Kansas State University

Wilcox Wind Project Development Report

WILDCAT WIND POWER

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1 – Wind Farm Design

1.1 - Overview

This year, we were tasked with finding an area in western South Dakota to develop a 100-MW Turbine Wind Farm. In the process of finding the ideal wind farm site, we surveyed wind distribution maps and analyzed the elevation and any topographical features using NREL's Wind Prospector tool that was provided. Shown in Figure 1 below, the area we chose is just north of Rapid City and 20 miles southwest of Union Center. We believe this area is best suitable for a wind farm because of its relatively minimal changes in elevation, naturally high wind speeds, proximity to existing transmission lines, existing homes, and electrical load, and its minimal impact on wildlife in the area. Obstacles we found with this site included the quality of backroads and the environmental conditions. To withstand the equipment needed to construct a wind farm, sections of back roads will need to be repaired or completely redone on the site. The site is mostly used as pastures, so the wind turbines will have a minimal impact on the purpose of the land. Furthermore, we noticed upon investigation of the site animal remains and geese feathers on the ground, so we concluded that there would have to be a plan in place to ensure that no further environmental damage would be taken as a result of the wind farm.

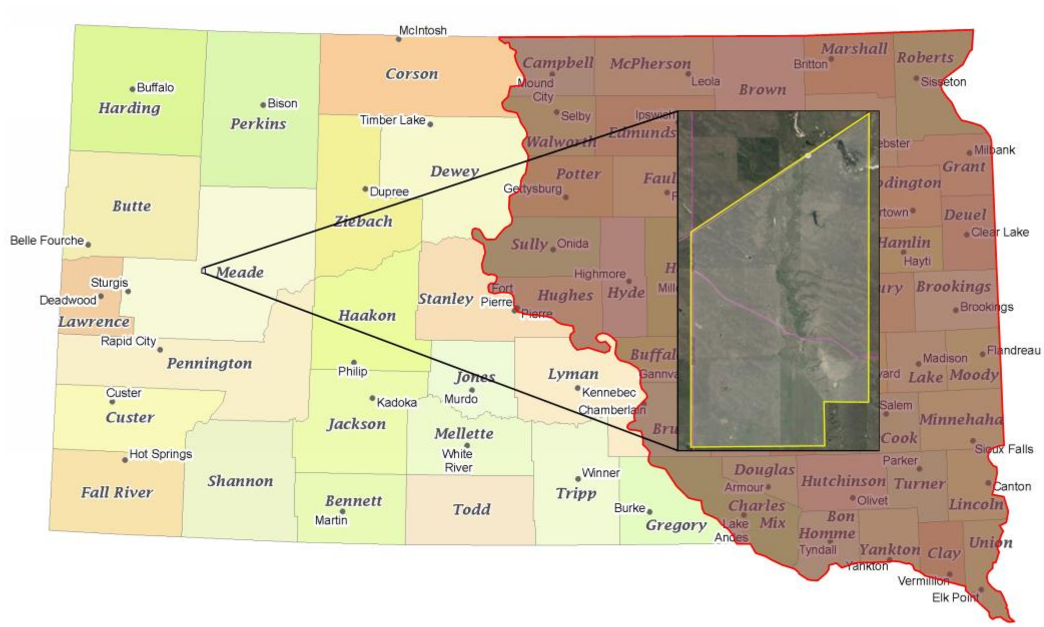

Figure 1. Site Location - https://www.cccarto.com/countyseats/southdakota/

1.2 - Layout and System Design

The first decision for turbine selection was manufacturer. We chose Vestas based on proximity to our site location. While GE and Siemens both have North American factories, they are significantly further than the Vestas facilities, which are all located in

