# The Pennsylvania State University

# Fairpoint Wind Farm

Project Development Team Report

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**Submitted to** 2021 COLLEGIATE WIND COMPETITION
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# Contents

# 1 Executive Summary

Happy Valley Energy Corporation, HVEC, was tasked with siting a 100 MW wind farm in Western South Dakota. The team analyzed the region's wind resource, environmental attributes, and stakeholder engagement and proposed the development of a 97.2 MW wind farm in Meade County, South Dakota (SD) 4 miles NNW of Union Center, SD. The team sited and optimized the wind farm using the wind resource assessment and site suitability software, Continuum 3.0 and the National Renewable Energy Laboratory's (NREL) Wind Prospector. NREL's System Advisory Model (SAM) and their Job and Economic Development Impact (JEDI) Model were used for the financial analysis.

The final turbine layout had a net annual energy production of 337.6 GWh/year with a total installed cost of $106,336,800. The net capital cost of our project is $118,401,672, which includes the operation and maintenance (O&M) cost over the project lifetime and construction financing fees. The proposed project has a total installed cost of $1,094/kW and an LCOE and PPA price of $0.0324/kWh and $0.0336/kWh, respectively.

# 2 Site Description and Energy Estimation

## 2.1 Preliminary Site Selection

HVEC initially researched the Western counties of South Dakota, SD, for their wind resource using NREL's Wind Prospector. The siting team selected three sites as described in Table 1 and shown in Figure 1. The siting team selected Site # 2 due to its high annual average wind speed and proximity to transmission lines, as well as its minimal environmental impact. All three sites had the potential for similar fauna species present including: the Little Brown Bat, Northern Long-Eared Bat, Tricolored Bat. Additional potential for Bald Eagle and Whooping Crane, which are found statewide, exist as well, however Site #2 was selected due to minimal impacts with respect to the aforementioned species.

**Table 1: Potential Site Locations[1]**

| Site # | County | Latitude and Longitude | Wind Speed (m/s) | Terrain | Vegetation |
|---|---|---|---|---|---|
| **1** | Harding | 45.66, -103.97 | 8.06 | Flat | Buffalo Grass |
| **2** | Meade | 44.64, -102.7 | 9.68 | Flat | Buffalo Grass |
| **3** | Butte | 44.99, -103.48 | 8.63 | Mountainous | Wheat Grass |

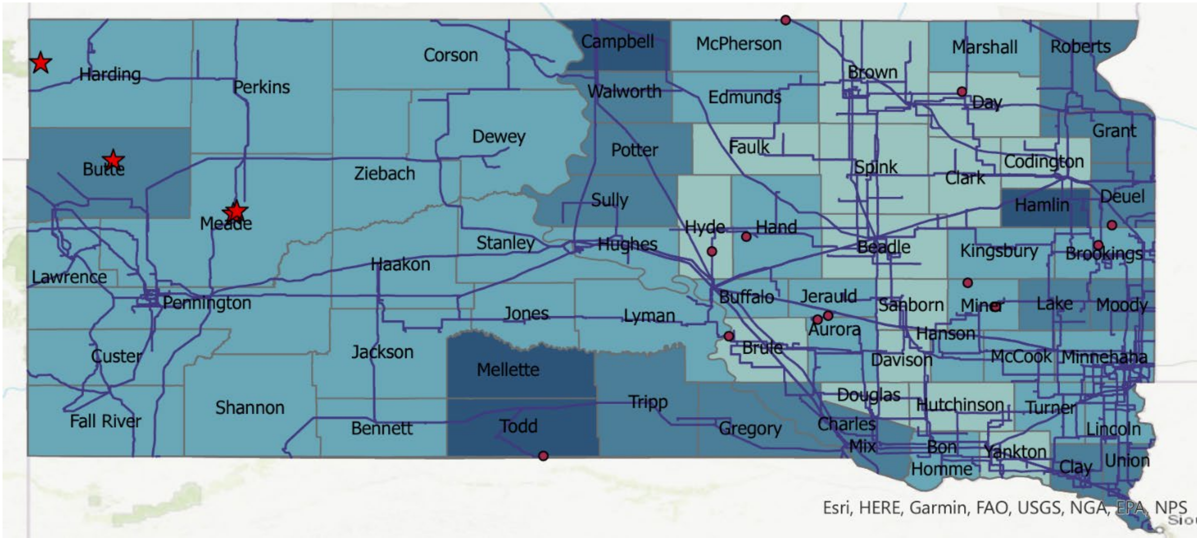


**Figure 1**: Transmission lines; Note that the Meade County Site is near a major transmission line.[2]

### 2.1.1 Ordinances and Setbacks

The development of this project must follow safety, aesthetic, and decommissioning rules set by the Meade County Commission. All turbines must be neutral color—gray or white; have no artificial lighting—except what is required by the Federal Aviation Administration (FAA); have no public display of advertisements—except for turbine manufacturer and facility owner and operator identification, and all powerlines between turbines must be stored underground.[3] The project must be setback at least two times the height of the turbine from the nearest participating property line and public road and five times the height of the turbine from the nearest non-participating property line.[3] Shadow Flicker must be at a maximum of 36 hours per year.[3] Wind turbines are prohibited within the airspace of Ellsworth Airforce Base, however this is 60 miles away from the project site and the closest airport is 52 miles away. HVEC, the developers, are responsible for any road damages caused by transport and construction of the project.[3] Furthermore, all wind energy conversion systems (WECS) must conform to industry standards—including the American Engineering Certification, the International Building Code, and the National Electric Code—and must be equipped with controls and brakes for emergency shutoff, where applicable.[3] These rules were incorporated into the final proposed project design.

### 2.1.2 Permitting

HVEC must obtain a permit from Meade County before the project's construction. The application for this permit must demonstrate the wind farm will comply with the above discussed ordinances and any others from the source used. This application must contain an overview of the project, evidence of an agreement between the property owner and the project operator, information on the ownership of the properties on and adjacent to the proposed project, and a site plan showing the turbines, MET towers, setback lines, access roads, electrical cabling to interconnection, buildings, and transmission lines.[3] This application must also contain decommissioning information for all equipment, and a copy of an agreement between the facility owner and the electricity off taker.[3] After the application is submitted, the project developers will be notified by the Meade County Director of Equalization and Planning of the application status. Then, the project will be presented to the public and County Commission to answer public questions and make comments on the proposed project.[3]

