Design Project
SREE 4001 – Efficient Energy Conversion
Wind Power Generation in Iqaluit

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1.0 EXECUTIVE SUMMARY

This report discusses the pre-feasibility study of a wind power plant project proposal in the city of Iqaluit located in the Iqaluit, Nunavut, Canada. The power plant would use 2 Enercon-E70 2.3MW turbine. to generate a desired power capacity of 4.6MW. Nunavut is a remote province which is separated into multiple small separate communities that have their own respective grids. They depend heavily on fossil fuel for electricity generation [1]. This has had a negative impact on the environment and health of the population due to excessive carbon dioxide emissions related to the use of diesel generators as well as transportation [1]. From the economic point of view, the dependence on fossil fuel has also taken its toll economy of the region [1]. Nunavut has one of the highest electricity rates in Canada due to the high cost of transportation and purchasing [1]. This design is not intended to replace the current power generation technologies, at the present time. The purpose of this project is to design and implement microgrids, in Nunavut, that are powered by wind energy. It will provide a clean and sustainable source of energy that will reduce the dependence on fossil fuel, reduce CO_2 and other GHG emissions as well as electricity rates. It will also improve the economic situation of the region by providing employment opportunities and bringing new investments. It would reduce the grid loads and provide backup in case of outages by designing storage components.

The pre-feasibility study found that the proposed project is technically feasible. The wind turbine selected can operate in such low temperatures (up to -40^{o}C) in Northern Canada [2]. The issue may be that there is high-maintenance, but there are no on-site technicians available. The research is limited and huge costs to fly in to maintain and repair the windmills would be a major concern, but it can create future jobs in Iqaluit. This project is also economically feasible because the economic analysis suggest that payback period will be 15 years for a 20-year project with an IRR of 2.8%. The installation of a 2-turbine plant would lift a 17.54% weight off the diesel consumption and reducing the costs by $140m yearly. Hence, this would be a viable option for reducing electricity costs or lifting the fossil use weight of off the government. This project is environmentally feasible, and it will be worth implementing since this can help to reduce greenhouse gases emission by 3 tonnes per capita which can reduce the effect of climate change. The implementation of this project will not be life-threatening to the animals or birds and one would ensure that the project installation will protect the animal habit avoid any ecological disturbances. Recommendations would be to push for some government funds are available to help with the costs of the project. It can help reduce the payback period and incentives can help encourage a community to use renewable resources.

In this report, the Iqaluit geographical region is briefly introduced as well as the feasibility of the analysis, main drawbacks, if implementation is worth it and recommendations regarding the proposed project will be discussed in this report.

2.0 BACKGROUND

Iqaluit is the capital city of Nunavut, located in northern Canada by Frobisher Bay. The city has a population of around 7,250 people. Every single one of those people have a need for heating, warming up food and other electrical services. Currently Iqaluit gets its energy from Qulliq Energy, who is the only power utility provider in the territory.

The territory differs from other provinces and territories in the country when it comes to electricity grids. The main difference is that Nunavut does not have a shared community grid. Every community has their own local, independent grid. They operate as micro-grids serving only one community at a time. The fact that this is how it operates brings challenges to the control of the energy network.

Some of the challenges include such as when a power outage or a power surge occurs, there is no other city of grid to get or dump the extra power, which means that in any case of emergency the whole community can go into a blackout without any other source of energy coming their way. They have mitigation systems, such as an emergency generator sets that are kept around the city for this kind of problems.

The power is generated using diesel generators. The diesel is shipped into the city at the end of every summer when accessibility through water is optimal. The territory has 25 power plants that feed all communities, and all of them use diesel as their primary fuel. The use of a different, natural resource to produce energy can offset the amount of diesel they use which would entail having more money for other activities in the territory. Figure 1 shows a map of all Nunavut, and its primary fuel sources. It can be observed that in Iqaluit the primary fuel source is petroleum, in the form of diesel.

The city does not count with natural gas or natural gas liquids plants. Other sources of energy include solar panels that have been installed over some of the power plants and in over the Arctic Winter Games Arena and Arctic College as a pilot project of how this renewable would perform up north.

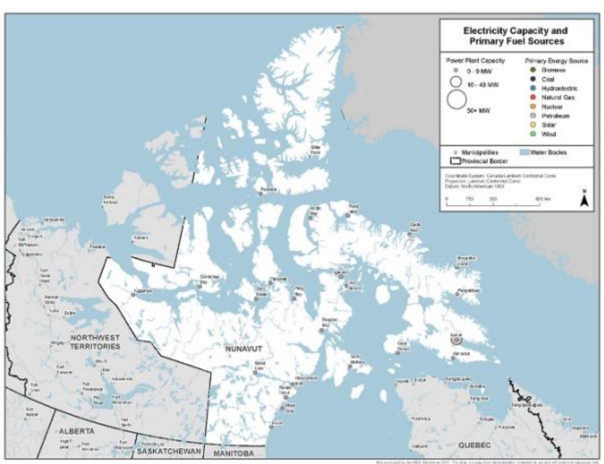

Figure 1: Electricity Capacity and Primary Fuel Sources Map

Wind energy has been exploited for thousands of years, from propelling boats down the Nile river to pumping water, to grinding grain [5]. Not until the late 1800s and early 1900s was it used for electricity generation and like any new power source, several issues arose such as power quality, constant stalling, cost, size, etc [6]. It wasn't really until the oil shortage during the 1970s that wind energy was considered seriously since new electricity production methods were vital [5]. What pushed wind turbine evolution even further was that fact that it a zero-emissions source and with new environmental regulations emerging regarding greenhouse gases and other pollutants in the atmosphere, wind energy was and is still seen as a solution. Several countries respective governments offer incentives and using resources such as LDC's, micro and nano-grid installations became more and more popular.