Colorado. Due to the site chosen, we considered several turbine options based on their compatibility with the site. The primary components that qualified a turbine for the site were wind class and hub height. We identified that an IEC IIA/B at an approximately 100m hub height would be ideal for our target wind speed of 8.5m/s. After eliminating all models by Vestas that did not fit those qualifying criteria, we considered maximum noise and sweep area per MW. The reason we also considered these factors were because noise is a major complaint by the local community and minimized sweep area reduces avian fatalities, another complaint. Using these qualifications, we chose the Vestas V136-3.45MW IEC IIB with 112m hub height. We will utilize 28 turbines for a total of 96.6 MW to meet our desired generation values. For transportation of turbines, Vestas has four North American factories, all of which are in Colorado. Our team will be utilizing the Pueblo Tower Factory, Brighton Nacelle Factory, and the Brighton Blade factory. The primary reasons for these decisions are that the Brighton Blade Factory is the only factory that makes the blades compatible with the V136-3.45MW. The other factories produce other blades; however, they are not compatible with the turbines that were considered for the site.

For the site design, we considered the area's wind resource, land analysis, sound production, and the turbines' wake effects. Prior to the site design, areas that were considered undesirable for construction were eliminated as potential locations for turbines and an area of 300m around the home on site was eliminated to reduce the noise experienced by the landowners. The area's wind resource was determined using a wind rose diagram from the Faith municipal airport, and it is determined that it most commonly blows on an axis pointing NW/NNW to SE/SSW. To minimize wake effects, the turbines were spaced 2 turbine diameters parallel from each other and 5-10 turbine diameters behind each other. Finally, we utilized the site's elevation to slightly alter some turbine locations to allow a higher altitude of hub height.

