Kansas State University
Wind Turbine Technical Report

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Site Description

In the report submitted last year, we found that an area to the northeast of McPherson, Kansas was a viable site for our hypothetical wind turbine. In the process of finding the ideal wind farm site, we surveyed wind distribution maps and analyzed the elevation and any topographical features of areas that were 100 miles out from Kansas State University. The area has an average annual wind speed of 9 m/s at 100m above the ground. The area was found to be of low risk with any issues that could arise in regard to animal species or the use of the land. We observed that there would need to be some repairing of the back roads leading to the turbine site, among other things. We observed that our chosen site was mainly used for growing crops and that there is a possible obstacle of running power lines underground from the turbines to the nearest substations because of gas and fiber optic lines in the area. 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. Although there are some risks with this site, it still has relatively high wind speeds and avoids any wildlife conservations. We used the Vestas V136-4.3MW model for our turbines, and we estimated we would need 24 of these turbines. The total cost of the turbines themselves was estimated to be $85,680,000 in total. This turbine site would have produced the required 100 MW of power, and would have satisfied the land owners in the area as well.

Design Changes

With the parameters set by the committee and the land we had access to, our previous design needed to be four rows of six turbines in order to minimize the effect on wildlife while also staying within the land confines and not entering protected areas. In order to truly maximize the AEP in that area, we would have changed our configuration to two rows of twelve turbines in order to minimize the wake effect and therefore maximize the production of our turbines. Although, when it came to our overall NAEP, our numbers turned out to be very similar to those calculated last year. This was since employees of Vestas commented on how accurate the power curve model and Weibull distribution looked given the lack of accessible data, so we modeled our calculations off of those numbers to have them look very similar. Another aspect of the design we decided to keep was the model of turbine used in the farm. Again, given our accuracy in predicting the numbers that the Vestas turbines can produce, it made sense to keep those in the farm instead of trying to predict a different, potentially more, or less, efficient turbine. But, if we were to have chosen a different turbine, we would have looked in the class III range since much of the wind at our farm location exists below the optimized part of the Vestas power curve. We would have preferred one rated for lower speeds, and this is a large contributor to our relatively low annual production. The annual power that we calculated is lower than it should be, and our capacity factor is roughly twenty percent lower than expected in turn. So, our power calculation may have been somewhat flawed and changed to more accurately represent our expected numbers. The siting team from last year's competition performed well, so this year we did not want to discredit them by changing multiple aspects of the design. The design overall did not change very much, if at all, due to this reason.

Financial Analysis

In conducting the financial analysis for this wind farm, several parts came into play. The financial analysis is broken into initial costs, annual costs, production, taxes, and depreciation. With limited access to proprietary information and professional experience, estimations became essential to conduct the financial analysis. Several assumptions were taken into consideration in to accomplish this. Among these are:

- Annual energy production, O&M would be consistent for the life of the project with no catastrophic failures.
- Inflation will be disregarded, and analysis will be in 2017 USD.
- Tax rates do not change for the life of the project.
- The project will begin construction in 2019.

Initial Cost

The calculation of initial cost involved the cost of site preparation, balance of plant, and the obvious cost of turbines. Site preparation is mostly focused on building up the county access roads to withstand the weight of heavy equipment entering the site and installation of transmission lines from the turbines to the substation and to the grid. Balance of plant is the segment where maintenance shops and offices as well as the substation and other holdings that go to the day-to-day operation of the plant goes. Each of these segments were calculated using what information was available. The rest, the team utilized estimates provided by the DOE 2017 Wind Technologies Report. To calculate initial cost of our financial analysis, the team simply summed each segment individually to reach a total initial cost of $156,240,000 which is close to average for the Midwest region in which the McPherson, KS farm would reside.

The turbines used in this case are the Vestas V136-4.2MW turbines which we estimated to cost $3,570,000 per turbine. To accommodate the 100 MW capacity required by the constraints of the competition, the project would need to utilize 24 such turbines. These turbines were chosen for several reasons including their larger nominal power rating per turbine that necessitates fewer total turbines to accomplish the full 100 MW capacity, seven fewer than the next best option. Using fewer turbines also allows the project to use less land which is essential given its proximity to protected lands and the team’s wish to avoid disrupting these as much as possible. Other considerations for initial cost were done using the Wind Technologies Report. In all, estimated cost of installation of the turbines, balance of plant, and site preparation totaled to another $700/kW of capacity. In total, estimated initial cost totals to $156,240,000.00, or $1550/kW, average for farms in the Southwest Power Pool (SPP), (Wiser, 2018). These calculations can be found in **Figure 1**.

