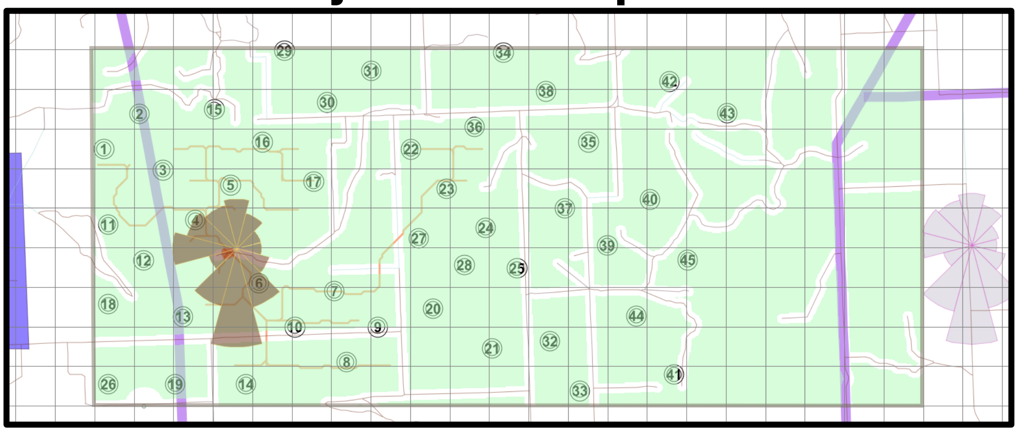
Northern Arizona University
2020 Collegiate Wind Competition: Project Development



Written Report

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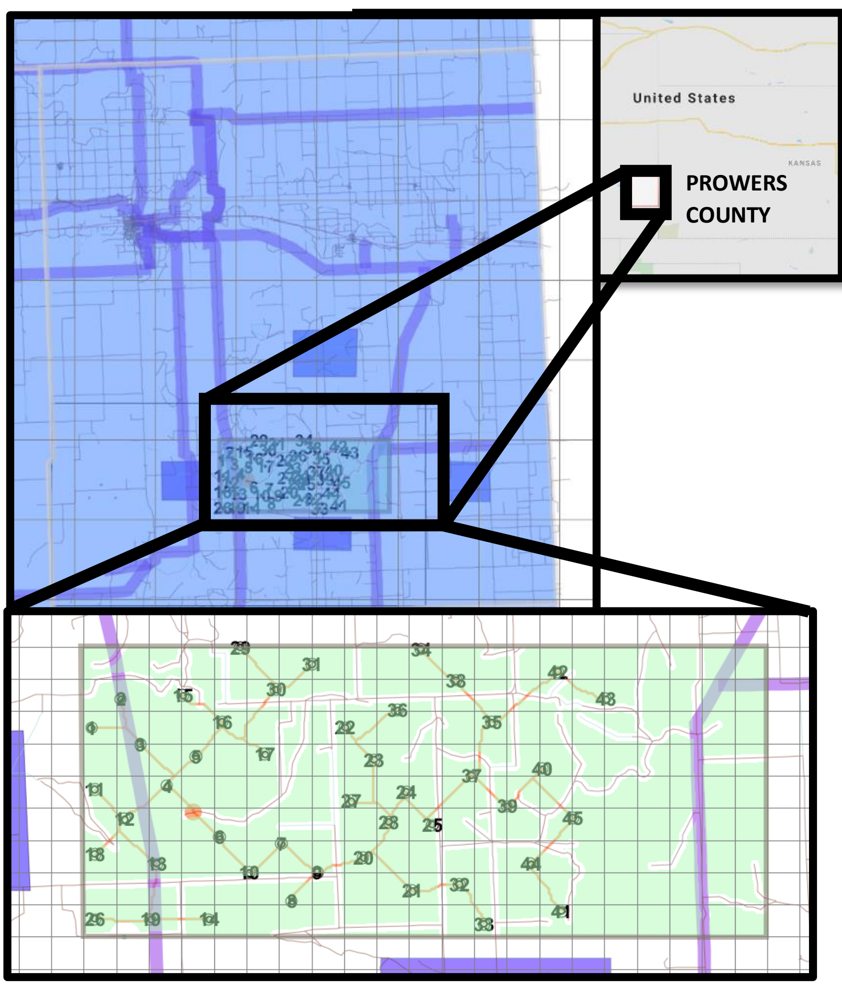
Section I: Introduction

Abstract

The Project Development Team from Northern Arizona University proposes its wind power plant design, location, and project cost to the Collegiate Wind Competition, sponsored by the United States Department of Energy. This proposed plant features 45 Vestas V-120 turbines in the south end of Prowers County, accessible by road and near two transmission lines. The power plant holds a maximum rated power of 99 megawatts and has an estimated array efficiency of 98.1%, using NREL's Wind Toolkit data at 100-m hub height. Related county, state, and federal regulations permit construction of the site given that the team abides by all ordinances. The project will support local wildlife organizations to mitigate any significant losses caused by the wind farm to endangered species in the region. Future structural and transmission risks on the site can be reduced through safe standard operating procedures. The capital expense for the project is expected to be $167.5M and with an operational and maintenance fixed annual cost of $2.925M/year for the project's 20-year life span, assuming a flip partnership with debt financial model. Regarding the financial model of the project, a long-term power purchase agreement of 3.97¢/kWh was verified to keep the site profitable.

