Wind Turbine Team at Virginia Tech
Siting & Project Development Written Report
2020 U.S. Department of Energy Collegiate Wind Competition
Virginia Tech

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COLLEGIATE WIND COMPETITION U.S. DEPARTMENT OF ENERGY

VIRGINIA TECH

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Abstract

This report details the design process (and the financial potential) for a proposed wind farm in Eastern Colorado. Research on the regional conditions of Eastern Colorado was completed and a site in southeast Prowers County, CO was selected for the placement of the wind farm. Detailed cost and financing research were performed and input into the NREL System Advisor Model (SAM) software. Several optimization iterations of the design and financial model were performed to create the most profitable and realistic project plan. Based on our model, the project would be financially successful through establishing a PPA at market competitive rates.

Site Plan and Selection Methods

Selection Methods

The team conducted background research utilizing eight selection criteria for siting a wind farm: wind resource, the locations of existing wind farms, terrain, access to transmission, access to transportation, land ownership, environmental factors, community factors, and permitting.

The profitability of a wind farm is largely determined by the amount of power that can be produced, and power is a function of the average wind speed and wind speed distribution. Because of this, wind resource data was utilized to select the top three counties in Eastern Colorado for our project site. Then, the other categories were used to further select to the final site.

Top Three Sites

Within Eastern Colorado, the average wind speeds range from 5 to 9 m/s at an 80-meter hub height [1]. The counties with the highest average wind speeds include Las Animas County, Baca County, Prowers County, Kit Carson County, and Cheyenne County. The team selected three regions with a high wind resource, but without an existing wind farm: Prowers County, Cheyenne County, and a site spanning both Las Animas and Baca Counties [1]. The rest of the site selection criteria were researched for these top three sites (Table 1).

Final Site Selection

A decision matrix was generated to assist in the down selection to the final site. Selection criteria were given weights (Table 2) based on how important they are to site a wind farm, given the conditions in Eastern Colorado. Specifically, higher weights were attributed to categories that could completely prevent wind farm development or most significantly impact the financial success of the project. After determining the scores for each county in each category based on the research in Table 1, Prowers County was selected as the final site.

Table 2. Decision Matrix Weights

	Wind Resource	Terrain	Vegetation	Animals	Land Ownership	Transmission	Transportation	Permitting	Community Factors
Weight	10	6	2	3	5	9	7	8	4

Table 1. Site Selection Criteria

	Cheyenne County	Prowers County	Las Animas & Baca Counties
Wind Resource [1]	• 6.5-8.5 m/s	• 6.5-8.5 m/s	• 6-9m/s
Terrain [1]	• 0-3%	• 0-3%	• 0-13%
Transmission [2]	• High Voltage Line in eastern portion of county	• Two existing high voltage lines in western portion of county	• High voltage lines located in central Baca county and western Las Animas County
Transportation [3]	• Interstate 70 in neighboring county • Route 287 & Route 40	• Route 50 & Route 385	• Interstate 25 • Route 160
Land Ownership	• 6th least dense populated county in Colorado [4] • Population density ~ 1 person per square mile [4]	• Most important industry is agricultural [5]	• In the midst of a severe drought since 2010 - prompting many people to leave. May potentially be seeking other means of economic prosperity [6]
Environmental Factors	• No threatened, endangered, candidate, or proposed species [7] • Landcover: mainly planted/cultivated, grassland/herbaceous [1]	• Threatened and Endangered Species: Black-footed ferret, Least Tern, Piping Plover [8] • Landcover: mainly grassland/herbaceous, planted/cultivated [1]	• Threatened and Endangered Species: Canada Lynx, Mexican Spotted Owl, New Mexico meadow jumping mouse, Wolverine, Black-footed ferret [7] • Landcover: mainly deciduous forest, evergreen forest, shrubland, grassland/herbaceous, plant/cultivated [1]
Community Factors	• Average income is close to or below poverty line [4] • Several existing wind farms	• 4,258.77 sq. km [9] • Population: 12,034 [9] • Average household income: $34,391 [9] • High school graduates: 79% [9] • Bachelor Degrees: 14% [9] • Several existing wind farms [10,11]	• A group called Baca Green Energy, which consists of local farmers and landowners, is trying to establish a wind farm near Springfield. The group is hoping to build a large wind farm of 100 or more generators. [12]
Permitting	• Land Use Permit • Conditional Use Permit • Wind Energy Rules Document [13]	• Special Use Permit [14] • Possible Floodplain Development Permit [14]	• Wind farms are only allowed in the Agricultural (A) and Ranchette (RA) zoning districts [15]

Wind Resource

The wind speeds in southern Prowers County are approximately 8.0-8.5 m/s at 80m [1] making this a site with optimal wind resource.