Initial Cost	
Cost per kW installed	$ 1,550.00
kW installed	100800
	$ 156,240,000.00

Figure 1

Revenue

In order to find the Net Annual Energy Production (NAEP) of the farm, many factors had to be considered. Average wind speed at the hub, direction of wind, wake effects, hub height, efficiency of the turbines, etc. A Weibull distribution was made using wind speeds and the average number of hours per year where that wind speed is recorded at our farm location. From that, a power curve for the Vestas 136-4.2MW turbine could be made using the power outputs from this model at a given wind speed. Unfortunately, our total output came out to be lower than expected once wake effects and wind directions were considered, which could be attributed to the fact that the model chosen last year is not optimized for the majority of the wind speeds occurring on site. But, once all factors were calculated in, the total NAEP for the farm came out as 208,978,261.88 kWh. After averaging this with our previous year's NAEP we found an annual estimated production of 221,386,620 kWh.

Upon finding total energy calculated per year, the team multiplied this by a PPA that would be determined later in the analysis to establish revenue. The team determined a Return on Investment (ROI) of 11% after financing would be favorable given the >10% profit margin seen by most wind farm operators (Wiser, 2018). Using this along with a profit based (revenue - taxes - expenses) net present value analysis (NPV) the team found a necessary PPA of $175.69/MWh which is very unfavorable for the local market which experiences an average PPA of $14/MWh. This work is shown in **Figure 2**.

Income	
Production (MWh)	221,386.62
PPA	$ 175.69
Annual Revenue	$ 38,896,145.79

Figure 2

Operations and Maintenance

Operations and Maintenance (O&M) is the annual cost to operate the farm. In our example, this includes cost of utilities for balance of plant, turbine maintenance, administration costs, employee wages, and land leasing. EDP Renovaveis (EDPR), a large wind farm owner in the U.S., reports an average O&M of $53/kW-year. This includes supplies and services to the turbines ($33/kW-year), employee wages ($11/kW-year), and leasing ($9/kW-year) (Wiser, 2018). Our model makes use of this number minus the leasing costs. Instead, our project adopted a model used by EDP Renewables at another local wind farm.

Our leasing model the team leases from all the land owners with land directly under and around the wind farms. In doing so, land owners with no turbines or transmission lines running through their farms are compensated for the disturbance created by the wind farms. Additionally, the team plans to donate an additional $150k per year to the county public fund in lieu of taxes not paid from the PTC. The team took this approach due to the poor report that wind energy has with the locals of this county following a failed project in the 90's that sought to build on protected lands and paid little regard to public perception. The hope is to reverse that poor public image of wind energy and garner additional support to from the local government and its citizens. In total, the team sets aside 8% of revenue to go toward land leasing that will then be distributed to the land owners with a preferred rate obviously going to those with land hosting turbines, then transmission, then benefactors of our version of EDPs "good neighbor" program.

Taxes and Production Tax Credit

Before taxes can be calculated, revenue and depreciation must be found. Depreciation allowed the project to claim tax credits due to the reduced value of our assets (turbines and balance of plant) over time. Depreciation was calculated using MACRS 20-year depreciation schedule which combines Double-Declining Balance and straight-line depreciation over the 20-year "useful life" of the turbines (IRS, 2018). The MACRS method is complicated to explain, so it is included in its own column of our cash flow analysis to demonstrate how our assets were depreciated over the life of the project. We can see that the credit from this allows us to claim exemptions averaging $7.6 million per year. This depreciation is shown in the cash flow table shown in **Appendix C**.

The production tax credit (PTC) has long been a point of contention in the wind industry. It's been a means of inviting investors to jump into the wind industry by easing the costs going into constructing and operating a farm. In the past, the PTC entitle new farms to $0.023/kWh produced for the first 10 years of operation. Beginning in 2017, there has been an easement in this credit of 20% per year, leading to an eventual expiration of the credit beginning in 2020 (DOE, 2018). The team assumed that the project would begin construction in 2019 to take advantage of the PTC before it finally expires. By doing so, the project can claim a credit of $ 0.0092/kWh produced through year 10 of the project. Across the first 10 years, this allows the team to capture $20,367,569.14 in tax credits. This adds up to approximately $2 million per year in positive cash flow.

