Project Development Report

Washington State University-Everett with Everett Community College

MAY 23RD, 2021

Team Members

Alyssa Gorrell WSU-Everett Team Lead	Sarah Hastings WSU-Everett Aerodynamics	Kaitlin Jones WSU-Everett Project Development	Melody Ripsom WSU-Everett Digital Content Creator
Isaiah Funston WSU-Everett Team Lead	Jessica Kupcake WSU-Everett Digital Content Creator	Sam Ayars EvCC Electrical Design	Elena Bahr WSU-Everett Social Media Manager
Kaleb Willis WSU-Everett Rotor Design	Minhkennedy Pham WSU-Everett Rotor Design	James Garfield EvCC Electrical Design	Kayla Haus WSU-Everett Outreach Coordinator
Tahier Seid WSU-Everett Rotor Design	Eliza Goodwin WSU-Everett Project Development	Ben Austin EvCC Communications	Elijah Lovold EvCC Electrical Design
Nathan Blackwell WSU-Everett Content Creation and Digital Outreach	Jackson Wagner WSU-Everett Control System Design		

Advisors

Dr. Gordon Taub WSU-Everett Principle Investigator	Joe Graber EvCC Co-PI	Mike Patching EvCC Co-PI

Red Owl Wind Farm

EWETmedia@gmail.com

Table of Contents

I. Introduction

For this year's project development challenge, the objective was to design a wind farm in Western South Dakota with an overall power output of less than 100MW. The primary objective was to develop a farm with maximum profitability while minimizing environmental and community impact. Achieving this goal is a long and multifaceted process. It begins with learning about the basics of building a wind farm and stepping through the process step by step. Last year was Everett Wind Energy Team's first year participating in the Collegiate Wind Competition, and the focus was learning. This year's goal was to apply our knowledge and advance in the competition. Unfortunately, last year's wind farm yielded disappointing results due to lower expected wind resources. Therefore, this year's primary focus was to use available wind resources as the primary consideration and let all others be additional considerations.

We designed the Red Owl Wind Farm (ROWF) based on criteria in the middle of Meade county, located in Western South Dakota. Due to the high wind resources, ease of accessibility, and gentle terrain, the proposed ROWF has an extremely high potential to be financially lucrative. This report will adhere to the following structure to explain our findings. Section 2 explains why and how our team selected the ROWF site over other possible locations. Section 3 details the overall design of the ROWF. Section 4 contains the financial analysis and all of the monetary considerations. Finally, Section 5 provides the conclusion for our project and highlights any last noteworthy pieces of information.

II. Site Selection

During last year's competition for the team's wind farm, the primary issue was the overall lack of wind at the selected location. Instead of the wind speeds being the primary consideration, it a secondary concern. Learning from last year's mistake, the primary factor for selecting a location this year was the available wind resources at any given site. A wind resource map as seen in **Figure 1** was consulted to identify the regions with the highest potential. From this map, only locations with wind resources rated as "excellent" or better were chosen for further examination. Next was the process of narrowing down sites through analysis. The next criteria for choosing a location was researching the various Native American Reservations that occupy large areas of the state.

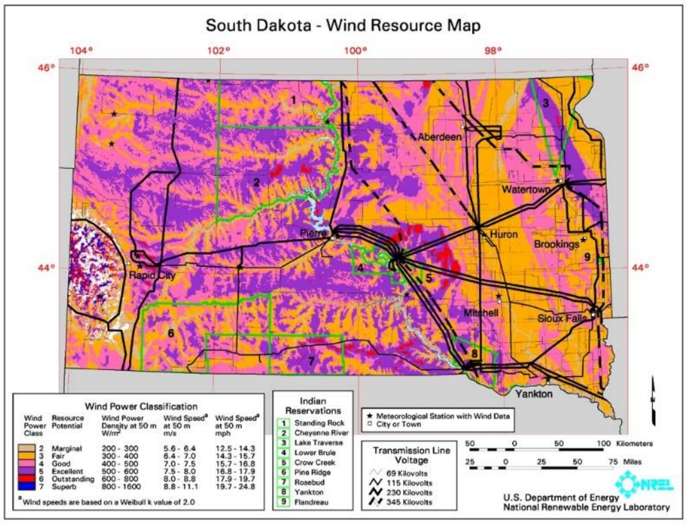

Figure 1: South Dakota Wind Resource Map and Transmission Lines

Initially, the team believed building a wind farm in one of these reservations could provide a sizable economic opportunity for the resident tribes, as many of the reservations are among the country's most impoverished areas. The idea was that a theoretical partnership with the tribe would be a much-needed economic boost for the site. However, due to the potential insensitivity of approaching actual landowners and regional officials with a purely hypothetical project, this route was ruled out. Talking about a possible financial gain without any real plans for development for the landowners could have been perceived as insensitive to their current situation. From this consideration, we removed all tribal lands from consideration.