Site Description



This site is located in Prowers County and is easily accessible by Highway 385 for material transport. The site is also located near two independently owned transmission lines that the wind farm could connect to with relative ease. The site location is on non-irrigated land that has a relatively flat terrain and is away from major cities and airports. The site has an IEC wind class rating of IB at an average elevation of 1170 meters.

Legend	
Green	Site Area
Purple	Transmission Area
Blue	Unusable Land
Black	Turbine Location
Red	Road
Orange Lines	Cabling
Orange Spot	Substation

Figure 1: Site layout with geographic reference

The 45 wind turbines are spaced at a minimum of seven rotor diameters apart with relative setbacks to roads and structures. Foundation and site maintenance will be carried out regularly to monitor and ensure the site is safe and productive. Any road access for turbine transport near the area will be standardized to local law while prepared to receive wide loads.

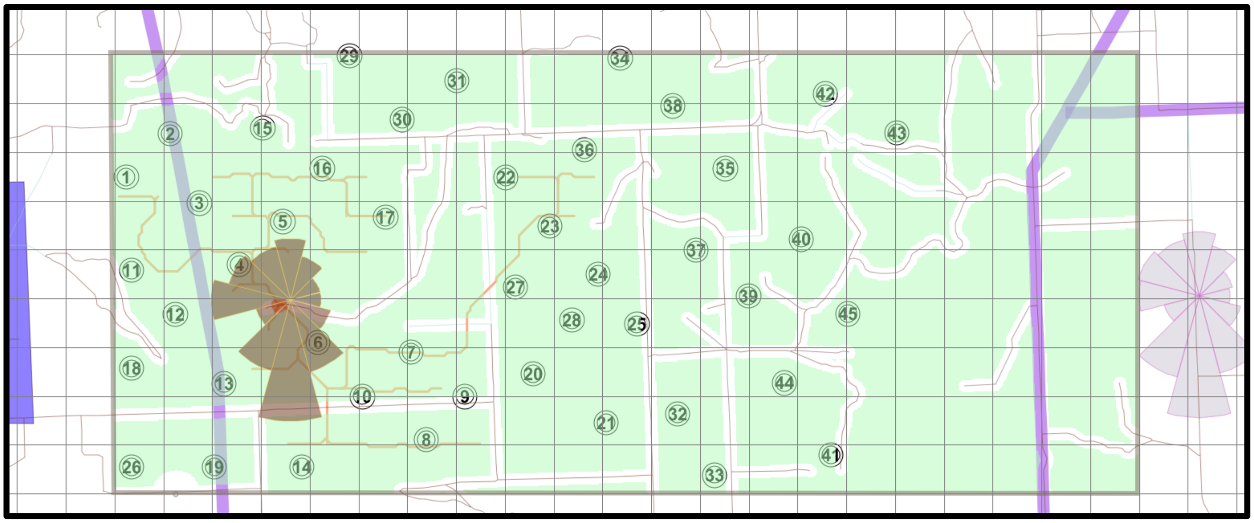


Figure 2: Close up of site layout

Wind Resource

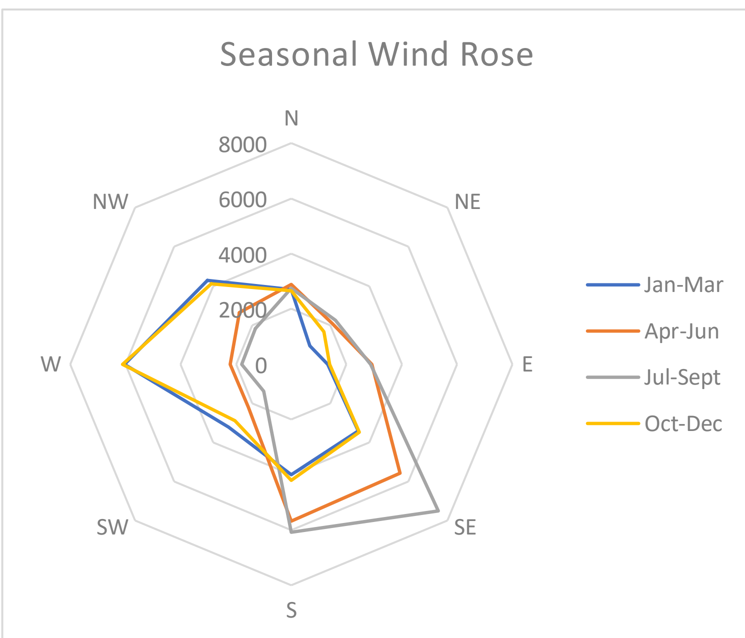


Figure 3: Quarterly wind rose.