Existing Wind Farms

In Eastern Colorado there are several existing wind farms that must be avoided when selecting a new site. Wind farms near our selected area include Colorado Green Wind Power [16] and Twin Buttes II Wind Farm. [17]

Terrain

In Prowers County, the land has consistent 0-3% slopes throughout [1] which allows for simplified construction and lower associated costs.

Access to Transmission

There are two high voltage transmission lines that run from north to south through Prowers County [3] that could be utilized to connect the proposed wind farm to the grid.

Access to Transportation

Highway 89 runs from north to south through eastern Prowers County and U.S. highway 50 runs from east to west north of the project area. [2] Both will offer easy main highway access to the project site for mobilizing turbine components.

Environmental Factors and Vegetation

The site vegetation is mainly prairie grass, shrubs, or agricultural land cover. [18] There are very few documented endangered species in eastern Colorado with the black-footed ferret and the least tern being the only listed endangered species in Prowers County. Additionally, there is one threatened species listed - the Piping Plover. [7] However, it appears that the primary habitats of these species are not in the southeast section of the county, in which our project will be located. [8]

Community Factors

The Prowers County population density is about 7.3 people per sq. mi [5] and the average household income is $34,391 [19]. With the US national median household income being $59,039 as of 2017 [20], Prowers County's average household income is significantly lower. NREL's Jobs and Economic Impacts (JEDI) model [21] shown in Table 3 indicates the wind turbine project will stimulate the local economy during wind farm construction and wind farm operation. The low population density is advantageous due to the abundance of ideal open spaces for wind farm development throughout the county. Lastly, the team interviewed several Prowers County local government representatives, each were in favor of and expressed excitement for wind farm development in their area. [22]

Land Ownership

The team coordinated with the Prowers County Assessor's office to determine parcel divisions and land ownership throughout the county. It was determined that the majority of the land in the project area was farm or ranch land making it ideal for wind farm development. Additionally, the estimated value of the parcels in the area were especially low, with many parcels over 100 acres being valued at less than $20,000. [23] This allows for low cost land leasing for the project.

Table 3. JEDI Local Economic Impacts Summary

Local Economic Impacts - Summary Results				
	Jobs	Earnings	Output	Value Added
During construction period				
Project Development and Onsite Labor Impacts				
Construction and Interconnection Labor	60	$3.74		
Construction Related Services	5	$0.42		
Total	64	$4.16	$4.54	$4.23
Turbine and Supply Chain Impacts	186	$11.09	$32.38	$16.41
Induced Impacts	92	$5.06	$15.02	$8.74
Total Impacts	**342**	**$20.32**	**$51.94**	**$29.38**
During operating years (annual)				
Onsite Labor Impacts	6	$0.41	$0.41	$0.41
Local Revenue and Supply Chain Impacts	9	$0.58	$2.35	$1.62
Induced Impacts	7	$0.40	$1.19	$0.69
Total Impacts	**22**	**$1.39**	**$3.96**	**$2.72**

Permitting

At the federal level, the US Army Corps of Engineers requires renewable energy developers to obtain Nationwide Permit 51. [24] The US Fish and Wildlife Service requires developers to purchase an Incidental Take Permit when their activities are "reasonably certain" to harm endangered or threatened species [25], however this permit is not anticipated to be necessary for this project because there are no threatened or endangered species with a primary habitat on the site.

The state of Colorado requires developers to obtain a Certificate of Public Convenience. [26] At the local level, a special use permit is required from the Prowers County Planning Commission. [27] Zoning permits are required from the Prowers County Land Use Department. [28]

Detailed Design

Turbine Selection

Turbines used for nearby Colorado wind farms were compared to determine local technology trends. The surrounding wind energy projects used 1.5 and 2 MW turbines, and most were supplied by either Vestas or GE. [29,30,31,32] Market trends from NREL's 2018 Wind Technologies Market Report stated that the average nameplate capacity for turbines installed in 2018 was 2.43MW, with an average hub height of 88.1m and average rotor diameter of 115.6m. [33] This data was used to determine aspects of popular and successful turbines so that the selected turbine for our site would be similar.

The location of manufacturing plants for the three largest wind turbine manufacturers (Vestas, GE, and Siemens-Gamesa) [34,35,36] were compared to find a manufacturer with locations geographically closer to the Prowers County Wind Farm. This will significantly lower transportation costs. Vestas has manufacturing plants for all wind turbine components within Colorado and was chosen to provide turbines for the Rush Creek Wind Farm specifically for its proximity to their project. [37]

Based on market trends for turbine size and geographic proximity to the manufacturing plant, we decided to select a Vestas V90-2MW turbine. Additionally, the NREL cost and scaling model used to approximate cost for wind turbines is based primarily upon the rated capacity and rotor diameter of the turbines [38], so our turbine was selected as one of Vestas's smaller options to optimize cost based on this model.

