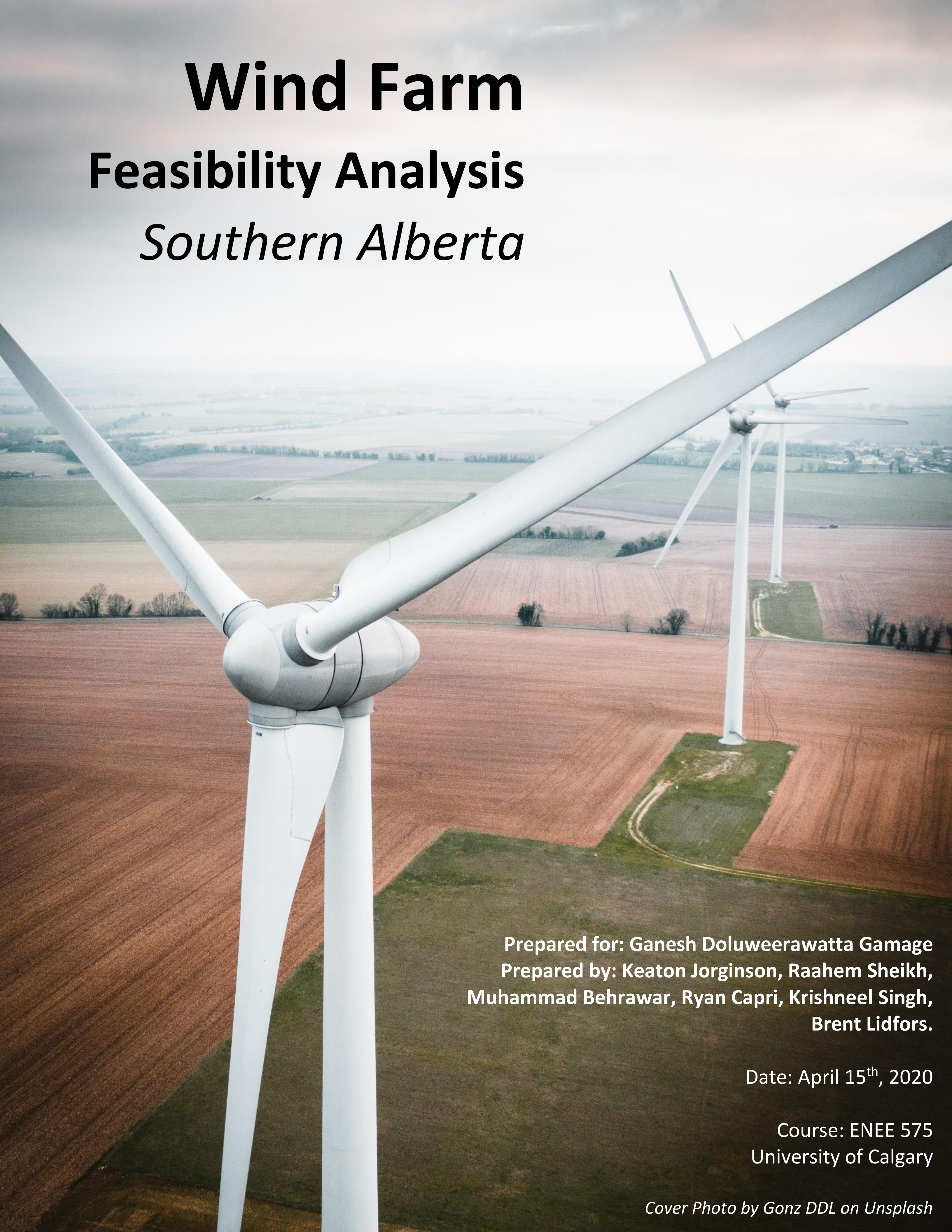

Wind Farm

Feasibility Analysis

Southern Alberta

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EXECUTIVE SUMMARY:

Development of a wind farm constitutes a significant capital expenditure and countless man hours for location selection, engineering design, simulations, cost estimates, regulatory processes and other considerations. This requires a thorough study where resources are required to facilitate all further analysis and ultimately recommend a project as feasible or not.

Alberta is a predominately oil and gas energy hub. However, Alberta is also home to some of Canadas most prolific wind resources in the southern region. Minimal elevation changes and a steady wind stream that originates in the Rocky Mountains facilitates this, and the recent addition of new and upgraded transmission lines in the region to supply the provinces energy grid further strengthens this locations stranglehold on the wind energy market.

A location near the Whitla Substation 251S was identified. This location offers ripe resource potential with an average wind speed is 7.84 m/s and facilitates close tie-in access to the energy grid. Located at 49.756667, -111.302778 this site is only 18 km from the closest substation. The cost of land-based wind generation in the region ranges from $28 -54 per MWh as seen in the LAZARD. This is the cheapest electricity production method other than solar photo voltaic power. The 20 mile^2 parcel of land selected is located adjacent to Suncor's Forty Mile and Capital Powers Whitla Wind Farm.

The arrangement of 35 Vesta V112 3.0MW wind turbines in a staggered pattern will ensure maximum utilization of the winds resource potential. This configuration will achieve a nameplate capacity of 105 MW. The plant will generate over 300 GWh per year with a capacity factor of 35.1%. Wind in the region approaches from the west and is greeted by a row comprised of seven wind turbines, followed by 5 subsequent rows downwind. Spacing between turbines of 8 rotor diameters and more importantly 15 rotor diameters downwind ensures minimal array losses. The significant 15 rotor spacing was found to minimize array losses to 11% (The typically accepted range is 10 – 40%). Vesta turbines were chosen due to their sound business model and world class management, which will ensure the turbines will remain serviced for the 25-year expected lifespan of the windfarm. Furthermore, the V112 has a low cut in speed of 3.0 m/s and a rated wind speed of 12 m/s. Compared to its competitors, this will ensure the winds resource potential is maximized and therefore monetized.

Details of the cost analysis yield a levelized cost to install the windfarm of 1,645 $/kW. Other wind resource plays in the 100-200 MW range from 2015 reveals the average price then was $ 1,572 $/kW. With inflation accounted for, the price per kW realized is acceptable. Furthermore, with appropriate loan rates, depreciation and federal incentives accounted for, a 25-year service life Net Present Value (NPV) of $63,145,198 will be realized from this project. Additionally, the Return on Investment (ROI) was determined to be 11.51%, an acceptable percentage for projects of this nature. These calculations were based on an average sell rate of 6.67 c/kWh, which is a historically low price for electricity. A sensitivity analysis performed further concluded the profitability of the project yielding an NPV of ~21 million dollars should the price for electricity drop another 20%. This indicates the farm is capable of weathering short and even long-term price collapses. Compared to the neighboring Whitla Wind Facility, the economics are comparable and demonstrate the strong economic fundamentals for the proposed development of the wind farm.

INTRODUCTION & BACKGROUND:

Global Landscape of Wind Power & Global Resource Potential

Wind power is becoming increasingly cheaper as progress is being made throughout the world on becoming less reliant on non-renewable sources of energy. Due to the increasing affordability of wind power the installed capacity of wind power has grown steadily year by year and as of 2018 it sits at 591 Gigawatts. While wind installed capacity is not growing at the same rate as solar and does not currently match the installed capacity of hydropower, it still is a major source of energy in the renewable energy market. As for the potential of wind power it has been estimated that just using the power generated by land with higher than average wind speeds the amount of power produced would be 627000 TWh which is roughly 4 times greater than the primary energy supply of the world in 2017. [1]

Albertan Landscape of Wind Power & Albertan Resource Potential

Wind power is being steadily adopted by the rest of the world and that same sentiment holds true for Alberta. As of December of 2019, there is an installed capacity of 1685 MW in just Alberta making it 3rd largest source of wind power in Canada. With 202 MW of that installed capacity just coming in 2019 and with 38 current wind power projects currently ongoing in Alberta it can also be said that there is room for major growth of wind power in Alberta. [2]

Cost of Wind as Evaluated by LAZARD

The levelized local cost of wind power is also low compared to many other sources of energy with LAZARD reporting it as 28 to 54 dollars per MWh on land. At the low end it is cheaper than any other source of renewable or conventional energy production methods. At the high end of the range it is only more expensive than thin film solar PV which is used at a utility scale and gas combined cycle. [3]

Types of Wind Turbines Used in Wind Farms

The wind turbines used to produce energy are of two main types, horizontal axis wind turbines and vertical axis wind turbines. Horizontal axis turbines thrive in places that are extremely open and have lots of vertical space as such they are mainly used in wind farms. While vertical axis turbines tend to be more compact and are better suited for more urban locations. The turbine chosen for this feasibility study happens to be a 3-bladed horizontal axis wind turbine due to their efficiency in wind farms and the chosen location.

Steps Taken to Design and Evaluate a Wind Farm

To design and evaluate a wind farm there are some necessary steps that must be taken. The first step is to do a wind resource assessment after which a location must be chosen. The next step involves choosing a type of turbine and developing an energy model. The following step involves considering the layout of the turbine, the losses associated with it, connection to the grid and finally the environmental impact of the turbines. While making those assessments the economic aspect must also be considered by doing a cost, financial and sensitivity analysis. Finally, to do a full evaluation everything has to be taken in and discussed in terms of feasibility both technical and economic while also understanding the limitations. The wrap up involves comparing the design and evaluation to similar projects and putting forth a recommendation.

