University of Maryland Wind Turbines

2020 Collegiate Wind Competition

Project Development Report

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1 Executive Summary

The midwestern United States has ample wind-resource opportunities for successful wind farm development. This report, completed by the University of Maryland Wind Turbines Team, describes the plan for a 100 MW wind farm design located in eastern Colorado and a financial analysis describing its 20 year life cycle. The location of the wind farm is Logan County in northeastern Colorado. The land within Logan County consists mostly of prairie, which will minimize any negative ecological impact of our wind farm on forest dwelling birds and animals.

The turbine model is the Vestas V136-3.45 MW model which has a rated output of 3.45 MW each. This turbine model is ideal for the wind speed class in Logan County. In our final wind turbine layout in the National Renewable Energy Laboratory (NREL) System Advisor Model (SAM), 28 turbines are specified to create a Nameplate Capacity of 96.6 MW. Adding one more turbine would push the Nameplate Capacity to exceed the required 100MW, so the number was kept at 28 turbines. SAM was then used to simulate a 20 year financial analysis and energy prediction.

A cost of energy and cash flow analysis was completed to produce a nominal Levelized Cost of Energy (LCOE) of 4.48 cents/kWh and a real LCOE of 3.68 cents/kWh (Table 5). The end-goal of a wind power project is to produce the lowest possible LCOE.

2 Site Description and Energy Estimation

2.1 Site Location Decision

The Wind Ranges and Transmission and Road Access Map (Figure 1) was utilized to pick the top five potential counties. Geographic data obtained from Colorado State University's Geospatial Centroid to display the major roadways and power transmission lines in the state of Colorado. A one mile buffer was created around roads and transmission lines to show locations where there is easy road access for construction and close transmission access to decrease costs. Wind speed data from NREL at 80m was overlain onto the map and clipped so wind would only display in the created buffer. The 95th percentile winds are shown in red and labelled "High Wind Speeds," 90th percentile winds are shown in pink and labelled "Medium-High Wind Speeds," and 85th percentile winds are shown in orange and labelled "Medium Wind Speeds."