OpenWind Model

The detailed site design for the wind farm was constructed in AWS Trupower's Openwind software. The Openwind model was created using shape files of highways, waterways, lots, main roads, local roads, and parcels provided by the Prowers County Assessor.

Elevation and land cover raster layers were imported through the Openwind file menu and trimmed around the site to simulate terrain and roughness. A Wind Resource Grid (WRG), obtained from AWS Trupower's Windnavigator, was imported into the model to supply wind resource data. Specifically, a WRG was utilized to create the wind resource layers in Openwind. Once the WRG was imported into the model, a wind map layer was created using the wind resource, terrain, and roughness data.

A turbine type file was created to define the V90-2MW turbine as the turbine used in the layout. This file included data on the size, capacity, and cut-in wind speed of the turbine.

The model was first run to optimize for energy production. However, the financial impacts of constructing lengthy transmission lines and access roads can outweigh the benefits of optimized energy production. Therefore, the model was run a second time to optimize for minimal transmission line and access road construction to minimize costs, as well as cost of energy. This resulted in the site layout shown in Figure 1. This was then used to determine the length of new transmission lines and access roads that will be built on the site.

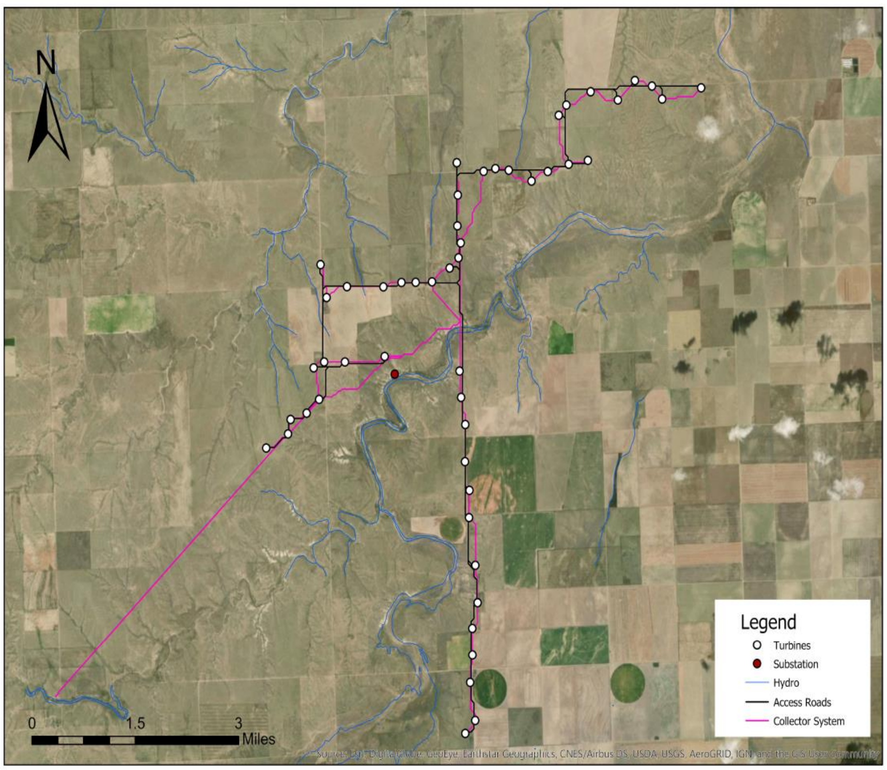

Figure 1. Final Site Layout

Net Annual Energy Production

The final OpenWind model resulted in a wind farm layout that would produce a net annual energy of 475,750 MWh/yr at a 54.27% capacity factor. While this capacity factor is fairly high compared to average wind farm capacity factors [39], a revised capacity factor for our wind farm is discussed in further detail in the "Model Outputs" section below.

Costs Summary

The capital costs for the proposed wind farm are outlined in Table 4, below. Purchasing the turbines, construction, and installing electrical infrastructure account for the majority of the capital costs while turbine maintenance is the costliest annual operating expense.

