The Pennsylvania State University
Wind Energy Club
Project Development Team Report

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1. Executive Summary

The Penn State Wind Energy Team was tasked with developing a 100 MW wind farm in Eastern Colorado. Upon analysis of the region's wind resource, the availability of transmission capacity and siting guidelines in Eastern Colorado, the team has developed a plan for siting a 99.9-MW wind farm in Prowers County, just south of Lamar, CO. The topography of Prowers County is relatively flat as it resides in the Eastern Plains of Colorado and the vegetation consists of mostly range-lands with little greenery. The Wind Farm was sited and optimized using OpenWind and the net annual energy production was determined. Adjustments were made to the nearly final design layout to reduce inter-farm transmission line length and therefore cost. The wind farm consists of 37, 2.7 MW IEC Class III A turbines. A Levelized Cost of Energy (LCOE), Power Purchase Agreement Price (PPA), and cash flow analysis were conducted using System Advisor Model (SAM). The initial capital expenditures, operating and maintenance costs were analyzed using the Job and Economic Development Impact Model (JEDI).

The final turbine layout had an annual energy production of 398.8 GWh/yr, with the initial capital expenditure summing to $1,454/kW. The Prowers County site had an operation and maintenance cost of $38/kW. The LCOE and PPA are $26.4/MWh and $28.7/MWh, respectively. The Prowers wind site plans on selling its energy to the Tri State Generation and Transmission Association (Tri-State) and their 43 members to help them meet their goal to provide 50% of their energy from renewable energy resources. The project yields a 9.30% IRR for its investors. Additionally, Prowers County Master Plan states the desire to attract a wind developer to develop a wind project in the Southern portion of the county, making this proposed wind energy in Prowers county quite pertinent to local goals.

2. Site Description and Energy Estimation

2.1 Site Selection and Siting Challenges

The team began by setting out to find an ideal region of the state to build a wind project based on the available wind resource and transmission infrastructure. At first, five counties were considered to be a potential location for the wind project based on these parameters. Those counties were Sedgwick, Philips, Kit Carson, Prowers, and Baca. After looking at average wind speeds, transmission availability, and existing wind farms, through Wind Prospector[1], Google Earth[2] and ArcGIS[3], Prowers was selected for the proposed wind project location.

Prowers County's topography is relatively flat as it resides in the Eastern Plains of Colorado. There is farmland in the area with a few rural residential houses and range-lands filled mostly with short prairie grasses, blue grama, buffalo grass, alkali sacaton, galleta, saltgrass, and sand dropseed.[4]

When determining the specific site, transmission lines were assessed to determine which offered ease of access and could handle the capacity of a 100 MW wind farm. Three transmission lines were considered in Prowers County, a 115 kV line owned by the Tri State Generation and Transmission Association, a 69 kV line owned by Southeast Colorado Power Association, and a 230 kV that was built for Colorado Greens and Twin Buttes wind farms. The 69 kV line was dismissed because it doesn't have a high enough voltage to handle a wind project of this size. To choose between the remaining two transmission lines, the wind resource was investigated further as well as proximity of existing projects. The area surrounding the 115 kV line indicated a better wind resource within close proximity compared to site availability near the 230 kV line. This led to the decision of choosing the site next to the 115 kV line. This location is around 19 miles south-east of the town of Lamar in Prowers County and can be seen in Fig. 1 along with the closest wind project, Colorado Greens. The project would likely tie into the transmission line via a three-ring bus breaker.

Some of the challenges that the site faced was that the location had many dry riverbeds, which limited some of the locations in which a turbine could be built. Also, Prowers County's only policy regarding wind energy, for the city of Lamar, was for projects < 5 MW in scale. No other laws or regulations regarding large scale wind farms were identified. Projects are considered on a case by case basis. The city of Lamar only had a policy regarding smaller wind projects that don't surpass 5 MW. This made it difficult to gather any information about permitting and regulations in the area, thus standard practices were applied.