### 2.1.3 Stakeholder Approaches

South Dakota, as of 2019, had over 800 wind turbines across the state with 19 active wind farms and a capacity of over 1,500 MW.[4] The South Dakota government appears to have a favorable viewpoint of wind energy and other renewable sources as seen in its 2008 voluntary renewable portfolio objective of having 10% of all electricity generated from renewable sources by 2015.[4] Many utilities reached this goal, but some challenges were met along the way such as transmission capacity, competition from fossil fuels, and intermittent supply.[4] Western South Dakota communities have a favorable viewpoint of wind energy, as a project was proposed by the community of Faith, SD, in which a wind farm would be built and operated with the hopes of creating an opportunity for economic development and would generate revenue that would be used to pay for a new school in the area. The small schoolhouse in the town of about 200 people had been condemned and insufficient funds were available from the state to build a new one.[4] The proposed project was 120 MW and would produce enough electricity to power 56,000 homes.[5] Unfortunately, this project was never completed. It faced several challenges such as finding a financeable PPA from a creditworthy utility along with issues of transmission capacity. The project was also subject to wheeling charges and the Federal Energy Regulatory Commission Large Generator Interconnection Policy since it was greater than 100 MW. Although this project was never completed, it shows the community support and its perceived positive impact on the community. Due to the size of the proposed site, the aforementioned charges and policy does not apply to Site #2, henceforth referred to as the Fairpoint Wind Farm.

## 2.2 Wind Resource Assessment

Wind resource data obtained from the Wind Toolkit[9] for years 2010 – 2013 at heights of 50 m and 100 m were analyzed using Windographer,[6] a wind resource modeling software. Based on results from this, the Fairpoint Wind Farm experiences an average annual wind speed of 8.31 m/s at 117 m. As illustrated in the wind rose diagram in Figure 2, the predominant wind direction is from the northwest. Figure 2 also depicts the proportion of wind energy as it varies with directions between 292.5 and 315 degrees, which were found to provide the majority of the energy. Wind direction is critical in determining turbine layouts due to turbine wakes—the consequent losses from them are highly influenced by predominant wind flows.

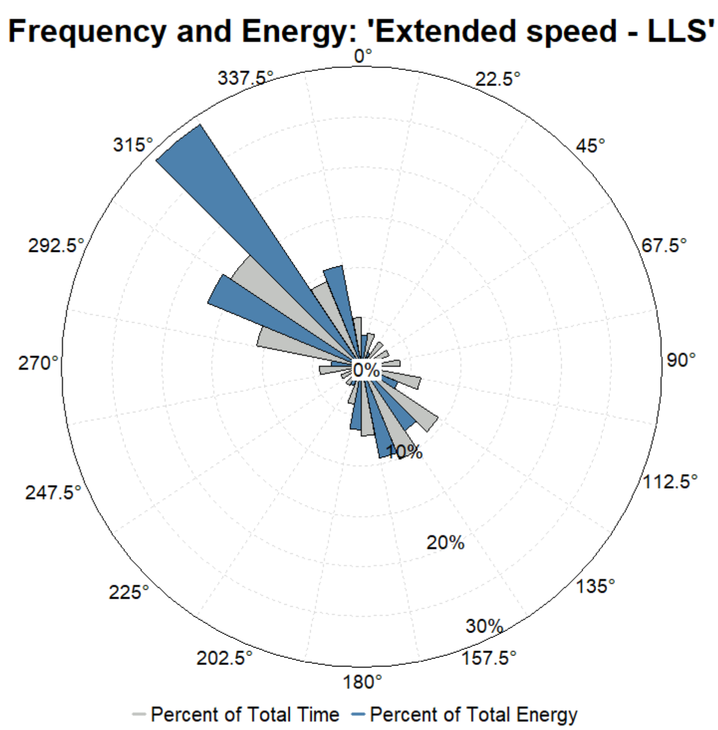


**Figure 2:** Wind Direction Frequency and Energy at 117 m

Peak energy demand in South Dakota for the winter months (e.g. from Oct 1st to May 31st) typically occurs between 5-9 am and 5-9 pm.[7] Figure 3, shows the diurnal and monthly average wind speeds for the proposed project site at the project's hub height of 117 m. Wind speeds are generally higher in the winter from about 6 pm through to 9 am. Given this schedule, the power production and demand schedules are viable, and have been determined by HVEC to be profitable.