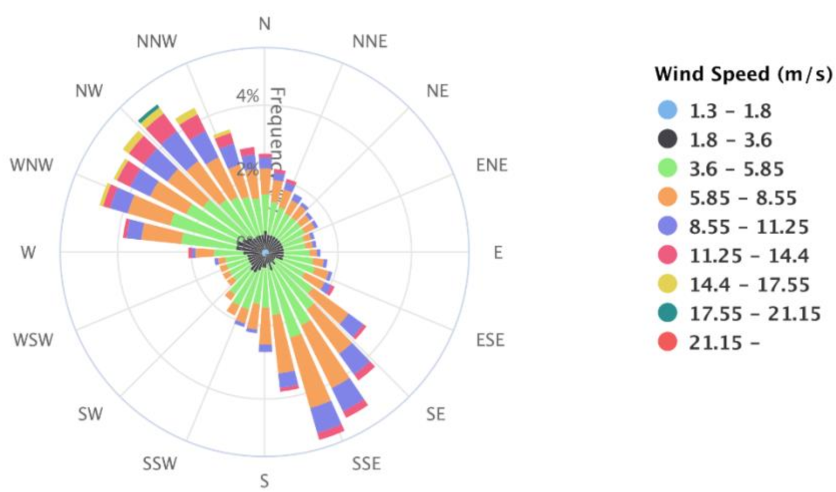

Figure 2. Wind Rose Diagram - https://mrcc.illinois.edu/CLIMATE/welcome.jsp

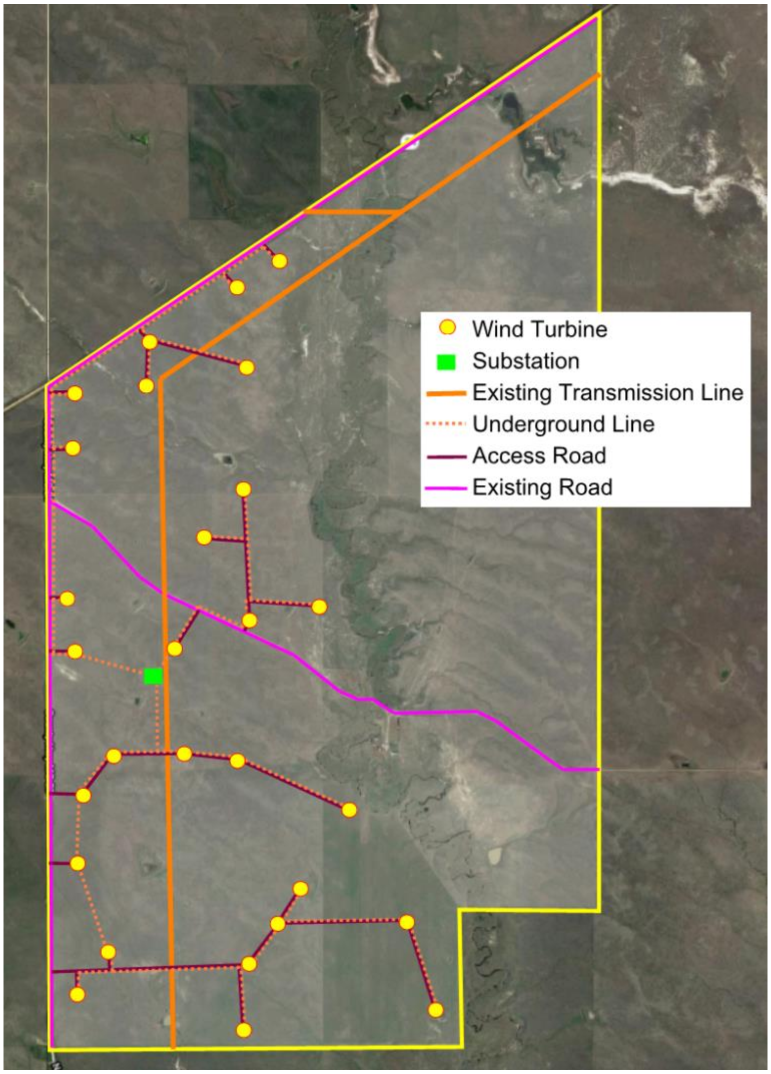

Figure 3. Site Layout

We considered four types of foundation designs: gravity spread, piled, and anchored foundations. Without proper soil testing, exact decisions on foundation choice cannot be responsibly chosen. However, our team did research on multiple factors that would play into that decision to make a preliminary prediction on foundation choices including seismic hazard, bedrock levels, and costs. Upon final analysis, an anchored foundation is the only feasible option and will cost $200,000 per turbine, a median value. Using "A Compilation of Vs30 Values in the United States" published by the USGS Earthquake Hazards Program, we approximated the time-averaged shear wave velocity as 228.5 m/s using VS30 data points TH.1083, TH.845, TH. 846, and TH.1086 due to their proximity to the site, which would mean a moderate level of seismic activity. All data points were taken between depths of 15.5m and 20.9m which would be in a range that would affect the turbine foundation. This data is somewhat far away, so it could be unreliable. Nevertheless, seismic hazard is still a potential concern. This eliminates the potential for gravity spread mat. According to ArcGIS software, by Esri, bedrock levels onsite lie between 0-200cm as shown in Figure 5 below. We overlayed a map of bedrock depth with an outline of the site location. Bed rock depth should still be measured; however, this map gives a reasonable approximation for considerations. Given the design constraints created by shallow bedrock and seismic activity, direct anchor foundation is the only feasible choice.

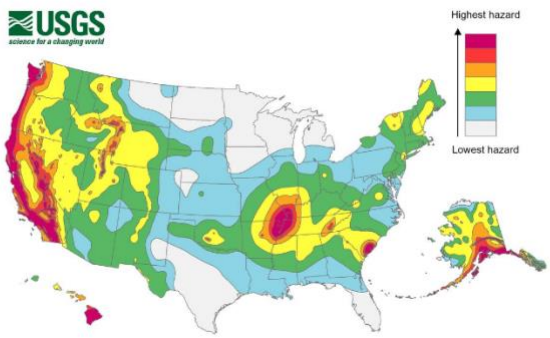

Figure 4. USGS Earthquake Hazard Map Figure 5. Bedrock levels of site.

1.3 - Net Annual Energy Production

Using NREL's System Advisor Model (SAM), we calculated the Wilcox Wind Farm to produce 265.834 GWh annually. To find this we assumed base electrical, environmental, and operational losses along with using a simple wake model to determine wake losses.