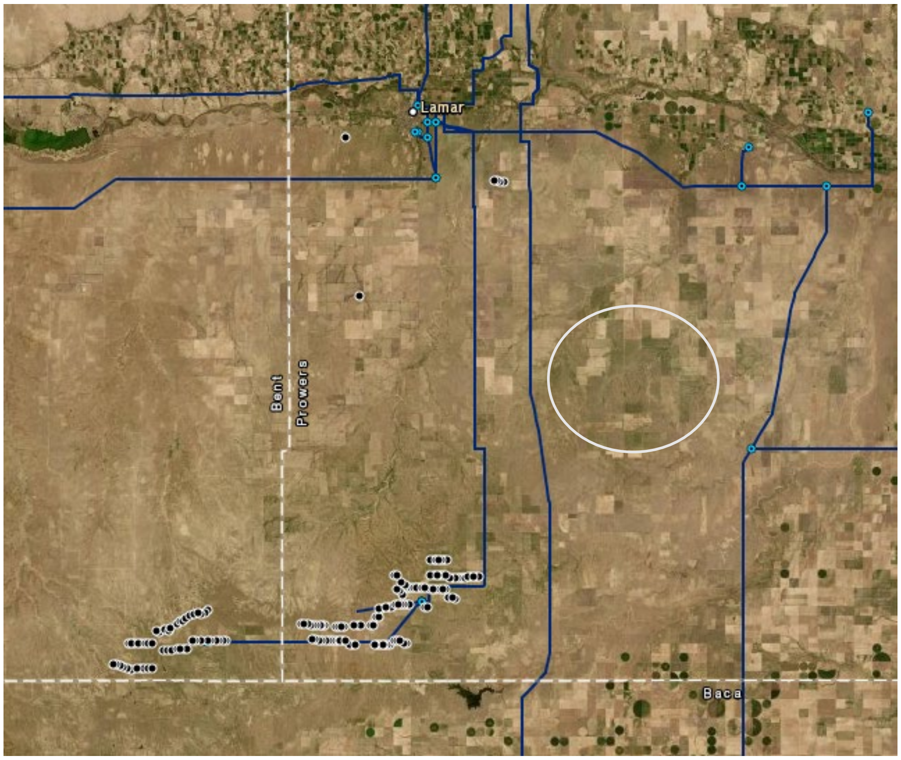

Figure 1: Satellite image of Prowers County with a circle representing the site location and blue lines representing transmission lines.[3]

2.2 Resource Assessment

Based on results from Windographer[5], a wind analysis software, using data from the Wind Toolkit[6,7] for years 2011 and 2012, the Prowers site experiences an average annual wind speed of 8.11 m/s at 100 m.[5,8] As seen in Fig. 2, the predominant wind directions are from the south as well as the west, while Fig. 3 shows that most of the energy is in the wind is coming from the south. This plays a major role in determining turbine layout because more wake losses will occur if turbines are placed in a north-south orientation. Fig. 4 shows that wind speeds are higher during night time compared to day time and since peak energy demand in Colorado is from 5 – 9 pm from October to April, more energy is being produced during peak hours and therefore more profit is made.[9] During the rest of the year, the peak times are from 2 – 7 pm which is not near the peak energy generation but more profit is being produced compared to from 10 am – 2 pm.[9]

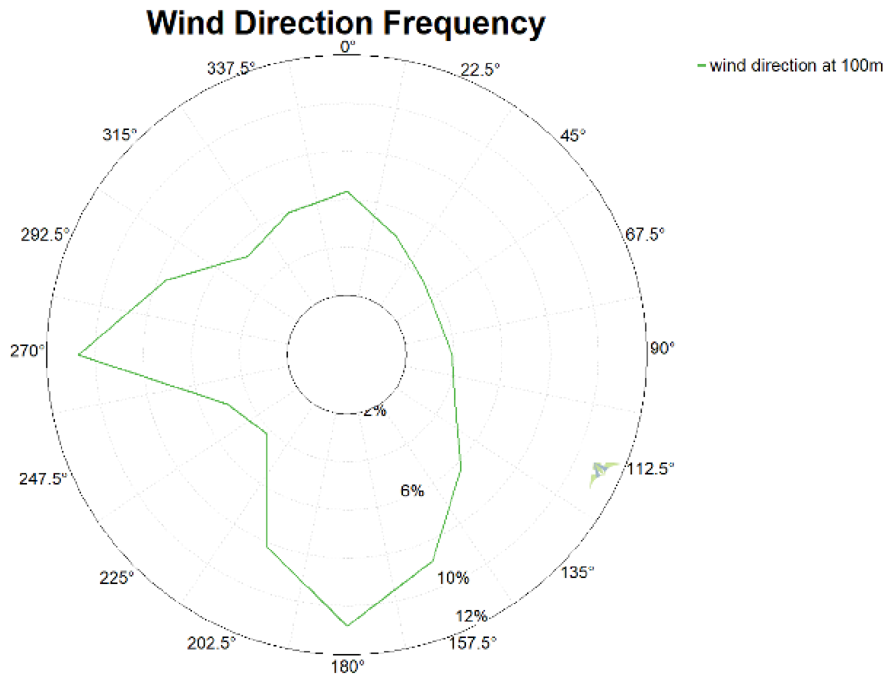

Figure 2: Rose Chart representing the wind direction frequency.[5]