| Mean of 117 m extended wind speed (m/s) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hour | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | All |
| 00:00-01:00 | 9.224 | 8.529 | 8.729 | 8.975 | 8.833 | 8.517 | 8.302 | 8.164 | 8.617 | 8.908 | 8.862 | 9.057 | 8.728 |
| 01:00-02:00 | 9.294 | 8.573 | 8.691 | 8.931 | 8.784 | 8.426 | 8.181 | 8.034 | 8.556 | 8.939 | 8.855 | 9.088 | 8.697 |
| 02:00-03:00 | 9.356 | 8.604 | 8.664 | 8.867 | 8.723 | 8.362 | 8.029 | 7.915 | 8.487 | 8.972 | 8.856 | 9.097 | 8.662 |
| 03:00-04:00 | 9.398 | 8.607 | 8.675 | 8.85 | 8.68 | 8.3 | 7.905 | 7.84 | 8.375 | 8.976 | 8.826 | 9.051 | 8.624 |
| 04:00-05:00 | 9.559 | 8.686 | 8.769 | 8.877 | 8.653 | 8.191 | 7.72 | 7.761 | 8.345 | 9.056 | 8.935 | 9.14 | 8.641 |
| 05:00-06:00 | 9.553 | 8.702 | 8.795 | 8.863 | 8.654 | 8.2 | 7.677 | 7.687 | 8.245 | 8.98 | 8.906 | 9.103 | 8.614 |
| 06:00-07:00 | 9.553 | 8.688 | 8.794 | 8.873 | 8.553 | 8.074 | 7.549 | 7.645 | 8.122 | 8.948 | 8.891 | 9.036 | 8.56 |
| 07:00-08:00 | 9.54 | 8.688 | 8.745 | 8.758 | 8.218 | 7.645 | 7.071 | 7.401 | 8.006 | 8.898 | 8.869 | 8.934 | 8.396 |
| 08:00-09:00 | 9.522 | 8.691 | 8.547 | 8.284 | 7.811 | 7.308 | 6.535 | 6.839 | 7.689 | 8.777 | 8.827 | 8.843 | 8.136 |
| 09:00-10:00 | 9.432 | 8.493 | 8.187 | 7.998 | 7.82 | 7.401 | 6.532 | 6.648 | 7.249 | 8.37 | 8.643 | 8.745 | 7.957 |
| 10:00-11:00 | 9.09 | 8.138 | 7.996 | 8.068 | 7.938 | 7.465 | 6.614 | 6.709 | 7.166 | 8.053 | 8.265 | 8.496 | 7.832 |
| 11:00-12:00 | 8.725 | 7.91 | 8.015 | 8.198 | 8.03 | 7.478 | 6.628 | 6.793 | 7.215 | 8.057 | 7.992 | 8.2 | 7.77 |
| 12:00-13:00 | 8.562 | 7.919 | 8.134 | 8.325 | 8.127 | 7.496 | 6.646 | 6.871 | 7.304 | 8.15 | 7.963 | 8.076 | 7.797 |
| 13:00-14:00 | 8.582 | 8.026 | 8.279 | 8.412 | 8.167 | 7.489 | 6.66 | 6.921 | 7.386 | 8.289 | 8.042 | 8.118 | 7.863 |
| 14:00-15:00 | 8.644 | 8.133 | 8.368 | 8.504 | 8.18 | 7.521 | 6.66 | 6.944 | 7.514 | 8.431 | 8.144 | 8.203 | 7.936 |
| 15:00-16:00 | 8.728 | 8.238 | 8.446 | 8.573 | 8.226 | 7.57 | 6.696 | 6.984 | 7.614 | 8.528 | 8.205 | 8.315 | 8.009 |
| 16:00-17:00 | 8.654 | 8.108 | 8.412 | 8.59 | 8.302 | 7.702 | 6.846 | 7.157 | 7.646 | 8.416 | 8.174 | 8.383 | 8.032 |
| 17:00-18:00 | 8.787 | 8.081 | 8.338 | 8.571 | 8.286 | 7.77 | 6.959 | 7.254 | 7.67 | 8.311 | 8.342 | 8.597 | 8.08 |
| 18:00-19:00 | 8.983 | 8.189 | 8.325 | 8.449 | 8.195 | 7.776 | 6.982 | 7.216 | 7.689 | 8.431 | 8.604 | 8.831 | 8.139 |
| 19:00-20:00 | 9.08 | 8.372 | 8.566 | 8.501 | 8.099 | 7.828 | 7.085 | 7.377 | 8.021 | 8.671 | 8.725 | 8.927 | 8.27 |
| 20:00-21:00 | 9.1 | 8.444 | 8.819 | 8.811 | 8.384 | 8.029 | 7.497 | 7.851 | 8.462 | 8.827 | 8.783 | 8.959 | 8.497 |
| 21:00-22:00 | 9.12 | 8.448 | 8.862 | 8.955 | 8.712 | 8.311 | 7.97 | 8.247 | 8.701 | 8.842 | 8.824 | 8.985 | 8.666 |
| 22:00-23:00 | 9.146 | 8.456 | 8.826 | 8.979 | 8.864 | 8.475 | 8.289 | 8.413 | 8.71 | 8.849 | 8.864 | 9.009 | 8.742 |
| 23:00-24:00 | 9.184 | 8.458 | 8.773 | 8.976 | 8.864 | 8.526 | 8.349 | 8.379 | 8.672 | 8.885 | 8.873 | 9.029 | 8.749 |
| All | 9.117 | 8.382 | 8.532 | 8.633 | 8.379 | 7.911 | 7.308 | 7.461 | 7.978 | 8.648 | 8.595 | 8.759 | 8.308 |

**Figure 3:** Wind Resource 12 x 24, Diurnal and Monthly Average Wind Speeds (m/s) at 117 m [6]

## 2.3 Turbine Selection

The International Electrotechnical Commission (IEC) standard—IEC 61400–1[8] specifies classifications of wind turbines based on meeting load scenarios for different wind resource conditions such as: mean wind speed, air density, turbulence intensity, and flow inclination.[8] Turbine manufacturers follow this standard to ensure minimal excess wear/damage from harsher weather conditions than the turbine is designed.[8] The proposed Fairpoint Wind Farm's wind resource data was compared with the IEC 61400-1 standard to first identify the best suited turbine Class.[8] The main parameters considered in the turbine suitability analysis include the annual mean wind speed at the hub height ($V_{ave}$), the 50- year extreme wind speed averaged over 10 minutes ($V_{ref}$), and power law exponent; while the flow inclination angle, Weibull shape factor, and the average air density where also considered.[8] Turbulence intensity statistics for the site were not available at the time of the study. A worst-case scenario was assumed using a type A turbine. Results are shown in Table 2. The site was determined to be best suited for a Class II A turbine with the site values within or very close to all of the thresholds set by this IEC turbine class.[8] The characteristics which met the standard for class IIA are highlighted in green text in the site value column of Table 2, while the characteristic which exceeded the threshold, the power law exponent, is indicated in red text.

| Table 2: Turbine Selection Based on Site Characteristics | | | | |
|---|---|---|---|---|
| **IEC Characteristics** | **IEC Turbine Classes** | | | **Site Values** |
| Fatigue-related Characteristics | I A Standard | II A Standard | III A Standard | Meade County |
| **$V_{ave}$** | Below 10 | Below 8.5 | Below 7.5 | 8.43 |
| **Flow inclination** | Below 8 | Below 8 | Below 8 | 0-2.29 |
| **Annual avg air density** | Below 1.225 | Below 1.225 | Below 1.225 | 1.102 |
| **Weibull Shape factor** | Above 2 | Above 2 | Above 2 | 2.652 |
| **Power law exponent** | 0.2 | 0.2 | 0.2 | 0.206 |
| **$I_{15}$ %** | Below 16 | Below 16 | Below 16 | unknown |
| **$V_{ref}$** | Below 50 | Below 42.5 | Below 37 | 31 |

Most of the characteristic values for the proposed project site were derived from 2010-2013 Wind Toolkit data for the site.[9] MERRA-2 reference data was also used to evaluate $V_{ref}$[15]. The flow inclination was derived from an elevation profile evaluation using Google Earth.[10]

With the appropriate turbine class determined, three class IIA turbines were evaluated for the proposed project. All three were Vestas models with industry performance specifications provided by a Vestas Technician.[11] The specific turbine performance details were entered into the System Advisor Model (SAM).[12,13] It was found for this project that the Vestas V126–3.6MW, IEC Class II A turbine, had the best performance, as shown in Table 3.[8,12,13]

| Table 3: Turbine Comparison | | | |
|---|---|---|---|
| **Turbine** | **AEP** | **Capacity Factor** | **LCOE** |
| *Model Name* | *MWh* | *%* | *$/kWh* |
| **V126-3.6** | 337,571 | 39.6 | 0.0324 |
| **V117-3.45** | 307,361 | 37.7 | 0.0346 |
| **V117-4.3** | 339,851 | 33.4 | 0.0399 |

The V126-3.6MW has the best capacity factor and LCOE, but slightly lower AEP when compared to the V117-4.3, however the far more competitive LCOE solidified the choice. The main design specifications for the V126 – 3.6MW are shown in Table 4. These turbines were purchased in 2020 by HVEC, establishing safe harbor for the proposed project and eligibility for the 2020 PTC tax credit, which will be described in further detail in section 4.3 of this study. The project must be commissioned by the end of 2024 to effectively make use of these turbines towards meeting the 2020 PTC value.

