithm was chosen because it places the turbines in rows to reduce infrastructure costs. Fifty iterations were completed and the five site layouts with the highest energy production were further analyzed. Using a measurement tool in WindFarmer, these five layouts were compared by the approximate length of roads. The selected layout has a theoretical AEP of 438,602.09 MWh, the shortest length of access roads at 5.48 miles, and 16.85 miles of transmission lines. We chose to focus on reducing infrastructure costs they are a large percent of construction cost. Since all five layouts had a very similar annual energy production, they were compared by road and transmission line lengths.

Table 1: Impact of Optimizing Turbine Layout

Layout	Total Access Road Length	Underground Transmission Line Length	Overhead HV Line Length	Number of Different Landowners	Buildable Area
2018	7.48 miles	24.5 miles	2.26 miles	29	14.75 sq. mi
2019	5.48 miles	14.59 miles	2.26 miles	15	12.35 sq. mi

There are many benefits in changing the layout of the turbines which are reflected in Table 1. The total length of the access roads was reduced by 2.0 miles, and the total length of the transmission lines was reduced by 9.91 miles. This was accomplished by using the symmetrical layout optimization and organizing the turbines in rows. This reduction in transmission line length would result in a project savings of $500,000 [4]. The turbines were also placed closer together, which reduced the number of different landowners by 14 and the buildable area by 2.4 square miles. Saving 2.4 square miles of high-quality farmland would save the local farmers in lost production. Overall, this reduces the cost of labor and land easements during the development and construction phases as well. However, in our financial model, it was hard to accurately quantify the labor and materials reductions. Hence, we did not make any changes to labor cost or materials.

One other design change made was to add real time sensors to fix yaw adjustments. The Vestas V136-3.45 has condition monitoring sensors to detect potential failures and allow time for preventative maintenance. In addition, installing real time sensors to adjust the yaw alignment of the turbines would allow operators to maximize the energy output of the wind farm. Adding yaw alignment sensors have been proven in the field to increase energy output by 1.8% [5]. For a sensor that costs $1000-$2000, that is a significant return on investment. As our wind farm has 29 wind turbines, a conservative cost estimate to implement these sensors is $58,000. The increase in MWh/year would be 7895 MWh, which equals a profit of $257,794/year based on our power production agreement (PPA). Even if every single sensor had to be replaced once every 4 months, it would still be profitable. Another added benefit of the sensor is that optimizing the yaw angle can reduce the stress on the blades, which can increase their lifespan.

Financing

JEDI Model

The foundation of our cost analysis came from the NREL (National Renewable Energy Laboratory) distributed wind JEDI (Jobs and Economic Development Impact) model [6]. Based on wind farm development information received from engineering professors, professionals in the wind industry, and competition organizers NREL's JEDI model for distributed wind was found to be the most detailed and accurate. A project engineer from MidAmerican Energy even told us the JEDI model is used in industry for preliminary estimates by development companies.

The basic project data inputs into the Jedi model were the location, year of construction, and the money value. Our turbine size is 3450kW and a project size of 100MW, resulting in 29 turbines. These were the only necessary inputs; however, the JEDI model was edited to be more specific to our wind farm. The first change to the JEDI model was to the electrical material costs for installing and purchasing the electrical transmission lines. The length of transmission lines needed for our wind farm was known and the total cost was calculated to be $729,500 [4]. Since this is the total cost, it was split evenly and added to labor and material costs. Other costs were made to the appropriate section of the model.

Initial Capital Costs

The total BOP after adjustments to the JEDI model would be $38,091,670. This covers all the materials and labor. It will cost our project another $119,575,952 for turbines, towers, blades, and shipping. Appendix 1: JEDI Model O&M Costs and Construction Costs has the major capital costs and a detailed breakdown of these costs can be found in our portfolio.

Land Lease

The BOP (Balance of Plant) land easement costs and O&M (Operations and Maintenance) land lease costs are based on a land lease contract for placing wind turbines on private land. The reference contract, from Infinity Renewables, for a property in southwest Minnesota that is within 150 miles of our site and it can be found in our portfolio. Since it is close to our site, the same payments to landowners was used in our cost analysis. For our cost analysis, it is assumed that neither the development nor construction phase would take more than a year. The site is on highly developed and high-quality farmland according to the American Farmland Trust, so higher prices are expected [7]. After the first year, the operations fees are $1.75/MWh produced for the first 15 years.