Table 4. Accumulated Costs

Initial Capital Costs	**Cost**
Wind Turbines	$ 91,861,700
Access Roads	$ 725,200
Staging Area	$ 953,000
Turbine Foundations	$ 3,470,000
Turbine Transportation	$ 3,827,800
Electrical Infrastructure	$ 10,115,900
Resource Assessment	$ 101,000
Control and Electrical Hardware	$ 500,000
Construction Costs	$ 12,000,000
Office Space	$ 225,000
Engineering and Surveying	$ 161,000
Land Development Permits	$ 2,900
Total	**$ 123,943,500**
Annual Operating Expenses	**Cost**
Land Leases	$ 300,000
Maintenance	$ 3,092,400
Daily Operations	$ 577,400
Administrative and Legal	$ 300,000
Total	**$ 4,269,800**

Initial Capital Costs

Engineering and Surveying

Our 100MW wind farm in Prowers County will likely cover roughly 10,000 acres [40] and will require a detailed layout accounting for existing ground conditions, grades, and property lines. A quote was given by North Star Surveying, located in Pueblo, Colorado. [41] They estimated that a full survey of our site would cost $32,000 and an additional $79,000 to create a civil design and layout of the site. [42] A geotechnical survey is also necessary before foundations can be built. This will cost approximately $1000 per foundation. [43]

Resource Assessment

Wind resource potential can be found in two ways - construction of met masts that measure conditions for extended periods of time at specified heights or using remote sensing such as SODAR and LIDAR technology. [46] We have narrowed down the general location for our site and implementing a met mast in that area would give sufficiently reliable data. A 100m met mast will cost $100,000 and an additional $1000 for land leasing costs. [44]

Roads

Construction of roads on our site is dependent on the layout of the turbines. Each turbine, the staging area, and the office each require an access road for maintenance and construction purposes. A typical access road costs $37,000 per quarter mile on flat terrain [45] as is present in Prowers County. The OpenWind model provided an estimate of 4.9mi of necessary access roads resulting in a cost of $725,200.

Staging Area

The parcel shown in blue in Figure 2 was selected as the site of the staging area to then be utilized as the site for the wind farm's office and maintenance space. This is a small parcel for the county but is still approximately 160 acres. [23] Land near our site is selling for about 870 $/acre [46] so we estimate buying this parcel for about $139,000. An average of 10 acres of cleared land is needed for a staging area [47] which is estimated to cost $814,000 in addition to the cost of purchasing the land.

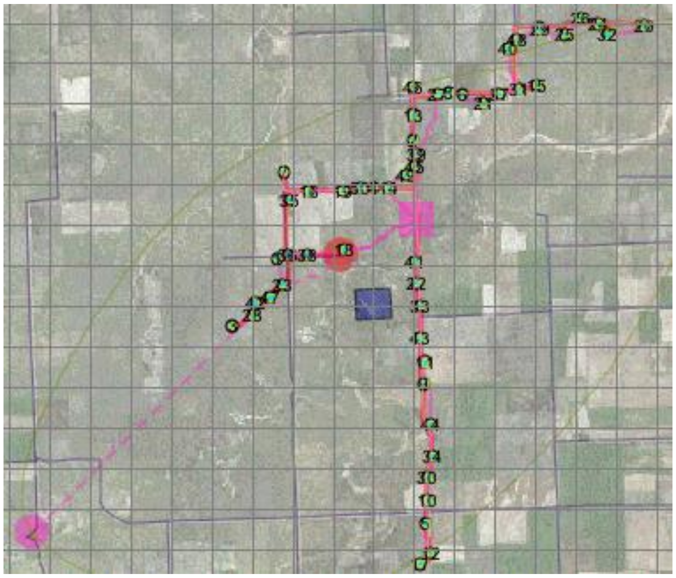

Figure 2. Staging Area Location

Office Space

A 3000 square foot office space will be constructed on the project site. It will cost $5,000 to buy a land parcel [23] and ProEst, a construction estimating software, estimates that the construction of a metal office building will cost $70-$110 per square foot. [48] Building in Prowers County is relatively cheap due to the rural location, so $70/sq. ft was assumed. Property taxes for the building will be $785 per year, based on the property taxes from a similarly sized office building in Lamar. [49]

Due to county zoning regulations, 7 parking spaces are required for the office. [50] 10 will be constructed to ensure adequate space for employees, costing $10,000. [51] Based on a report from Iota Communications in 2016 [52], utilities for Colorado office buildings were $1.69 per square foot, annually. Over the 20-year lifespan of the farm, the office building total cost will be $342,000.

We also considered purchasing an existing office building in Lamar, 30 minutes from the wind farm. Assuming that utilities and property taxes would be the same in Lamar as on-site, the space would cost $265,000 over the lifetime of the project. [53] Despite this alternative being cheaper, we opted for the on-site office space. Having an office close to the wind farm will make maintenance more convenient for the turbine technicians employed by the farm.