| Table 4: Turbine Design Highlights | | | | | |
|---|---|---|---|---|---|
| **Turbine Model** | **Rated Output (kW)** | **Rotor Diameter (m)** | **Hub Height (m)** | **Cut-in Wind Speed (m/s)** | **Cut-out Wind Speed (m/s)** |
| V126 - 3.6MW IEC Class II A | 3600 | 126 | 117 | 3 | 27.5 |

## 2.4 Detailed Layout

Windographer,[6] ArcGIS Pro,[2] and Continuum 3.0[14] were used to determine the optimal layout for the proposed project site. Wind resource data obtained from NREL's Wind Toolkit at two locations on the site were run in Windographer[6] and compared with long term reference NASA's MERRA-2 data using Windographer's Measure Correlate Predict tool.[6,15] This was applied in Continuum 3.0 for the Met Sites, where the two data sets assisted in creating a wind flow model derived from a deep array wake-model and log-law shear profiling equations.[14] Elevation data was obtained from the U.S. Geological Survey[16] and landcover from National Landcover Database,[17] cropped using ArcGIS Pro, and input into Continuum 3.0.[2,14]

The turbine layout on Site #2 underwent numerous iterations by HVEC's siting team. Eight layouts were evaluated and three were used as a baseline to analyze the effects of wind direction, elevation, and landcover on the annual energy production (AEP). Accounting for the property line setbacks, reasonable land use, and the limitation of road construction were not included in this initial analysis. The property lines were added onto the map in ArcGIS, while consideration of the property and road setbacks as well as safety setbacks from open water sources in the area were also considered. Multiple orientations of strings of turbines were explored. The strings were oriented such that wind originating from the predominant wind direction would only see two rows of turbines, minimizing wake effects. The final layout proposed, shown in Figure 5, features two strings, oriented nearly linearly from the southwest to the northeast. The project would require six unique landowners to participate in the planned project. Reference distances between turbines and to the transmission line can be seen in Figure 4. By drawing a rectangle enclosing all the turbines, the total area used is approximately 14.8 km$^2$.

Most turbines are placed on grassland or pasture, except for three which are sited on cultivated crops. Along the site, there is a county road that has a 230 kV transmission line. The closest turbine to the line is approximately 575 m away at which point a 3-ring bus breaker would be used to tap into the grid. Without considering the many truck trails already made on the site to access crops or open water areas, the total distance of road needed to be constructed sums to 10.36 km and can be seen in Figure 4. This cost of road construction can be significantly reduced if already existing truck routes are able to be utilized to access the turbines.

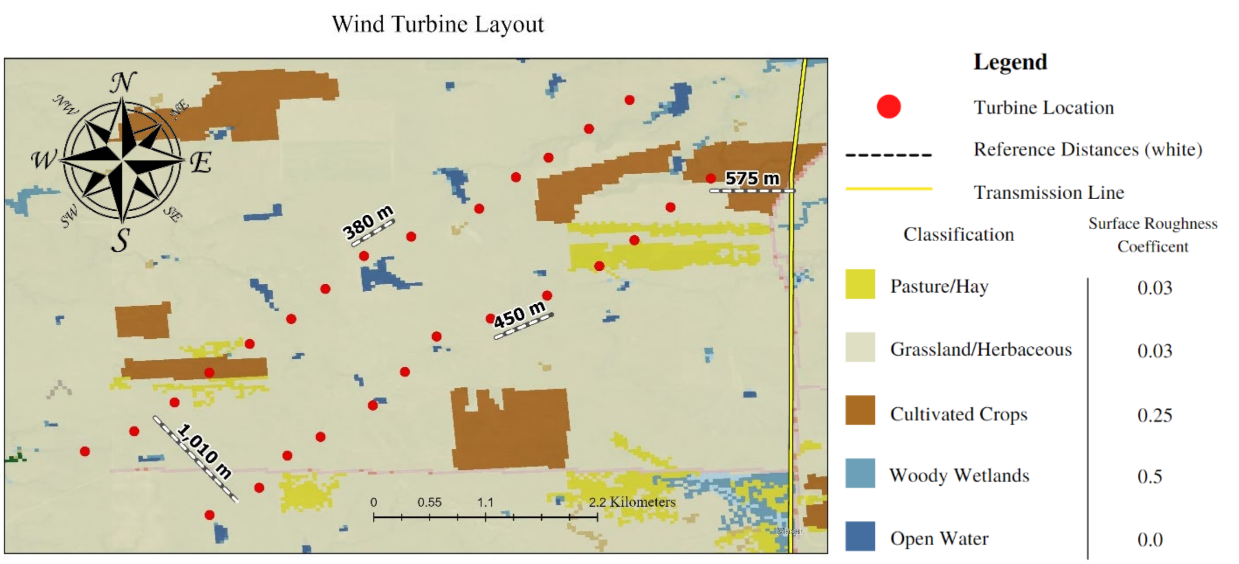


**Figure 4:** Final Layout from Continuum[14]

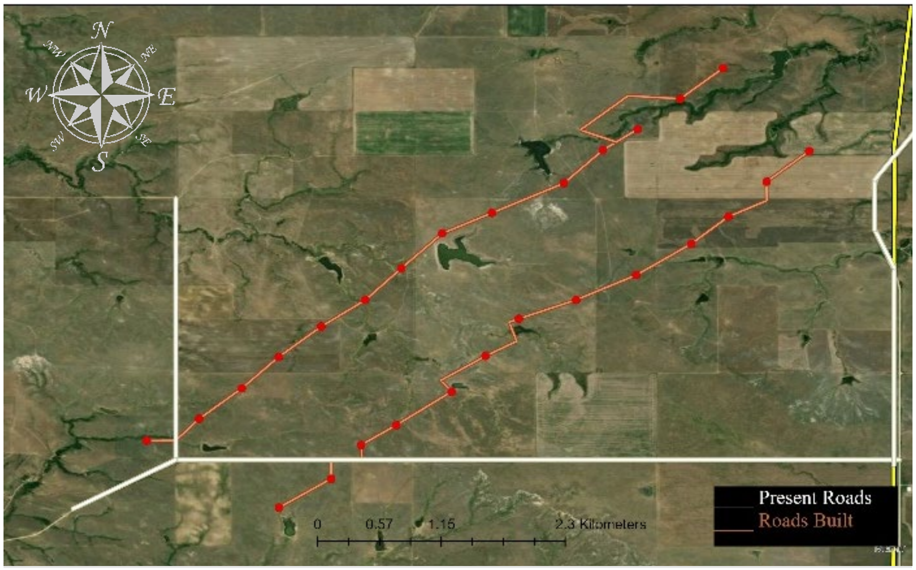


**Figure 5:** Final Layout with Roads Between Turbines from Continuum[14]

Figures 5-7 cover aspects of site suitability, such as potential ice throw distance, sound levels, and shadow flicker, respectively. Using ArcGIS,[2] the closest resident to any turbine is more than 1.4 km away; therefore, there is minimal concern that any homes will be affected by the wind farm. According to analysis done in Continuum,[14] the furthest ice throw is 500 m; residential homes experience no shadow flicker hours, and residents will hear ~ 20 dB of sound during high turbulence.[14] (The vertical and horizontal axes in Figures 5-7 show the coordinates in UTM.)

