NORTHERN ARIZONA UNIVERSITY

College of Engineering, Informatics, and Applied Sciences

Wind Turbine and Solar PV Power Plant Development Report

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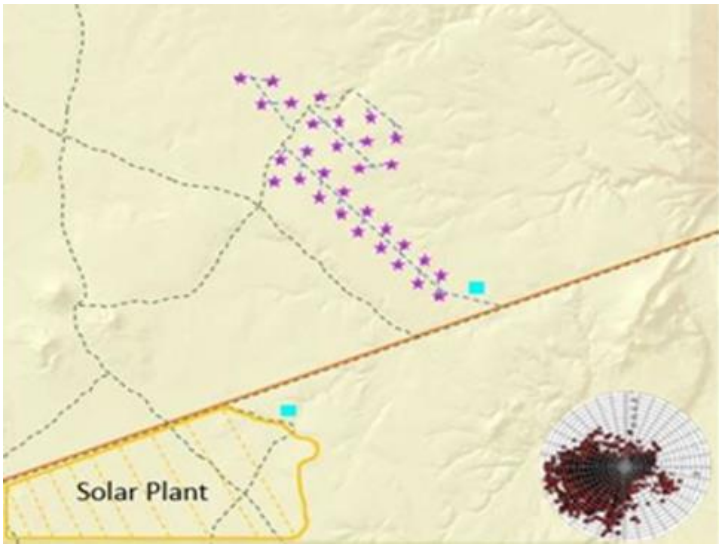

Collegiate Wind Competition 2019

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1 Brief Site Description

1.1 Top 3 Sites

Team NAU's 2018 team was tasked with determining a site, with specific turbine layout, for a 100-megawatt (MW) wind power plant within 100 miles of Northern Arizona University's (NAU) Flagstaff campus [1]. The 2018 team utilized the National Renewable Energy Laboratory's (NREL) free online program, Wind Prospector [2], to locate areas of high wind resource and existing high voltage transmission lines. NAU selected three sites and compared their characteristics in Table 1-1. The Grey Mountain site was eventually selected. Figure 1-1 displays the restricted vicinity for the site, the three potential sites and the buildable area of the site that was eventually selected.

Table 1-1: Evaluation of Top Sites

Site	Pros	Cons
Willaha	Buildable terrain	Near the Grand Canyon National Park
	Sections of private property	In the wake of an existing wind power plant
	Low vegetation density	Lowest wind resource of evaluated sites
Grey Mountain	Buildable terrain	Possible eagle nesting area
	Low vegetation density	With in the view shed of the Navajo nation
	Sections of private property	
Mormon Lake	Highest wind resource	Known eagle nesting area
		High turbulence intensity
		Unfavorable ground conditions for building
		Mainly national forest land

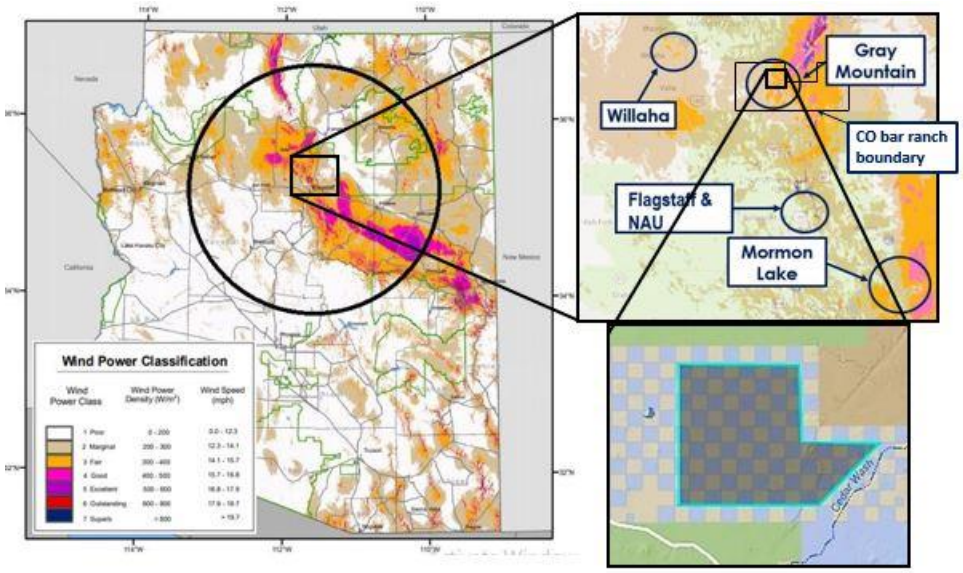

Figure 1-1: State of Arizona with 100-mile radius around NAU with section view of 2018 sites [3]