Land Development Permits

At the local level, a special use permit costing $350 and zoning permits costing $50 for each turbine are required. [54] Additionally, there is a county consumer use tax of 1% on equipment that is installed in Prowers County if it was not purchased in the county. [27] This tax applies to the turbines.

At the federal level, a $100 Incidental Take Permit is required when activities are "reasonably certain" to harm endangered or threatened species, but we do not anticipate this being necessary for our farm. [25]

Foundations

A table of the weight of materials [55] was sourced for the V90-2MW foundation. As of October 2019, the material costs amounted to $3.47M for 50 foundations (Table 5).

Table 5. Approximate Cost of Foundation Materials

Material	USD per Ton
Steel [56]	570
Concrete [57]	50
Iron [58]	93

Turbine Costs

NREL's WISDEM turbine cost model [59] was run in Python using inputs specific to the V90-2MW turbine. The equation behind this model is NREL's Cost and Scaling Model. [59] The resulting mass and cost values for each turbine component are summed by the model to then output a total turbine mass in kilograms and cost in US dollars per kilowatt. This value was then multiplied to find the total cost for our 50 2MW turbines to be $91,861,647.

Turbine Component Transportation

The turbine chosen to be used in the project is the Vestas 2 MW turbine, manufactured in Pueblo, Colorado. [60] According to a 2016 NREL study for the Rush Creek wind farm, it is estimated that the cost of transportation to a wind farm site in eastern Colorado, such as our site in Prowers County, would be $36/kW. [37] Multiplying this factor by the project's 100MW capacity and adjusting for inflation this cost is $3,827,836. [61]

Turbine Installation

Installation of the turbines requires the rental of a crawler crane and assembly of all components. The majority of costs accumulate from crane rental. Installation would likely be about $120,000 per MW producing a total cost of $12,000,000 for installing all 50 turbines. [62]

Electrical Infrastructure

The cost of transmission from a switchyard (small substation) to an existing substation is around $500,000 per mile [63] making it very expensive to transmit our low voltage to an existing substation over 15 miles away. The cost of a substation includes the generator step-up unit, the control house, and the relay and monitoring system for a total cost of $5,809,836. [64] The best course of action is therefore to build a substation on-site and tie into existing transmission lines much closer to our site.

Transmission from the substation to the tie-in for our wind farm site is a distance of 11.5 miles. [65] The costs of transmission were estimated using the MISO transmission line cost tool. [66] The right of way for a 115 kV transmission is 90 feet meaning 125.5 acres over the length of the transmission distance. The easement cost for the land is $2,095,850 per acre for flat, open land. The grading cost is $265 per acre coming out to $33,258. The structures for 115 kV transmission cost $619,560 per mile which totals to $7,124,940. The transmission line costs $56,148 per mile coming out to total $645,702 for the 11.5 mile length. The total therefore for transmitting from the on-site substation to the existing 115kV transmission line 11.5 miles to the west would be $9,899,750.

Interconnection cables are run throughout the wind farm site and connect the turbines, feeding electricity to the substation and outlet transmission system. [67] Our OpenWind data outputs 29 miles of required on-site transmission line. Combining the cost of poles, 1/0 ACSR (53mm^2) conductor wire, pole top components (pin, insulators, cross arm), and guy lines results in a cost of $5,714 per mile. [68] Transportation and labor cost was found to be $1,738 per mile. [68] For our 29 mile interconnect system the cost would therefore come out to $216,108. This cost added to that of the transmission from substation to grid tie-in is $10,115,858.

Control and Electrical Hardware

A supervisory control system is required to be designed and purchased separately apart from the individual turbine control systems. The team consulted with an industrial automation firm which estimated the total cost of the system to be approximately $500,000 for the site. [69]

Annual Operating Expenses

Land Expenses

It is estimated that on average in the United States a fair market value for a land lease is $8000 per year per turbine. [70] However, the Rush Creek Wind Farm development in Eastern Colorado is in an environment very comparable to Prowers County and is expected to pay the equivalent of $6000 per year per turbine. [71] Thus, it is reasonable to estimate a payment of $6000 per year per turbine for our farm as well.

Maintenance

The average overall maintenance costs combine expected costs based on energy output and average costs per megawatt-hour output of unplanned maintenance. [72] NREL identifies average annual maintenance costs to be $0.0065/kWh in their 2016, 2017, and 2018 reports accounting for inflation. [62,73,74] This means, based on net annual energy production, annual maintenance costs for our wind farm in Prowers County will be $3,092,375.