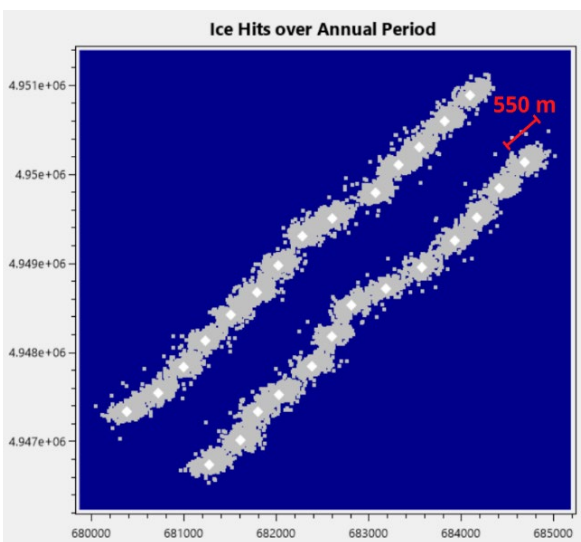


**Figure 6:** Ice Hits and Ice Throw Scenario.[14]

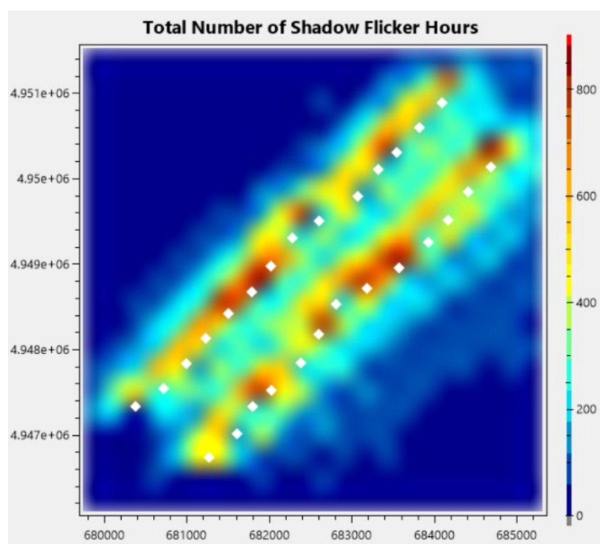


**Figure 7:** Shadow Flicker Hours experienced.[14]

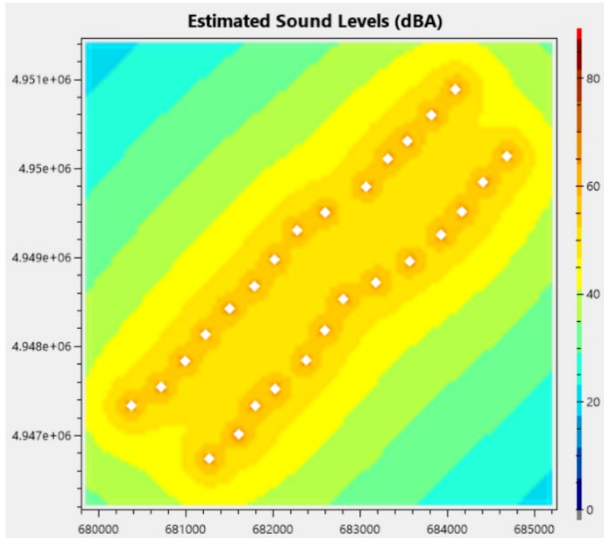

**Figure 8:** Estimated Sound Levels (dBA). Right axis shows the sound level.

### 2.4.1 Gross Annual Energy Production

Based on the final layout, the wind resource conditions, and the Vestas V126-3.6 MW turbine selected for the project, the gross annual energy production for the site can be evaluated. Probabilities of production values at three different confidence intervals are shown in Table 5. It should be noted that prediction bias of roughly 1-2%[18] is common in the P50, P90, and P99 values, meaning that wind farms are often underperforming by as much as 2%.[18] These values are also used to inform stakeholders of their financial risk when investing; however, they each are over differing time horizons. P95 is used by the Tax Equity Investor over a 10-year time horizon, while the Debt Equity Investor uses the P99 value over a one-year period, and all stakeholders use the P50 value to determine how well the turbine will operate and drives the LCOE.[18]

| **Table 5: Summary of Gross Annual Energy Production Values (MWh)** | | | |
|---|---|---|---|
| Percentiles | P50 | P90 | P99 |
| | 409,905 | 408,473 | 407,305 |

### 2.4.2 Wake Effect and Other Losses

HVEC's siting team analyzed the site's annual energy production using three wake models—the Jensen (Park), Eddy Viscosity, and Eddy Viscosity Deep Array Wind Model (EV-DAWM)—and compared them to determine the net annual energy production for the proposed site as well as overall and wake losses. Table 6 provides a summary of the results of this analysis. The losses are presented as a function of the annual energy production (P50). Other losses considered by Continuum 3.0 include power curve degradation, turbine availability (due to O&M), wind flow model accuracy (speed and direction), extreme wind situations, wind variability, icing, grid losses, shear, and the possibility of catastrophic event.[14]

| Table 6: Summary of Net Annual Energy Production | | | |
|---|---|---|---|
| Model | Net Annual Energy Production (MWh) | Overall Wake Loss (%) | Overall Loss (based off P50 value) (%) |
| Jensen Model | 340,849 | 7.87 | 16.95 |
| Eddy Viscosity Model | 346,114 | 6.45 | 15.56 |
| Eddy Viscosity – Deep Array Wind Model | 337,593 | 8.74 | 17.64 |

Figures 9.a and 9.b, show the resulting wake map using the EV-DAWM model, where Figure 9.a. illustrates the overall average effect of wake on wind speed incorporating all wind directions, while Figure 9.b. illustrates the impact on wind speed when the wind blows from the predominant wind direction out of the northwest. EV-DAWM provides the highest estimation of wake loss, which is the worst-case scenario and has thus been used in the financial analysis.