ANALYSIS:

The following section covers the detailed analysis of this feasibility study. This includes all detailed design and calculations. Items such as proposed location, resource availability, grid design and turbine specification can be found below. A complete project model completed by SAM software will also be shown illustrating plant information, power curves and other relevant data. Additionally, an economic study was completed including a sensitivity analysis to aid in evaluating the economic feasibility of the project.

Technical:

This section of the analysis discusses the design of the proposed wind farm. This includes all details required for specifying and connecting the proposed power plant. A greenhouse gas analysis will also be attached to this portion of the document.

Wind Resource Assessment

Due to Alberta's available wind energy and vacant space, southern Alberta was targeted as a lucrative center for development of a moderately sized wind farm. Southern Alberta is home to some of the highest sustained on-land wind speeds anywhere in Canada as depicted in the average wind speed figure below. It can be seen the wind speeds in this area of the country average at least 7 m/s (location permitting).

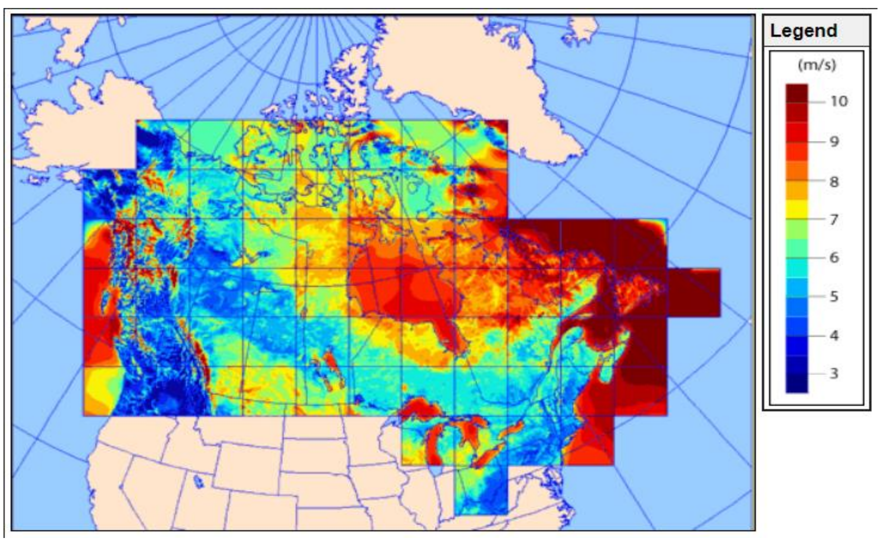


Figure 1 Global Map - Wind Atlas - Environment and Change Canada [4]

Details pertaining to the proposed development of a wind farm rely on two salient fundamentals, the average wind speed in the area and the projects relative proximity to the consumer. Unfortunately, Southern Alberta is largely devoid of major substations and population centers. Several exceptions exist however which were identified, and further analysis conducted upon. Recent infrastructure upgrades at the Whitla Substation 251S (located at NW 33-7-9-W4) and associated transmission lines drew keen eyes. Over the past 5 years, a transmission line was constructed to connect Altalink's pre-existing Whitla Substation to Capital Power's recently built Shamrock Substation. [5]

Additionally, transmission lines to the Bowmanton Substation completed construction in 2014 to "connect new wind-generated power to Alberta's electric system" with other transmission lines in the area upgraded to 240 kV as well. These developments were part of the Southern Alberta Transmission Reinforcement (SATR). [6]

With a strong network grid established in the area, and Medicine Hat's growing population (which in 2009 consumed 700 GWh), construction of a wind farm nearby proved to be the most viable development location. [7] [8]

Two sets of wind speed data are collected and compared. "The Wind Integration National Dataset (WIND) Toolkit" [9] and "International Renewable Energy Agency (IRENA)" [10] are compared and revealed to have only a 7% error in their averages. Furthermore, the distribution as illustrated in figure 2 have shown to be relatively similar. The IRENA data set was utilized as it was accessible at time of the analysis.

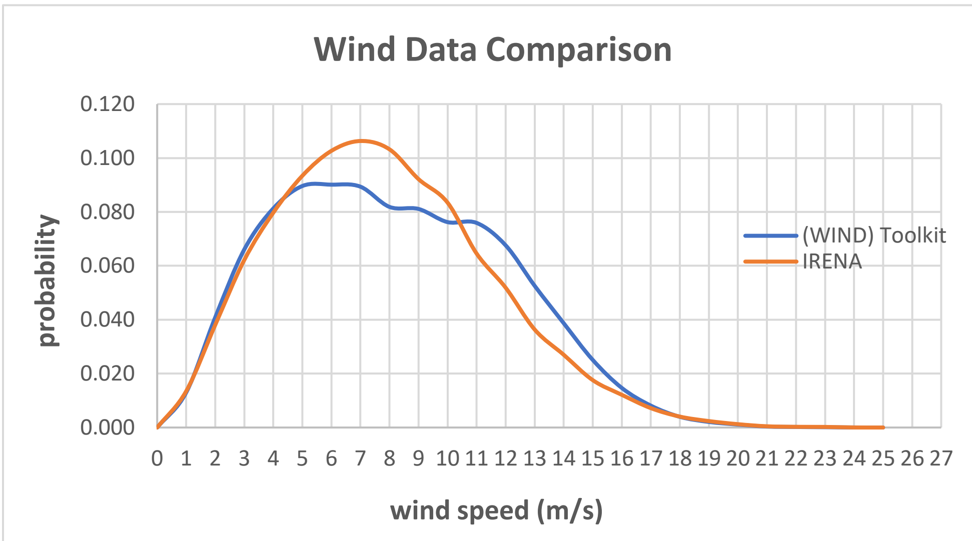


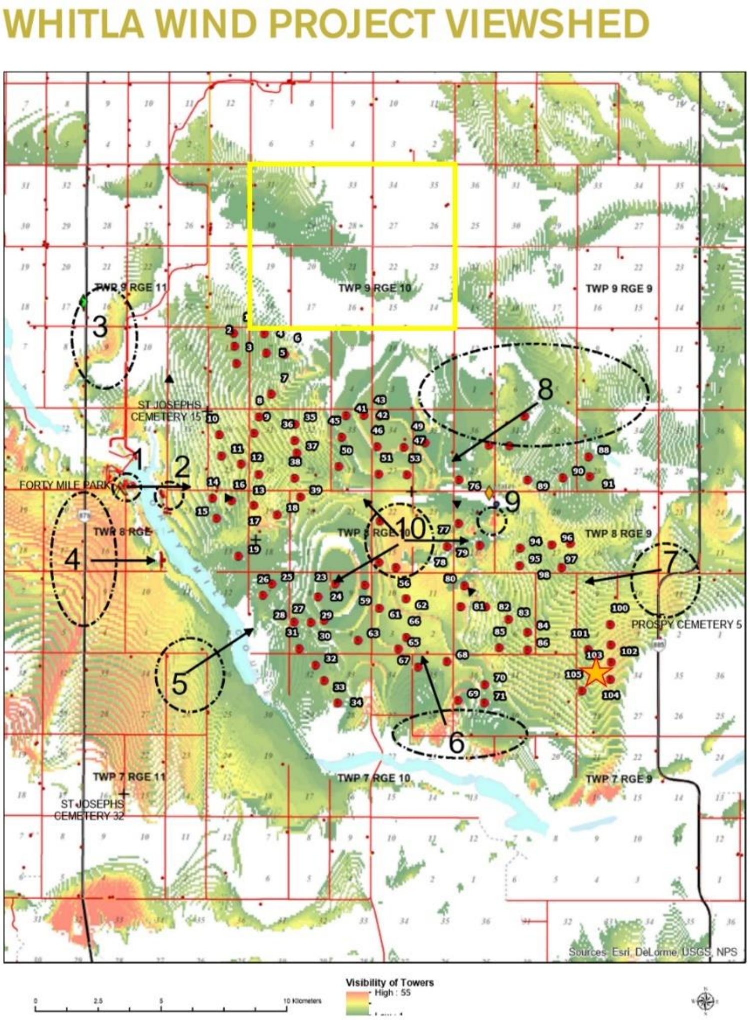
Figure 2. Wind Data Comparison Between (WIND)Toolkit and IRENA datasets

Location Selection

The local landscape, as depicted in the figures below with the proposed wind farm location demonstrate development is ripe in the area east of the Forty Mile Coulee near the small town of Maleb. Countless reasons to support capital projects in this area include an average wind speed north of 7.5 m/s at a 100m hub height and a relatively flat landscape which maximizes power generation potential. Additional proponents to development in the vicinity include ease of road access and privately-owned land with owners who have a demonstrated history of working with energy companies.