Daily Operations

Long term employees necessary to run and maintain a wind farm of this size include one office manager, one project manager, and five wind turbine technicians. Typically, one project manager is needed for a 100MW [75] farm and one turbine technician is needed for every 10 turbines. [76] The salary of an office manager in rural Colorado was determined to be approximately $70,000 per year [77] making the cost of the employee, after accounting for benefits and other employment expenses, $91,000 per year. [78] The cost for a project manager, based on a job average salary of $100,220 in Colorado [75], is around $130,286 per year. For each turbine technician, the entire expense will be approximately $70,044 per year, totaling $350,000 per year for all five technicians. [76] Comprehensively, the final cost for long term employees amounts to $571,500 per year.

Administrative and Legal Fees

According to Windustry, annual administrative and legal fees concerning taxes, contracts, billing, and insurance settlements total approximately $6,000 per turbine per year. This results in a total administrative and legal cost of $300,000. [45]

Decommissioning Costs and Salvage Value

An estimate done by Xcel Energy on the Nobles Wind Energy Project put decommissioning cost at $397,000 for a 1.5 MW turbine. [79] Adjusting for the increased size of our turbines (2 MW), decommissioning cost is $26,466,667 paid at the end of the project lifespan.

The salvage value is calculated based on the weight of the turbine. Vestas lists the V90-2MW turbine at 240 tons. [80] The metallic composition of one turbine is 86% steel, 2% aluminum, and 1% copper. The blades and the rotor are composed of unsalvageable materials that will go to a landfill. According to a decommissioning report by the Buffalo Ridge II Wind Farm, the tower and nacelle are 90% salvageable. [81] The current national average market prices of these materials were used to calculate the salvage value. After adjusting for inflation, the salvage value is projected to be $2,425,668 in 2020 dollars. [82]

Financing

Model Selection

NREL's System Advisor Model (SAM) software was selected by the team for financial modeling of the wind farm. Some modeling iterations were performed using Prof. Ed Bodmer's On Shore Wind Excel Model [83], but this was determined to be less ideal for running multiple iterations of the model. The team was familiar with the SAM model, which enabled rapid iterations.

Incentives

The Production Tax Credit (PTC), which offered 2.5cents/kWh at full credit has been in the process of phasing out for several years. Recently the PTC was extended through 2020 for partial credit, but the future availability of the PTC beyond this is very uncertain. [84] Because of this uncertainty, the team has modeled a conservative estimate by choosing not to utilize the PTC. This ensures that the success of the farm is not dependent on beginning construction before the end of the year. The investment tax credit provides a tax credit for all wind turbine projects below a capacity of 100 kW. [85] However, our turbines would not qualify for this tax credit.

Another incentive is renewable energy credits (RECs), which is a form of certificate that is awarded after a green energy source creates 1 MWh of energy. However, due to the booming renewable energy market in Colorado there is a very high supply of RECs in the western United States. Consequently, the credits sell for only $1 each, which would provide a yearly revenue of up to $410,965. [86]

Power Purchase Agreement

Terms of Power Purchase Agreement

A Power Purchase Agreement (PPA) is a contract that defines the terms in which energy will be bought by a utility company. [87] The agreement for this wind farm was constructed as a Partnership-Flip with debt. This PPA structure includes equity investment from a tax investor and construction and term debt. Terms of the PPA would be negotiated between the developer, a tax investor and the regional utility provider. The term for this PPA will be 20 years and it is assumed that the utility will buy 100% of the electricity generated by the farm.

Prowers County local utilities are Southeast Colorado Power Association (SECPA) and Arkansas River Power Authority (ARPA). SECPA does not currently have any PPAs with wind farms, but they offer an option for their customers to purchase "wind energy" at a higher rate through agreements with other utilities. [88] ARPA does currently purchase wind power and states that the company is committed to finding new sustainable energy sources. [89]

Associated Loans

The construction of the project will be financed through the use of a construction loan. Construction loans are designed to pay upfront for the project construction. Construction loans typically have interest rates of 5.75-6.75% and a lower interest rate can be granted once the project reaches stabilization. [90] For modeling purposes an interest rate of 6.25% on the construction loans was used because it was the average of the typical interest rates.

To finance this project, we plan on taking a 15-year loan at 6.1%, interest payable annually. [91] We have decided to take a 15 year loan out instead of a 20 year loan, which will give us a more favorable rate and higher return on equity as well as allowing the last five years of the project to be much more profitable. [92] However, this will mean that our annual debt payment is higher and increases the likelihood of default. To assure the banks that the payments will be made, we have a targeted Debt Service Coverage Ratio (DSCR) of 1.3. This means that our net income is expected to be 1.3 times higher than our annual debt payments. [92] Our anticipated financing through debt is 60% of the total capital cost. [92] We believe that this is the most optimal and realistic debt structure that can maximize our return on equity.