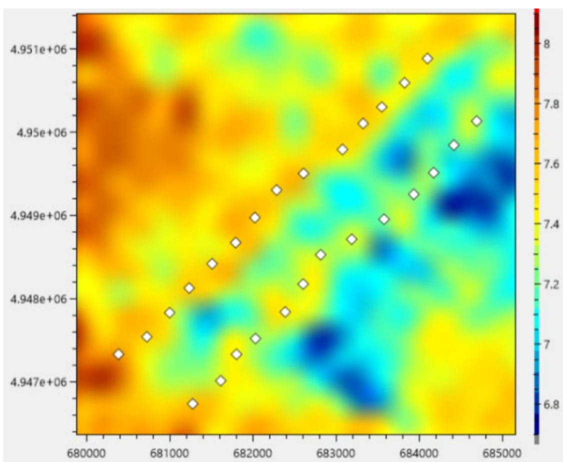


**Figure 9.a:** Loss of wind speed (m/s, right axis) as a function of all wind directions

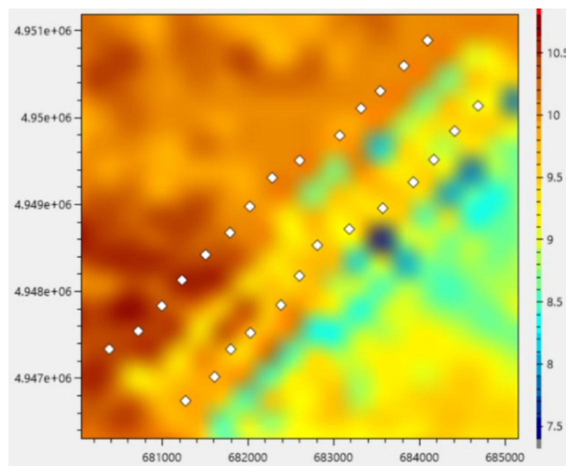


**Figure 9.b:** Loss of wind speed (m/s) as a function of the primarily wind direction bin of 315°

# 3 Financial Analysis

HVEC used the System Advisor Model (SAM)[19] to perform a financial analysis on the proposed Fairpoint Wind Farm. In SAM, the financial analysis was modeled as a Power Purchase Agreement (PPA) partnership flip with debt. This model allows for the specification of either the internal rate of return (IRR) or the PPA price. Utilizing the parametric simulation within SAM, the optimal IRR can be found that minimizes the Levelized Cost of Energy (LCOE) while still making the project viable to the investor, keeping their Net Present Value (NPV) positive.

## 3.1 Project Costs

NREL's 2020 Job and Economic Development Impact (JEDI) Model[20] was used by HVEC for the assessment of the total capital expenditure costs. Inputs to the JEDI model include location (South Dakota), size of project in MW (97.2), turbine specifications as outline in Table 4, construction year and duration (2020 and 9 months), distance to interconnect, 575 m, and interconnection voltage (230 kV). Outputs for the model are shown in Figure 10.

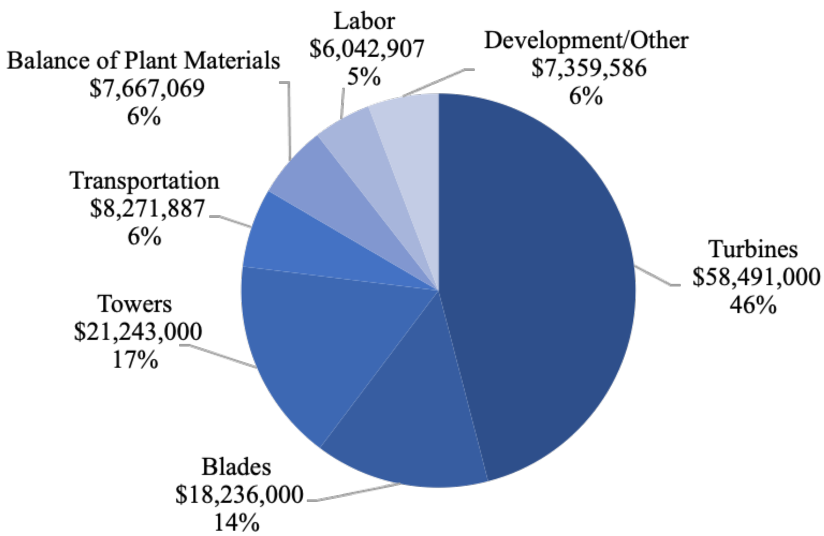


**Figure 10:** Capital Expenditure Breakdown from JEDI Model[20]

In 2019, the reported wind turbine transaction price per unit of capacity was reported to be in the range of 700-900 $/kW, and more specifically for Vestas turbines, similar to the one used in this project, it was around 850 $/kW.[21] A Cold Weather Package provided by Vestas was considered as a precaution as the lowest standard operation threshold for the V126-3.6MW turbine is -20°C and the minimum long term temperatures for the site were found to be -29°C. The cost of the package was $500,000/turbine, however the team deemed the package unnecessary with temperatures less than -20°C only 0.23% of the time over a 40 yr period based on the extended wind resource assessment completed using MERRA-2 data.[11,22]

Lawrence Berkeley National Laboratory reports in its 2019 report,[21] the average annual operation and maintenance cost for projects in the 100 MW range to be between 20-35 $/kW-yr. To allow some room in the limited data available, 30 $/kw-yr was applied in the financial analysis. Using the JEDI model,[20] the balance of system cost was determined to be $242/kW for the interconnection voltage of 230 kV and distance to interconnect of 575 m. Total annual O&M costs equate to $2,993,095, or $30.86/kW. Parameters that make up the total annual project costs are broken down by percent in Figure 11.

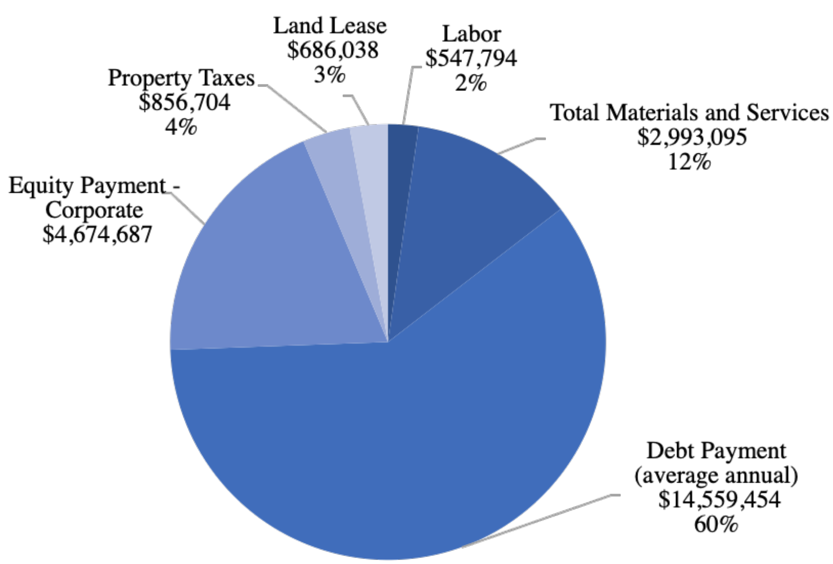


**Figure 11:** Annual Cost Breakdown from JEDI Model[20]

## 3.2 Workforce Impacts

The JEDI model[20] was used to analyze the workforce impacts of the proposed project, and provides extensive economic analysis pertaining to the local community. Development costs for labor encompasses the creation of 162 jobs in the 9-month construction period with an additional 25 jobs created during the 20-year operational period. Land leasing and property taxes paid during construction and operation will provide millions of dollars to the local economy and community.