After taking depreciation and charitable write-offs from donating to the county out of revenue, taxable income was uncovered. State and Federal taxes were calculated from this number with State taxes having precedence over Federal. Corporate taxes for the State of Kansas are calculated using a flat 4% of taxable income with an additional 3% being taken for every dollar over $50,000 (Kansas Department of Revenue, 2018). Federal corporate income tax was a flat 21% of after state tax income.

Conclusion

Upon current analysis of this project, the team cannot recommend moving forward with this project. At a desired ROI of 11%, the project's PPA is just not competitive with the current market. As stated before, the project would greatly benefit from the use of turbines more suited for the site that could more efficiently capture energy from the wind at the speeds available. Hopefully, these turbines would cost less per unit capacity, so overhead cost would be limited as well and minimize PPA. This would lead to significant increase in revenue. Additionally, the project could benefit from selling its production tax credits to aid in mitigating the cost of financing. Final cash flow graph is shown in **Figure 3**.

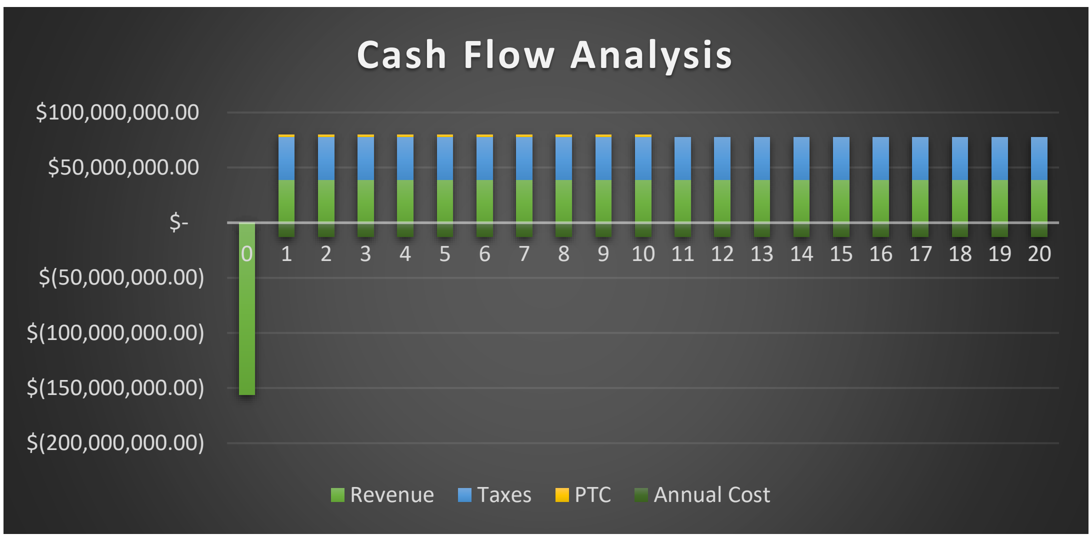
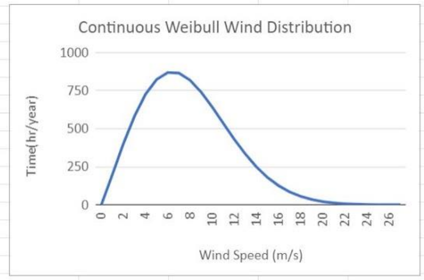