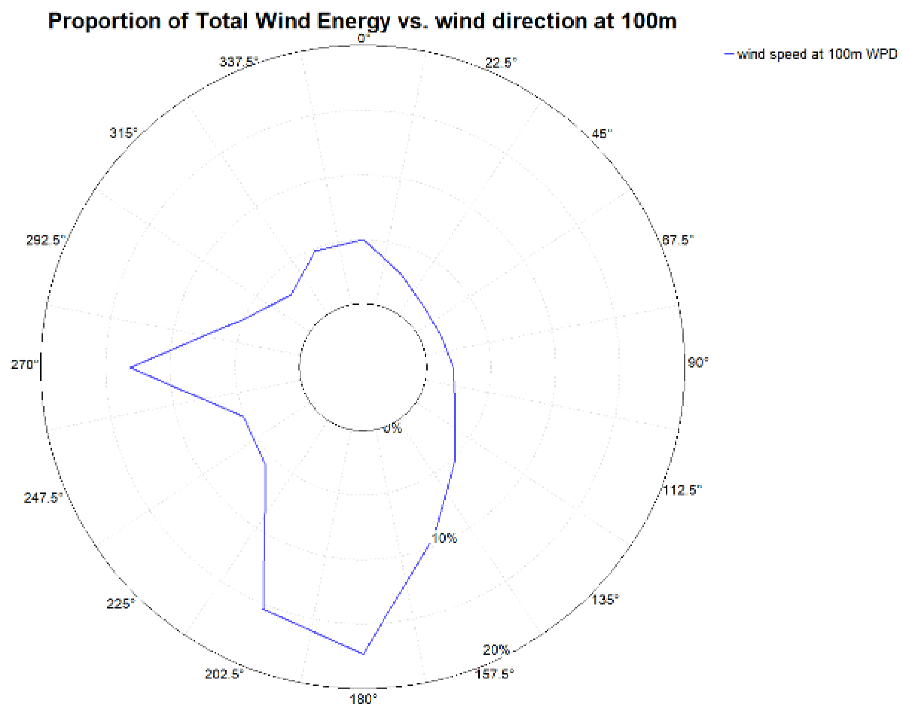

Figure 3: Rose Chart Representing the Proportion of Total Wind Energy vs. Wind Direction.[5]

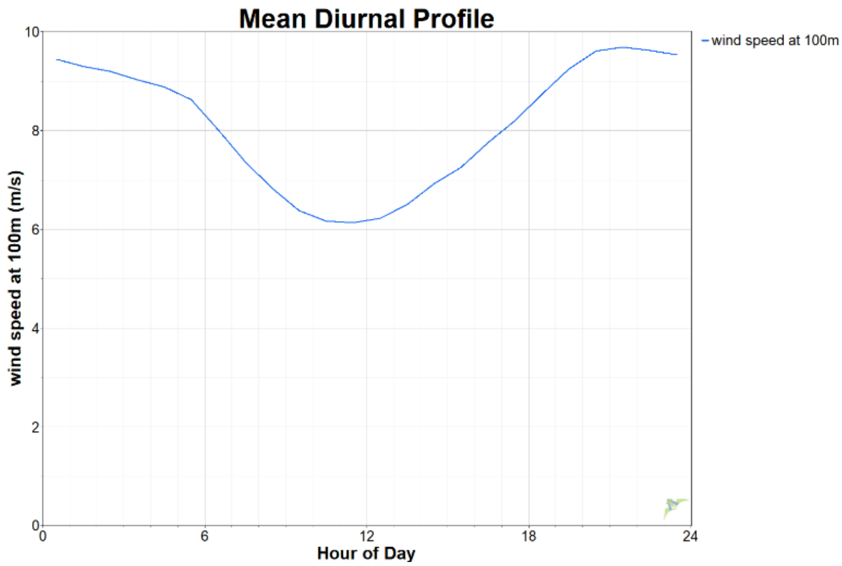

Figure 4: Wind Speeds vs Hours of Day for the Wind Farm Site in Prowers County

2.3 Wind Farm Layout

2.3.1 OpenWind

The optimum layout of each turbine was identified using OpenWind[10] with 50 m WRG wind resource data purchased from UL Renewables for the location shown in Fig. 1. OpenWind is an open source software application used to model wind farms. It allows users to design wind farms and calculate energy production, turbine wake losses, and turbine suitability. In OpenWind, a polygon was created that represents the area in which turbines are allowed to be placed. This allows for control over where the turbines can be placed.

The areas that were considered when placing turbines were houses, waterways, roads, trees, and existing wind farms. A representative from the wind project development industry shared with the team the typical industry standards setbacks for avoiding those areas. Houses had a distance of four rotor diameters that turbines cannot be built within. This is to reduce noise impacts and minimize any shadow flickering that may be present in those houses when the sun passes through the plane of the turbines as seen by the homes. Waterways and dry riverbeds had a distance of at least 1.1 times the hub height where a turbine cannot be built. This is in case a turbine falls which allows the turbine to be recovered with ease and to avoid blocking the waterway. Roads had a distance of at least 1.1 times the height where a turbine cannot be built. This is so that the turbine doesn't block access to major roads and cause traffic problems if it falls. Trees had the biggest radius which is five times the hub height. This is to avoid the potential harm to any protected species that have been known to reside in trees in Colorado, such as Golden and Bald Eagles. Even if the tree isn't currently inhabited by an Eagle, one can move to it at a later date.

To reduce wake losses, a distance of 5 miles was set between this farm and any existing or in development farms in the area. These parameters were created in Google Earth then imported to OpenWind for the polygon creation. Fig. 5 shows the parameters on Google Earth while Fig. 6 shows the polygon that has been adapted to those parameters. More turbines are currently being built for the Colorado Greens wind farm which are located 5 miles south-west of this site as seen in Fig. 7. The turbines in the site must have sufficient space between them to reduce the wake effect on each other. A distance of five rotor diameters was set for turbines that are upwind in the predominant wind direction (South) from each other and a distance of three rotor diameters was set for the transverse direction. Fig. 8 shows the current layout of the

37 wind turbines in the site. The layout follows a random design rather than a straight line to reduce wake effects from upwind turbines in the farm.