Using NREL's Wind Prospector [1], the team gathered data on wind resources in the area, the team created wind roses to understand the various wind directions. The wind source in the selected site predominately comes from the southeast direction during the spring and summer, while during the fall and winter seasons, the wind comes from the west. The wind rose displayed in Figure 3 illustrates the difference in predominant direction by season. The values in Figure 3 represent frequency of wind coming from a given direction. This illustration provides the team with a guide on how the wind turbine layout needed to be oriented to achieve the 98.1% array efficiency.

Turbine

Table 1: Vestas V 120 turbine specifications

Vestas V120 [3]	
Rated Power Output	2,200 kW
Rotor Diameter	120 m
Wind Class	IEC IB
Hub Height	92 m
Cut-in Speed	3 m/s
Cut-Out Speed	25 m/s
Recut-In Speed	23 m/s

The top three turbine suppliers based on the "2018 Wind Technologies Market Report" were considered: Vestas, GE Wind, and Siemens Gamesa [2]. The Vestas V120 was selected because it is currently being manufactured in Colorado, data was easily accessible online, and it meets the chosen site's IEC wind class of IB. The Vestas V112 was also considered; however, after talking to a Vestas representative, the team was advised not to use the V112 as it is an older model. The Vestas representative also recommended the hub height of 92 meters for the V120. Research into the nocturnal jet in Colorado indicated that having a lower hub height would be beneficial since the jet stream would be lower at night. Table 1 lists turbine specifications for the V120.

Permitting

The state of Colorado does not have wind farm-specific regulations and mostly defers to the counties (§ 30-28-106 (3)(a)(VI)) [4]. Colorado statute §29-20-108(2) requires that all county ordinances are followed, and permits are obtained [5]. Once local permits are obtained, the state statute § 40-5-101 requires that a certificate from the Public Utilities Commission is obtained before construction begins [6]. Colorado Statute § 30-28-106 (3)(a)(VI) also mandates that the counties provided access to the appropriate conditions for alternative energy sources within their master plans [4]. Prowers County's master plan includes the goal of wanting to attract large scale wind farms to the southwestern portion of the county [7]. The proposed plant is located in the southern portion of Prowers County on zone A-2 non-irrigated land which can be seen in Appendix A. Prowers County requires the filing of Zoning Permit A-2, which can be seen in Appendix B. The minimum requirements for Zoning Permit A-2 are listed in table 2. Prowers County also requires that a Special Use Permit be submitted and reviewed by the Land Use Office [8].

Table 2: Minimum requirements for zoning permit A-2 non-irrigated land [8]

Lot Area	>35 Acres
Lot Dimensions	140 ft. x 140 ft.
Lot Coverage	25%
Front Yard Setback	50 feet
Side Yard Setback	10 feet
Rear Yard Setback	15 feet

The Federal Aviation Administration (FAA) also has regulations that wind farms need to follow if the turbines are over 200 ft. above ground level. The V120 turbine exceeds 200 ft.; thus, at least 45 days before construction, the FAA Form 7460-1, Notice of Proposed Construction or Alteration, will need to be filed with the FAA [9]. The turbines on the site will also have to follow the FAA's Obstruction Marking and Lighting regulations: turbines must be white or light gray and have synchronized red lights on nacelles [10]. The red lights will be activated at night and added on to some turbines so there are no gaps along the perimeter more than 804 m [10]. Red lights will also be added to the interior of the turbine cluster so there is no gap greater than 1.6 km [10].

Wildlife and Mitigation

USFWS established guidelines for wind development to protect important wildlife species. The Migratory Bird Treaty Act (MBTA) establishes four treaties that provide international protection of migratory birds [11]. Under the 16 U.S.C. 668 also provides legal protection that prohibits the take, sale, purchase, or barter, transport, export, or import of any bald or golden eagle [12]. The eagles' habitat in relation to the site and Prowers County is illustrated in Appendix C1 and C2. Furthermore, the 16 U.S.C. 668c, includes prohibiting to pursue, shoot, shoot at, poison, wound, kill, capture, trap, collect, molest, o disturb the eagles [8]. Also, in 1973, congress enacted the Endangered Species Act (ESA), 16 U.S.C. 1531-1544 [12]. Two species in the Prowers county are listed on this act which includes the Greater Prairie Chicken and Whooping Crane, both habitats are illustrated in Appendix C3 and C4.