The next factor that we evaluated was the proximity of sites to transmission lines and major roadways. For developing any wind farm, the cost can be greatly reduced by strategic planning in transmission lines and roads for accessing the turbines. To limit these costs, the wind farm can be placed in a location with close access to existing infrastructure for each. While roads are standard, high-powered transmission lines are far less common. Thus, proximity to major transmission lines was the next factor for eliminating areas. Another significant consideration to account for is the availability of a large tract of land that could be developed into a wind farm. While farming does not automatically rule out a location for a wind farm, it is dependent on what type of farming is occurring. For example, wind farms can easily be paired with livestock farming such as cattle due to the free-roaming nature of livestock. However, this is not the case for large crop fields that require extensive sprinkler systems that would be interfered with by turbines. Therefore, large areas with no more than a few crop fields or buildings are ideal. The final consideration is the terrain of the area. A rugged site with steep elevation gradients can make the site difficult to develop.

We looked at the environmental impact the Red Owl Wind Farm Site in Meade County, South Dakota, would have with the help of the ENVS 493 class from Western Washington University. Our environmental impact analysis includes many factors, such as environmental justice, geological impacts, impacts to wildlife, air quality, impact on habitat, water quality, and more.

The landscape of South Dakota is primarily made up of many rolling plains with herbaceous vegetation. The Red Owl Site contains these plains while also having other habitats, including wetlands and agricultural land (cultivated crops and hay/pasture). Agricultural land makes up 12% of the Red Owl site, while wetlands make up 2,169 acres. With care being taken during construction not to contaminate the water, we have found that the impact on water would be minor. The geological and sediment makeup of the Red Owl Site consists of claystone and siltstone (deep clay, shale, sandy/silt loams). During construction, 300 acres of land will temporarily be disturbed with a permanent site disturbance of 100 acres. This impact on the site's geology is minor.

South Dakota has rich, diverse wildlife. Terrestrial species include antelopes, coyotes, and prairie dogs; aerial species include birds and bats. The bird variety consists of 28 species of raptors, such as bald and golden eagles. The Red Owl Site has a limited population of elk. Threatened species include the northern long-eared bat and black-footed ferret. While the effects on terrestrial wildlife have not been as extensively researched, wind turbines can be harmful to birds and bats due to collisions and barotrauma in bats. However, there are ways to mitigate some of the adverse effects, such as removing any factors of the landscape that encourage birds of prey to hunt near the turbines and putting serrations on to the leading edges of turbine blades to lower noise. Our findings conclude that the impact on wildlife should be minor.

Red Owl is the most accessible site with 2-4x as many local roads throughout the area, and construction here would create a minor impact on transportation. There is a low density of archaeological sites in Meade County compared to the rest of South Dakota, so the impact on historical sites is negligible. Regarding noise, the existing background noise at Red Owl is low at approximately 20-25 decibels. Temporary construction noise and the low 43-decibel hum of a finished turbine would only impact the site's noise in a minor way. The impact to air quality would also be minor during construction, operation, and maintenance. Along with monetary compensation to the landowners, lower utility bills, and cleaner energy, the citizens would be impacted positively.

Upon taking all of these factors into account, three possible sites were determined. The three sites that best fit the criteria for a location are the three areas highlighted in red in **Figure 2**. The three sites were named Shadehill, Bixby, and ROWF based upon geographical features and regional names from top to bottom. Each of the three sites had its particular strengths and weaknesses compared to the other options. Each of the three sites met the criteria already discussed, along with the environmental and community factors used to decide which three locations to utilize. A partnership was formed with a sister Western Washington University program to conduct the environmental study and write an environmental impact statement.