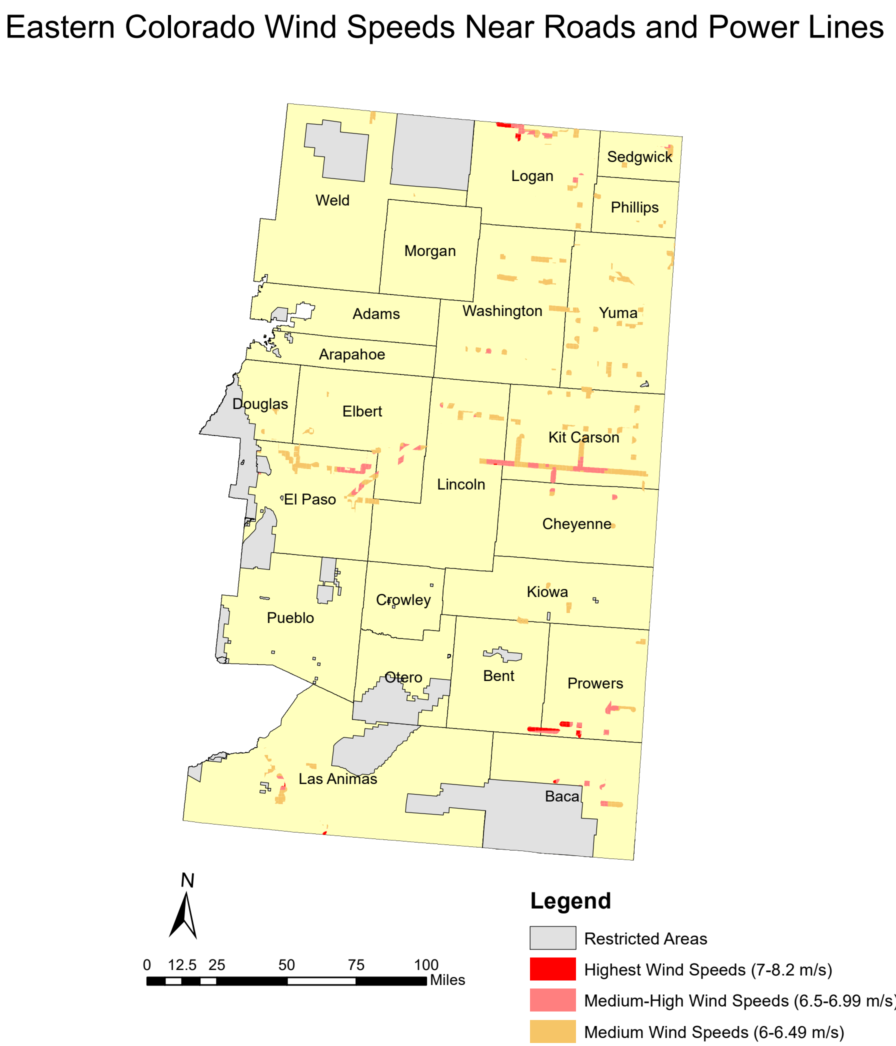

Figure 1: *Eastern Colorado Wind Speeds Near Major Roads and Power Lines*

Using ArcGIS, the team selected the areas within one mile of both the major roads and power lines and cropped away all the wind data from other, less accessible areas. Figure 1 highlights the upper fifth percentile, as well as two more data segments for approximately the next fifteen percentiles. This gives a graphical representation of desirable areas in eastern Colorado for wind farms, and informs the wind resource and transmission and road access decision factors. Based on figure 1, the top five counties were chosen for inclusion in the Pugh matrix below. These five counties are: Logan, Los Animas, Prowers, Bent and Kit Carson.

Our team began the site selection process by identifying the main criteria for selection and assigning weight values to them. We then created a Pugh decision matrix (Table 1), which aided us in making our final site location decision. The criteria and weighting are as follows: wind resource 20% ; transmission and road access 20%; wildlife 5%; land availability 10%; community factors 10%; asset and recycling potential 10%; local ordinances 10%; and taxes and incentives 15%. The weighting of each criteria was based on the scoring in the Collegiate Wind Competition Rules and

Requirements, as well as based on our prior research done on the wind farm siting potential in eastern Colorado.

Table 1: *Pugh Matrix*

				Alternatives				
Criteria	Weight of out 100	Relative Weights	County 4: Bent	County 1: Logan	County 2: Los Animas	County 3: Prowers	County 4: Bent	**County** 5: Kit Carson
Wind	20	20.0%	0	1	-2	1	0	-1
Transmission/ Road Access	20	20.0%	0	2	-1	2	0	2
Wildlife	5	5.0%	0	0	0	0	0	0
Land Availability	10	10.0%	0	-2	0	-1	0	0
Community Factors	10	10.0%	0	1	-2	1	0	2
Asset disposal/ Recycling Potential	10	10.0%	0	1	1	-2	0	-2
Local Ordinances	10	10.0%	0	-1	0	-1	0	0
Taxes/Incentives	15	15.0%	0	0	0	0	0	0
Sum Pureto Weights	100	Weighted Totals		0.50	-0.70	0.30	0.00	0.20
Max/Min Rating	±2	Rank		1	5	2	4	3

After assigning scores for the criteria for each county, Logan County and Prowers County came in first and second place respectively. Although Prowers County seems to have slightly more land availability (fewer current wind farms), Logan County is closer to a Vestas Manufacturing Plant, which will make the Life-cycle sustainability of a wind farm in Logan County more viable. For this reason, Logan is our final choice for our wind farm site. Details on triple bottom line opportunities such as end-of-life recycling are discussed in more detail in Section 4 of this report. Additionally, the local rules and regulations of Logan County are favorable and the roads and transmission infrastructure are also more established, with two other wind farms located nearby. For this reason, Logan County is our final choice for our wind farm site.

The exact location of the wind farm in Logan county followed the wind, power lines, and roads delineated in (Figure 1). There are two wind farms on either side of the proposed site, but the turbines are spaced so there is no interference in energy capture in our site or the surrounding sites. The soil was analyzed using the USDA's Web Soil Survey. The dominant soil series in the area of interest are Platner, Rago, and Dacono loams. These soils form in wind deposited sediments or old alluvial terraces that are not affected by flooding or ponding. The landforms are flat and the land use is agricultural. These factors make the site easy to access. Although the soil has high clay activity, the clay content is not high enough for clay swelling to be a concern, and the climate is not wet enough for wetness to be a concern in these areas. The soil is formed from mafic materials and it is unaffected by long-term saturation, so the building materials for wind turbines will not be damaged as a result of geologic factors (Web Soil Survey 2020). This location is also not listed as a restricted area and is not in the path of migratory birds. Since the wind farms will be built on agricultural land, impact on the local ecosystem is minimal.