1.2 Final Site

As shown in Figure 1-1, the proposed site consists of checkerboard layout of private land, the CO bar ranch, and Arizona state trust land. Both land types will be used in this hypothetical wind farm via a 50/50 split of land usage which was suggested by the landowner. Finally, the 2018 team researched the permits associated with building a wind power plant in Coconino County. These permits include a conditional use permit (general permit for a project of this scale), an incidental take permit from the U.S. Fish and Wildlife services (mitigation in the event an eagle is killed on the site), right of way permits (for access and use of the Arizona state land within the site), and a permit or agreement with the Arizona Corporation Commission to tie into the existing 500-kilovolt (kV) transmission line [4].

2 Design Changes

2.1 Turbine Selection

NAU's 2018 team had selected the MingYang 3.0 -135 onshore wind turbine for the site. Since this turbine is not available in the United States the 2019 team determined that researching other turbines would be beneficial to the project. Table 2-1 is a compilation of the criteria used by the current team to select a turbine for the site [5].

Table 2-1: Turbine Selection Criteria

Turbine	Available in the U.S.	IEC Wind Class	Cut in speed (m/s)	Cut out speed (m/s)	Rated power (kW)	Hub height (m)
Vestas 136-3.45	**yes**	**IIB or IIIA**	**3**	**22.5**	**3450**	**82 or 132**
Vestas 150-5.6	yes	S	3	25	5600	105 or 166
GE Cypress 4.5	yes	IIS	NA	NA	4500	79
GE 127-2.2	yes	III	3	NA	2500	101 or 121
Goldwing 82-1.5	no	IIIA	3	22	1500	70 or 85

The V136-3.45 MW turbine was eventually selected due to it having seven hub heights that are rated for class IIIA wind, while also producing 3.45 MW of power. From the seven hub heights available, two were evaluated (82-meters and 132-meters), one that keeps the turbine below the FAA's 500-foot threshold and the other below their 700-foot threshold. As will be discussed in more detail later, the levelized cost of energy (LCOE) was calculated for both hub heights, and the final hub height will be discussed in the financial analysis section of this report.

2.2 Resources and Terrain

The current turbine layout took 43 iterations to get the thirty-one individual turbines placed on the proposed site [6]. The team used elevation, net energy output, and total wake efficiency to determine the best locations for each turbine. Iteration one was mainly driven by providing a one-half mile from any ridge lines in order to stay out of eagle territory. The layout was then iterated by focusing on turbine wake and placement to increase the power output. Other iterations were performed with the goal to get the most power out of the land while staying away from Federal land and the Navajo Nation. NAU's final iteration was additionally driven by infrastructure cost. The current layout has accessible roads, but NAU anticipates building new roads and widening pre-existing roads for better accessibility. Due to Arizona's abundant solar resource NAU is proposing to build a 200 MW solar plant to allow the site to be more financially feasible. The data used in WindFarmer was collected via NAU's anemometer loan program [7]. The layout of the wind and solar plant is shown in Figure 2-1.