In the following figures, the proposed wind farm project location is depicted by the yellow rectangle, which outlines a 20 mile^2 land mass with high wind speeds and close relative proximity to the Whitla Substation only 18 kilometers away from the center of the proposed location (49.756667, -111.302778). The Whitla Substation is depicted by the red-orange star located at NW 33-7-9-W4. Two industrial wind farms are neighboring the proposed development location. These stations are owned by Capital Power and Suncor. Capital Power's Whitla Wind 1 Farm completed construction in 2019, and is comprised of 56 Vesta V 136 turbines, for a rated output of 201.6 MW. The development of this plant can be seen in the figure below on the left.

Further development in the area was announced by Suncor with construction beginning in late 2019 as well. Their planned wind farm spanning 50,000 acres and comprised of 89 wind turbines for a rated output of 400 MW. Suncor's farm will tie into the Granlea Substation, ensuring a tie in for the farm at the Whitla Substation will be attainable with the installation of a 240 kV circuit breaker and construction of the aforementioned short transmission line. The Suncor proposal can be seen in the image above on the right. [11]



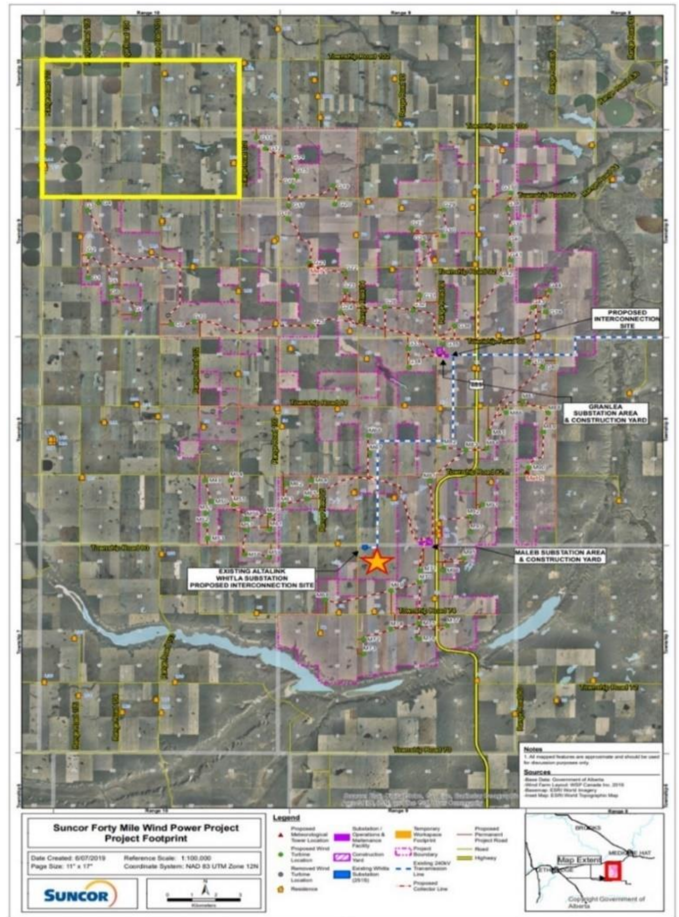


Figure 4 Whitla 1 Location **Figure 3 Suncor Location**

Furthermore, this parcel of land has a reduced value due to neighboring developments. The combination of the land straddling both Capital Power's and Suncor's wind farms in addition to the landscape north exhibiting tortuous qualities were the main factors for this. Installation of a large wind farm is not ideal the further one develops north. As a result, it was possible to fit a small wind farm with strong average wind speeds, low array losses and relative proximity to the Whitla Substation for tie into the grid. Further details pertaining to the associated costs of procurement and development will be covered in the economic calculations.

Energy Model

The data below details the energy simulation completed by the SAM software [12]. Details regarding the selected turbine, losses, layout, emissions, and grid connection will also be discussed in full.

Energy Production

The farm produces 323 GWh of energy per year at a capacity factor of 35.1%. The p90 of the farm is 273 GWh per year. This means that the farm will be producing 273 GWh of energy at least 90% percent of the time. This is detailed below where the figure illustrates the monthly energy production of the 35 turbines.

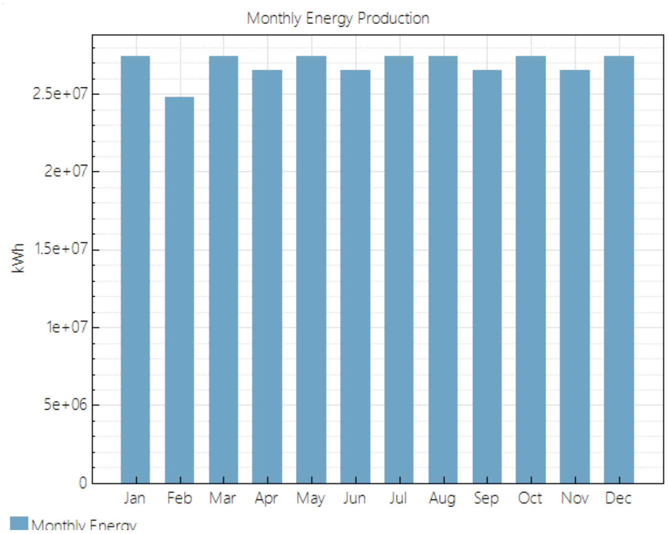


Figure 6 Monthly Energy Production

The total losses within the model sum up to 28.7% and the breakdown is detailed in the figure below. The biggest portion of the losses as discussed later in the report is wake losses. The complete SAM simulation with all details pertaining to this model will be attached to the report.

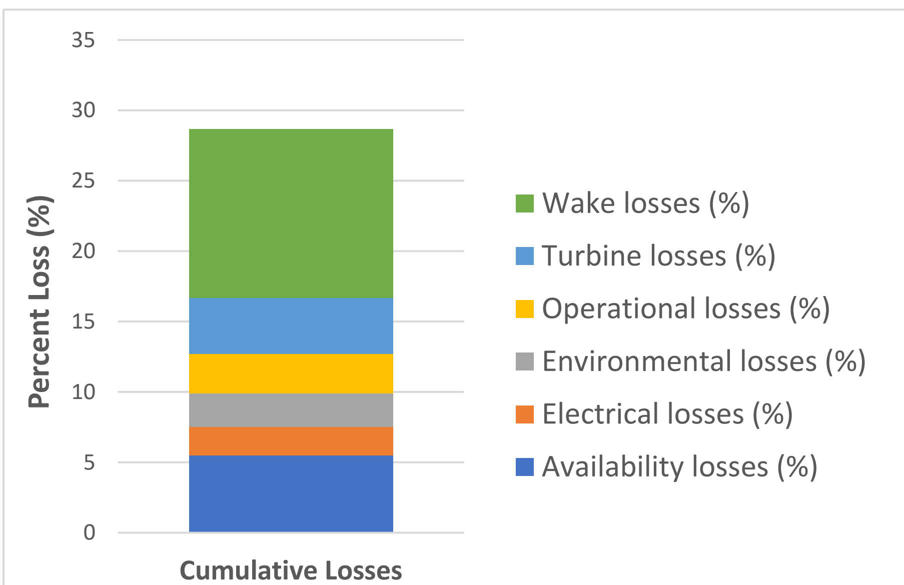


Figure 5 Cumulative Loss Model

Type of Turbine Selected

The proposed wind turbine for this farm is Vestas esteemed V112 – 3MW variant. Despite being geared towards offshore deployment, the V112 serves as an ideal turbine for wind resources here in southern Alberta. A low cut-in wind speed of 3.0 m/s in addition to a rated wind speed of a mere 12 m/s will ensure the highest capacity factor is realized of the nameplate capacity. Most wind turbines have a cut in wind speed of 5.0 m/s and a rated speed of 14 – 15 m/s. With wind resources averaging 7.84 m/s at the installed height of 100 m, the efficiency of Vestas V112 will prove immensely beneficial and a more reliable source of energy will be generated as a result. A comprehensive data sheet of the V112 can be seen below.

Figure 8 vestas V112 Turbine [25]

Datasheet

Power

Rated power:	3,000.0 kW
Flexible power ratings:	-
Cut-in wind speed:	3.0 m/s
Rated wind speed:	12.0 m/s
Cut-out wind speed:	25.0 m/s
Survival wind speed:	-
Wind zone (DIBt):	-
Wind class (IEC):	-

Rotor

Diameter:	112.0 m
Swept area:	9,852.0 m²
Number of blades:	3
Rotor speed, max:	17.7 U/min
Tipspeed:	104 m/s
Type:	54.6
Material:	-
Manufacturer:	-
Power density 1:	304.5 W/m²
Power density 2:	3.3 m²/kW

Gear box

Type:	spur/planetary
Stages:	4.0
Ratio:	-
Manufacturer:	-

Generator

Type:	Synchronous permanent
Number:	1
Speed, max:	-
Voltage:	-
Grid connection:	IGBT
Grid frequency:	50/60 Hz
Manufacturer:	-

Figure 7 Vestas V112 Turbine Data Sheet [26]

Further benefit of utilizing a Vesta turbine is predicated on their sound business model, strong management and demonstrated history of producing technologically innovative wind turbines while offering a reliable product line. Many wind turbine manufacturers have failed in this regard. A perfect example is that of REpower, whose 5M-117m wind turbine was considered from this project. However, like many others, REpower has since followed for insolvency as they came under pressure due to equipment pricing and R&D costs. [13] As a result, despite being owned for several years by Suzlon (once the 5th largest wind turbine supplier, and global top ten ranked till 2014), their products are no longer available, and their European service fleet has been sold to Siemens Gamesa as of 2019.