## 3.3 Incentives

Several key incentives are available for wind energy projects in the U.S and South Dakota. The main incentive being used currently is the Production Tax Credit (PTC), which allows for an inflation adjusted dollar amount per kilowatt-hour of generated electricity to be returned as a tax credit. The current value for the PTC is $0.015/kWh (as the project is using safe harbored turbines purchased in 2020) and can be applied to the first ten years of production.[23] A PTC escalation rate of 2.50% per year was included in the model to account for the average inflation rate. An additional incentive is the Renewable Energy Facility Sales and Use Tax Reimbursement program which can provide a reinvestment payment of up to the full amount of sales and use tax paid on the project. This program is intended to help projects that would otherwise not be viable without the reinvestment payment.[24] With this in mind, the Fairpoint Wind Farm would have a high likelihood of qualifying for this program if it can prove in its application to the Governor's Office of Economic Development (GOED) that it is necessary to the project's financial viability. This is accounted for in the financial analysis by setting the sales tax to zero, which in South Dakota would normally be 4.5%.[25] Additionally, the project is eligible for the 5-year modified accelerated cost recovery system (MACRS). This allows for faster depreciation in the first few years of the project, which allows for higher tax deductions to attempt to offset the initial capital expenditure of the project and helps to quickly pay back the tax equity investor in the early years of the project.[26]

## 3.4 Decommissioning Costs

An abundance of natural and financial resources are used in the construction of a wind farm, and it is important to recoup as much of these costs as possible at the end of the project's lifetime. One way to incorporate this into the net salvage value is to account for the scrap value of the metals used in the hub, tower, and nacelle. Utilizing a Decommissioning Cost Estimate Report done by the Cassadaga Wind Farm in New York,[27] an estimate of the net salvage value of this project at the end of its lifetime was performed. This report estimates the weight of the hub, tower, and nacelle to be 35, 256, and 120 tons, respectively. The hub is reported to be composed of 100% steel, while the tower and nacelle are 80% steel and the nacelle 5% copper. The salvage value of steel and copper in 2017 were 235 $/ton and 4,180 $/ton, respectively.[27] With the compositions and scrap prices known, the net salvage value was determined for the project's 27 turbines to be $2.8 million or 2.87% of the total installed cost. These values should be conservative due to the turbines in this study being Gamesa 126–2.625 MW at a hub height of 102 meters which is a smaller turbine and a shorter hub height than the one analyzed for the proposed project.[28]

An associated cost of operating a wind farm is the decommissioning of its structures, turbines, and roads. Since the JEDI model does not include the costs of decommissioning the study used in the above paragraph for net salvage value was also used to determine this additional cost. The Cassadaga Wind Farm Decommissioning Cost Estimate determined a turbine decommissioning cost of $98,200 per turbine.[27] This accounts for transportation to the site, removal and deconstruction of each turbine, transportation of turbine parts, and the removal and disposal of petroleum, oil, and lubricants contained within the system. In order to remove the turbine foundations, it was estimated that it would cost $28,700 per foundation which includes excavation, demolition, disposal and backfilling of the foundations. This study estimated that the decommissioning of the interconnection station to be $29,200. With the Fairpoint Wind Farm being 27 turbines at a higher height and a larger turbine than that described in the study, it was estimated that the costs would be approximately 20% higher for this project. This makes the total decommissioning cost

$4,146,600. To incorporate this into the financial analysis this was added to the operation and maintenance costs, removing the net salvage value.

### 3.4.1 Debt/Equity Financing

Typically, a Debt Service Coverage Ratio (DSCR) in the range of 1.1-1.4 is set for a project, depending on the type of asset, but for wind farms the typical range is 1.3-1.5.[29] A value of 1.3 was used for the proposed project thus maximizing the portion of the capital costs that could be borrowed via debt, to utilize the lower interest rate compared to an equity rate, but still within an acceptable range for the financial institution. This financial model assumed that an annual interest rate of 3.5% for debt could be attained for a project of this magnitude.[30] For the tax equity partner, a rate of 9% was applied in order to keep the investor NPV positive. The result was a debt and equity split value of 44.6% for equity and 55.4% debt. The equity flip structure would put 98% of the financial burden on the tax investor with 2% to the project developer before the flip in year 10. South Dakota has the benefit of having zero state income tax, but the federal income tax of 21% was still applicable for the project.[31,32]

### 3.4.2 Construction Loan

A loan is also needed by HVEC to finance the construction of the wind farm, which is included in the total debt percent of 55.4% as outlined above. Credit lines and loans are the most popular models for financing wind energy projects.[33] The financial model for the Fairpoint project assumes a $106,336,800 loan to cover the core construction period with an annual interest rate of 4% and a 1% up-front fee which equates to $1,063,368, and results in a financing cost of $2,126,736. The HVEC team will seek to acquire the construction loan from a bank; however, it is important to note, this method is not always suitable for all developers given high interest rates and risk for the lender during the construction period.[33] After the construction period, the loan will turn over to project term debt to be fully paid off in year-20 via the terms described above. An additional development loan is not required for the project as it has been covered by HVEC internally.[34]

## 3.5 Market Constraints and Opportunities

Using the cost inputs, incentives, and financial parameters defined in the section above along with the annual energy production found using Continuum, an LCOE and PPA price were determined for the proposed project site. The LCOE and PPA for the proposed Fairpoint Wind Farm were determined to be $0.0324/kWh and $0.0336/kWh, respectively. According to the 2020 Lazard Cost of Energy, the typical range of LCOE's for wind energy is $0.026-0.054/kWh.[35] From this cost comparison the LCOE of this project is competitive in the range of typical values. For the SPP region, the average LCOE for 2019 was $0.03284/kWh. This is very close to the value determined for the Fairpoint Wind Farm of $0.0324/kWh.[36] According to the 2020 Wind Technology Data Update,[21] the average value of of PPA prices are between roughly $0.02/kWh and $0.04/kWh.[21] The main concern of this project would be whether it could attain the PPA price determined in the financial analysis. The higher than average required PPA price could influence the project's ability to get financing. Other than this concern the project is seen as a feasible wind project. HVEC is in negotations with a yet to be named big-box retail corporation which has recently made an announcement about a commitment to achieve 50% of its electricity supply to be sourced from renewable resources by 2024, within the time horizon of the proposed project.