2– Community and Environmental Impact Analysis

Our preliminary analysis draws from the 2016 *Willow Creek Wind Energy Facility Final Environmental Assessment*, published by the U.S. Department of Energy for Butte County South Dakota. Butte County, which neighbors Meade County, should provide an excellent assessment of potential environmental risks in the construction of a wind farm. For context, the proposal outlined in that document plotted 45 turbines with a combined 103 MW capacity. Ultimately, their project and our own are nearly identical in scope, and likewise in consequences.

2.1 - Land Use

The site is currently occupied by ranchland, which should inflict a minimal environmental opportunity cost on our project. In fact, relatively robust existing roads should reduce potential impact from access construction. Moreover, data from the South Dakota Geological Survey shows that our plot has already been sighted and drained of petroleum resources by Phillips 66. well API number 4009320023. This hole, like others in the area, is plugged and abandoned, so we concluded that our team did not have any competition for land use.

2.2 - Air/Water Resources

While East Elm Creek passes through our site, our risk of a substantial water resources impact is nonexistent. The site is located in the Missouri River drainage area, but the Willow Creek assessment found that grazing has rendered the plant life a non-substantial retainer of rainfall, meaning that we do not increase the potential for flooding in the area. The assessment also found that any risk to air resources was likewise minimal. Most pollutants would be generated from maintenance and construction vehicles, which are negligible in comparison to existing agricultural equipment present in the surrounding region.

2.3 - Wildlife Impact

The Willow Creek assessment is particularly effective in identifying potential risks to regional wildlife. The report found that there would be unavoidable negative impacts during construction, but that permanent habitat loss would be minimal. In fact, the report pointed to existing ranching operations as basis for the claim that, within a short period of time, local fauna would have no trouble co-existing with development. In the context of migratory species, concerns typically manifest for bird and bat species. First, the Willow Creek assessment found only 4 cases of acoustical interference out of 15,000 bat passes. Second, low bird fatality rates for wind turbines with respect to other causes allow us to crystalize our focus on exclusively endangered species. For the region in question, that (*Grus americana*). These cranes migrate between central Canada to the gulf coast of Texas—twice annually crossing the State of South Dakota as shown in *Figure X*. Our selection is intentionally placed west of the migration path to ensure that the species would not be impacted. In fact, much of the population decline is a direct consequence of various human factors that have constricted Whooping Cranes' flyway: our project is not one. Figure 6 below displays the whooping cranes' flyway along with stopping points shown with black and grey marks.

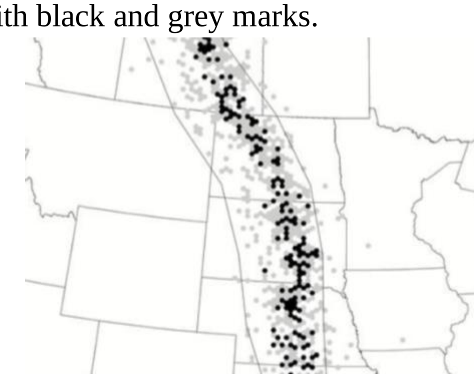

Figure 6. Detail of the Whooping Crane flyway.

2.4 - Permitting Concerns and Community Impact

Regrettably, wind turbines live and die on politics. Despite the numerous advantages, many lawmakers are unwilling to place farms within their constituencies. However, our selection takes this into careful consideration. The selected site falls within Meade County South Dakota, governed by a 5-member commission. Uniquely, the seat of Meade County, Sturgis, causes wide population variance, which allows maximum political strength: commission districts 2, 3, and 4 are clustered near Sturgis. Our site stands in district 1: an expansive area with low population density. This means that the support of the 1st commissioner is not crucial to the approval of the project. Rather, most of the commission sees only the benefit of reduced-cost electricity to urban and suburban residents. Ultimately, this insulates our site from any potential permit opposition. Fortunately, our selected site is uniquely appealing from the view of a policymaker. Specifically, the terrain of the land renders it unsuitable for crop growth. As a result, there is little opportunity cost for choosing to establish a wind farm this area. The northern portions of Meade County are especially population sparse. The land we selected is in fact under the control of a single owner, and it is unlikely that our project will be noticeable to most residents. Our relatively small impacts on land, water, air, and wildlife resources all play a role in how favorably our efforts are perceived by the public. That said, we have taken cultural assets seriously when making design choices. One technical change was made to accommodate an intersection of environmental, public relations, and economic concerns: specifically, Pheasants. The hunting of these birds is incredibly popular, serving not only as a source of revenue for the state, but as a matter of cultural importance to residents. Pheasants, though they possess the ability to fly higher, typically remain close to the ground. This caused us to prioritize higher hub height models than we might have otherwise: yielding a minimized regional impact without substantially altering turbine function.