With these regulations set in place, there will be a set of biologists to do pre-construction surveying to find any wildlife habitats in the area. There will also be a project dedicated to revegetating the area to support wildlife returning after construction. After construction and start of the wind farm, the site's personnel will be conducting data collection of bird strikes that involve weekly recordings of bird carcasses to keep track of fatalities. Yearly impact reports will be generated and sent to U.S. Fish and Wildlife to determine if turbines cause high levels of fatalities. If needed, studies have shown turbine curtailment at wind speeds lower than 5.0-6.5 m/s helps reduce bat fatalities by 50% or more [13]. Furthermore, GPS transmitters and camera-based systems can be implemented as part of "informed curtailment" that signals to shut down a string of turbines for a given amount of time [13]. If needed, high frequency (ultrasonic) sounds and implementing reflected echoes from objects from the surroundings will be set in place to keep birds or bats from the turbine's blades [13]. As a whole, the wind farm personnel will work with different organizations such as, Bats and Wind Energy Cooperative and National Wind Coordinating Collaborative in the area to find a solid plan to continue to help wildlife in the area

Risk Analysis

The turbines will undergo long transport to the site, so 4.5-meter-wide access roads will be paved to each turbine pad to mitigate delivery issues. Furthermore, the elevation change in the area is low, reducing risk of heavy compensation to level the terrain. Survey samples of the soil will be taken into account to ensure a reliable base for turbines. The wind farm's cabling will be placed underground to reduce visual impacts and marked to locate damages. The operation and maintenance of the wind farm will have a set schedule to ensure the systems are maintained and working as needed. Turbines that strike birds will be documented to abide by the regulations that protect the wildlife in the area, as well as maintenance will be done to ensure the turbines were not damaged.

Section II: Financial Analysis

Costs Summary

Overall, the site's projected capital cost is $167.5 M. This entails initial construction, turbine purchase and placement, road improvement, and transmission lines. Operating and maintenance costs, on average, are $4.5M yearly to account for wages and turbine, road, and any other minor repair or replacement. While these costs do not incorporate any investment or loan rates, these are found to be reasonable with current market reports.

Capital Expense

Table 3: Table of capital expense item costs and total

Capital Expense Breakdown	
Construction Cost	$40.9 M
Operating and Maintenance Expenses	$2.93 M
Cost Per Kilometer of New Road	$0.20 M
Transmission Line Construction per Mile	$0.91 M [14]
Cost of Substation	$7.45 M [14]
Cost Per New Turbine	$2.27 M
Total Capital Expense	$167.5 M

The capital cost for the site considers the functions needed to bring this wind power plant to commercial operation. Based on a quote from a Vestas representative, the Vestas V120-2.2MW per-turbine cost would be $2.27M. Additionally, an acceptable and safe substation for the site would cost $2.93 million
to transform and transport the energy. A base cost for the substation is just above $1.6 million, with additional costs based on the kilovoltage expected and the number of kilovolt-amps running through the site. For this project, a 100 MVA was assumed to meet the average amperage of the interconnected transmission lines. Transmission lines constructed will meet the standards of the linking lines. While some properties of the lines are unpublished such as normal amperage, current load, and additional requests prior to interconnection, a $0.91 million cost per mile provides a buffer to construct and connect to the energy grid.

Operational & Maintenance Expense

Table 4:Summary of O&M estimates

Expected Cost Based on Vestas Quote	
Est. yearly O&M Cost per turbine	$ 65,000
Number of Turbines (V120)	45
Total Est. O&M Cost	$ 2.93M
O&M cost [$/kW-year]	50.89
Reserve Fund	
Total in Reserve (for the last 8 years)	$ 9.9 M

The Vestas Representative provided an estimate for what the yearly cost for O&M per turbine for 20 years. For all 45 Vestas V120 turbines the expected O&M cost per year is estimated to be $2.925M (50.89 $/kW-year). This expected O&M cost only covers the turbines; thus, within NREL's System Advisory Model (SAM) the team created a reserve fund of $9.9M that would be built over the first 12 years of the project and spent on O&M once the project flips over from the investor to the developer. A summary of the estimated O&M based on the Vestas quote and the reserve fund is represented in table 4.

Bankability, Risk and Alternatives Evaluation

For the bankability, the team used NREL's SAM to conduct a financial analysis model for the wind farm. Within the SAM, the team conducted a simulation using a partnership flip with debt financial plan to generate a power purchase agreement (PPA) to negotiate with Tri-State; if not, the team will reach out to the Public Service of Colorado, a subsidiary of Xcel Energy. The team selected this financial plan because it is most commonly used for wind farms, in addition, this setup will allow investors to benefit from the Production Tax Credits (PTC) for the first 10 years and the project will be funded.