The overall project layout will have 30 miles of underground transmission lines and 6 miles of road built. Fig. 9 shows the transmission line layout that has been optimized through OpenWind. This process required creating an access point to the grid and a substation. The process moves turbines from the best energy capture location to a new site if the price of building the transmission lines exceeds the profit that the wind turbine would make at that location. This optimization process moved the furthest most turbines closer and reduced the length of transmission lines from 33 miles in the previous design to 30 miles.

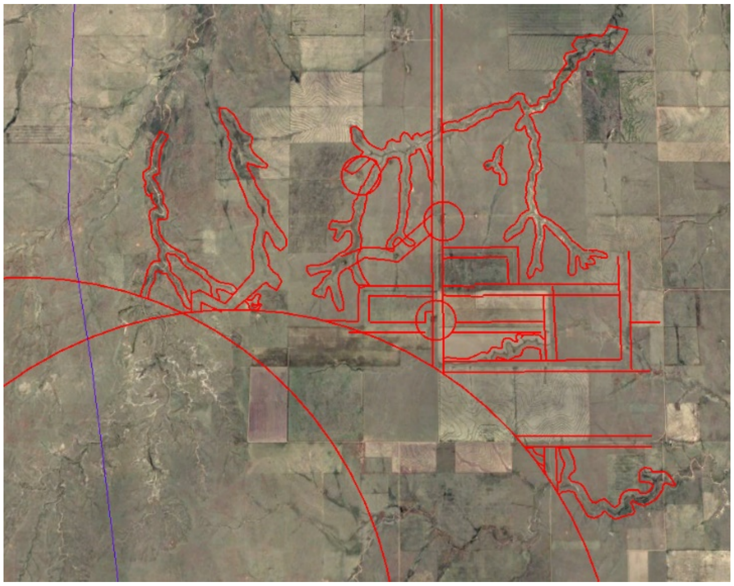

Figure 5: Wind Farm Site Parameters on satellite picture from Google Earth.[11]

Figure 6: Wind Farm Site Parameters in a Polygon on OpenWind.

Figure 7: Satellite Overview of New Wind Turbines in development in Prowers County.[11]

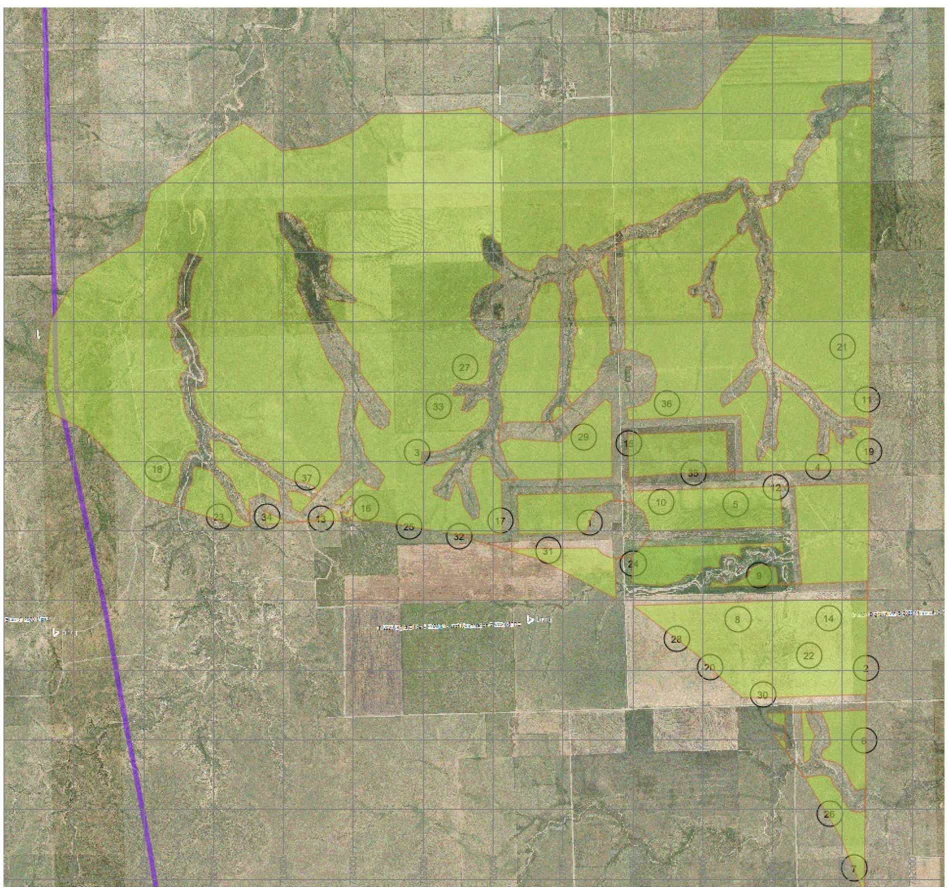

Figure 8: Wind Farm Site Parameters in a Polygon on OpenWind including Turbine layout inside the Polygon[10]