2.2 Wind Farm Design - *Terrapin Ridge Wind Farm*

The first step in selecting the turbine model was to identity three manufacturers to compare and contrast. We chose Siemens, GE, and Vestas because of their ability to customize their turbine designs to fit the compatibility of individual farms. Regarding the specs of the turbine, area is the limiting factor, so maximising MW per turbine is a priority. Therefore, we looked at the 3-4 MW platforms for each manufacturer. These turbines with a greater power output would reduce the amount of individual turbines needed in order to reach the 100MW total needed for our farm. We also looked at the hub heights of the several manufacturers and decided that the 80m hub height range would best maximise wind speeds. The next important factor to consider is the diameter of blades and how the site wind speed requires a certain length. The wind speed for our site is classified as an IEC class II, a relatively medium to low wind. This requires the chosen turbines to have blade diameters between 40-43 meters (Gipe, 2006). Finally, narrowing down our choice to a single model became evident when the proximity to manufacturing and recycling sites was factored in. Vestas has manufacturing sites in central Colorado relatively near our proposed site, making transport of the turbine components more manageable and more cost effective than transportation of parts from Siemens or GE. Our final decision was the Vestas V136-3.45 MW (Vestas, 2020).

2.3 Energy Estimation and Net Annual Energy Production

Originally, the team intended to use Openwind to design our wind farm layout and energy capture capabilities (Figure 2). Openwind is a program that is based on Geographical Information Systems (GIS) software and can help developers design, optimize and assess wind projects (Openwind). A single 25x25 kilometer squared 200m Wind Resource Grid (WRG) from AWS Wind Navigator was utilized to create our farm layout in Openwind (Figure 2). In industry, WRGs are typically used for initial wind energy estimates, and not used for detailed energy estimates. However, the use of a WRG in Openwind to produce an energy estimation was deemed sufficient for our educational purposes. Figure 2 shows a square, which is the Wind Resource Grid from UL; warmer colors indicate greater wind resource in the area. The green areas show a 1 mile buffer of overlapping roads and power lines. The larger dots represent our proposed turbines and the blue dots display wind turbines from current farms.