Vestas on the other hand offers a significant safety net. As the largest wind turbine supplier with forward thinking ideology, they are most likely destined to remain in the industry for generations to come. Just this year they went so far as to announce a zero-waste management strategy, set to roll out over the next two years for their turbines. [14] Technical excellence such as this in today's world of climate concerns will only aid in further solidifying their position. The executive decision was therefore made to seek a higher capital raise in return for the reliability and assurance the Vestas turbines will provide by remaining repairable over their expected lifespan of up to 25 years. This ultimately ensures the accuracy of the NPV calculations and business feasibility over the years.

Greenhouse Gas Analysis

The greenhouse gas emissions involved with the development of wind turbines are associated with the manufacturing, construction, installation, and maintenance stages. These emissions are found to be proportionally low, estimated at 60kg/GJ. Both the embodied energy required to develop the wind turbine, and any involved "bought" energy is equal to 5% or less of the energy produced for the turbine over its lifespan. In the case of using 3.0MW turbines in this project, this figure is approximately 2.9-4.4% depending on their lifespan. [15]

Array Losses

Wind turbines spacing is essential to maximizing efficiency on a large scale, if the wind stream that feeds a turbine is "dirty" or affected by a sister turbine efficiency drops a considerable amount. It is for this reason that on a basic level, wind turbines are recommended to be spaced a minimum of 7 rotor diameters apart. Serval strategies can be used to help mitigate the wake effect from neighboring turbines and turbulent air. For example, wind is typically less turbulent the further it is from obstructions on the ground, this is one of the reasons as to why wind turbines are being constructed taller and taller. [16]

If wind turbines are installed in proximity, the rotation of each rotor disturbs the air and creates a "wake" or turbulent flow that impacts the wind turbines around it in all directions. Therefore, the layout in a wind farm is extremely important in design as it can affect the energy output of the plant.

Delving further into the optimization of wind turbine layouts requires multiple parameters to be considered. Accurate array losses are extremely difficult to predict and warrants its own study to be completed with precision. The data of aerodynamic performance of wind turbines is predicted via extremely complex numerical models and algorithms. For this reason, the group will be using best judgement as recommended by previous studies to determine spacing and a reasonable loss factor. The proposed turbine layout as a result of said analysis can be seen below in the Turbine Layout section.

As mentioned above, separate studies are required to determine accurate array loss factors and optimal row spacing. For example, a study was completed by members from the Massachusetts Institute of Technology with the goal of finding an accurate algorithm to determine the optimal spacing of wind turbines. Some of the key details and results can be found below.

Number of turbines	N
Wind velocity Wind direction	v $0^0 < \theta < 360^0$
Farm radius	r
Rotor diameter	R
Weibull distribution for wind speed Weibull shape parameter Weibull scale parameter Wind direction distribution	$p_v(v,k,c) = k/c(v/c)^{k-1}e^{-(v/c)^k}$ k c $P(\theta)$
Expected power of a single turbine	$E^i[\eta]$
Piecewise power curve of turbine	$\beta(v) = \begin{cases} 0 & v < v_{cut\_in} \\ \lambda v + \gamma & v_{cut\_in} \le v \le v_{rated} \\ P_{rated} & v_{rated} < v < v_{cut\_out} \end{cases}$

Figure 9 Parameters utilized in the determinization of the optimal turbine spacing [27]

Working with the above parameters, significant consideration needs to be paid to the wake created by a turbine. The implications of this cannot be understated, if the wake created by each turbine is not considered, it is assumed the air stream that is impacting each turbine is identical. This however is far from the case, as the wake created by the propulsion of a turbine can significantly impact the performance of downwind turbines by changing the shape of the Weibull distribution. Accurate modelling here is critical. The paper mentioned above uses the modified Park wake model where a proximity constraint is used as a function of the rotor radius. This is standard in the wind turbine industry. The goal of the algorithm used is optimize total energy produced by the fam. The algorithm can be seen in the figure below.

Algorithm 1 Procedure for evaluation of wake effects due to park model

Given $\{X, Y\}$ as turbine locations $C_T \Leftarrow$ thrust coefficient, $\kappa \Leftarrow$ spreading factor;
$a = 1 - \sqrt{1 - C_T}$, $b = \kappa/R$, $u \Leftarrow$ unit step function, $o = (x_i - x_j)cos\theta + (y_i - y_j)sin\theta$;
$d_{i,j} = \|o\|$, $\alpha = tan^{-1}\kappa$
for $i = 1$ to number of turbines **do**
  for $\theta = 0^0$ to 360^0 **do**
    for $j = 1$ to n-1 and $j \neq i$ **do**
      $\delta_{i,j} = cos^{-1}\{\frac{o + R/\kappa}{\sqrt{(x_i - x_j + (R/\kappa)cos\theta)^2 + (y_i - y_j + (R/\kappa)sin\theta)^2}}\}$
      $Vdef_{(i,j)} = u(\delta_{i,j} - \alpha)\frac{a}{(1 + bd_{i,j})^2}$
    end for
    $Vdef_i^\theta = \sqrt{\sum_j (Vdef_{(i,j)})^2}$
    $c_i(\theta) = c_i(\theta) \times (1 - Vdef_i)$
  end for
end for

Figure 10 Park Wake Model Algorithm [27]

In the algorithm the wake effects "i" change the wind resource available to each turbine in all directions reducing the Weibull scale parameter (or freestream wind resource). This algorithm was run with several constraints in place, namely an upper bound such that wind turbines could only be placed in a certain area with a proximity constraint. This determines the minimal distance two turbines can be installed. The minimal distance is derived from the previously mentioned rotor diameter in addition to a proximity factor based on the make and model of the turbines.

Since these resources are not available for public use however, the group is adhering to the 7 rotors of horizontal spacing as mentioned above. This bodes well with regards to minimizing wake losses and is frequently used in practice. Furthermore, the paper suggests a design of placing turbines on a basic grid "proved to serve as a very good starting point, as the initial distance between the turbines is maximized in a naïve way. Thus, the wake effect is already reduced to some extent".

Another paper, titled "Wind Turbine Separation Distances Matter" further expands on the industry standard concepts referenced to minimize array losses. In said paper Peter R Mitchell speaks to the drawbacks of recommended turbine spacings of 7 – 8 rotors downwind, as it has been proven to still allow "turbulent air exiting one turbine to retain significant turbulence when entering the next". [17] As a direct consequence of this recommended spacings should therefore be "considered as an unfortunate compromise". He proceeds furthermore to state that the most efficient turbine spacing, has been shown to be 15 rotor diameters. Which is what is utilized within the design. Wake is predominantly produced down-wind of a turbine, hence the additional consideration here.

Furthermore, reduced rotor spacing also contributes to the following consequences:

- Increased wear on the turbine components, ultimately increasing early failure rates.
- Increased audible noise.
- Increased infrasound and low frequency noise.

Therefore, with the proposed design it is not unrealistic to assume 11% array losses as recommended by figure 11. This is largely a result of optimal rotor spacing and significant spacing between rows of wind turbines. While land utilization is not ideal (more turbines could comfortably be installed), array losses are minimized, providing the most efficient use of capital and a good compromise.

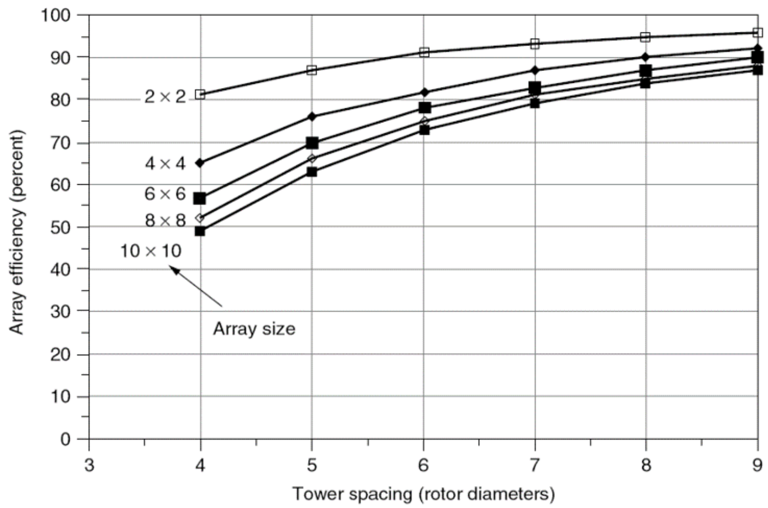


Figure 11
. Impact of tower spacing and array size on performance of wind turbines. [30]

Turbine layout

As mentioned in the wind resource assessment the wind primarily blows trough from the west. As seen in the wind rose below, figure 12, the wind farm will be facing west accordingly.