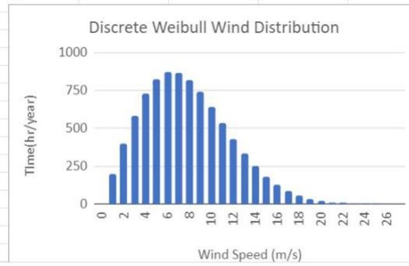
Figure 3

Appendices

Wind Speed Calculation

Constants			Probability Distribution	
Average Wind Speed at Hub Height in m/s	8.811571	Wind Speed in m/s	Weibull Distribution	Hours per Year
Average Wind Speed at 110m in m/s	9	0	0	0
Shape Parameter (a)	2.07	1	0.02264158346	198.3402712
Hours per Year	8760	2	0.04588221072	401.9281659
Power Law alpha value	0.222	3	0.06661100794	583.5124296
K-value	2.07	4	0.08302955386	727.3388918
		5	0.09401781169	823.5960304
scale parameter (b)		6	0.09915469846	868.5951585
		7	0.09868868917	864.5129172
		8	0.0934222368	818.3787944
		9	0.0845299563	740.4824172
		10	0.07334861911	642.5339034
		11	0.06117929925	535.9306615
		12	0.0491335856	430.4102098
		13	0.03804126666	333.2414959
		14	0.02842125785	248.9702188
		15	0.02050491852	179.6230863
		16	0.01429368739	125.2127015
		17	0.009631520959	84.3721236
		18	0.006275710594	54.9752248
		19	0.003955219742	34.64772494
		20	0.002411659696	21.12613894
		21	0.001422911627	12.46470586
		22	0.0008124931108	7.117439651
		23	0.00044904738	3.933655049
		24	0.0002402348596	2.10445737
		25	0.0001244180908	1.089902476
		26	0.00006238210193	0.5464672129
		27	0.00003028202908	0.2652705748

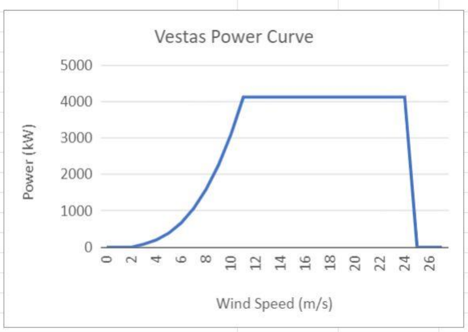




Appendix A

Energy Production

Constants			Probability Distribution		Wind speed in m/s	Power(kW)	Energy (kWh)
Average Wind Speed at Hub Height in m/s	8.811571	Wind Speed in m	Weibull Distribution	Hours per Year	0	0	0
Average Wind Speed at 110m in m/s	9	0	0	0	1	0	0
Shape Parameter (a)	2.07	1	0.02264158346	198.3402712	2	0	0
Hours per Year	8760	2	0.04588221072	401.9281659	3	83.70	48839.99036
Power Law alpha value	0.222	3	0.06661100794	583.5124296	4	198.40	144304.0361
K-value	2.07	4	0.08302955386	727.3388918	5	387.50	319143.4618
		5	0.09401781169	823.5960304	6	669.60	581611.3181
scale parameter (b)		6	0.09915469846	868.5951585	7	1063.30	919236.5848
		7	0.09868868917	864.5129172	8	1587.20	1298930.822
		8	0.0934222368	818.3787944	9	2259.90	1673416.215
		9	0.0845299563	740.4824172	10	3100.00	1991855.101
		10	0.07334861911	642.5339034	11	4126.10	2211303.502
		11	0.06117929925	535.9306615	12	4126.10	1775915.567
		12	0.0491335856	430.4102098	13	4126.10	1374987.736
		13	0.03804126666	333.2414959	14	4126.10	1027276.02
		14	0.02842125785	248.9702188	15	4126.10	741142.8163
		15	0.02050491852	179.6230863	16	4126.10	516640.1277
		16	0.01429368739	125.2127015	17	4126.10	348127.8192
		17	0.009631520959	84.3721236	18	4126.10	226833.2751
		18	0.006275710594	54.9752248	19	4126.10	142959.9779
		19	0.003955219742	34.64772494	20	4126.10	87168.56187
		20	0.002411659696	21.12613894	21	4126.10	51430.62283
		21	0.001422911627	12.46470586	22	4126.10	29367.26774
		22	0.0008124931108	7.117439651	23	4126.10	16230.6541
		23	0.00044904738	3.933655049	24	4126.10	8683.201556
		24	0.0002402348596	2.10445737	25	0	0
		25	0.0001244180908	1.089902476	26	0	0
		26	0.00006238210193	0.5464672129	27	0	0
		27	0.00003028202908	0.2652705748		AEP(for one turbine)	15535404.68
						Efficiency	42.2%