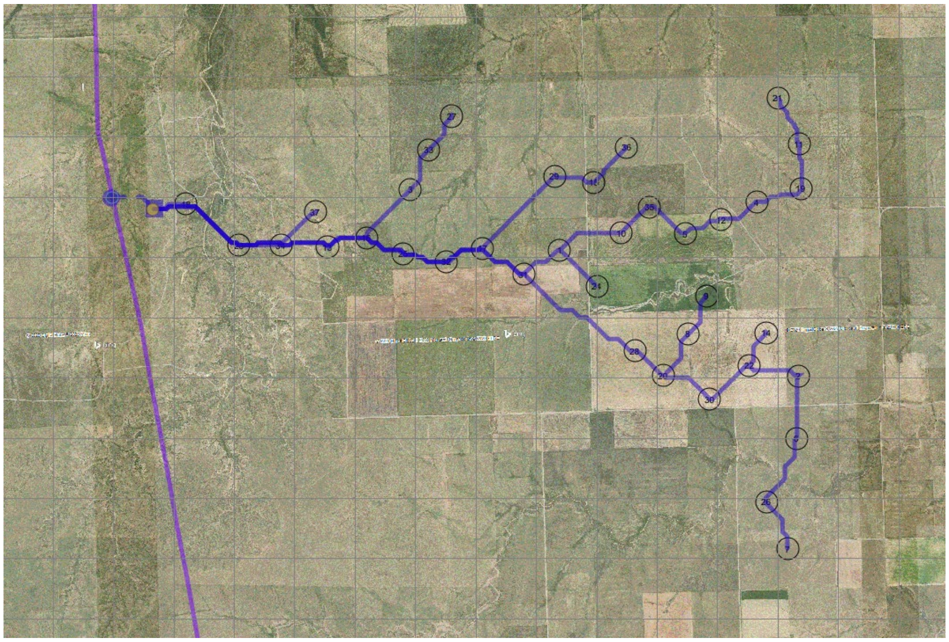

Figure 9: Grid Connection, Substation, and transmission line layout for the wind farm on OpenWind[10]

2.3.2 Community and Environmental Impact Mitigation

Due to the terrain of Prowers County, the site is relatively easy to access and does not require significant landscape alterations to transport and build the turbines unlike other wind farms that are located in hilly terrain or forested areas. Several of the setbacks for homes, waterways, dry riverbeds, roads and existing wind farms were described in Section 2.3.1 of this report while additional environmental considerations are discussed below.

Trees are rare in the area but are important since they are considered suitable homes for birds and raptors which may be protected species. The site didn't show any trees via observation through Google Earth. If a tree were found on a site visit, then the layout would be changed so that no turbine is located within 500 m. This radius is set as a precaution to avoid harm to any protected species inhabiting the trees.

Prowers County is one of the few counties that contains Lesser Prairie Chickens which have experienced significant decline in population and habitat over the decades.[12] Even though it is a ground dwelling bird, some concern has risen regarding wind turbines affecting their behavior.[12] If Prairie Chickens were to be close to the site, then with the help of the Natural Resources Conservation Service (NRCS) in Colorado, the Lesser Prairie Chicken initiative (LPCI), which offers conservation programs to farmers through the NRCS, can be adapted to provide solutions for any problems that could endanger the population of the Prairie Chicken.[12]

Bats are also known to live all across Colorado and therefore precaution must be taken when building a wind farm. Table 1 shows some of the bat species that might live in Prowers County with how likely their presence is.[13] Because of the abundance of bats, a study must be conducted on the site to assess local bat species presence and activity and how building a wind farm might affect it. Some of the most common ways to assess bat presence is using mist nets and acoustic detectors that detect and record calls of echolocating bats.[14] If it turns out that building a wind farm will affect bat population during a particular season and specific wind conditions, then solutions can be implemented that can reduce bat fatalities. Operational minimization is currently the most effective method of reducing bat fatalities at wind turbines.[15] The main strategy is to raise the cut-in wind speeds for the turbines by 1.5 to 3 m/s.[15] This strategy limits blade rotation which is the primary cause of bat deaths during high risk periods such as low wind and fall migration periods.[15] This strategy leads to 1-3% losses in annual power production but can lead to the reduction of bat fatalities by 93%.[15] Another way to reduce bat fatalities is by deterring them from the wind farm using Ultrasonic Acoustic Deterrents (UADs). UADs are devices that emit a loud high frequency noise that deter bats from the location by jamming their echolocation. It decreases fatalities while keeping the wind farm at normal operations.[16] UADs are still experimental technology that shows great potential and once it is fully developed, it will eliminate any risk towards bat population without the loss of production.