Total elevation change across the landscape is only ~10m, this is ideal for a wind farm. The NW and SE corners of the have an elevation of 840m, while the NW corner is 835m and the SE corner 845m. Elevation changes across the area are minimal as well, with the highest point of 865m residing near the center of the plotted area. The landscape does not appear to have any significant slope; unfortunately, a topographic map was unable to be sourced for further analysis. Despite this, the location proves ideal for a wind farm location as the presence of hills and valleys are not prominent, which can considerably decrease turbine performance as a direct result of said features potentially generating turbulent air flow.

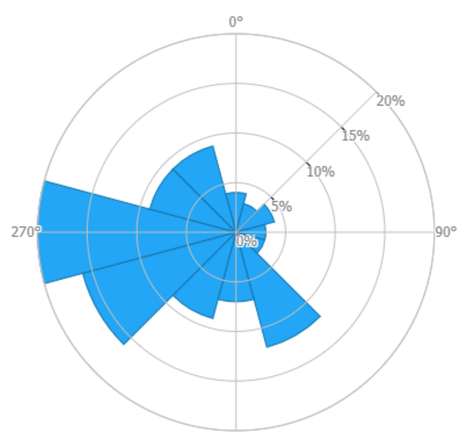


Figure 12 Wind Rose

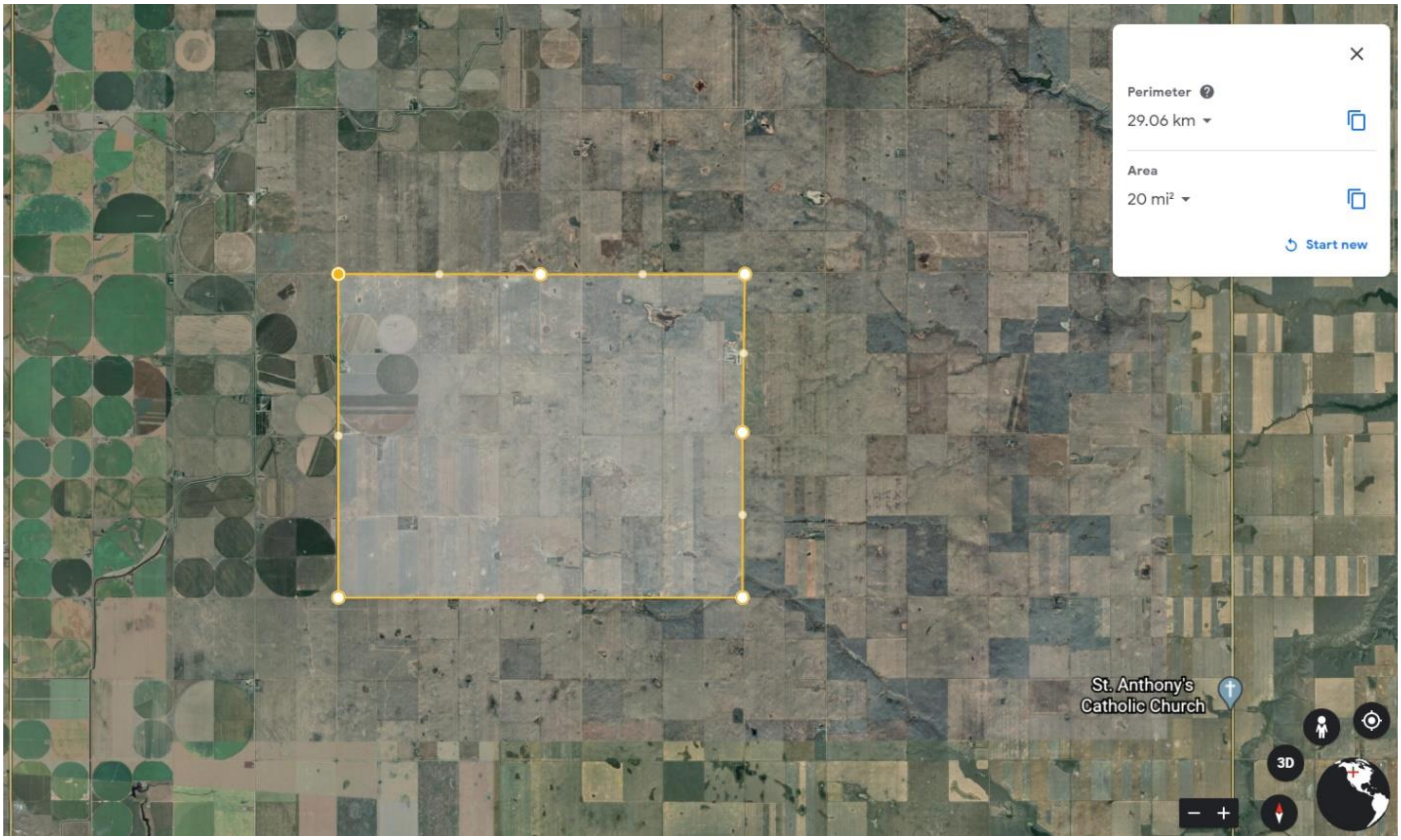


Figure 14 20 Square mile Wind Farm Location

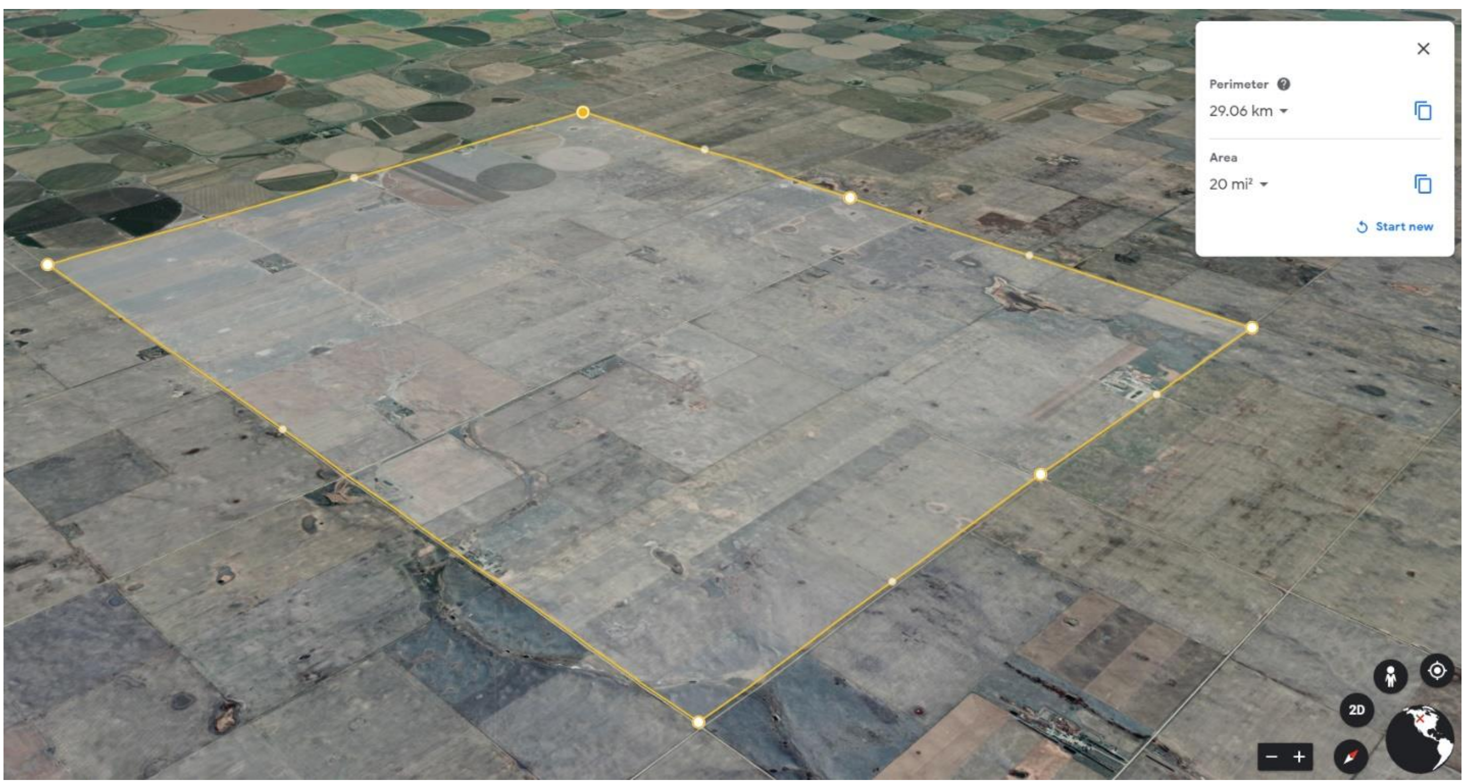


Figure 13 Land Elevation Variance

Lastly, the turbine layout can be seen below. This figure was generated as part of the SAM simulation. As discussed above turbines should be a minimum of 7-rotor diameter lengths apart. To exceed the rule of thumb an 8-rotor diameter turbine spacing was implemented. This was coupled with a 15-rotor diameter row spacing as recommended in the paper above. Neighboring wind farms however exhibit tighter spacing, with approximately 1.1 mile2 utilized per Vesta V136 on both Suncor's Forty Mile and Capital Power's Wind Power farms. The proposed development of the farm clocks in at approximately 1.75 mile^2 per turbine. However, the increased spacing coupled with recommendations through other studies and reports aids in putting into context the realized 11% array losses on the wind farm.