One initial advantage to the ROWF location was the number of residents within or near the proposed boundary of the wind farm. The number of affected residents was roughly 40 individuals in a 5-mile radius around the farm.

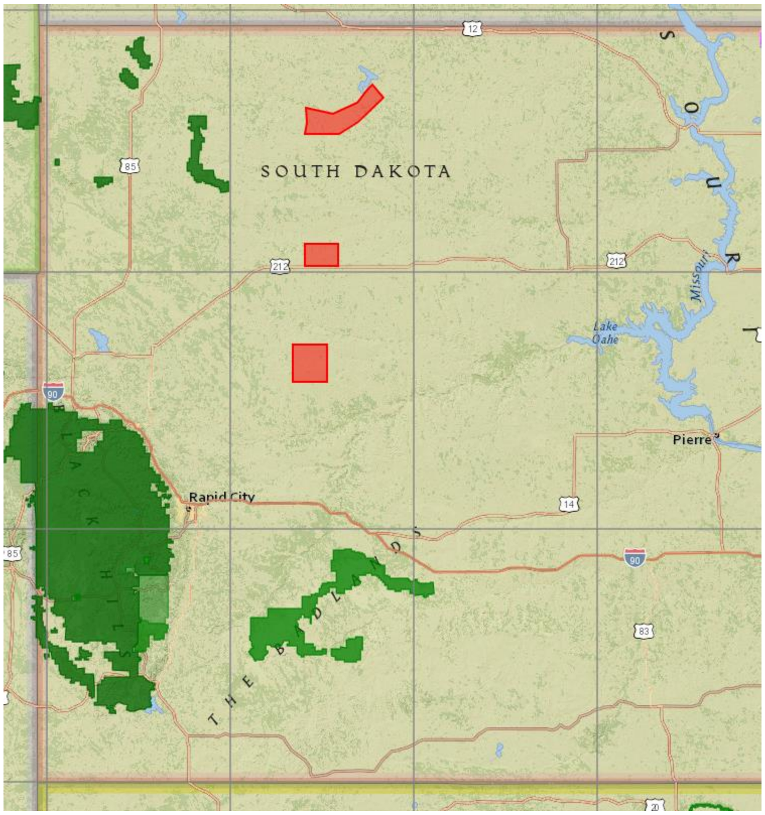

Figure 2: *Final Site Possibilities for Wind Farm*

III. Site Design

Having selected the ROWF as the location for the wind farm, the design process for the site began. The Openwind software was utilized to complete the design of the farm. Using Openwind, the goal is to use as many parameters as possible to enable the software to operate the supplied data to determine the optimal wind farm design. One significant aspect of this is restricting the software on where precisely the software can place a turbine. The first step in setting the parameters for the turbine locations was to establish the boundary of the wind farm. This boundary is shown in yellow as seen in **Figure 3**. Once the general boundary of the site was determined, various layers of additional information were necessary. This information included shapefiles for roads, transmission lines, and substations. Following this, areas were marked as "off-limits" for any turbines. These areas included crop fields and buildings (residences or other) which would are affected. These areas were then marked with red, as seen in **Figure 3.** Once all of the pertinent information for human-made infrastructure had been marked, data for the elevation and land cover in the area was uploaded. The gradients for the elevation within the site were determined by using this geographical information. From this elevation gradient, areas with steep slopes can be eliminated from possible turbine use. The last step to determine the buildable areas for the turbines was to set buffers around each of the non-buildable various regions. The buffers for each feature were established as seen below in **Table 1** to give a significant separation. These buffers are the last tool needed to be able to calculate the buildable areas within the software. **Figure 3** shows the resulting buildable areas for the turbines highlighted in green.