3 – Financial Analysis

3.1 - Assumptions

The majority of our financial assumptions come from the Levelized Costs of New Generation Resources in the Annual Energy Outlook 2021 (LCNGRAEO) created by the US Energy Information Administration (EIA). This document was created as a support document of Levelized Cost of Energy (LCOE) findings and includes general assumptions applicable to the entire plant. We assume the plant will come online in the year 2025, which is consistent with the assumptions and figures found in the LCNGRAEO. General assumptions include the following. The U.S. economy remains at a stable level and does not suffer a catastrophic failure or meteoric rise. The U.S. does not enter any additional major armed conflicts that require the reduction of energy prices or eminent domain of land used for energy production. The level of technology used in energy production and collection will continue constant iterations, but no dramatic innovations that would significantly change the way in which energy is collected or distributed. The U.S. rate of inflation will follow estimations and be 2.37% in the year 2025. While renewable energy production is historically dependent upon politics, we have chosen to assume that whatever administration is in power at the time will not dramatically change the policies and laws that dictate wind production.

3.2 - Market Conditions

We've identified 7 applicable market conditions that could affect our farm.

Financing: Our farm relies on an initial loan to fund the construction. If financing rates are particularly high or market uncertainty is scaring away investors, the project could fail before it begins.

Interest rates: As states above, our farm relies on loans for initial capital. If interest rates skyrocket, we could be required to raise our LCOE to pay for the increased loan repayments.

Asset prices: If the land we need to build on or any of the components of the turbines increase in price, then the initial loan amount would need to be increased. With that comes the aforementioned raise in LCOE.

Inflation: Obviously, a rise in inflation will require us to secure more funding, leading the previously mentioned LCOE raise.

Competition: The area we are building in is prime real estate for wind farms. A neighboring competitor would most likely drive our prices up.

Consumer/business demand: Demand for our energy obviously affects our revenue. We are located near Rapid City South Dakota, the second largest city in the state. They're population is currently growing at a rate of 1.5% per year, so there is an increasing demand for energy.

Taxes and regulations: Our farm benefits greatly from current clean energy incentives and tax policies and would be hurt by their loss. For this project we assumed that current taxes and regulations will continue to exist throughout the farm's lifetime.

The LCNGRAEO shows that the estimated LCOE for our region is $0.04742 per KWh, so our LCOE should remain within 10% of that to remain competitive in the market.

3.2.1 - Incentives

The major incentive for Wind farms is the production tax credit, (PTC) which was introduced in the Taxpayer Certainty and Disaster Tax Relief Act of 2019. The PTC grants at credit of $25 per Megawatt hour (MWh) to all onshore wind facilities in construction as of 2016. This credit is still available to plants until 2025, but at a decreasing value. Based on the findings of the LCNGRAEO, our farm would be eligible for 60% of the credit, amounting to $15/MWh. The PTC is applied for the first 10 years of plant operation. Wind farms also benefit from double-declining accelerated depreciation, which allows the farms to expense their depreciation at an increased rate. This in turn allows for them to receive more fund from the PTC to pay for that depreciation.