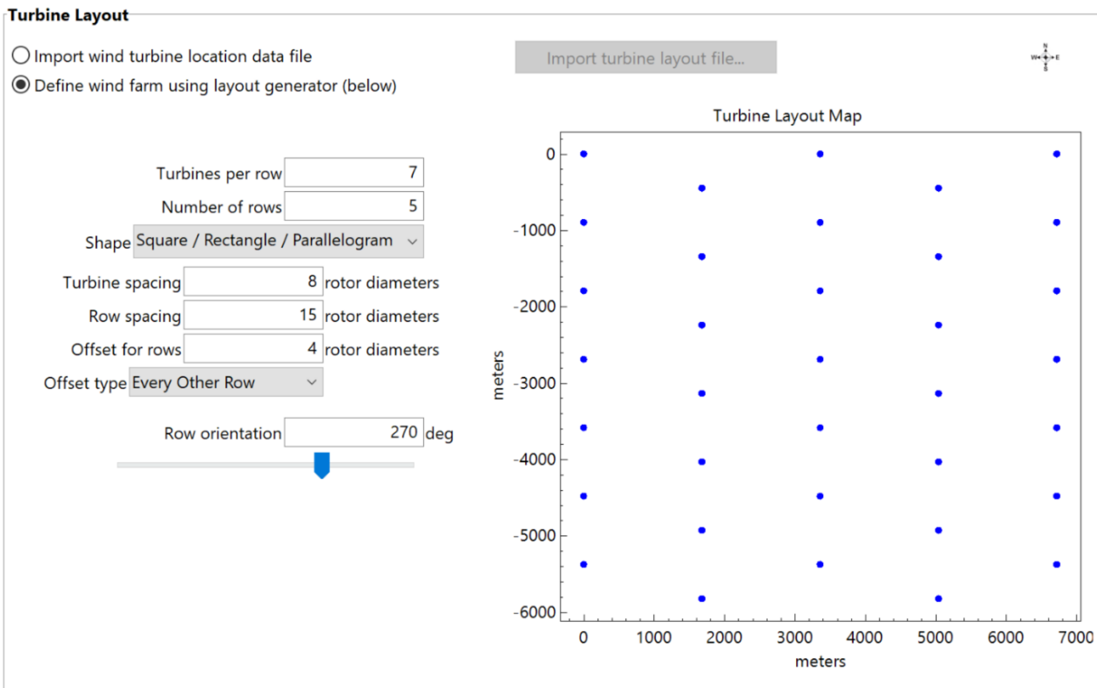


Figure 15 Proposed Turbine Layout

Connection to Grid

The plant is to be tied in to the Whitla Substation which is 18km away from the plants center. This will require ~20km of 240kV power transmission line to be installed underground connecting the new 105 MW plant to the recently upgraded substation. Approval must be granted by the Alberta Utilities Commission to proceed with this plan. This is the same procedure Capital Power had to follow when requesting to connect to the existing substation owned by Altalink.

ECONOMIC ANALYSIS:

A detailed economic analysis was completed on the proposed wind turbine power plant. This analysis was completed like the energy model, through SAM software. This analysis for the purpose of this report includes the most relevant information in running an economic feasibility study. The total capital cost of installing such a facility was modeled. Additionally, the financial implications of running the facility were also tabulated. Key figures to help determine economic feasibility such as net present worth, cash flow, payback period and return of investment were all determined and will be further discussed below.

Cost Analysis

The first portion of the economic study that was completed was a cost analysis. This portion of the study determines the overall cost to install and operate the facility over its 25-year lifespan. This cost analysis is broken down into two sections. System costs and financial parameters. System costs include all charges in bringing the facility from a potential project to operating conditions. The financial parameters determine figures that impact the plant over its lifespan. Also included within the cost analysis was government incentives which help fund the project and electricity rates. The amount at which the plant can sell electricity is a key factor as this is the source of revenue. All these topics will be covered in detail below.

System Costs

SAM software was used to estimate the total capital investment for the plant. As seen in the figure below, SAM calculates the price of the facility per unit energy ($/kW). The turbine cost is predicted by the 2017 average cost to install a land base wind turbine with a plant capacity of 1MW or greater. The balance of system cost is calculated from data pertaining to the construction and install of the facility. Examples of parameters include:

- Terrain
- Distance to interconnect
- Travel
- Contingency (20%)
- Development fee

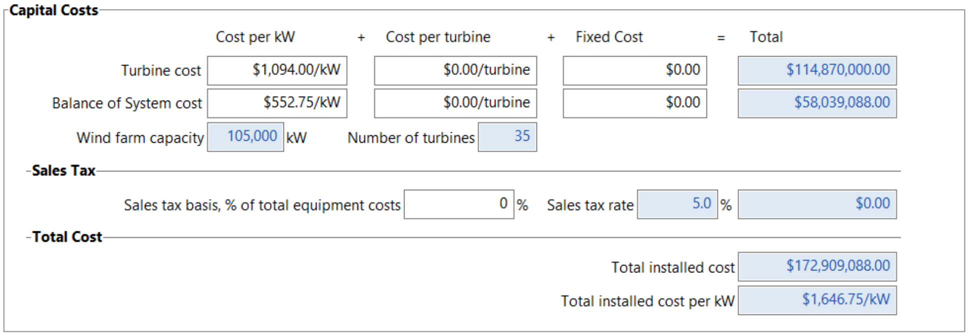


Figure 17 System Capital Cost

As seen above, the levelized cost to install the wind farm is 1,645$/kW. The figure below gives a reference to where the cost of this project stands in comparison to other projects in 2015. The proposed farm's nameplate capacity is 105MW. This falls in the 100-200MW bracket where the average price is 1572$/kW. Given this data with inflation 1,645$/kW is reasonable and makes sense when referenced to the levelized costs of other projects. The complete install cost to complete construction on the Wind farm is $172 Million. The neighboring Whitla 1 facility has twice the nameplate capacity and was constructed for $315 Million. This is important because it puts the capital cost in perspective and once again shows SAM software's estimates are accurate in comparison to completed projects.

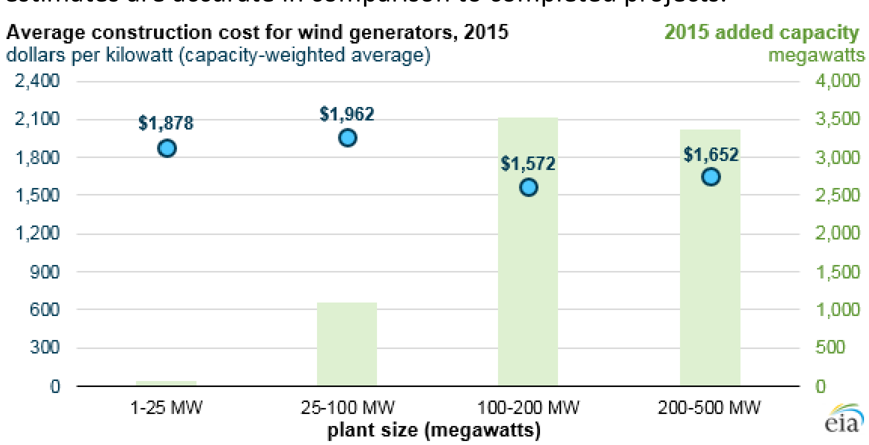


Figure 16 Average Cost Per Unit Capacity 2015 [28]

Financial Parameters

The next section within the SAM tool is the financial parameters. The complete financial parameter page can be seen in the screenshot below. It was assumed the complete project would be funded from a secondary source through a loan. Typical loan rates on such projects range from 7%-11% but SAM recommended a 7.5% interest rate. The loan is to last the entirety of the project which has a final salvage value of 10% the initial cost. Inflation and discount rate are key parameters for such a project, so SAM uses past data from similar models to predict these values.

Tax info was collected directly from the government of Canada and Alberta respectively [18] [19]. Additionally, it was calculated that for such a faculty ~0.27% of the assessed value is to be paid as property tax. [20]

NOTE: Depreciation was calculated on a straight-line basis over a 25-year period for both federal and provincial rates.