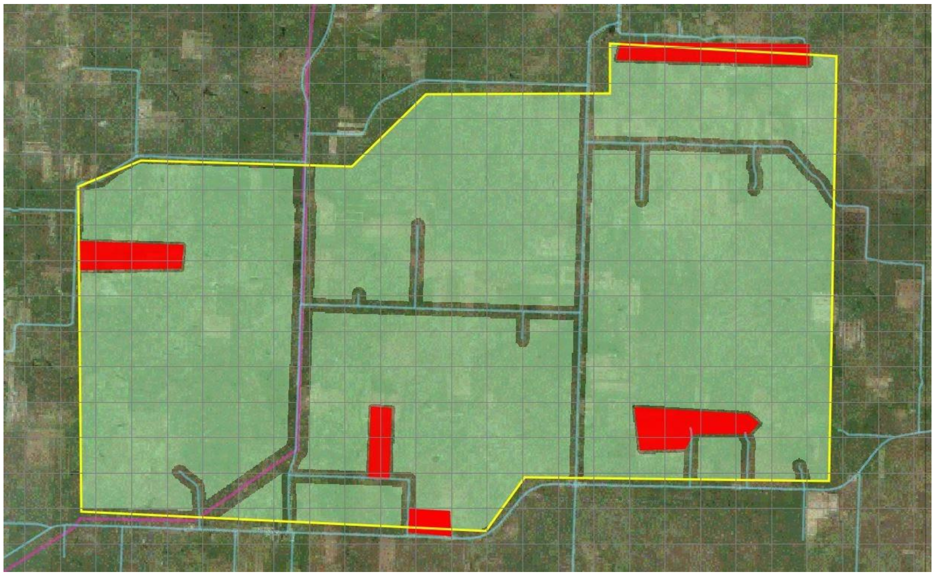

Figure 3: *Buildable land for wind farm*

Table 1: *Turbine setback buffers*

Protected Zones with Buildings (m)	Roads (m)	Transmission Lines (m)
100	200	300

The next step following the definition of the buildable areas for the turbines is to create a wind map for the farm. This map was already established when the elevation, ground cover, etc., were added to the program. Additional information on wind data was needed, along with the previously mentioned geographical features. This wind data comes in MET mast data which was purchased for the specific coordinates. An order is placed for wind roses in any location. Using these locations, an advanced computer model simulates the conditions in the area and delivers approximate data for the average wind speeds, directions, and frequency for each location. This MET mast data is then added to the software as seen in **Figure 4.** Using the data from this MET mast data and the geographical information for the site, Openwind can generate an approximate map of the wind in the area. From this wind map and the buildable area shapefile that was developed prior, the optimization for the turbines could begin.

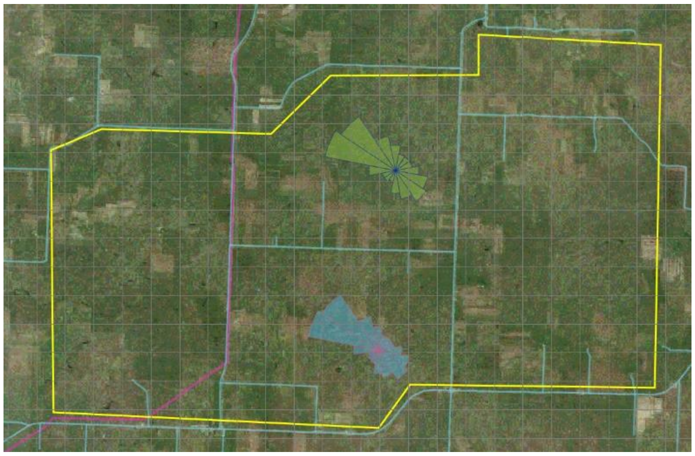

Figure 4: *MET mast data within wind farm Boundaries*

For the optimization process, the main additional piece of information needed is what wake model the optimizer should use to determine how each turbine affects the ones around it. The DAWM Eddy-Viscosity model was selected due to its more extensive calculations for the wake. While it is more computationally expensive, it was considered beneficial to get more accurate results for wake interference. After fiddling with the turbine placement and running the optimizer, the farm was found to have a capacity factor of 59.03%, seen in **Figure 5.** One can observe two things from this turbine configuration. First, it can be seen that the turbine placement generates the most power when the turbines are placed along the ridges with exposure to the dominant wind direction, which tends to be in the Northwest direction. The other noteworthy bit of information in the layout of the turbines is how they are placed concerning each other. For any wind farm, the turbulence caused by turbines in their wake can significantly decrease the performance of any turbine behind it relative to the current wind direction. To mitigate this issue, the DAWM Eddy-Viscosity wake model was used to ensure that the turbines affect each other as little as possible. In **Figure 5,** the turbines are arranged to form a line perpendicular to the most prominent wind direction. These turbines will have an optimal arrangement, which harnesses wind power for the majority of the time. Any wind blowing parallel to the turbines' lines