Table 1: Bat Species and their Occurrence Likelihood in Prowers County[13]

Common Name	Scientific Name	Occurrence	Abundance
Big Brown Bat	*Eptesicus fuscus*	Likely to occur	Unknown
Big Free-tailed Bat	*Nyctinomops macrotis*	Likely to occur	Unknown
Hoary Bat	*Lasiurus cinereus*	Known to occur	Common
Red Bat	*Lasiurus borealis*	Known to occur	Rare
Silver-haired Bat	*Lasionycteris noctivagans*	Likely to occur	Unknown

2.3.3 Turbine Selection

Turbine selection included an analysis of best overall performance on the project site while also meeting the IEC 61400 – 1[17] standards. The IEC 61400-1 specifies classifications for wind turbines based on meeting a variety of wind load scenarios for different wind resource conditions such as mean wind speed, air density, turbulence intensity, flow inclination angle, and extreme wind conditions. When a turbine is selected that is not suitable for the site, premature wear on the turbine can happen or less energy may be produced when a turbine with a high capacity is used in a low wind area.[18] The characteristics for each IEC turbine class were compared to the wind data collected for each proposed turbine site at the Prowers wind site (provided via OpenWind' s Suitability analysis). The three main determinants for turbine selection are V_{ref}, the 50-year extreme wind speed averaged over 10 minutes, V_{avg}, the annual mean wind speed at the hub height, and V_{e50}, the 50-year extreme gusts averaged over 3 seconds. The Prowers site matches the characteristics of a Class III A turbine in all categories but V_{avg}, which is slightly higher than the IEC standard (0.1 m/s above the standard). Thus, a Class III turbine was chosen due to meeting the specifications of the Prowers County site. Due to turbulence, density and inflow angle at the site being lower than the IIIA standard, this slightly higher average wind speed is not concerning. Table 2 provides an overview of the site analysis for several IEC turbine classes. With all other parameters well under the load thresholds of the turbine, the Class III A turbine will provide the greatest capacity factor and energy output for the site.

The turbine used for the modeling in OpenWind was the Alstom ECO 122 Class IIIA turbine. This turbine has a 122 m rotor diameter, a 2.7 MW rated power and a 98 m hub height was used. Even though the Alstom Turbine was chosen as the optimal turbine in the OpenWind model, these Alstom turbines are no longer produced due to the company being purchased by GE in 2015. Therefore, the turbine parameters for the Alstom turbine were put into System Advisor Model (SAM),[8] a techno-economic software tool which was used for the financial analysis of this project. This was done for modeling consistency in the financial analysis, as the Alstom ECO 122 Class IIIA turbine was not in the SAM turbine database and there are also only a few turbine models available in OpenWind. Analyzing current turbines on the market, a similar turbine would be the GE 2.75 MW, 120 m rotor diameter model, as it meets the site's needs. The turbine parameters used to define the Alstom turbine in SAM are displayed in Table 3.

Table 2: Turbine Selection Based on Site Characteristics[6]				
Site Characteristics	**IEC Turbine Classes**			**Site Values**
Fatigue-Related Characteristics	I A Standard	II A Standard	III A Standard	Prowers Site
Flow Inclination Angle (°)	*Below* 8	*Below* 8	*Below* 8	<0.32
Annual Average Air Density (kg/m^3)	*Below* 1.225	*Below* 1.225	*Below* 1.225	1.079
Weibull shape factor	*Above* 2	*Above* 2	*Above* 2	2.1-2.2
I_{15} (%)	*Below* 16	*Below* 16	*Below* 16	10.1-10.5
V_{ref} (m/s)	*Below* 50	*Below* 42.5	*Below* 37.5	31.8-32.9
V_{avg} (m/s)	*Below* 10	*Below* 8.5	*Below* 7.5	7.4-7.8
V_{e50} (m/s)	*Below* 70	*Below* 59.5	*Below* 52.5	44.5-46.2

Table 3: Turbine Design Specifications for SAM					
Turbine Model	Rated Output (kW)	Rotor Diameter (m)	Maximum Tip Speed (m/s)	Cut-in Wind Speed (m/s)	Cut-out Wind Speed (m/s)
Alstom ECO 122 Class 3A	2700	122	79	3	25

2.4 Net Annual Energy Production

The net annual energy production was determined using OpenWind and then matched in SAM. The use of OpenWind is described in more detail in section 2.3.1 OpenWind. The net annual energy production value generated by OpenWind is considered to be more precise as the turbine layout is optimized for the site with wake flow analysis included, whereas SAM's energy modeling is does not take into consideration specific site details. The net annual energy produced by the project, as determined by OpenWind came out to be 398.8 GWh/yr.

3. Financial Analysis

3.1 Capital Expenditures

The total installed cost was determined using the Job and Economic Development Impact Model (JEDI) developed by NREL as well as the 2018 Wind Technologies Market Report.[19,20] The JEDI model is an input-output model that is spreadsheet based using Microsoft Excel. The model using specific data based on user inputs such as location, resources available in the area, the operating costs, and financing plan. Construction is assumed to be completed by the end of 2020 and the size of the wind project is 99.9 MW, which is inputted into JEDI to properly assess the costs and economic impacts. An analysis based on an input-output model is dependent on the assumptions made by the model such as projected inflation, the projected salary of workers, and cost of equipment.[19] The values used in the JEDI model are considered to be reasonable values for Prowers County Colorado. The values forecasted are not assumed to be precise, but rather be an approximate estimate of the overall impact on the community.[19] A summary of Capital Expenditures from the JEDI model is shown in Table 4. These costs do not include sales tax due to the Sales and Use Tax Exemption for Renewable Energy Equipment in Colorado.[21] The installed project cost for the Prowers site was determined to be $1,454/kW. According the 2018 Wind Technologies Report, the interior region of the United States has the lowest installed costs in the country, with an average of $1,400/kW.[20] This is due to the interior region having a flat terrain that hosts larger capacity projects on average, so a cost of $1454/kW is consistent.