3.2.2 - Taxes and Policies

Policies that will affect our facility were identified from the Upper Great Plains Wind Energy Final Programmatic Environmental Impact Statement, (PEIS) created by the U.S. Department of Energy (DOE) in 2015. Major tax policies are detailed in 3.2.1. Authority to act upon the following laws has been delegated to state authorities. Regulations specific to South Dakota are detailed in 3.7.6.2 of the PEIS. South Dakota Administrative Rules Chapter 20:10:22 et seq. require proponents of wind farms to apply for a permit to the South Dakota Public Utilities Commission. The applicants must "address the purpose and need for the facility; provide general descriptions of facility components, of the impacts on the physical environment and terrestrial and aquatic ecosystems, and of the impacts on water and air quality; and provide additional information related to wind turbines such as noise, reliability, warning lights, setbacks, clearing required, tower configurations, and interconnections to the transmission grid." The facility is also required to maintain an escrow account large enough to fund facility decommissioning.

3.3 - Cash Flow Analysis

We utilized System Advisor Model (SAM) to create our cash flow analysis and verify our facts and figures. The cash flow analysis can be split into two sections: during construction and during standard operation. During construction, the only near cash asset present will be the loan amount of 81.5 million, identified in the initial capital costs below. This will be a lump sum held be the ownership and disbursed to project management every pay period. During operation, the farm will generate revenue through selling the produced energy. We have identified the LCOE to be $0.04998 per KWh (calculation found in section 3.3.3). That value multiplied by 28 turbines producing 258,802,016 Kilowatts of energy equals approximately 12.94 million dollars in cash asset to operate the farm every year. Yearly turbine energy production found in SAM simulation.

3.3.1 - Initial Capital Cost

Turbines

Purchase Price	Number of Units	Erection Cost	Total Cost
$1,730,000	28	517,500	**$48,957,500**

Foundations

Material Price	Number of Foundations	Total Cost
200,000	28	**$5,600,000**

Access Roads

Cost Per Square Foot	Square Footage	Total Cost
$1.27	419,447	**$532,698**

Initial Site Clearing

Cost Per Square Foot	Square Footage	Total Cost
$16.00	50,000	**$800,000**

Electrical Components

Cost Per Foot	Feet	Total Cost
$1200	13560	**$162,720**

Man Hours

Number of Months	Hours in Month	Number of Workers	Total Hours
10	480	50	**240000**

Labor

Cost Per Man Hour	Number of Man Hours	Total Cost
$20.00	240000	**$4,800,000**

Shipping

Part	Distance (Mi)	Train Cars Required
All Nacelles	427	28
V136 Blades	427	84
Supplementary Wiring	427	20
Total Distance (Mi)	12914	
Cost Per Mile	**Miles**	**Total**
$52.56	12914	**$678,759.84**

Accounting for a 9% tax rate and additional costs for financing and debt up front, the initial capital costs will be $81,496,776 or $1455.30 per KWh. These values were verified in our SAM simulation.

3.3.2 - Annual Operating Expenses

Our operating cost was calculated using SAM software. We calculated a yearly $700,000 fixed O&M cost, and a $42 per KWh cost for preventative maintenance, corrective maintenance, and spare parts), land lease costs, annual property tax, asset management, operational insurance, and scheduling fees. This value was calculated using guidelines from SAM which identified a fixed cost of $25,000 per turbine per year. Suggested insurance values per turbine is $15,000 per year, and salary figures from the US Bureau of Labor Statistics gave us $674,000 in labor costs per year. There is also a

$20,000 warranty on each of the turbines We are using a depreciation rate of 1.89%, and a maintenance rate of 0.94% as identified in our SAM simulation.

Fixed O&M Costs

Cost Per Turbine	Number of Turbines	Total Cost
$25,000	28	**$700,000**

Insurance

Cost Per Turbine	Number of Turbines	Total Cost
$15,000	28	**$420,000**

Depreciation

Initial Capital Cost	Depreciation Rate	Total Cost
$81,496,776	1.89%	**$1,538,250**

Maintenance

Initial Capital Cost	Maintenance Rate	Total Cost
$81,496,776	0.94%	**$769,125**

Warranty

Cost Per Turbine	Number of Turbines	Total Cost
$20,000	28	**$560,000**

Salary

Value identifies as $674,000 per year for all employees involved with the operation of the facility. Annual operating expenses are equal to $4,661,375 or $0.01801 per KWh. Decommissioning Escrow account will remain at 15.1% of initial capital cost equaling $12,306,000.