In the simulation, the team found with an internal rate of return (IRR) of 9% and a flip year at 12 years would be sufficient. Other assumptions include turbines cost at $1,030/kW determined by Vestas representative, operation and maintenance fixed annual cost at $2.925 M, with an interconnect voltage at 203 kV, 5.0 miles from interconnect, a DSCR at 1.2, with a production tax credit at 0.015 $/kWh for 10 years. Within the SAM simulation, the team researched a sales tax exemption for purchasing turbine equipment in Colorado. This sales exemption in Colorado was not extended into 2020, so the team kept the SAM default value of 4% [15]. The NREL SAM Inputs are listed in Table 4 for reference. The SAM software simulation resulted in a Levelized Cost of Energy (LCOE) of 3.56 ¢/kWh and a PPA price of 3.97 ¢/kWh.

Table 4: NREL SAM Inputs

Metric	Value	Reference
Total Losses	19.674%	[16]
Uncertainties	SAM Default Values	
Degradation	SAM Default Values	
Turbine cost	$1,030/kW	Vestas Representative
O&M Fixed Annual Cost	$2,295,000/year	Vestas Representative
Interconnect Voltage	203 kV	[17]
Analysis Period	20 years	CWC Rule Book
Federal Income Tax Rate	21%	SAM Default Value
State Income Tax Rate	4.63%	[18]
Sales Tax	4%	SAM Default Value [15]
DSCR	1.2	
IRR Target	9%	
Target Year	12 years	
Share of Equity	Investor: 85% Developer: 15%	
Production Tax Credit (PTC)	0.015 $/kWh, 10 years	[19]

Table 5: NREL SAM Outputs

Metric	Value
Annual Energy Output	410.67 GWh
Capacity Factor	47.4%
Levelized Cost of Energy (real)	3.56 ¢/kWh
PPA Price (Year 1)	3.97 ¢/kWh
Levelized PPA Price (real)	3.49 ¢/kWh
Investor NPV Over Project Life	$164,367
Developer NPV Over Project Life	$81,633
Net Capital Cost	$169.1M
Equity	$78.2M
Size of Debt	$90.9M
Debt to Equity Ratio	1.16

Comparing these prices to the Levelized Cost of Wind Energy from Lawrence Berkeley National lab, the interior has 3.368 ¢/kWh and the west being $5.628 ¢/kWh, the team's LCOE result is within the range of the two costs comparisons, which can verify the result is justifiable for the regions [20]. Another source the team compared their results to is the Lazard's Levelized Cost of Energy Analysis [21] that provided a range of 1.10-4.5 ¢/kWh. Further results are shown in Table 5.

In the SAM simulation, one of the team's goal was to target a net present value for both the investor and developer to be as close to zero and a positive value to assure they both do not owe a large amount, a couple of millions of dollars, at the end of the project. The debt to equity ratio demonstrates the project will be profitable but with a small amount of debt.

To get a visual representation, the team generated a cash flow analysis within SAM to illustrate the cost and revenue over the years, shown in Figure 4 below. At the beginning the investors put a large amount of investment into the wind farm yet has an incoming flow of cash until the flip year, then the developer starts to gain money at the end of the project's life.