Table 4: Capital Expenditures from the JEDI Model	
Equipment:	
Turbines Cost	$64,202,872
Blades Cost	$15,030,773
Towers Cost	$16,641,213
Transportation Cost	$11,487,805
Balance of Plant:	
Construction Cost	$15,513,905
Transformer Cost	$1,754,944
Electrical Cost	$1,849,830
HV Line Extension	$3,379,022
Labor:	
Foundation Cost	$1,256,883
Erection Cost	$1,423,598
Electrical Cost	$2,074,611
Management Cost	$1,076,520
Misc.	$5,515,879
Development/ Other:	
HV Sub./ Interconnection	$2,843,660
Legal Services:	$1,160,677
Total Net Capital Expenditures Cost:	$145,212,192

3.2 Operational Costs

The Operating Costs were also generated using the JEDI model, the input-output model created by NREL, described more in 3.1 Capital Expenditures. The Operation and Maintenance (O&M) costs are broken down by Labor, and Material and Services costs in Table 5. Data on specific O&M costs are not widely available, however, data on cumulative O&M costs were collected by Berkeley Lab and displayed in the 2018 Wind Technologies Market Report.[20] The O&M costs are highly dependent on project age and data shows that projects installed in the last decade experience lower O&M costs, with an average of $29/kW.[20] The Prowers County site is assumed to have an O&M cost of $38/kW based on the JEDI Model analysis shown in Table 5.

Table 5 Operational Costs from the JEDI Model:	
Labor:	
Field Salaries	$283,819
Administration	$45,411
Management	$113,658
Materials and Services:	
Vehicle Costs	$95,795
Misc. Services	$37,360
Fees, Permits, Licenses	$18,680
Insurance	$718,464
Fuel (vehicle) Costs	$37,360
Spare Parts Inventory	$2,128,091
Tools/ Misc.	$317,561
Payments:	
Debt Payment	$16,008,847
Equity Payment	$5,140,052
Property Taxes	$567,022
Land Lease	$299,700
Total Operating and Maintenance Costs:	$25,811,820

3.3 Financial Analysis

A financial analysis for the Prowers wind site was modeled using SAM, described previously in section 2.4 Net Energy Production. The SAM model was run to model the wind farm power output under the parameters of a power purchase agreement (PPA) with Debt. The PPA setting assumes the project is grid-connected and the wind farm earns revenue through the generated sales of electricity, where the project is often owned in a leaseback arrangement.

The U.S. Congress extended the Production Tax Credit (PTC) and Alternative Investment Tax Credit (ITC) for all wind energy projects that begin construction before December 31, 2020.[22,23] The PTC incentive provides 1.5 ¢/kWh (60% of the full credit value of 2.5 ¢/kWh) for the initial 10 years of electricity generation of the project for utility scale wind farms for projects beginning (or achieving safe harbor) in the year 2020.[23] The ITC incentive provides a credit for 12-30% of investment costs at the start of the wind project depending on when it is initiated; however, wind projects cannot receive both the PTC and ITC credit.[22] The Prowers wind farm plans to use turbines purchased by the project developer in the financial year of 2016. Using turbines purchased in 2016 allows for the project to be eligible for using the full 2016 PTC rate of $0.025/kWh (adjusted for inflation) for 10 years escalated at 2.50%/year.[23,24] Along with the federal tax credit, wind projects are allowed to apply accelerated depreciation through the Modified Accelerated Cost-Recovery System (MACRS). A 5-year MACRS was used in the SAM model for this project. With both the federal PTC incentive of $0.025/kWh and the MACRS combined, 50% of the project's initial costs can be seen through tax savings depending on project performance.[24]

Additionally, the state of Colorado has Enterprise Zone Tax Credits to incentive business to locate in economically distressed areas by providing a New Employee Tax Credit of $1,100 per new employee.[25] Furthermore, Due to Prowers County being denoted as a county with EZ Enhanced Rural status, an additional $2,000 credit is given for every new employee.[25] If the employees receive health insurance from the Project Developer, another $1,000 per employee is distributed.[25] Therefore, for every new employee the Prowers wind farm creates, there will be an $4,100 flat rate tax credit for the first two years of the project.[25] The JEDI model provides an estimation on jobs created in Prowers County. The JEDI model predicts 322 jobs will be made during construction and 22 jobs will be generated during operation, for a total of 344 jobs. With 22 new long-term employees, the Prowers wind farm would receive at least a $90,200 tax credit for the first two years.[25]

The Debt Service Coverage Ratio (DSCR) was inputted at 1.3, to reduce risks and ensure the project can repay principal and interest payments on debt. The share of equity is spilt 98% and 2%, by the tax investor and developer, respectively. The tax equity investor pre-determined internal return on investment is 9% and the interest rate on debt was set as 4%. These values were suggested by industry as typical for current renewable energy projects.