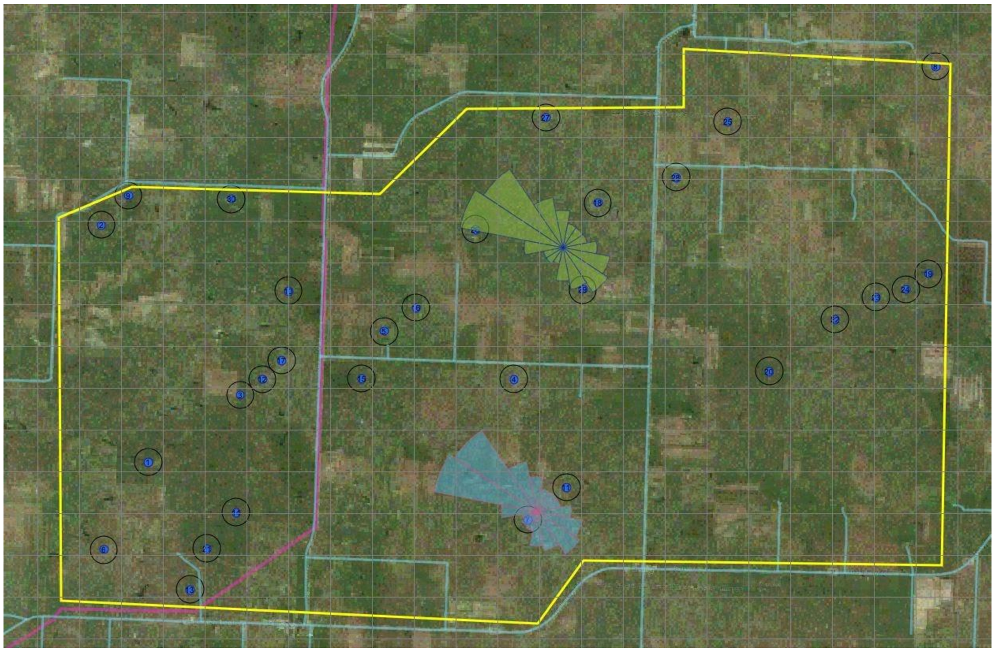

Figure 5: *Turbine layout for proposed wind farm*

is relatively infrequent and has low wind potentials. Therefore, wake from the turbines in the rows will only occasionally affect the turbines surrounding them. Additionally, these rows of turbines are placed 1 or 2 miles apart, so the flow of the wind returns to normal by the time it reaches the next row.

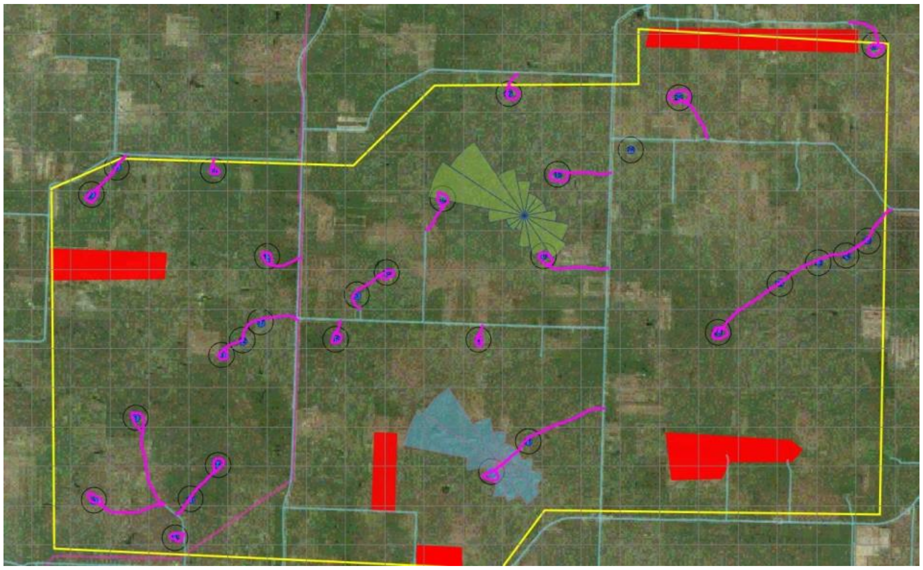

Figure 6: Proposed road configuration for wind farm

With the turbines placed in their final positions, the subsequent significant development is to plan out where the roads need to be established to access the turbines. These roads enable the trucks carrying the turbines, cranes, and additional construction vehicles to reach the various sites and build the turbines. Furthermore, it provides access down the road for maintenance on the turbines. Due to the plentiful roads in the area, only a few roads need to be installed to access the turbines. No more than 10-15 miles of roads are necessary for accessing the entire wind farm. The proposed layout for these roads can be seen in **Figure 6.** An additional feature noted in this figure regards road elements with roundabouts that allow large vehicles to turn around.