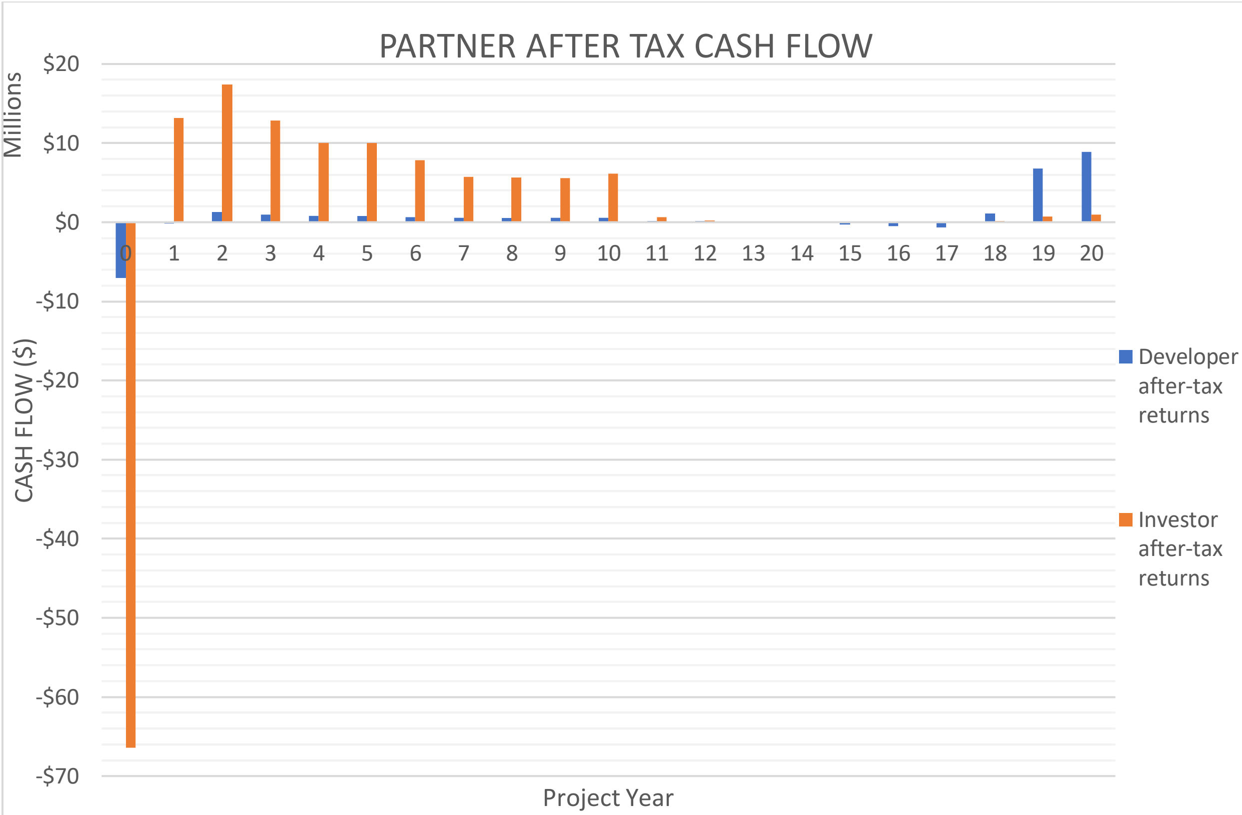


Figure 4: Cash flow of the wind farm after-tax for developer and investor.

Financial Risk and Alternatives

The wind farm will face potential bankable risks, so the team developed alternatives to mitigate them. The first is construction risk that could involve delays in the supply chain for parts that result in slowing down construction. A delay due to construction could be mitigated by also setting aside a contingency fund as well as guarantees and punitive payments if needed [22]. Regulatory risks can also affect the project, which may include the Production Tax Incentive that expires within 10 years shorter than the 20-year lifespan of the project. To mitigate this, the team will create a plan to possibly repower the site such as switch blades or other major parts to re-power the plant to apply for another PTC if possible. Last is market and selling price risk include the uncertainty of a guaranteed price to sell the farm's energy. This risk can be mitigated by establishing a stable PPA price to ensure there will be a flow of revenue throughout the project's lifespan.

Section III: Design Changes

Site Location

Prowers County, since the team's initial conceptualization and decision, had been solidified as the county where the site would be located. However, the site area within the county had altered multiple times during the design process. The final micro-siting and site area have been presented previously in the report.

The rules and requirements set by the Collegiate Wind Competition prohibited proposals on existing wind farm locations. After re-evaluating the area, the team's earlier selected site would have been located uncomfortably close to another site. Thus, to abide by the rules and respect the growing area of other sites, the proposed site was set back to a more central region of Prowers county.

This repositioning also affected the micro-siting process due to the increase in local roads. Additionally, the wind rose data suggested that the wind direction will seasonally shift from southeast to west. To reduce the wake losses caused by this shift, the turbines were offset relative to the longitude and latitude axis.

Turbine

The turbine selection was affected by numerous variables throughout the process. The first regards the wind rose data. From the collected information, a hub height nearer to the same height as the meteorological mast will be more accurate to our calculations. Furthermore, the lower hub heights were unusable with the program's data. This prevents any data from being collected and eliminates the selection.

Because the hub height variations are determined by the model, we had to change hub heights when switching models. When speaking with a Vestas representative, the team concluded that a newer model should be used. While this required a change in a hub height, the turbine met the same meteorological masts requirements.