Financing Options

The PTC and ITC financing options were compared to decide which one is more economical for our site. To optimize the cash value of the tax credits and depreciation, the largest loan a tax equity investor would give was first determined, given a rate of return of 10%. The rest of the money was assumed to come from a large lender at a 5% interest rate over 15-20 years. Our team found that it is more economical for us to take advantage of the ITC over the PTC.

With the PTC, both the construction lender and tax equity investors could not be paid off in 20 years unless given lower interest rates. The best-case scenario using the PTC involves a six-year tax equity investment of $53,769,250 (32.5%) with the other $111,808,671 (67.5%) coming from a large lender [8]. The PTC from years 7-10 were then applied to the loan from the large lender. In this scenario, we would still be $5 million in debt at the end of the 20 years. In the best-case scenario using the ITC, it would take 15 and 6 years to pay off loans from the lender and tax equity investors. This case involves a loan of $82,540,754 (71.2%) from a large lender, and the other $33,363,791(28.8%) from a tax equity investor [9].

A novel financing idea that could be applied is to use the levelized O&M costs in our payment calculations. In our land lease contract, we pay the landowners $1.75 MWh for the first 15 years. By using the levelized cost, we would distribute those land lease payments over 20 and not 15 years. If we used levelized O&M costs with the PTC, the tax equity investor could be paid off in 6 years and the large lender could be paid off in 18 years. If we used the levelized O&M costs with the ITC, the tax equity investor could be paid off in six years and the large lender could be paid off in 13 years.

Using the levelized O&M costs with the ITC is the most profitable financing method for our project. Once the loans are paid off, the farm will have a revenue of $59,586,801. After taxes and O&M costs, this would be $39,930,700. If O&M costs were not levelized, the most profitable scenario would still be to use the ITC, but profits would be $16,819,500. Another standard we considered while financing is the interest payments. When using the levelized O&M costs with the ITC we saved $2,580,244

Appendix 2: 20-Year Wind Farm Cash Flow Analysis shows the cash flow diagram for our wind farm using the levelized O&M costs. Our internal rate of return (IRR) was calculated using the excel internal rate of return spreadsheet equation and it was found to be 9.994%.

Loans

As there are many stages to the construction of a wind farm, there are also different stages to financing a project. The wind farm will utilize three different types of loans: development, construction, and permanent. A development loan covers the costs of interconnection deposits, PPA deposits, and site assessment costs. In the initial development stages, "many entities act as development financiers in order to claim a seat at the project table" [10]. These entities could be general contractors or turbine manufactures looking to either obtain the bid during the EPC (Engineering Procurement Construction) phase or use of their turbines at the site. Smaller investors tend to invest more in the development stage because larger financial institutions are not as willing to take the risk early in the project's life.

Construction loans come into effect after the development phase. Because the costs are so high during this phase, large lenders typically provide the necessary capital. These loans are under strict terms as to how and when the sponsor gets the money. Construction loans will generally have a staggered payment system set up so that certain project milestones must be met before more money is lent. Milestones provide the lender insurance that the project is progressing as planned. This staggered payment system also reduces the time for outstanding balances and interest accumulation for the project sponsor. After the project has reached its COD (Commercial Operation Date), the sponsor will convert their expensive construction loans into a long-term loan. The terms of this permanent loan are much lower than the construction loans because the risk to the lender has dramatically decreased after the COD date.

Net Annual Energy Production

WindFarmer calculated the annual energy production based on input data (wind data, turbine data, etc.), wake effect, and control hysteresis. The AEP was adjusted to make it more realistic using a time-based availability, an estimate of the amount of time that the turbines actually produce electricity over the year. According to a production loss assessment sponsored by the European Wind Energy Association from 2016, the average time-based availability is 4.03%, with losses coming from turbine error, gird error, ambient error, and curtailment [11]. Assuming a percent loss of time results in an equivalent percent loss of energy production, the adjusted AEP is 438,602.09 MWh. This makes the capacity factor of the wind farm 50.04%. At a PPA sales price of $40/MWh, the yearly revenue is estimated to be $17,544,100.