To finance the other portion of the project, we will use equity, which is the money that our investors have put into the project. We would need 40% of our total costs to be financed from equity. [92] The target equity investor internal rate of return (IRR) was set at 12% for this model. This falls on the high end of the typical goal of 7% to 12% for a wind farm. [93] We chose the value of 12% because it provides our investors with the highest return while still maintaining a reasonable cost of energy. This higher return was deemed critical for a project that would no longer be able to provide tax benefits as an incentive for investors.

Additional Model Inputs

Site Information

General information on the wind farm project site was put into SAM for background information on the productivity of the farm. First, a wind resource file for the southeastern Colorado flatlands was imported from SAM's wind resource library. The Vestas V90-2.0MW was selected from SAM's wind turbine library as this is the turbine that the team has selected to be utilized on this project. The hub height was set to be 95m and the shear coefficient to be 0.14. Additionally, the layout of the turbines across the farm was imported to SAM from OpenWind.

Tax and Insurance Rates

The federal income tax rate of 21% [94] and the Colorado state income tax rate of 4.63% were used. [95] Colorado tax rates for business, property, and sales/use are 0% [96] for the purposes of this project. The expected insurance rate is 2.5% annually. [45]

Time-of-Delivery Factors

Generic Summer Peak was selected as no reliable data could be applied specifically for Colorado. This time-of-delivery factor brought the capacity factor of the wind farm output by SAM to a more realistic 37.2% as opposed to 47% with the uniform dispatch factor.

Reserve Accounts

Reserve accounts of 6-12 months for working capital and debt service are typically held by developers. [97] For this model, the median of 9 months of operating costs were held in the reserve accounts at an interest rate of 2.4%, a SAM default rate.

Model Outputs

Analysis of the model reveals that the real resultant levelized cost of energy (LCOE) is 7.31 cents/kWh. This project can be profitable for all parties involved if the electricity is sold at the levelized real PPA price of 8.57 cents/kWh. Colorado average electricity market costs are 9.01 cents/kWh and 11.47 cents/kWh for commercial and residential markets, respectively. [98] Because this farm can sell energy at a cost lower than those values, **we believe it will be very competitive in the electricity market and therefore successful.**

The resulting investor net present value (NPV) over the project life is $10,058,242. The resulting developer NPV over the project life is $36,632,000. These are shown annually based on the partnership flip PPA structure in Figure 3. Because tax credits are not utilized in this model, this farm will likely attract investors that are different from the historically standard wind project investors. Previously, large corporations have invested because they benefit the most from the tax credits, but perhaps now wind projects will appeal more to smaller investors as a way to earn money rather than tax benefits. The resultant net capital cost from the model is $153,593,840, the total calculated equity for the project is $65,679,936, and the total calculated debt is $87,913,912.

Annual energy production is 326,218,400 kWh based on a 37.2% capacity factor output from SAM. There is some discrepancy between these energy production and capacity factor values and those output from the OpenWind model. OpenWind provided a significantly higher capacity factor of 54% based on more specific wind resource data. Additionally, the time of delivery factors selected for the SAM model may produce some inaccuracy in the energy output. Because the OpenWind data is more precise and resulted in a higher energy production, and there are uncertainties with the SAM model inputs, the SAM model results are likely rather conservative.