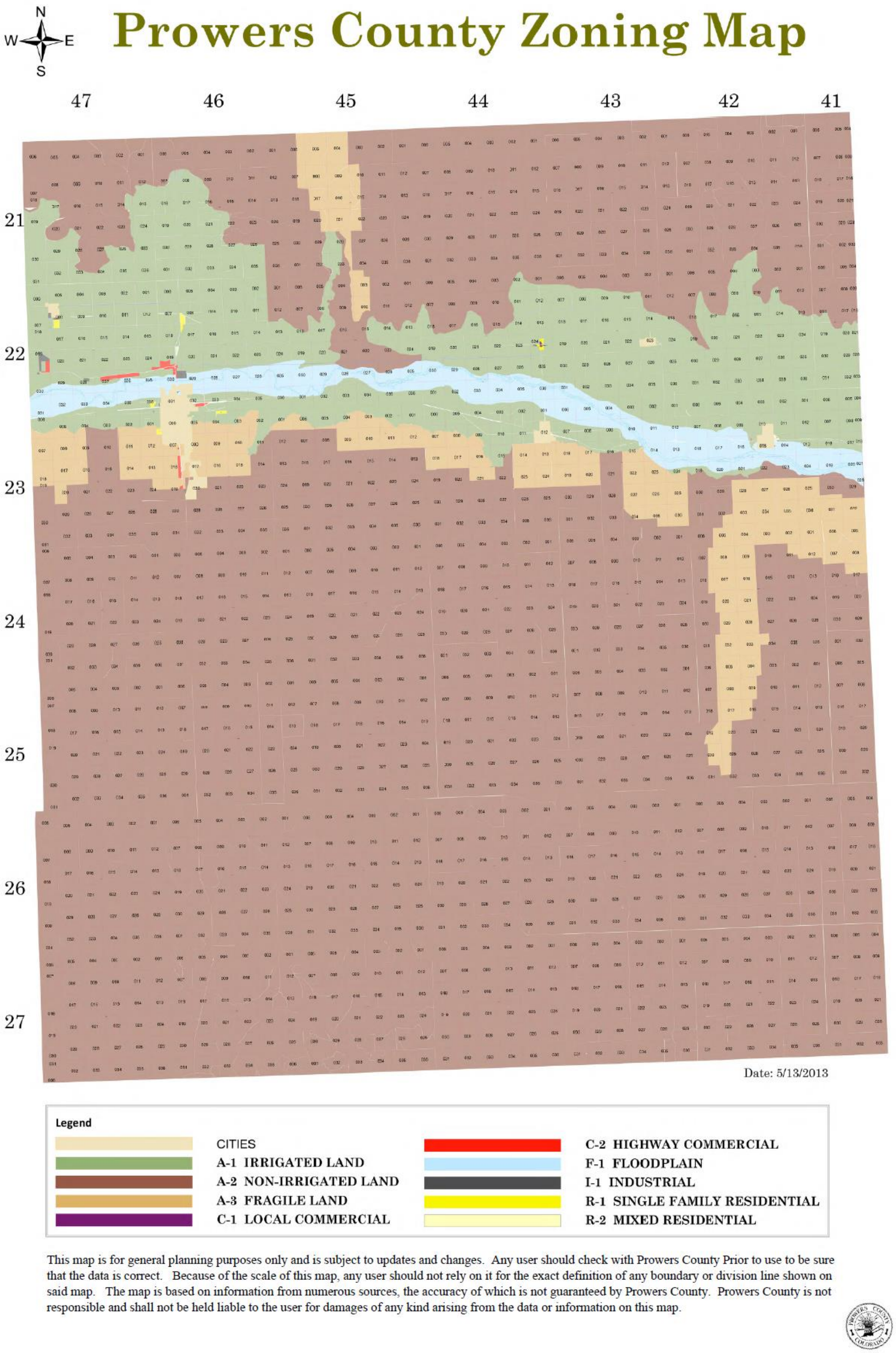
Financial Analysis

The cost of the project has been fine-tuned with new information. From the construction of the project to the updates in financial analysis software, the team made constant alterations to both meet the investment recommendations and the low capital cost. The final software used was an NREL model that input our operating costs, among several desired outcomes, and calculated a capital cost and necessary investment information. This was selected over the hand calculations by the team.

The team also initially conducted estimation calculations for the O&M which was based on the NREL's 2006 "Wind Turbine Design Cost and Scaling Model" report [23]. When the estimations produced by the NREL report was compared to the "2018 Wind Technologies Market Report" and "2018 Cost of Wind Energy Review" it was found that the O&M estimations were higher by an average of 38 $/kW-year than the markets current O&M ranges of 33 and 59 $/kW-year [2,24]. After communicating with the Vestas representative and the NREL consultants the team decided to use Vestas' O&M price and create a reserve fund for additional O&M outside the turbines for after the flip year. Based on this information, the first two methods would be deemed less significant to the final report's figures.

Appendix

Appendix A: Prowers County Zoning Map [25]



Appendix B: Prowers County A-2 Zoning Permit [26]

PROWERS COUNTY ZONING PERMIT APPLICATION

A-2 Non Irrigated Land District **Permit Number—**

TO BE COMPLETED BY APPLICANT

Date:__________ Telephone Number:__________

Property Owner:__________

Mailing Address:__________

Physical Address:__________

Email:__________

Legal Description of Property:__________

Acreage of Property:__________

Describe all Structures Currently on Property:

Describe All Current Land Uses of Property:

Proposed Use For This Property (Please be Specific):