Taxes

To calculate income tax, the federal and state income tax rates were found. The federal corporate income tax rate is 21% [12]. We calculated our state income taxes following the equation from the NREL CWC Webinar Part 2 [13]. Our total yearly income tax is estimated to be $5,499,631. The property tax rate for the site was found by taking the assessed value per turbine [14] and following the instructions from the Webster County Tax Department [15]. As noted, this amount is $10,187.18 per year. We received a document of the appraised value of a wind turbine in Webster County from the Webster County Assessor's Office. The special valuation is as follows in Table 2.

Table 2: Webster County Property Tax Special Valuation

Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7+
0%	5%	10%	15%	20%	25%	30%

The appraised value of our turbines is $707,820. Over our 29 turbines and following the Webster County property tax instructions, our income tax would be $388,083 per year. After the special valuation, our levelized property tax was $10,187.18 per year.

Depreciation

Depreciation is another incentive that can be capitalized on by a sponsor to fund their project. Depreciation allows a company to write off a certain percentage of their assets value as it ages and loses value. Theses tax savings can be significant for the wind farm as the wind turbines are worth over one hundred million dollars initially. Frequently, a project sponsor is too small to fully utilize the depreciation of their turbines, so they sell the rights to the depreciation of a turbine to a tax equity investor as a form of payment. Our depreciation schedule follows the IRS (Internal Revenue Service) guidelines for MACRS (Modified Accelerated Cost Recovery System) +30% bonus depreciation of a renewable energy project [16]. The savings on income taxes from the deductions is part of the money that will be used to pay back our tax equity investor. By giving our tax equity investor the rights to this depreciation, we can pay them a total of $59,767,250 by the PTC or $33,363,791 by the ITC. With the ITC, depreciation is calculated at 85% of the turbine value, not including transportation [17].

Return on Debt and Equity

Investors in the project are primarily concerned with the return on their investment. There are a few different options to pay them back. Our wind farm is eligible for 10 years of production tax credits (PTC) at $.0076/kWh which can be used to pay back the tax equity investor [8]. For our wind farm that would be a total PTC of $33,333,759 over 10 years. Another way we will pay back our tax equity investor is through the depreciation of the wind turbines. Following the MACRS depreciation timeline for a renewable energy project, the depreciation by year is found [16]. Depreciation of the turbines can be deducted from the tax equity investor's income tax. Tax equity investors tend to be massive entities, so they gain more benefits from the depreciation of the turbines over if the sponsor took the depreciation. The tax equity investor would be able to write off $45,809,188 from their taxes over the 6 years of the deductions if they took the PTC

An alternative financing option could be the ITC. The ITC can replace the PTC if a company chooses. Using ITC, our wind farm would receive a 30% credit on all installation expenses. The tax savings from the depreciation following the ITC would be $38,937,799.

The large lender will be paid using the revenue from the electricity sold. The energy produced would be sold to a wholesale buyer such a local utility MidAmerican Energy or Alliant Energy. The power purchase agreement between our wind farm and the wholesale buyer would be set at $40/MWh. This rate is based off the weighted averages sales prices from 2018 data at the Indiana Intercontinental Exchange Hub [18].

Insurance

Insurance is a small cost, but it is crucial. A very common insurance practice for a wind farm is "cradle to grave" [19]. Cradle to grave simply means the project is covered from the transportation, installation, all the way through decommissioning. It is important that the insurance plan has no gaps between phases in case of an accident or emergency. The insurance covers physical damage to the turbines from severe weather, transportation, and other accidents. In addition to physical damages, the insurance plan covers time delay like construction delays. This time delay coverage allows the wind farm to regain lost PTC. However, the plan does not allow missed ITC tax credit to be reclaimed.