The net present value (NPV) represents the present value of the investment at the end of the period of analysis including the costs. It is important for this number to be positive for both the investor and developer. From the financial analysis an NPV of $54,680 and $5,905,704 was determined for the investor and developer, respectively. In Figure 12, the project's after-tax cash flow can be seen. Shown in the initial year is the negative cash flow associated with the debt of construction, and in the years following the revenue from electricity and incentives can be seen. In Figure 13, the cumulative after-tax cash flow for the developer and investor can be seen. The cumulative cash flow is flat for the developer, while the investor is increasing significantly for the first ten years of the project becoming positive in year seven.

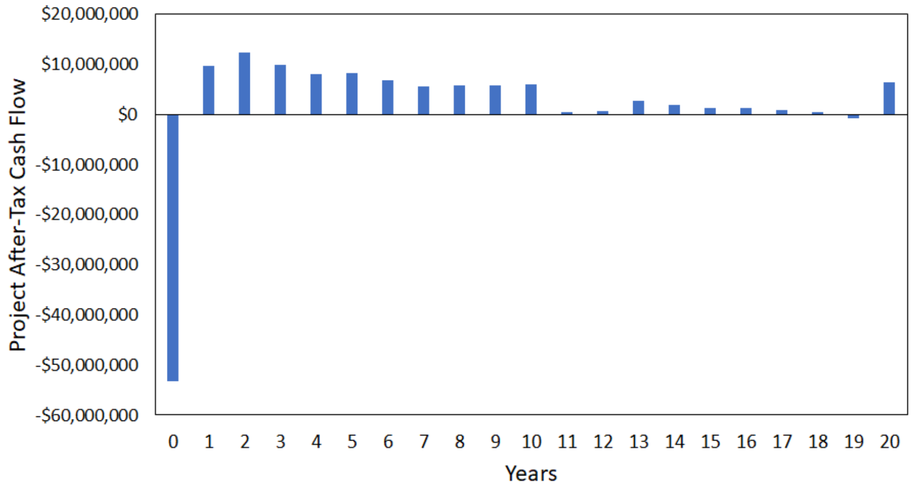


**Figure 12.** Project After-Tax Cash Flow

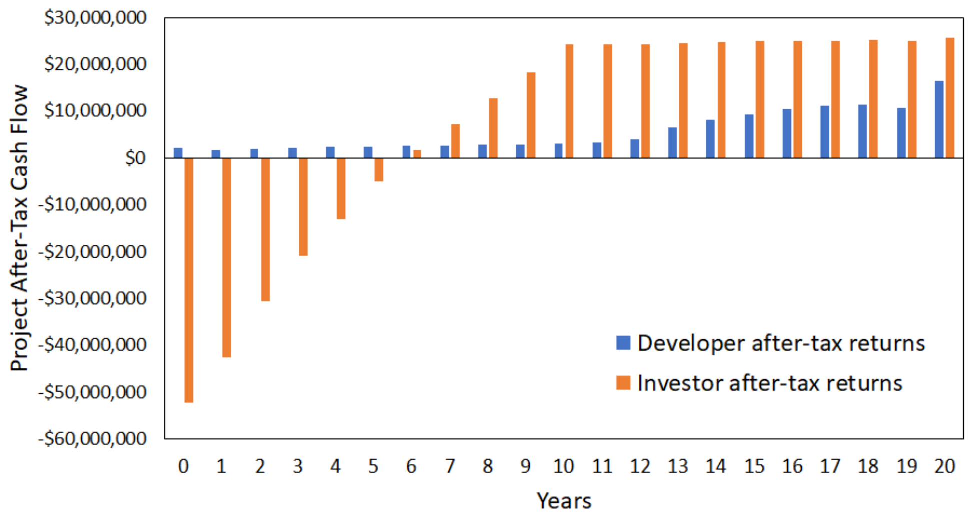


**Figure 13.** Cumulative Developer and Investor After-Tax Cash Flow

# 4 Optimization Process and Risk Assessment

The HVEC team down selected a site from a list of three potential locations in western South Dakota resulting in the proposed Fairpoint wind project. The team considered social, environmental, and stakeholder factors as described throughout the preceding report.

The optimal layout (shown in Figures 4-9) was obtained by continuously improving a layout chosen between three initial layouts using ArcGIS and Continuum 3.0.[2,14] They were made by importing elevation, landcover, and transmission line data into ArcGIS and using the Distance and Direction tool to accurately place them and ensure proper setbacks. All layouts were imported into Continuum 3.0 to run a wake loss analysis with its associated map to determine if the orientation caused more or less wake, as well as, if the turbines could be placed closer together. However, there are associated risks with the layout, including proper setbacks. South Dakota as a state requires a minimum of 1.1 times turbine height setback, while Meade County specifically requires at least two times the height of the turbine for participating owners and five times the height for non-participating owners. The current layout may need to be adjusted to meet these requirements depending on agreement of the six parties that own the land that the turbines are placed on.

Several risks are associated with the development of Fairpoint Wind Farm including: the competitiveness of the PPA price, grid stability, and landowner risk—namely, the risk that one or more landowners would not approve of the wind farm's development and construction. If any of these were to occur, adjustments by HVEC would need to be made to make the project viable. In the latter case, a new design and location would be necessary due to Meade County ordinances.[3] In addition, the HVEC team used Continuum over other software—such as WAsP and OpenWind—due to its reliability and the model's comparatively low model error as shown in Table 7.

**Table 7: Comparative Error Assessment Between Software**

| Software Name | Error (%) |
|---|---|
| Continuum 3.0 | 1.55 |
| OpenWind | 2.93 |
| WAsP | 3.34 |

# 5 Conclusion

Happy Valley Energy Corporation, HVEC, assessed a site in Meade County, South Dakota for the 2021 Collegiate Wind Competition. A 97.2 MW capacity project was determined to produce a net annual energy production of 337.6 GWh/yr, which does not consider prediction bias. With a project total installed cost of $106,336,800 or $1094/kW, the resulting LCOE and PPA were determined to be $ 0.0324/kWh and $ 0.0336/kWh, respectively.

The team selected an appropriate software which provided minimal error where possible, and also analyzed losses mentioned in the above report. It is the belief of the HVEC team that this site is viable, however further analysis may be necessary in some areas, such as with respect to the South Dakota State Law versus the Meade County, SD Ordinance 32 specifications. Overall, the HVEC team is confident in our evaluation of the potential for the Fairpoint Wind Farm, and suggest pursuit of its development.

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