Water Source:__________

Method of Wastewater Disposal:__________

Applicant Signature:__________

Revised: January 13, 2014

STAFF USE ONLY

	Minimum Requirements	Actual
Lot Area	> 35 Acres *	
Lot Dimensions	140 ft X 140ft	
Lot Coverage	25%	
Building Height	See Airport Overlay	
Front Yard Setback	50 Feet	
Side Yard Setback	10 Feet	
Rear Yard Setback	15 Feet	
Parking Space	See Section 15	
Loading Space	None Required	
Fences/Walls/Hedges	No Limitations	
Signs	See Section 17	
Performance Standards	N/A	

Is Property Located within Prowers County-Lamar Joint Planning Area? Yes ☐ No ☐

Is Property Located Within Airport Overlay? Yes ☐ No ☐

Is Property Located in a Floodplain? Yes ☐ No ☐

Reviewed By:__________ Date:__________

Appendix C: Wildlife in Prowers County

Figure C1: Golden Eagle Habitat in Prowers. [1]

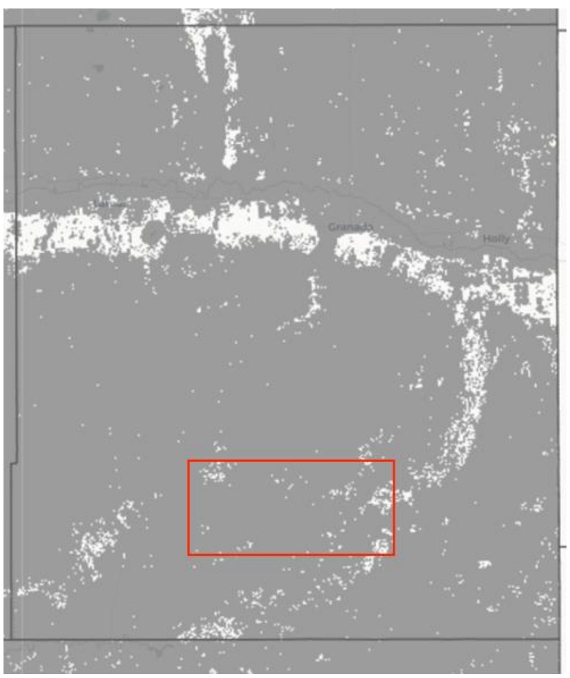


Figure C2: Bald Eagle Habitat in Prowers. [1]

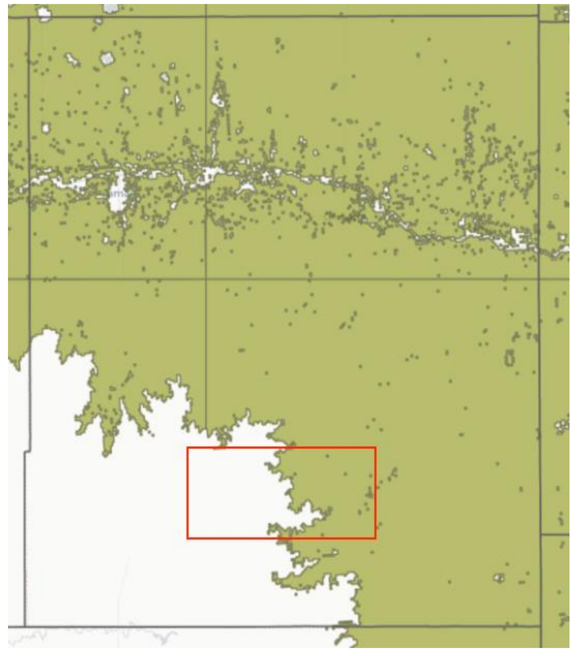


Figure C3: Greater Prairie Chicken Habitat in Prowers. [1]

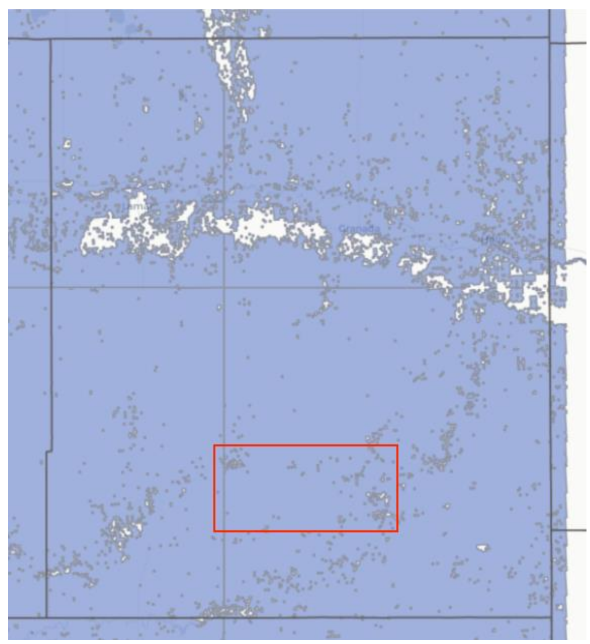


Figure C4: Whooping Crane Habitat in Prowers County. [1]

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