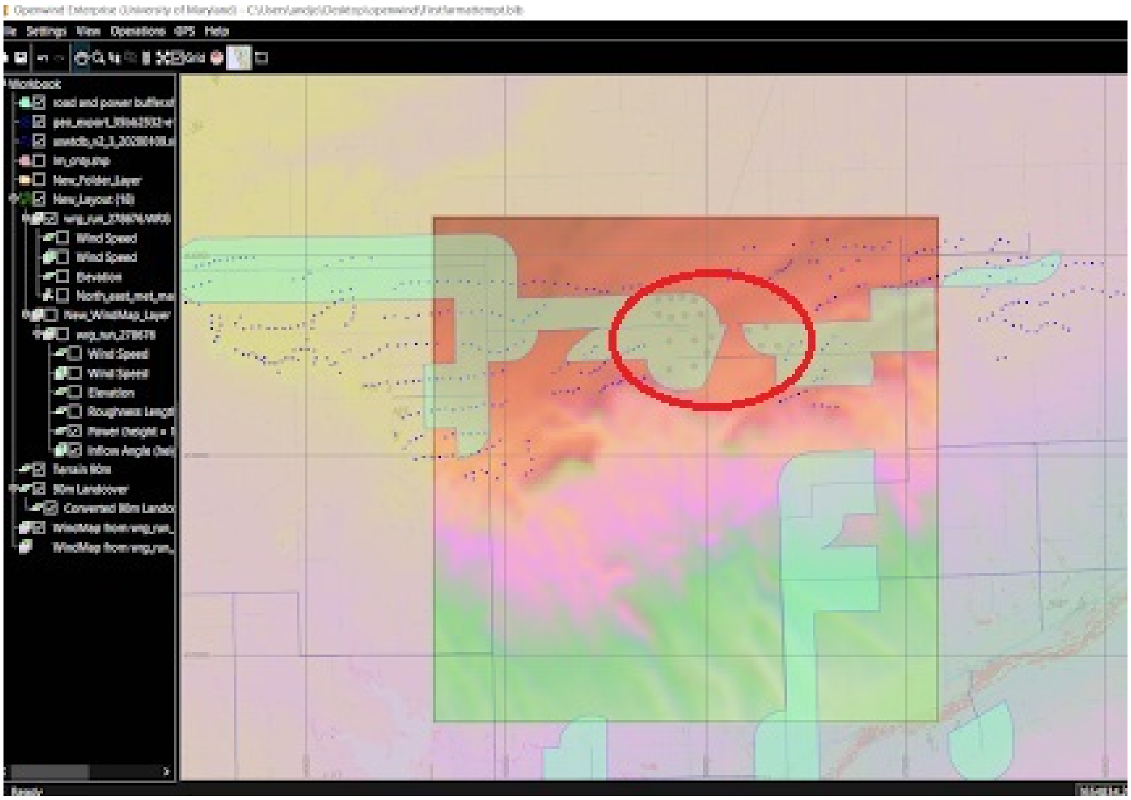

Figure 2: *Wind Farm Layout created in Openwind.*

However, due to complications arising from the COVID-19 pandemic and associated time constraints, we decided to use the NREL System Advisor Model (SAM) which is discussed in the following section. The data for OpenWind and SAM both come from Underwriter Laboratories, so they use information from the same data and models. OpenWind allows the user to model a specific 25x25km square of land, while SAM generalizes the northeast of Colorado as one region. Since our wind farm is in an area that has much more wind than the average in Northeast Colorado, the energy output from SAM is likely lower than what would be seen at our site. The Annual Energy Production (AEP) produced by SAM is 360,944,704 kWh with a Capacity Factor of 42.70 (Table 5).

3 Financial Analysis

3.1 System Advisor Model (SAM)

SAM is an open-source software produced by NREL to aid in decision making in the renewable energy industry (Blair, 2014). The purpose of SAM is to provide consistent and accurate technological and financial models across various renewable energy technologies in order to progress grid integration. SAM can model various types of renewable energy systems, including Wind Power. SAM has been verified by comparing some of its outputs to other models, such as Openwind (Modeling, 2019). The SAM financial models include: residential and commercial, Power Purchase Agreement (PPA), and third party ownership. Within the SAM interface, we selected the Wind Power Purchase Agreement

Single Owner layout with a 20 year time span. Inputs include: wind resource, wind turbine type, wind farm layout, grid limits, losses, uncertainties, lifetime and degradation, system costs, financial parameters, revenue, incentives and depreciation. Figure 3 shows the wind farm layout in SAM, which depicts an exact geometric grid of turbines; however, the layout of the real wind farm is not an exact square figure due to terrain restrictions. It was decided that the square shape is close enough to the real layout for SAM analysis purposes. More detailed outputs of SAM are included in Table 5 and Figures 4, 5 and 6. The inputs and outputs of the cash flow model are discussed in further detail in the following sections.