3.4 Cost of Energy (Cost/kWh)

Via the SAM analysis described in the previous sections, using the defined financial inputs and the energy production determined by OpenWind, a Levelized Cost of Energy (LCOE) as well as levelized Power Purchase Agreement (PPA) price can be determined along with a cash flow analysis for the project. The real LCOE comes out to $26.4/MWh while the PPA price result is $28.7/MWh. These are considered to be reasonable estimates for the Prowers Wind Project as LCOE prices were the lowest in the interior region of the U.S. with an average of $34/MWh in 2018 and can be as low as $27/MWh.[10] These values are further compared to regional values in section 3.4 Market Opportunities and Constraints.

The after-tax cash flow chart for the developer, investor, and total project are shown in Fig. 10. The Net Present Value (NPV) for the developer and investor are $12,088,355 and $805,650, respectively. Meanwhile, Fig. 11 shows the Cumulative After-Tax Cash flow for the project for the investor and the developer, showing it breaks even around year 6 of the project.

Figure 10: After Tax Cash Flow

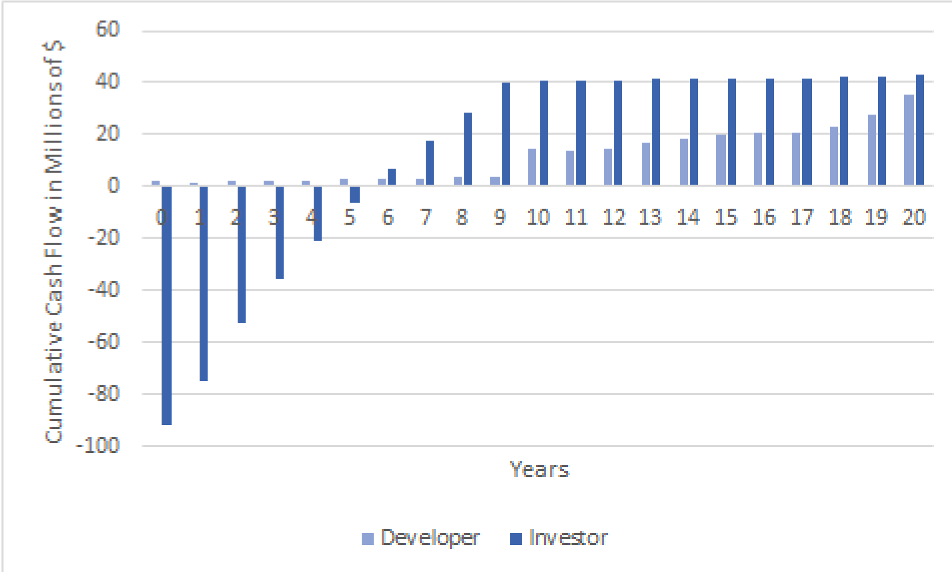

Figure 11: Cumulative After-Tax Cash Flow for Developer and Investor

3.5 Market Opportunities and Constraints

Having favorable market conditions is crucial for successful wind energy project development. According to Lazard in 2018, wind energy had a competitive unsubsidized LCOE to other energy sources, as it ranged between 29 to 56 $/ MWh.[26] Wind PPA prices have been at historical lows, according to the 2018 Wind Technologies Report, especially in the interior region of the United States. PPA contracts made in the fiscal year 2017-2018 averaged to be below $20/MWh.[10] However, the PPA agreements for the interior can range up to $40/MWh.[10] With the proposed project resulting in a PPA price of $28.7/MWh, this project should be quite marketable in the interior region.

The Prowers Project is connected to a 115 kV line owned by the Tri State Generation and Transmission Association (Tri-State). Tri-State is a not-for-profit cooperative power supplier that includes 43 electric distribution and public power districts in four states.[27] Tri-State has plans to provide 50% of the energy consumed by members to come from renewable energy resources by 2024.[27] Tri-State is currently adding two utility-scale wind projects to help meet this initiative and wants to continue adding wind projects. This project could be sold to Tri-State and their 43 members.[27] Furthermore, Prowers County Master Plan states goals they want the County to achieve, and goal nine is to find largescale energy producers to develop wind energy in the southern portion of the County.[4] This County goal shows the want for wind energy to be developed in the area.[4]

4. Discussion of Optimization Process

Through OpenWind' s layout optimization procedure, the Prowers Wind farm was able to optimize energy output. A variety of turbine types were explored as well, while also checking on the suitability for these devices at the chosen location (as described in section 2.3.3). After an evaluation of the optimal turbine placement, a few turbines were outliers based on their location, which would increase the cost to connect them into the system. Therefore, a transmission optimization was conducted to reduce transmission costs of the project with little effect on net energy output. This is described in more detail in Section 2.3.1.

5. Conclusion

The Prowers wind energy project completing construction by the end of 2020, generated an IRR at the end of the project of 9.30%. The annual energy production determined by OpenWind was 398.8 GWh/yr. The LCOE and PPA price are $26.4 /MWh and $28.7/MWh, respectively. These values were determined to be viable for a wind project in the region.

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