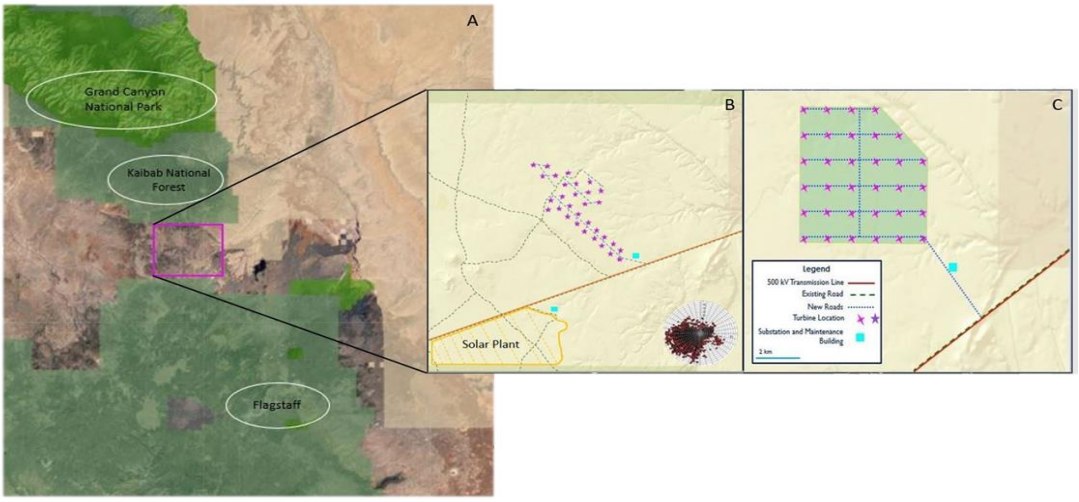

Figure 2-1: Boundaries of Site(A) NAU's CWC19 New Layout (B) NAU's CWC18 Old Layout(C)

In summary, NAU's 2019 team is proposing a three-phase building plan for the proposed site. Phase one, being a100 MW wind plant. Phase two, a 200 MW solar plant. This solar plant will consist of 563,381 solar panels and 80 inverters. This solar plant will allow the local prey base population to grow under the safety and cover of the panels, which will encourage eagles to move to the southwest away from the turbines. Phase three, battery storage for peak shaving. A summary of wind and solar is shown in Table 2-2.

Table 2-2: Specifications for Power Plants

Solar Plant					
SPR-P17-355-COM (panel)		*SC 2500-EV (inverter)*		*DuraTrack HZ v3 (tracking system)*	
Vmpp	43.6 V	Efficiency	98.60%	Tracking Type	Horizontal single axis
Impp	8.18 A	Max input voltage	1500V	Drive Type	Rotating gear drive
Voc	51.9 V	Max input current	3000 A	Backtracking	yes
Isc	8.68 A				
Wind Farm					
V136-3.45 MW IEC IIB/IEC IIIA					
Rated power	Cut-in speed	Cut-out speed	Re cut-in speed	Gearbox	
3450 kW	3 m/s	22.5 m/s	20 m/s	two planetary stage and one helical stage	

2.3 Roads and Transmission

As shown in Figure 2-1, the transmission lines are in proximity to the proposed plant. After permits are obtained from the Arizona Corporation Commission, interconnection fees will be approximately $500,000 [6]. In order to reduce costs, all the turbines will be integrated into the 500kV transmission line via a single junction. Additionally, as can be seen in Figure 2-1, the site contains existing service roads in going through the site with only a single short road needing to be constructed to complete the building and service of the site during its lifetime.

2.4 Feasibility and Permitting

Due to the **Navajo Generating Station (NGS)** closing soon in Northern Arizona, there will be 2.25 gigawatts of power removed from the 500kV line near the proposed site. This would allow room on the transmission line for the proposed power plants. Currently, there is no proposed source to replace the full 2.2 gigawatts of power capacity that will be lost when NGS closes, making the proposed 307MW (107MW wind and 200MW solar) power plants feasible as a partial replacement.

The requirements for Coconino County to approve utility-scale wind and solar projects, included pre-construction data on existing wildlife conditions, inventories of historic and archeological resources, transmission availability and an interconnection evaluation that was found to be favorable, construction-related impact mitigation for existing roadways, and plans for post-construction monitoring studies in accordance with guidelines from independent agencies and experts. The U.S. Fish and Wildlife Service, AZ Game and Fish Department, and the Natural Resource Conservation Service have been contacted to confirm their satisfaction of these requirements. This information was essential for decision-making bodies to make their educated choices leading to plant approval. Additionally, because the proposed site encompasses both state trust and privately-owned land, a right-of-way permit was obtained from the Arizona State Land Department governmental website to utilize the portion of the project land that will lie on the state-owned sections.

To be in compliance with the Federal Aviation Administration (FAA) guidelines, structures on the site had to be altered in accordance to AC 70/7460-1L, any permanent or temporary structure over 200 feet in height needed to be marked or lighted unless an FAA study has been conducted that they do not impair avian safety. These regulations differ at heights exceeding 500 feet and again at 700 feet for wind turbines, but with the team's chosen turbine the tip of the blades at top dead center will be well under the 500-foot threshold. For a clustered array of turbines lighting must be placed along the entirety of the wind farm perimeter with no unlit gaps more than 804 meters long. FAA L864 red obstruction lights must be used and are required to flash within 1/20 of a second of each other during night operation. Meteorological towers were also included in the wind farm to continue data collection and analysis of the site and had to be painted with patterned white and aviation orange paint, and in addition if their tower was guyed, the guy wires required aviation orange painted marker balls. An example of clustered layout lighting and meteorological tower marking is given in Figure 2-2 [8].