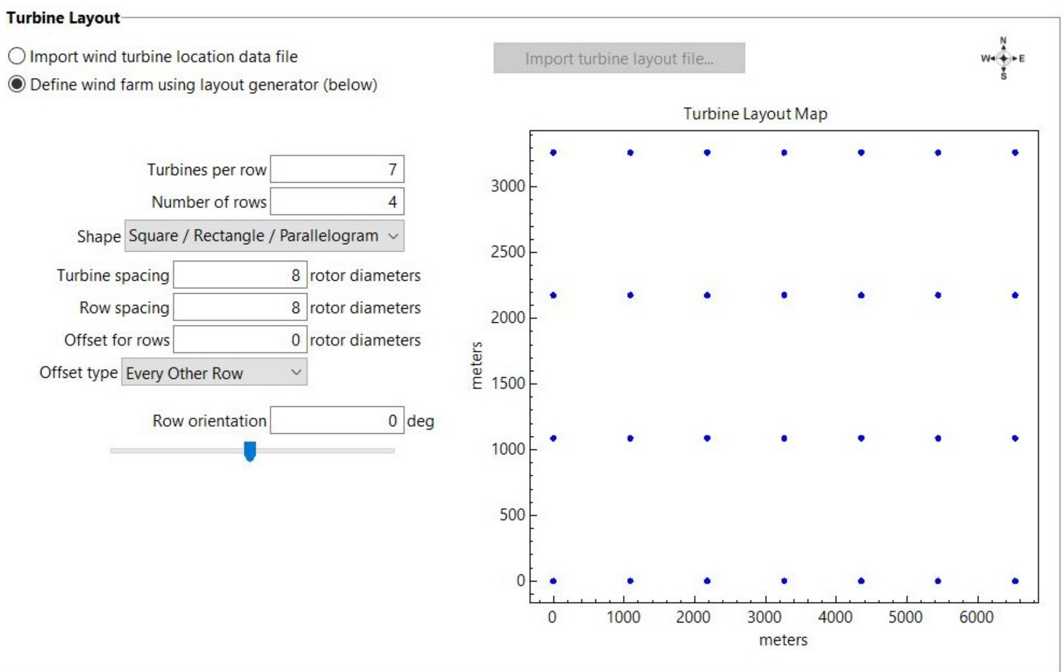

Figure 3: *Turbine Layout in SAM*

3.2 Jobs And Economic Devlopment Impact (JEDI) Model

The JEDI Land Based Wind model is an excel tool developed by NREL that aids developers in the estimation of the economic impacts of the construction and operation of land based wind power projects (Jobs, 2019). After consulting with Dr. Peter Sandborn, a mechanical engineering professor at UMD who teaches Engineering Cost Analysis, we decided that both the JEDI model and SAM are viable tools to aid in our financial analysis. The JEDI model can be adjusted to produce outputs based on location, nameplate capacity (MW), number of projects, turbine size (KW), number of turbines (auto-generated based on nameplate capacity and turbine size), installed project cost ($/kW), operations and maintenance cost ($/kW) and money value (dollar year). The final three inputs have a default option. We used the outputs of the JEDI model (Table 2) to input into SAM to produce a customized cash flow model in SAM.

Table 2: *Project Data Summary from JEDI Model (Jobs, 2019). Project data summary based on user modifications to default*

Project Location	COLORADO	
Year of construction	2020	
Total Project Size - Nameplate Capacity (MW)	100	
Number of Projects (included in total)	1	
Turbine Size (kW)	3450	
Number of Turbines	29	
Installed Project Cost ($/kW)	$ 1,488	($1,454 without taxes)
Annual Direct O&M Cost (%/kW)	$ 38.72	($38.00 without taxes)
Money Value (Dollar Year)	2020	
Installing Project Cost	**$148,793,703**	
Local Spending	$ 30,262,822	
Total Annual Operational Expenses	$ 26,345,053	
Direct Operating and Maintenance Costs	**$ 3,871,609**	
Local Spending	$ 985,611	
Other Annual Costs	$ 22,473,444	
Local Spending	$ 939,349	
Debt and Equity Payments	$ 0	
Property Taxes	$ 567,590	
Land Lease	$ 300, 150	

3.3 Initial Capital Cost

The first step in the cash flow analysis is calculating the initial capital cost. The initial output of the JEDI model is $148,793,703, without any manual adjustments (Table 2). The basic manual inputs were: location: Colorado, nameplate capacity (MW): 100 MW , number of projects: 1 and turbine size (KW): 3450. The JEDI model gives the user the option to manually input equipment costs and Balance of Plant (BOP). The BOP includes materials, labor, development and legal.

3.4 Annual Operating Expenses

The next step for the cash flow analysis is to calculate the operating and maintenance (O&M) costs which will include taxes and depreciation. The total annual operating cost output from the JEDI model is $3,871,609. The tax rates include state, federal and local property taxes. A depreciation schedule, or Modified Accelerated Cost Recovery System (MACRS) is included in the tax rate calculation. The recovery period for the depreciation of wind farms is five years and the five year schedule is included in table A-1 of "How to Depreciate Properly" (Internal, 2020). SAM calculates MACRS automatically in the "Depreciation" section when "5-year MACRS" is selected. The depreciation can be claimed when the property is placed in service. Here we are starting the depreciation at year 1, when O&M costs begin. The IRS will write off these expenses in the early years of the wind farm. Production Tax Credits (PTC) or Investment Tax Credits (ITCs) and incentives are also included. These values were all input into SAM.

3.5 Market Conditions

The Power Purchase Agreement (PPA) has been experiencing a decline since 2010, and this is most evident in the interior region. According to the 2018 Wind Technologies Market Report, the average

PPA in the interior region in 2009 was \$57/MWh, and in 2017, that decreased to \$20/MWh.

Production cost, demand, and supply are all factors contributing to a lower PPA in the interior region. The cost of producing turbines, cost of installation and cost of operation and maintenance have all declined. The interior region has good wind quality, attracting more businesses to the region. The market saturation resulted in steep competition, resulting in lower PPA across the region. Furthermore, technological advances have made the wind turbines more efficient and reliable, bringing down the cost even more.

Colorado has several incentive programs for the renewable energies sector, some of which include: sales tax incentives, rebate programs, loans, and grants. These factors in turn balance out the levelized cost of wind energy (LCOE). Because the interior region has the lowest PPAs, it also has a low average LCOE at \$34MWh. Denver, Fort Collins, Lafayette and Longmont expect to achieve 100% renewable energy use by the year 2030.

By keeping our PPA at 0.03 \$/kWh, we would have a competitive advantage against other wind farms and other electricity providers from other renewable sources.

3.6 Financing Plan

Turbine Transaction price began to experience a decline in 2009 and have continued doing so. Competition among manufacturers, and higher performance in the turbines have contributed to these price declines. Low cost projects are concentrated in the interior region with an average installed project cost of \$1,400/ kW. As the scale of the project increases, especially above a 50 MW range, the installed project cost decreases. The increased quality of the turbines has also contributed a decline in the operations and maintenance cost.