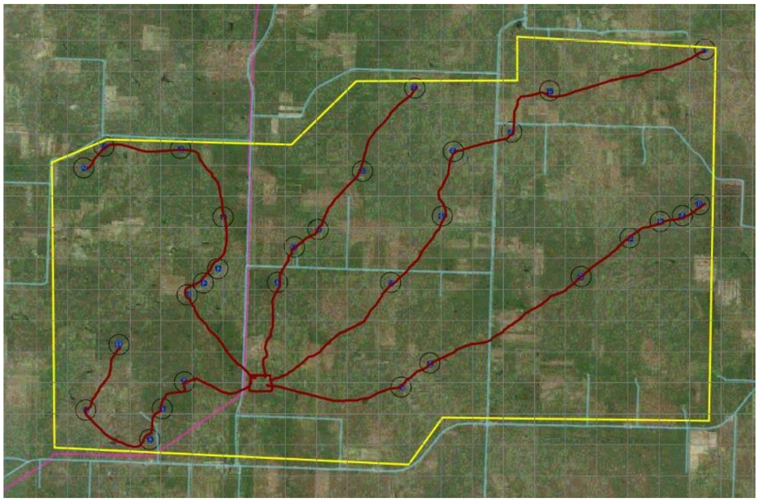

Figure 7: Proposed transmission lines and substation for wind farm

The final component of the wind farm design is the proposed transmission lines and substations, which are seen in **Figure 7.** Chains of turbines are all connected in series to the substation, which sits next to the central power line, shown in pink. The objective of these lines was to build as few as possible and have the substation located right next to the major power lines. One last note for these lines is that the vast majority of them would be buried underground to keep out of the way. The following section will delve into the financial aspects of this proposed wind farm.

IV. Financial Analysis

A. Overview

The JEDI model for land-based wind farms was used for the financial analysis. This model is an NREL tool intended to estimate the economic impact on the state and local communities near potential wind farms. This tool takes information about the possible site and determines the expected initial and ongoing costs. This information is needed for our analysis of the site and why it was chosen for use. The JEDI model is only used to determine an estimated initial and annual cost. Further calculations were conducted to determine the net income from the net energy production.

The model comes with default values that the user can override because not all information for this site is known. Information was manually inputted where possible, and the rest left as default. As we are not using the model for its entire purpose, some values do not affect our desired outcomes. For the values that cause an effect, the default values represent the typical value for most sites and are deemed sufficient.

B. Initial Costs

	Cost	Cost per kW
Equipment		
Turbines and other equipment (excluding blades and towers)	$57,888,000.00	$603.00
Blades	$18,048,000.00	$188.00
Towers	$21,024,000.00	$219.00
Transportation	$10,503,061.37	$109.41
Equipment Total	**$107,463,061.37**	**$1,119.41**
Materials		
Construction (concrete, rebar, equip, roads and site prep)	$6,568,097.21	$68.42
Transformer	$0.00	$0.00
Electrical (drop cable, wire,)	$2,230,962.14	$23.24
HV line extension	$1,563,881.15	$16.29
Materials Subtotal	**$10,362,940.50**	**$107.95**
Labor		
Foundation	$1,596,998.55	$16.64
Erection	$1,708,402.63	$17.80
Electrical	$1,196,870.05	$12.47

Management/Supervision	$1,543,295.60	$16.08
Misc.	$884,232.76	$9.21
Labor Subtotal	**$6,929,799.59**	**$72.19**
Development/Other Costs		
Materials	$2,953,822.53	$30.77
Labor	$1,265,923.94	$13.19
Engineering	$1,478,930.00	$15.41
Legal Services	$288,993.45	$3.01
Land Easements	$ 0.00	$ 0.00
Site Certificate/Permitting	$270,584.65	$2.82
Development/Other Subtotal	**$6,258,254.58**	**$65.19**
Subtotal (all cost without taxes)	**$131,014,056.04**	**$1,364.73**
Sales Tax (Material and Equipment Purchases)	$4,829,532.32	$50.31
Total	**$135,843,588.36**	**$1,415.04**