3.3.3 - Levelized Cost of Energy

The levelized cost of energy for our plant is **$0.04998 per kilowatt hour**. Our plant will produce 5,176,040,320 kilowatts of energy over 20 years (equation below) and our costs over that time will equal $172,439,783. Dividing these two gives us a LCOE of $0.02767, which we increased by 55% to $0.04998 to provide profit and capital for loan repayment. We checked this figure against one identified from the LCNGRAEO analysis of our region. We chose to compare it against unweighted LCOE estimation because it used variable that were the most similar our levelized capitals costs, fixed costs, and transmission costs. Our value is under the estimated cost given in the LCNGRAEO analysis of $0.04742, allows us to generate profit and remain competitive in the market. It includes the variance for our PTC and additional tax breaks from the above incentives, but our facility does not receive a levelized tax credit on the LCOE. This number is in 2020 dollar values and will increase with the 2.25% inflation as identified above.

9.24293 GWh x 28 Turbines x 20 years x 1,000,000 = 5,176,040,320 KWh over 20 years

3.3.4 - Financial Plan

The initial capital costs for our project will come from a new construction development loan through a bank. The bank will most likely require a 20-25% down payment for the project due to the inherent risk of new construction, so around 16.5 million dollars will need to be assembled or fundraised beforehand. As seen in section 3.3.3 above, we have placed our LCOE above its break-even point for the purpose of loan repayment and profit. Combining the increased LCOE and PTC approximately $7,462,556 is made above the break-even point the first 11 years of operation will dedicate the entirety of those funds towards loan repayment, eliminating it with interest at the end of the 11th year. After this the PTC will go towards property and sales tax, so overall profitability equals ($0.013835 x 258,802,016 KWh x 9 years) equaling a total facility profit of $32,224,733. This number obviously excludes unforeseen expenditures.

3.4 - Risk Management

Construction and operation of a wind farm is an expensive endeavor, and high costs equal high risk. Our farm will employ several comprehensive policies designs to mitigate possible risks. These include constant inspections, the cost of which is factored into the annual operating expense. The idea with these is to identify any potential risk long before it poses a serious threat. We will also maintain enough capital to fix any emergencies. This includes a basic reserve account included in the annual operating expense as well as the legally requires escrow account with enough funds to decommission the plant. Wildlife generally poses a threat to turbines, however, as seen in section 2.3 above, migratory species are not a concern. Another factor that poses significant risk to turbines are extreme temperatures. The average high and low temperatures in Rapid City, SD are 59.8 degrees Fahrenheit and 34.1 degrees Fahrenheit respectively. These are both well within the manufacturer's specification for the turbines, so extreme temperatures are not of concern. The design of the farm has eliminated any glaring areas of risk, so the best risk management strategy is constant upkeep and inspections.

3.5 - Long Term Outlook

Over the long term, the energy market serviced by our site is projected to expand. The growth in Meade County since 2010 stands at 11.4%, while nearby population center Rapid City 12.3%. Both figures are almost double the national average (6.3%) over the same period. Ultimately, this indicates an increased electricity demand in the region, in turn insulating the profit margins of our development.

4 – Optimization Process

4.1 - Overview

During our design and analysis of the Wilcox Wind Farm, we established a process of continually checking for areas of improvement in our design.

4.2 - Design Changes

During the site design, we changed our turbine selection when locating the turbine facilities, we would be buying from to minimize the travel done for shipping equipment. Our wind turbine layout was initially placed and simulated in the SAM model, but alterations in some turbine locations were made to minimize the wake effects and maximize generation.

4.3 - Financial Analysis

Optimization of funds and expenditures is essential to long term operation of the facility. The use of SAM software allowed us to meticulously adjust and alter our energy production and loan options to create the most economically feasible and efficient farm possible. We also heavily researched initial construction methods to find the lowest costs. This can especially be seen in our access roads. We utilized Bluebeam Revu to markup a map of our farm to optimize the required routes and turning areas. The area our farm is located in also allows for the greatest efficiency in energy production based off wind strength and topography, which increased our revenue and available funds.