A net capital cost of \$158 million would be needed to construct and operate our 100 MW wind farm. We would have an installed project cost of \$1,488/kW and an operations and management cost of 38.72/kW. The cost of the equipment which includes turbines, blades, transportation, and towers would be \$107 million. The Balance of Plant, which includes material, labor, and development/other cost would be \$37.8 million.

With an internal rate of return at 7.68% expected to be achieved in 20 years, we would have equity of \$100 and debt of \$58 million. We would have an annual interest rate of 7%, with 80% of our debt financed. Federal tax would be 21%/yr, state tax at 7%/yr, and sales tax at 5%/yr . Our annual insurance rate would be 0.5% of our installation cost. Our 20 year depreciation would be 3%, with an annual AC degradation rate of 0.5%.

3.7 Incentives

There are several incentives while operating a wind farm. These incentives began at the federal level. However, these incentives have been decreasing due to the Consolidated Appropriations Act which was passed in 2015. In 2016, wind farms received a 30% tax credit from the federal government, however that rate was decreased to a 24% tax credit in 2017, 18% tax credit in 2018, to a 12% in 2019, and only 6% in 2020 (Wind, 2020). In 2021 it is projected to no longer give a tax credit to wind farms. This act was passed to favor solar energy.

Table 3: *Chart of Federal Tax Credits beginning from 2016*

Technology	12/31/16	12/31/17	12/31/18	12/31/19	12/31/20	12/31/21	12/31/22	12/31/23
Wind Farm	30%	24%	18%	12%	6%	0%	0%	0%

With our wind farm located in Logan County, Colorado we will be discussing the tax credits at the state level. According to the Department of Revenue, the state income tax for Colorado is 4.63%. This is important to the amount of money wind farms can accumulate to keep the company afloat. The Production Tax Credit (PTC) provides a tax credit of 1¢–2¢ per kilowatt-hour for the first 10 years of electricity generation for utility-scale wind. The alternative Investment Tax Credit (ITC) provides a credit for 12%–30% of investment costs at the start of the project and is especially significant for the offshore and distributed wind sectors because such projects are more capital-intensive and benefit from the up-front tax benefits. In December 2019, Congress passed extensions of the PTC and ITC.

Table 4: *Dates and allowable tax credit in Colorado (DSIRE, 2018)*

If construction begins	**The Estimated allowable tax credit is:**
After Dec. 31, 2016	1.9 cents/kWh
After Dec. 31, 2017	1.8 cents/kWh
After Dec. 31, 2018	1.4 cents/kWh
After Dec. 31, 2019	1 cent/kWh
After Dec. 31, 2020	1.5 cents/kWh

A few assumptions were made in SAM. The default values in SAM for state income tax were kept because they were determined to be reasonable values by our financial consultant Dr. Sandborn.

4 Triple Bottom Line Opportunities

An important facet of renewable energy projects is to ensure that sustainability is at the forefront of design and planning. Sustainability is defined by the triple bottom line: good for people, planet and profit (University, 2020). Project developers who design sustainably seek to strike a balance between the environmental, social and economic realms. A wind power project that produces clean energy, but is ultimately harmful to the local community and ecosystems cannot be considered truly sustainable.

Social aspects of sustainability can include communicating with and providing resources to the local community. There are colleges in northeast Colorado that offer wind energy training courses and degrees. Our company could work with these colleges with internships and jobs for the local students. Nearby colleges have programs like the Colorado Wind Application Center at Colorado State University that offer wind energy education. These programs can be expanded with guided tours through our wind farm location and a walk through design process. These initiatives are crucial for improving local wind energy education and improving local education in wind energy.

This, combined with outreach to the general public, can improve public opinion of wind energy to make the implementation of wind farms easier in the future.

An environmental factor of sustainability is turbine layout. Turbine layout is the most important factor when conserving agricultural land. Layouts that follow a linear design allow for the landowners to utilize the land with minimal impact on farming patterns and other intensive land uses. Our wind farm layout follows this approach. Since the turbines are placed on the edges of farms, the impact on row cropping will be minimized and the disturbance to the landowners is minimized for both turbine construction and maintenance. These considerations also minimize the cost of buying land from the farmers and the loss of crop land to farmers.