A general liability policy is also in place for any property or physical damage to a third party due to operations of the wind farm. The standard JEDI model insurance prices were used as an accurate source for insurance prices could not be found. However, since our site is in Iowa, we can expect our insurance to cost more due to high wind risks. As well, we are in a highly developed area, with rich farmland. So, there is more of a chance for property or physical damage compared to a more rural site

Levelized O&M

From the JEDI model, the wind farm's annual O&M costs is $9,209,870. $5,888,440 comes from our income and property taxes, $767,554 from our land lease costs, and $2,353,541 from materials and services. However, after the fifteenth year, we no longer pay the land leases. Over the 20-year lifetime, the levelized costs would then be $8,817,650

End of Life

Since our cost analysis is for a 20-year expected project life, the costs associated with the wind farm's end-of-life are important to consider. This includes disassembly and removal of all the wind turbines, substations, underground collection lines, and ancillary equipment. The property needs to be restored which includes removing turbine foundations, removing crane pads, and striping and backfilling roads. Financial data was taken from a decommissioning plan created by DNV-GL for a 340MW wind farm constructed in 2018 in Poweshiek County, Iowa, only 150 miles from our site [20]. The plan assumes components of the wind farm will be disposed, sold for recycling, or sold for reuse. This model was scaled to fit our 100MW capacity. The total cost of disassembly, removal, and disposal would total $9,960,000 and used material and parts could be sold $11,249,000. The total decommissioning process would produce a net gain of $1,288,551.

Conclusion

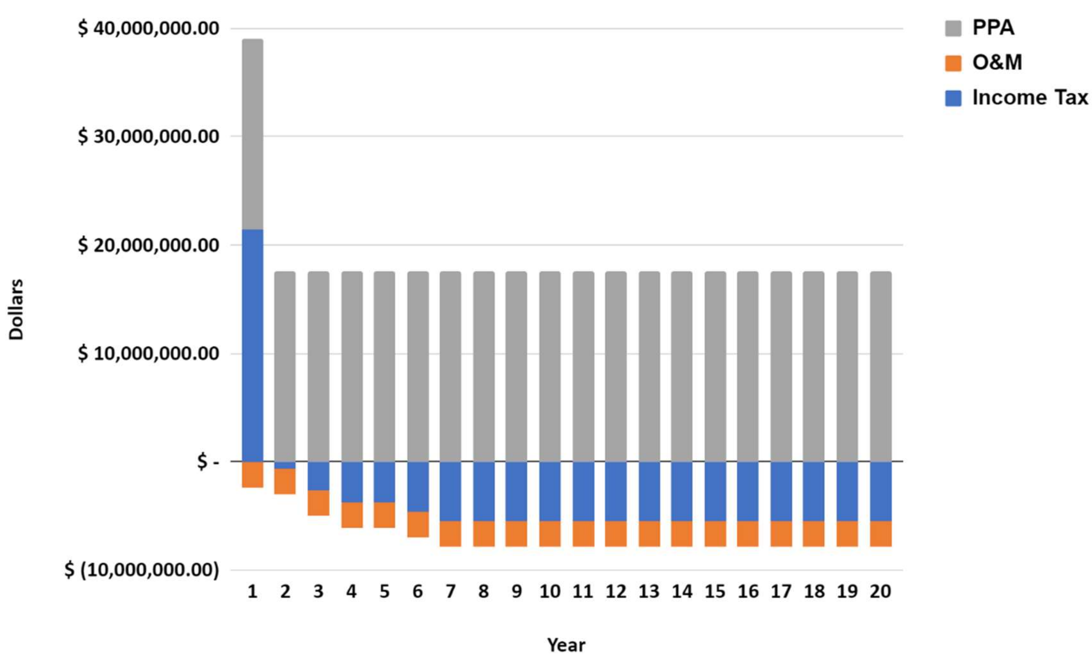
Many changes were made to the wind turbine placements from the layout used in last year's competition. These changes increased the profitability of our wind farm. Using the JEDI model as a base for the financial model and adjusting it to our site, the team determined important costs and the profit of the wind farm. There were many ways for us to make our project profitable. The best scenario would be to use the ITC with the levelized O&M costs. This method allows us to pay the most towards our loans in the initial years.

Appendix

Appendix 1: JEDI Model O&M Costs and Construction Costs

Construction Costs		O&M Costs	
Equipment Total	$119,575,952	Labor Subtotal	$446,459
Balance of Plant		Materials and Services Subtotal.	$2,353,541
Materials Subtotal	$23,304,968	**Sales Tax**	$103,877
Labor Subtotal	$10,210853	**Other Taxes/Payments**	$6,305,993
Development Subtotal	$4,575,860		
Sales Tax	$7,910,298		
Total	$165,577,921	**Total O&M Costs**	$9,209,870

Appendix 2: 20-Year Wind Farm Cash Flow Analysis



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