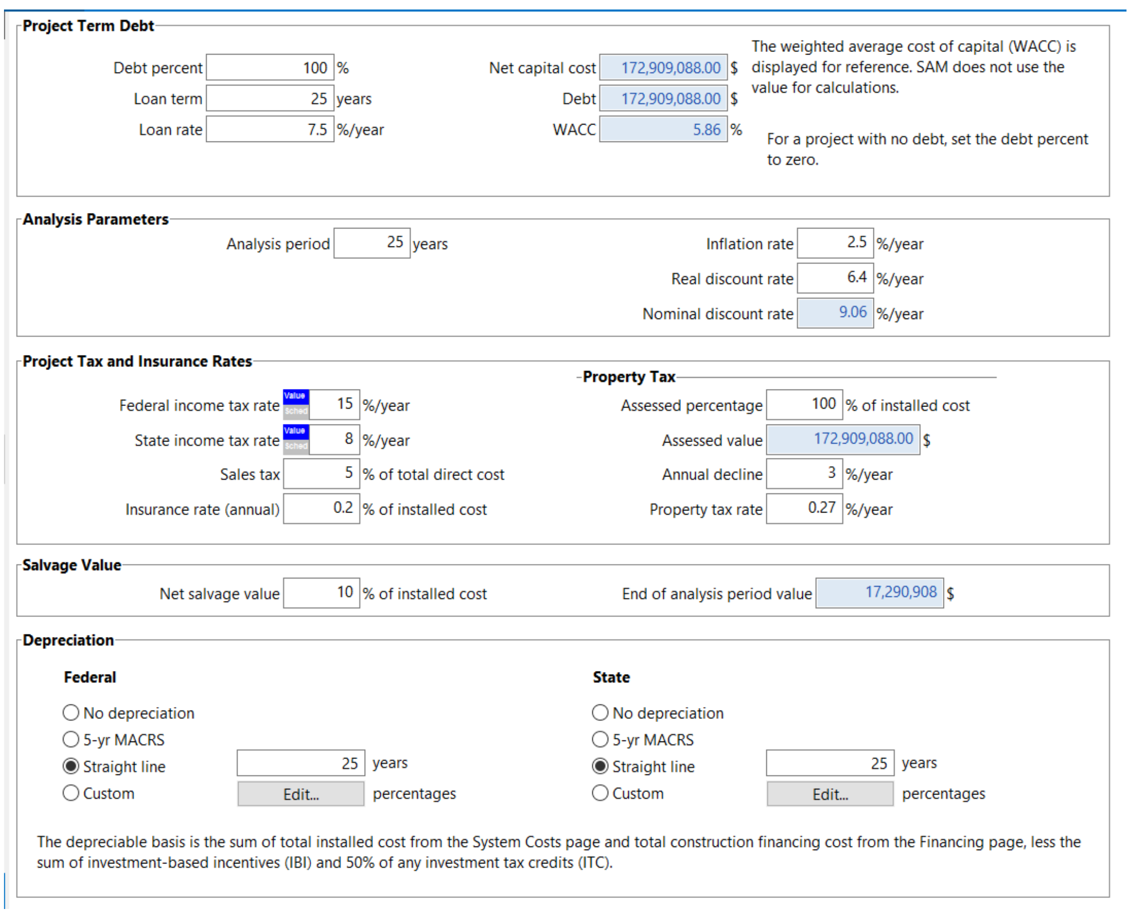


Figure 18 SAM Financial Parameters

Incentives

Because green energy is expensive governments often offer tax cuts or incentives to promote the building of net 0 facilities. In this case is was found that the “Wind Power Production Incentive Program” was implemented 2002 to encourage wind power growth in Canada. This incentive provides facilities with ~1c/kWh for installation of up to 1000MW in capacity. This is to be paid off over a period of 10 years. For this facility this ended up equating to $3,229,317 for the first ten years of the project’s lifespan. [21]

Electricity Rates

The electricity rate is possibly the most important factor within the study. This determines what power generated from the facility will be sold at to end use clients. This is a difficult parameter to specify, it is for this reason SAM allows data to be entered at different rates throughout the year as demand and the economy fluctuates. If data is available from the relevant energy providers or regulating bodies data can be imported directly into SAM in .csv format. This is the most accurate way to model the rate at which energy will be sold at because it considers demand and varying price. However, this data was not available for southern Alberta and another method had to be used. Using the AUC's (Alberta Utility Commission) history model an average price was selected to be used throughout the year. The graph below shows the varying rates per kilowatt hour for residential sale in Alberta from March 2018 to March 2020. The average regulated rate as seen below is 6.67c/kWh and this is what was used as the sell rate for the energy produced. It was also assumed that 100% of the energy generated was sold to consumers.

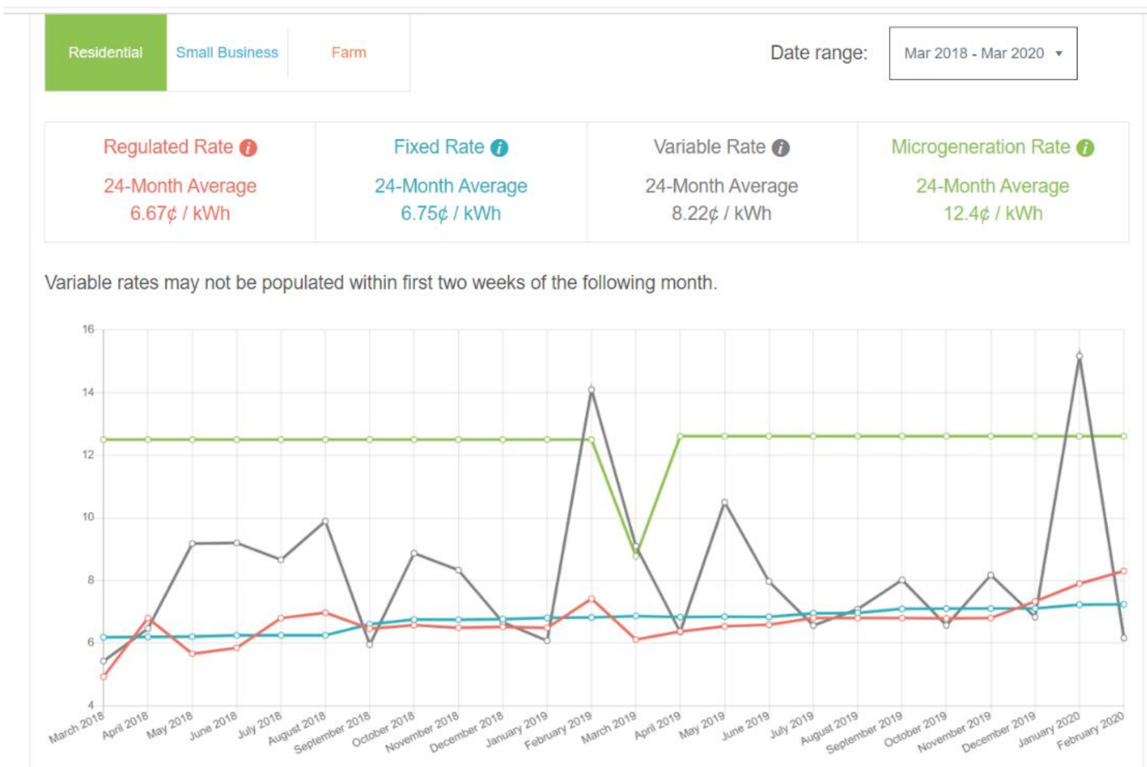


Figure 19 Average Alberta Electricity Rates from March 2018-2020 [29]

Results

Once all the data was collected to complete the simulation the results were calculated and tabulated, they can be seen below. The results are quite promising and there are some positive metrics that may make this project attractive to potential stakeholders. The most important value when evaluating such a project is the NPV (Net Present Value), this determines the worth of the project and if it will make or lose money. A positive number indicates a profitable project where in this case is what was calculated. The overall NPV of this wind farm was found to be $63 million dollars. Another key metric to be analyzed is the payback period. This shows the amount of time required to pay off the original capital of the project, in this case it is 9.2 years. For reference, the complete SAM file will be attached to this report for further detail and analysis of the results of this study.

Metric	Value
Annual energy (year 1)	322,931,712 kWh
Capacity factor (year 1)	35.1%
p90 Energy (year 1)	272,977,216.0kWh
Levelized COE (nominal)	4.41 ¢/kWh
Levelized COE (real)	3.50 ¢/kWh
Electricity bill without system (year 1)	$360
Electricity bill with system (year 1)	$-21,539,184
Net savings with system (year 1)	$21,539,544
Net present value	$63,145,948
Simple payback period	9.2 years
Discounted payback period	16.5 years
Net capital cost	$172,909,088
Equity	$0
Debt	$172,909,088

Figure 20 SAM Simulation Results

Financial Analysis

Cash flow and return of investment metrics are discussed below. These are key parameters in determining the economic feasibility of the site.

Cumulative Cash Flow Analysis

Seen below is an after-tax cash flow graph for year (0-25) of the project. This shows the overall cash flowing through the site on a yearly basis. In this case the cashflow for this project is positive for each year. Cash flow increase linearly each year as the loan is payed off. The flow dips at year 10 however, this is when the three-million-dollar production-based government incentive expires and is no longer provided to the site. After this point yearly cash gain continues to rise until the end of year 25 where the salvage value of the project is applied.