Logan county's prairie landscape is outside the range of most nesting birds and larger game due to the lack of forested area. Most of the recreational hunting and animal observing activities occur near the South Platte River, far from the proposed turbine construction site. The proposed turbine project poses minimal harm to ground based wildlife. Bird and bats that roost in trees pose the greatest fatality risk to wind turbines (AWWI, 2019). There is minimal forested area near the proposed site, therefore reducing the risk of turbine-induced bat and bird fatalities. To monitor the impact on flying animals, sensors can be installed on the turbines to count bird strikes as well as lights that deter flying wildlife from coming too close (AWWI, 2019).

The lifecycle and termination of the turbines must be considered in our sustainability analysis. Vestas has an initiative that will make their turbines 100% recyclable by 2040 however, in 2030 vestas believes to be near 85% recyclable (Richard, 2020). Vestas has convenient locations for their manufacturing sites relatively near our proposed site. The transport of the manufactured parts will save money on transport and provide a receptacle for the end of the life of the turbine materials. Our blades and turbine parts can be transported back to the Vestas factories, recycled, and reused after the lifetime of the materials, providing an environmentally sound decommissioning of the turbines.

5 Detailed Design & Conclusion

The location for our wind farm is located in Logan County in Northeastern Colorado. Most of Logan county's vegetation consists of 1-2 foot grasses that dominate the prairie/plain landscape. The native plants that are adapted to harsh winds, drought, and direct sunlight will be able to protect the exposed soil from wind and water erosion, protecting the bases of the planned turbines from other exposures. Logan county's abundance of surface vegetation is an asset that aids in the implementation of our wind turbines.

The turbines are placed in rows with at least 8 rotor diameters between each turbine and row. The site access roads will be constructed near the turbines and then connect to route 113 and then route 138. The transmission will go to 10000 CR 6, which is the nearest electrical substation approximately 49 miles away. The land lease costs are included in our financial models and will primarily be with individual landowners in the Logan County area.

The key parameters of the financial analysis are summarized in the detailed outputs of the SAM simulation is shown in Table 5.

Table 5: *SAM Simulation Outputs (data from: System, 2018)*

Metric	**Value**
Annual Energy (year 1)	360,944,704 kWh
Capacity Factor (year 1)	42.70%
p90 Energy (year 1)	305,109,952.0 kWh
PPa price (year 1)	4.00 ¢/ kWh
PPA price escalation	1.00 %/year
Levelized PPA price (nominal)	4.28 ¢/kWh
Levelized PPA price (real)	3.51 ¢/kWh
Levelized COE (nominal)	4.48 ¢/kWh
Levelized COE (real)	3.68 ¢/kWh
Net present value	-6345970
Internal rate of return (IRR)	7.68 %
Year IRR is achieved	20
IRR at end of project	7.68%
Net capital cost	$ 158,881,872
Equity	$ 100,135,640
Size of debt	$ 58,746,240

The use of the JEDI model and SAM aided our team in determining the cost of energy and cash flow analysis of the 20 year life cycle of the wind farm which can be seen in Figures 4, 5 and 6. Figure 4 describes the 20 year cash flow analysis including Annual Costs, Federal PTC Income, PPA Revenue and Federal Taxable Income.