C. Annual Costs

	Cost
Personnel Labor	
Field Salaries	$ 382,205.00
Administrative	$ 49,127.00
Management	$ 113,915.00
Labor/Personnel Subtotal	**$ 545,247.00**
Materials and Services	
Vehicles	$ 105,092.00
Misc. Services	$ 40,986.00
Fees, Permits, Licenses	$ 20,493.00
Misc. Materials	$ 81,972.00
Insurance	$ 788,192.00
Fuel (motor vehicle gasoline)	$ 40,986.00
Tools and Misc. Supplies	$ 266,409.00
Spare Parts Inventory	$ 2,334,624.00

Materials and Services Subtotal	**$ 3,678,753.00**

Taxes	
Sales Tax (Materials & Equipment Purchases)	$ 126,688.00
Other Taxes/Payments	$ 0.00
Total (with Sales Tax and Other Taxes/Payments)	**$ 4,350,688.00**
Debt Payment (average annual)	$ 14,976,010.00
Equity Payment - Individuals	$ 0.00
Equity Payment - Corporate	$ 3,989,026.00
Property Taxes	$ 847,872.00
Land Lease	$ 677,568.00
Total Annual Operating and Maintenance Costs	**$ 24,841,165.00**

As the site is pre-planned to operate for 20 years, the initial cost was divided evenly and added to the annual expenses for a total combined annual fee of $31,633,344.

D. Financing Options

Wind farms require a substantial financial investment before they can start producing any energy or revenue. The most common methods to pay are loans, investors, and tax incentives. Loans are large sums of money given, usually by a bank or other company, which must be paid back within a set amount of time and with added interest. Similarly, investors loan the project their personal funds and must be paid back within a time frame with additional interest.

Tax incentives are rebates provided by the government to promote a service or project. They can be applied to either the creation of the service or the ongoing productions from the project. Wind farms typically account for these incentives with the price to produce and sell energy, which, when combined, is called the Levelized Cost of Energy (LCOE). There are many different methods to calculate the LCOE with varying degrees of accuracy and complexity. The typical value ranges from $26.33 to $56.94 per MWh for a US-based, onshore wind farm, with the weighted average as $31.45/MWh [1]. This chosen value analyzes the financial potential of the selected site.

In the past year, the value and number of tax incentives have been continuously adjusted and prolonged to keep renewable energy sites functional through the financial crisis. A nationwide average value was chosen to keep the analysis consistent. South Dakota has made substantial progress in improving its renewable energy sector in the past few years [2] but is not yet a top producer, so the average LCOE value was chosen.

E. Financial Analysis Findings

Openwind found our site and turbine setup to yield an average net energy output of 502.88 GWh per year. At the assumed rate of $31.45/MWh, the annual net revenue is expected to be $15,815,705. This is less than our estimated total annual cost, making this project not financially viable. With the current design, a LCOE of $62.91/MWh would be needed to recover the total project cost by the end of its expected lifespan.

V. Conclusion

The goal for this year's competition was to learn from last year's project and to improve upon them. The primary issue with the previous year's farm was a general lack of wind resources. We were unable to possibly generate enough electricity from the available wind to make it profitable. This year's farm was placed at a location where the wind was the priority to combat this issue. All other factors were secondary to this consideration. The Red Owl location was selected due to an abundance of positive characteristics. Everything from easy access to roads and transmission lines to a minimal environmental impact. Upon choosing the location, the analysis of the site proved to be favorable as it had a calculated capacity factor of 59%.

References

[1] "Levelized Costs of New Generation Resources in the Annual Energy Outlook 2021," February 2021. [Online]. Available: www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf.

[2] B. Pfankuch, "Wind energy expansion in South Dakota to bring 888 more turbines, $3.3 billion investment," [Online]. Available: www.argusleader.com/story/news/2019/09/06/wind-energy-expansion-south-dakota-bring-888-more-turbines-3-3-billion-investment/2236210001/. [Accessed 9 September 2019].