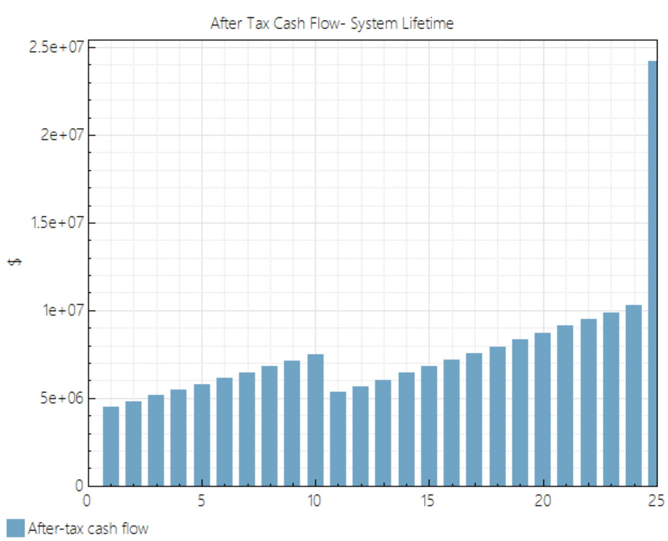


Figure 21 Cash Flow Diagram

By the end of the project $192,804,267 million dollars of pure profit is collected. This is a good profit margin and helps solidify the project economic feasibility.

Return on Investment (ROI)

ROI is another important metric in evaluating the worth of a potential project. This value is shown as a percent and measured the gain/loss of a project with respect to the initial investment. As a rule of thumb, a ROI greater than 10% shows a project is worth investing in. In the case of this power plant the ROI was found to be 11.51%. This was calculated independently but used values calculated from the SAM simulation. As previously stated, this ROI is greater than 10% which shows the project can be considered a good investment.

Sensitivity Analysis

A sensitivity analysis is also a good tool used in project feasibility studies. This data helps display the vulnerability of a projects worth if financial variables increase or decrease a certain percent throughout its lifetime. In this case NPV was plotted as a function of the following variables:

- Electricity rate
- Loan interest rate
- Operational rate
- Cost per kW to construct
- Each value was scaled independently in 10% intervals up to +/- 20%. The results ca be seen below.

As seen the data below illustrates the most dependent value in determining the projects NPV is the electricity sale rate. This makes sense however as this is the only source of income the project has which is key to ensure its viability. It is shown that NPV can decrease to as low as ~$21 million dollars if electricity rates were to decrease 20%. This is a considerable change as NPV reduces ~40 million dollars. With fluctuations this large it can be concluded that this projects value is extremely sensitive most notably to electricity prices.

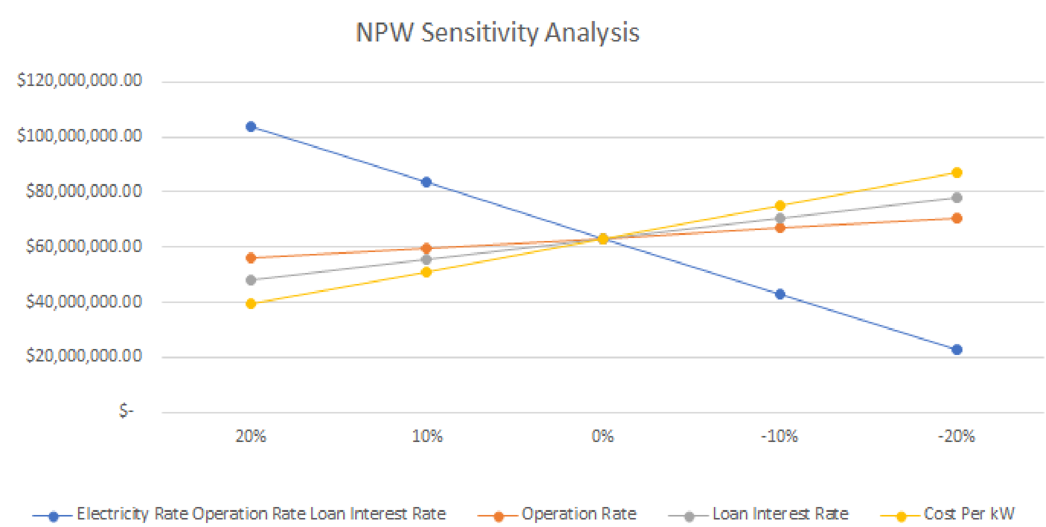


Figure 22 Sensitivity Analysis

DISCUSSION:

Now that all technical aspects of the proposal have been designed and simulated the feasibility of the project must be discussed. This is broken down into two sections, Technical and Economic.

Technical

The renewable energy system developed and analyzed has proven to be technically sound. The plant has been placed in a location where neighboring projects have proven ample amounts of wind energy is available to be harvested. Average wind speeds will produce over 300GWh of energy at maximum capacity and the large location allows for additional strategies to be implemented to reduce losses and maximize efficiency. This 105 MW farm has a capacity factor of 35.1% which falls in acceptable range. United States' average annual capacity factor for wind energy in the year 2019 was 34.8%. [22] These metrics are very realistic and comparable to similar projects. The energy generated within this facility will aid in feeding Alberta's increasing electricity demand and aid in reducing greenhouse emissions from toxic coal fired facilities.

Economic

Given the information discussed as a part of the economic study above the economic feasibility of the project can be determined. In the groups opinion the project can be recommended as an economically feasible project. This is mainly due to the following reasons:

- A positive NPV of over $60 million
- An end of lifespan profit of ~$190 million
- A ROI of over 10% (11.51)

The greatest risk presented in this project is shown in the sensitivity analysis. The project is most vulnerable to the cost of electricity. If this metric dips below 0.046c/kWh the projects NPV becomes negative as is no longer viable. This is unlikely though because the electricity rate would have to stay below 0.046c/kWh for 25 years which has never happened in any records collected from the AUC within the past couple decades.

Additionally, the levelized cost of electricity for this project is 3.5c/kWh. According to the Canadian Wind Energy Association (CanWEA) in 2017 Alberta yielded the lowest price ever paid for Wind energy in Canada at an average of 3.7c/kWh. This project real cost of electricity tops this value and would be a boastful achievement for Albertan energy and the energy sector. It is for all these reasons that this project can be deemed economically feasible and would be a good investment for stakeholders. [23]

COMPARISON TO THE WHITLA FARM

A comparison with other operational sites in the area is essential. It allows the project to be compared and validate the expected performance of the model to real-world values. The scope of comparison is to include both a technical and economic aspect. This should allow the group to gain a holistic understanding of the project, aiding in the final recommendation. The SUNCOR project also neighboring this facility is yet to be constructed so a comparison cannot yet be made.

Comparing size, the proposed farm has fewer turbines and a smaller name-plate capacity than the Whitla Farm. The proposed 35 turbines are rated at 3.0 MW for a total nameplate capacity of 105MW. This is compared to the Whitla 1 project with 56 3.6MW turbines with a rated output of 202MW [24]. Wind-speed data is also well established, as the proposed location is relatively close to the Whitla farm and retains the same geography. Therefore, they will be very comparable. The selection of the Vestas

V112 turbine is aimed at increasing the potential power generation at lower wind speeds due to its lower cut-in speed of 5.0 m/s vs 7.5m/s for the V136 Turbines in use at Whitla. With this turbine rated for a lower cut in speed the capacity factor of this site is expected to be greater than that of Whitla 1.

Array effect losses are also projected to be lower than the Whitla project due to staggered layout of the plots. The proposed plant has less turbines per square mile reducing the amount of disturbed turbulent air between rotors. The "rule of thumb" of 7-rotor diameters is considered a conservative estimate, and for the purposes of this project, is disregarded for a safer 15 rotor diameters. This departure from the norm has produced favorable results theoretically, and the combination of the smaller turbines and increased spacing should act to keep array losses in the 10-15% range.

Economically, the Whitla facility costed $315 million dollars to install. At roughly twice the capacity, this makes sense compared to the SAM estimate in this case where it is projected to cost $172 million dollars to construct the new facility. To put this into perspective the Whitla facility costed 1,559$/kW to install where the proposed site is projected to cost 1,646$/kW.

RECOMMENDATION:

Considering the points of analysis earlier discussed, the project is anticipated to be a success. From a financial perspective, the capital cost is $172m, while ROI is a reasonable 11.51%. Additionally, an-of-life profit of $190m is accumulated after 25 years. Comparing this to the neighboring Whitla Farm, the cost/MW is also very comparable at $1646/kW and $1559/kW respectively. It is also important to note that the Whitla project is built with the V136 turbines and tighter array spacing, while the proposed project uses the V112 Turbines and modified array spacing. It is entirely likely that these differences may increase this project's competitive edge over a similar, already proven example.

Reliability is no concern as the Vestas turbines used are industry-standard and have an expected lifespan backed by a proven manufacturer. Tie-ins can be negotiated with either the Whitla or the Granlea substations however the Whitla station provides a more logical solution.

Some points to consider regarding the validity of this recommendation are the sensitivity of the project to the cost of electricity and the interest rate. In the current economic setting these are subject to change but given historical pattern this is highly unprobeable.

With these considerations in mind, it is recommended that this project should be implemented.

CONCLUSION:

Wind power is currently a major source of energy in the world and is slated to grow more in the future to turn into a staple of power production for a large portion of the world. Although the cost of wind power in Alberta is expected to keep falling; there is a severe lack of installed wind power compared to the estimated capacity and this report echoes that viewpoint. This feasibility study has found both the technical and financial aspects of the set up proposed is a viable option and will produce positive results if installed.

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