Appendix B

Cash Flow Table

			Taxes								
	Revenue	Depreciation	Taxable Income	State	Federal	Total Taxes	ATC	PTC	Leasing	O&M	Profit
0	$ (156,240,000.00)						$ (156,240,000.00)				$ (156,240,000.00)
1	$ 38,896,145.79	$ (5,859,000.00)	$ 33,037,145.79	$ 2,311,100.21	$ 6,452,469.57	$ 8,763,569.78	$ 30,132,576.01	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 19,555,591.40
2	$ 38,896,145.79	$ (11,278,965.60)	$ 27,617,180.19	$ 1,931,702.61	$ 5,393,950.29	$ 7,325,652.90	$ 31,570,492.89	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 20,993,508.27
3	$ 38,896,145.79	$ (10,432,144.80)	$ 28,464,000.99	$ 1,990,980.07	$ 5,559,334.39	$ 7,550,314.46	$ 31,345,831.33	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 20,768,846.71
4	$ 38,896,145.79	$ (9,650,944.80)	$ 29,245,200.99	$ 2,045,664.07	$ 5,711,902.75	$ 7,757,566.82	$ 31,138,578.97	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 20,561,594.35
5	$ 38,896,145.79	$ (8,925,991.20)	$ 29,970,154.59	$ 2,096,410.82	$ 5,853,486.19	$ 7,949,897.01	$ 30,946,248.78	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 20,369,264.16
6	$ 38,896,145.79	$ (8,257,284.000)	$ 30,638,861.79	$ 2,143,220.33	$ 5,984,084.71	$ 8,127,305.03	$ 30,768,840.76	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 20,191,856.14
7	$ 38,896,145.79	$ (7,637,011.20)	$ 31,259,134.59	$ 2,186,639.42	$ 6,105,223.99	$ 8,291,863.41	$ 30,604,282.38	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 20,027,297.77
8	$ 38,896,145.79	$ (7,065,172.80)	$ 31,830,972.99	$ 2,226,668.11	$ 6,216,904.03	$ 8,443,572.13	$ 30,452,573.66	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 19,875,589.04
9	$ 38,896,145.79	$ (6,971,428.80)	$ 31,924,716.99	$ 2,233,230.19	$ 6,235,212.23	$ 8,468,442.42	$ 30,427,703.37	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 19,850,718.76
10	$ 38,896,145.79	$ (6,969,866.40)	$ 31,926,279.39	$ 2,233,339.56	$ 6,235,517.37	$ 8,468,856.92	$ 30,427,288.87	$ 2,036,756.91	$ (2,872,730.21)	$ (9,741,011.33)	$ 19,850,304.25
11	$ 38,896,145.79	$ (6,971,428.80)	$ 31,924,716.99	$ 2,233,230.19	$ 6,235,212.23	$ 8,468,442.42	$ 30,427,703.37		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,961.84
12	$ 38,896,145.79	$ (6,969,866.40)	$ 31,926,279.39	$ 2,233,339.56	$ 6,235,517.37	$ 8,468,856.92	$ 30,427,288.87		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,547.34
13	$ 38,896,145.79	$ (6,971,428.80)	$ 31,924,716.99	$ 2,233,230.19	$ 6,235,212.23	$ 8,468,442.42	$ 30,427,703.37		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,961.84
14	$ 38,896,145.79	$ (6,969,866.40)	$ 31,926,279.39	$ 2,233,339.56	$ 6,235,517.37	$ 8,468,856.92	$ 30,427,288.87		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,547.34
15	$ 38,896,145.79	$ (6,971,428.80)	$ 31,924,716.99	$ 2,233,230.19	$ 6,235,212.23	$ 8,468,442.42	$ 30,427,703.37		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,961.84
16	$ 38,896,145.79	$ (6,969,866.40)	$ 31,926,279.39	$ 2,233,339.56	$ 6,235,517.37	$ 8,468,856.92	$ 30,427,288.87		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,547.34
17	$ 38,896,145.79	$ (6,971,428.80)	$ 31,924,716.99	$ 2,233,230.19	$ 6,235,212.23	$ 8,468,442.42	$ 30,427,703.37		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,961.84
18	$ 38,896,145.79	$ (6,969,866.40)	$ 31,926,279.39	$ 2,233,339.56	$ 6,235,517.37	$ 8,468,856.92	$ 30,427,288.87		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,547.34
19	$ 38,896,145.79	$ (6,971,428.80)	$ 31,924,716.99	$ 2,233,230.19	$ 6,235,212.23	$ 8,468,442.42	$ 30,427,703.37		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,961.84
20	$ 38,896,145.79	$ (6,969,866.40)	$ 31,926,279.39	$ 2,233,339.56	$ 6,235,517.37	$ 8,468,856.92	$ 30,427,288.87		$ (2,872,730.21)	$ (9,741,011.33)	$ 17,813,547.34
										NPV	($0.00)

Appendix C

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