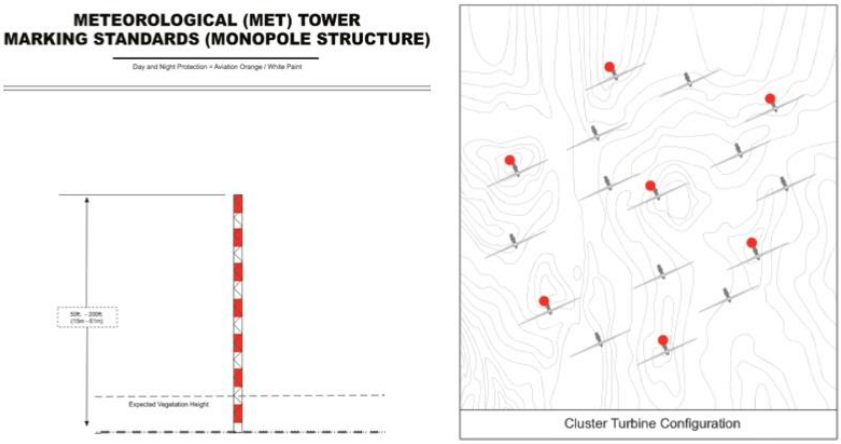

Figure 2-2: FAA MET Tower Marking and Array Lighting Guidelines

2.5 Outreach and Interviews with Third Parties

The 2018 team met with the Coconino County Planning and Zoning Board twice to assess the most important aspects of getting approval by the county. They directed NAU to obtain a Conditional Use Permit (CUP). The CUP is granted to projects that are in accordance with the objectives of the Zoning Ordinance and the purpose of the zone in which the site is located. While taking into consideration the use, operation and maintenance will not be detrimental to the public health, safety, welfare, or materially injurious to properties or improvements in the vicinity. Finally, the site must comply with each of the applicable provisions of the County Zoning Ordinance. To gain more information on the current policy of

Northern Arizona the 2019 team met with Billy Cordasco, the president of Babbitt Ranches the land for the proposed site, along with Tom Koronkiewicz, SWCA environmental consultant. During the meeting with Billy and Tom they outlined things that could be done to improve the sites chances of approval. One of the largest concerns that they highlighted was avian mortality. Brown bats as well as eagles populate the area of the proposed site, but after consulting with wildlife experts it was found that only eagle mortality would need to be focused on for our site [6, 4]. Through the AZ Game and Fish department along with the U.S. Fish and Wildlife, studies of the rate of eagle take are being conducted, a mitigation fund has been created in anticipation of any eagles that are incidentally taken and retrofit options are being kept available. This also provided the team with an opportunity to develop a new method of mitigation, and as mentioned above the solar power plant will be used to increase prey density to help keep the eagle population steady. From the Environmental Protection Agency, the team has obtained the 404 wetlands permit to protect water around the site. Tribal consultation and meetings have been conducted to avoid impediments later during the construction process.

Additionally, special consideration was given to emphasizing the 20-year tenure of the project and the team's investment to the success of the power plant. This included creating a decommissioning and restoration plan that will bring used land to the condition it was in before the project took place, how the project will positively impact the economy by reducing electricity costs to less than half the current rate. Finally, this power plant will improve the renewable energy image of Arizona as visitors of the Grand Canyon and current residents who will be noticing the project.

3 Financial Analysis

3.1 Initial Capital Cost

The initial capital costs associated with the proposed power plant were calculated using the National Renewable Energy Laboratory's (NREL) Wind Turbine Design Cost and Scaling Model [9]. This report was created in 2002 and therefore the values produced from the initial analysis were brought to present values by taking inflation into account. Table 3.1 contains key price points for the two hub heights that the team compared.