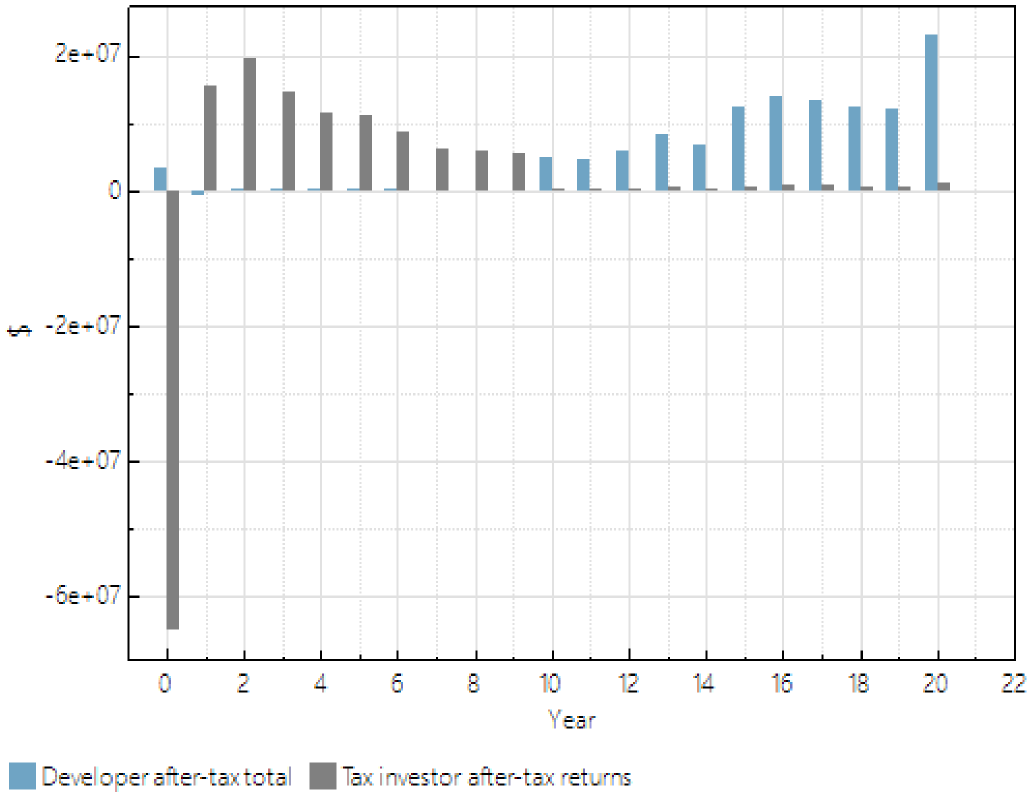

Figure 3. Partner After-tax Cash Flows

Optimization Process

Throughout the wind farm design process, innumerable small iterations through research, calculations, and design decisions were made. Once most of the project design had been finalized, the team made formal iterations of the SAM model. The changes and results of each iteration are listed below.

- A turbine layout was imported from OpenWind to replace the SAM generated layout of 2 diagonal lines of turbines. This significantly impacted the capacity factor and annual energy production, therefore lowering the PPA price
- RECs were accounted for as a utility production-based incentive at $0.001/kWh. This lowered the PPA price by approximately 0.1 cents/kWh which is not hugely significant, but still beneficial.
- The portion of the project funded through debt was changed from 50% to 60% and the loan tenor was changed from 20 to 15 years. This slightly increased the PPA price, raised the debt, decreased the equity, and lowered the DSCR, but was determined to be a more realistic representation of typical project funding.

- The construction loan interest rate was changed to 6.25% from 4% to more realistically represent the market.
- The investor IRR was increased from 8% to 9.5%. This increased DSCR, increased both developer and investor NPV, but more significantly the investor NPV. The PPA price only slightly increased with this change so the benefits to the developer and investor were determined to be more beneficial.
- The Generic Summer Peak time-of-delivery factor was applied rather than the Uniform Dispatch factor to apply a more realistic time-of-delivery pattern. This significantly decreased the capacity factor and increased PPA price. Although this did not appear beneficial to the profitability of the project, it was deemed more realistic because the current average capacity factor for installed wind is about 35%[39] and this adjusted our wind project's capacity factor, determined by the SAM model, from 47% to 37%. Some of the more recently installed wind farms are reaching capacity factors closer to 40%[99] so the capacity factor for our farm is within a reasonable range.
- An iteration was performed which applied a PTC credit at 0.019 $/kWh in an attempt to compare to the project financials modeled without the PTC. This significantly decreased the PPA price as was expected and demonstrated how much more profitable wind projects have the potential to be with incentives like the PTC.
- The final accepted iteration for the financial model of this project utilized an updated wind turbine layout from OpenWind that optimized for the cost of transmission lines and access roads. The investor IRR was also increased to 12% which increased the investor NPV significantly while only slightly increasing PPA price. It also utilized several aspects from other iterations to obtain the most realistic and optimal model.
- A comparative iteration was completed in which SAM's balance of station estimation capabilities were utilized to verify that our cost estimation was fairly reasonable. This showed that our estimate was slightly low so it is likely that our estimate was not entirely comprehensive, but was close enough to give a reasonable approximation.

Conclusion

After extensive research on the regional conditions of Eastern Colorado, a site in southeast Prowers County, CO was selected for the placement of this team's wind farm. The team performed detailed cost and financing research, and then modeled the proposed wind development in NREL's SAM software. Several optimization iterations of the design and financial model were performed to create the most profitable and realistic project plan. Finally, the team determined that this wind project would be financially successful based on this financial model because electricity could be sold at a PPA price that would be competitive in the current market. Financing strategies for the wind industry remain uncertain without the assistance of incentives like the PTC. However, we believe that the design and analysis process discussed throughout this report indicates that wind energy in Eastern Colorado will likely still be financially successful in the future. The Siting and Business Sub-Team of the Wind Turbine Team at Virginia Tech is proud to have been involved in the Collegiate Wind Competition and to have had the opportunity to learn about the wind industry through this challe

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