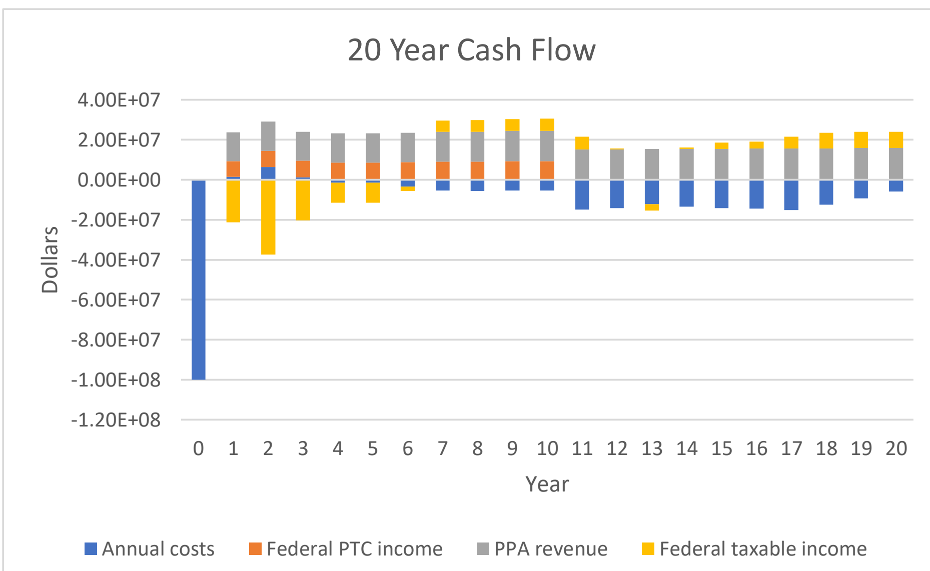

Figure 4: *20 year cash flow (data from: System, 2018)*

The After-tax maximum Internal Rate of Return (IRR) % curve in Figure 5 shows what IRR is realized in a particular year. The IRR is initially negative until year 7 (shown in the plot as zero), which indicates that there is no return during this time. Although the plot is zero, this is actually negative before year 7. The breakpoint occurs at year 7, after which it begins to increase in value. The percentage increases significantly in year 10, because of the Federal PTC. The IRR continues in an upward trend but slows down after year 10, which shows that the cash flow is still slightly ahead of the breakeven point.

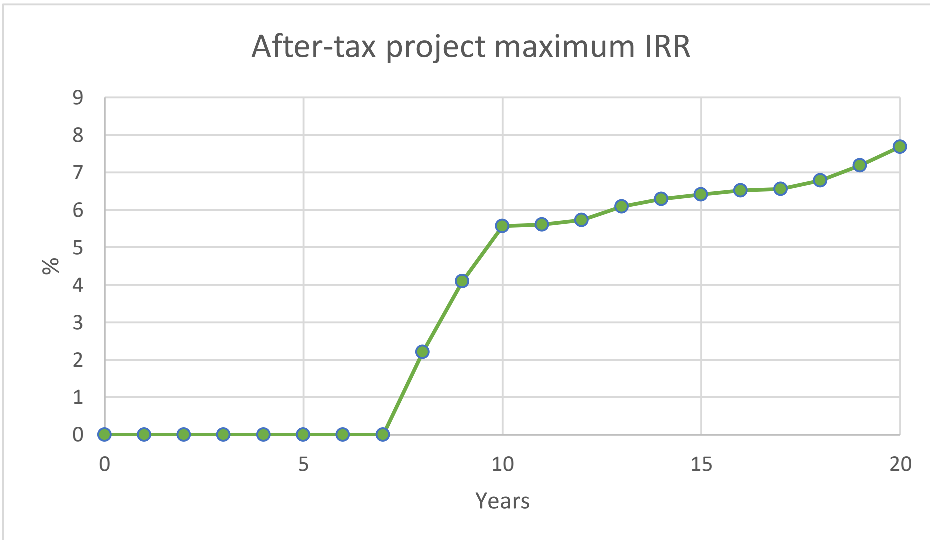

Figure 5: *After-tax maximum IRR (data from: System, 2018)*

Figure 6 shows a Total after tax returns cash flow, which gives a broad overview of the 20 year financial analysis of the wind farm.

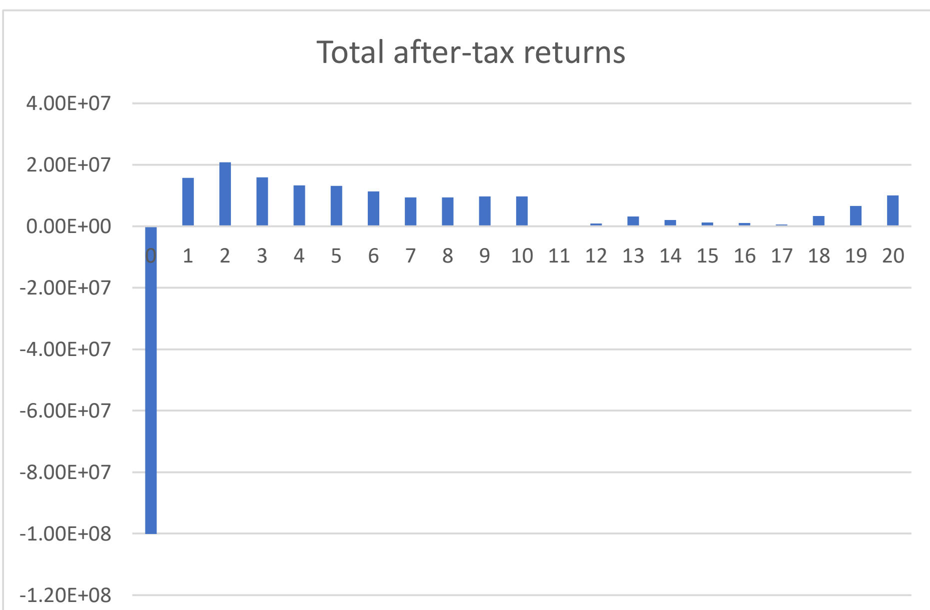

Figure 6: *Total after-tax returns (data from: System, 2018)*

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