3.2 Annual Energy Production and Operating Expenses

The Vestas 136-3.45 MW turbine was modeled using WindFarmer analyst in order to determine the net energy production for both the 132- and 82-meter hub height. Table 3-1 below displays the resulting power outputs. Like the initial capital costs the annual expenses were calculated from NREL's technical report and brought to today's values for this report. Three annual expenses were calculated: levelized overhaul and replacement costs (LO&R), operation and maintenance costs (O&M) and finally land lease costs [10].

3.2.1 Land Lease Costs

While meeting with the landowners it was agreed that a land lease agreement would need to include the ground where the turbines sit, the wind resource they utilize and the resource up wind of the power plant. Assuming that the land lease costs will total roughly about 1-4% of the annual revenue of the plant, values of 1% for upwind land, 1.4% for actual wind resource, and 1% for the used land were applied for estimated costs. These three leases were assigned values of 0.0064, 0.0046, and 0.0046 $/kWh respectively, and were determined by finding out which lease was the most valuable to the land owner.

Table 3-1: Initial Capital Costs per Turbine

Vestas 136-3.45 MW		
Component	**82-meter hub height (in $M)**	**132-meter hub height (in $M)**
Average Wind Speed (m/s)	9.34	9.91
Gross Energy (GWh/year)	454.9	478
Rotor	0.76	0.76
Drive Train, Nacelle	2.3	2.3
Control, Safety System, Condition Monitoring	0.49	0.49
Tower	1.01	1.63
Balance of Station		
Foundations	0.12	0.15
Transportation	0.38	0.56
Roads & Civil Work	0.22	0.22
Assembly and Installation	0.16	0.27
Electrical Interface/Connection	0.37	0.37
Engineering and Permits	0.11	0.11
Total Costs Per Turbine	**5.49**	**6.42**
Annual Expenses		
Expense	**Price ($ / kWh)**	
LO&R	0.0036	
O&M	0.01	
Land Lease Costs	0.0015	
Total Annual Expenses	**0.0155**	

3.3 Solar Costs

The costs associated with adding a 200 MW solar power plant were determined using NREL's System Advisory Model (SAM) with the expected tax rates and incentives for the area included into SAM's calculation. Table 3-2 below is a summary of SAM's outputs [11].

Table 3-2: Solar Power Plant Summary

Solar Power Plant	
Annual Energy Production (GWh/year)	451.1
Initial Capital Costs (in $M)	222.1
LCOE ($/kWh)	**0.043**

3.4 Incentives and Final Levelized Cost of Energy

According to the team's contact at the Coconino County offices, due to the location and size of the proposed power plant, a few incentives are currently applicable. First, the Business Energy Investment Tax Credit (ITC) which would provide a tax credit for 12% of the initial capital costs of the wind power plant. Second, the Renewable Electricity Production Tax Credit (PTC) which provides wind power plants $0.0038 per kWh for any facilities built in 2019. The PTC can be applied to a plant even if it is not fully developed by the end of this year, if all the necessary materials are purchased and, "safe harbored" with intent to complete building in the four years after the end of 2019. Since these are available in lieu of, not in addition to each other, one had to be chosen. The PTC will be applied to the project at the full rate for the first 10 years of operation, while the ITC is set to drop to 0% of expenditures after 12/31/2019, because of this the PTC will be applied to this project. In addition to that the Energy Equipment Property

Tax Exemption will be applied and can be worth up to 100% of increased value tax [12]. Several other incentives that could be applied to the project were not analyzed due to the lack of need to delve into the aspects of depreciation of book assets.

The levelized cost of energy was calculated for both hub heights as well as with and without incentives as can be seen in Table 3-3. Additionally, the LCOE was calculated for a combined wind and solar power plant as mentioned above that would make the site more financially feasible.

Table 3-3: Levelized Cost of Energy

	82- meter hub height	132- meter hub height
LCOE Wind Power Plant ($/kWh)	0.0541	0.0599
LCOE Wind + PTC ($/kWh)	0.0456	0.0507
LCOE Wind + PTC +Solar ($/kWh)	**0.0443**	**0.0468**

4 Summary and Moving Forward

Team NAU developed and optimized a wind power plant for phase one of a renewable energy power plant. In phase two of the project, team NAU is planning to capture some of Arizona's abundant solar resource by implementing a 200MW solar plant. This solar plant will allow the team to improve raptor population by increasing prey base via shelter. Lastly, team NAU plans to implement a battery storage system for peak shaving.

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