Nunavut is Canada's youngest territory, this also means that Nunavut significantly lacks in the amount of policy and regulations, let alone environmental and renewable energy policy. In 2007, the GN published *Ikummatiit: The Government of Nunavut Energy Strategy* which outlines the territory's plan to take advantage of their natural resources and further renewables in the region. Nothing has yet to be done but there have been several investigations done to determine the feasibility of both wind and hydro power in Nunavut [8]. Four years after *Ikummatiit* was published, *Paths to a Renewable North: A pan-territorial renewable energy inventory* was released which was basically a re-iteration of the previous report, the main difference is that the premiers of all three territories agreed to this commitment to renewable energy development.

Turbine technology has drastically improved since its initial construction thousands of years ago and especially in the last 30 years for both on and offshore turbines, has surpassed expectations [4]. Variable speed and frequency generators were critical for turbine advancements. This along with blade diameter and hub heights surpassing 100 meters, cut-in wind speeds extremely low, multi-megawatt power production, several airfoils, are all truly amazing feats. One of the most important achievements of the technology advancement for Nunavut is the ability for turbines to operate in temperatures as low as -40^{o}C.

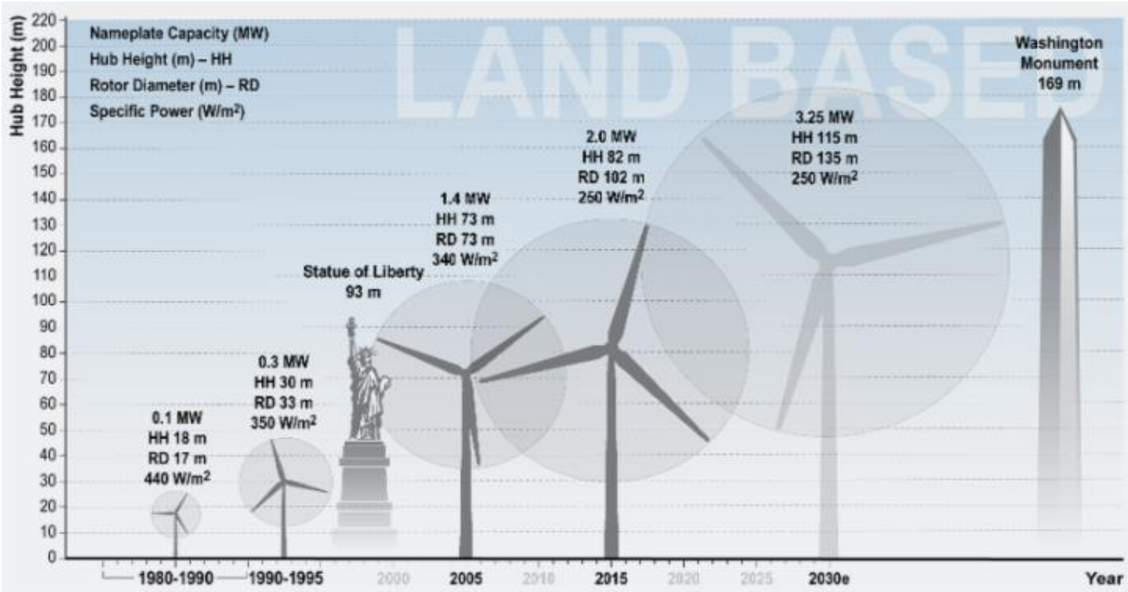

Figure 2: Onshore Wind Turbine Evolution Visual [7]

3.0 TECHNICAL ANALYSIS

3.1 Wind Turbine Selection

The first factor to consider when selecting the turbine for the region was the temperature as Iqaluit can reach extremely low temperatures, therefore a turbine that could operate in up to -40°C was chosen. The reason as to why this is so important is that not only do mechanical and electrical components respond differently at low temperatures, but ice buildup on the blades of the turbine has a significant impact on the aerodynamic properties of the turbine. This limits the number of manufacturers as turbine blade heating and de-icing technology are vital to successful operation.

United power has a turbine that operates in frigid temperatures but is designed for off-shore use with a higher cut-in wind speed. Due to the fact that Iqaluit is surrounded by ice the majority of the year and marine cabling being significantly costlier than land connections, United Power was not chosen. The turbine manufacturer selected was Enercon. The rotor blade heating system consists of a heater and a fan located at the rotor flange which are used to heat the rotor blades internally [11]. Enercon turbines not only meet the operational specifications of Iqaluit, but also due to their experience in Northern Canada. Enercon currently has 2 operational turbine sites; in northern Quebec at the Raglan mine and in the Northwest Territories at the Diavik mine. Iqaluit is located at 63.75°N, 68.52°W. Diavik mine is located close to the Nunavut border (62.45°N, 114.37°W) and has had 4 Enercon E-70 2.3MW installed producing 17 GWh annually which equates to 11.2% of the mines power in 2014 [21]. The E-82 3.0 MW turbine installed at Glencore Raglan mine has displaced 3.4 million liters of diesel and 9110 tons of GHGs over an 18-month period [13]. This is proof that wind energy is viable and successful in northern Canadian climates and since Iqaluit is at a similar latitude to the two installations listed above, wind power generation should be considered for Iqaluit.

Enercon produces several turbines with a variety of hub heights and rotor diameters. To select the appropriate wind turbine for Iqaluit so that energy storage would not be an issue, the size of the turbine was fit to the maximum electric load for Iqaluit.

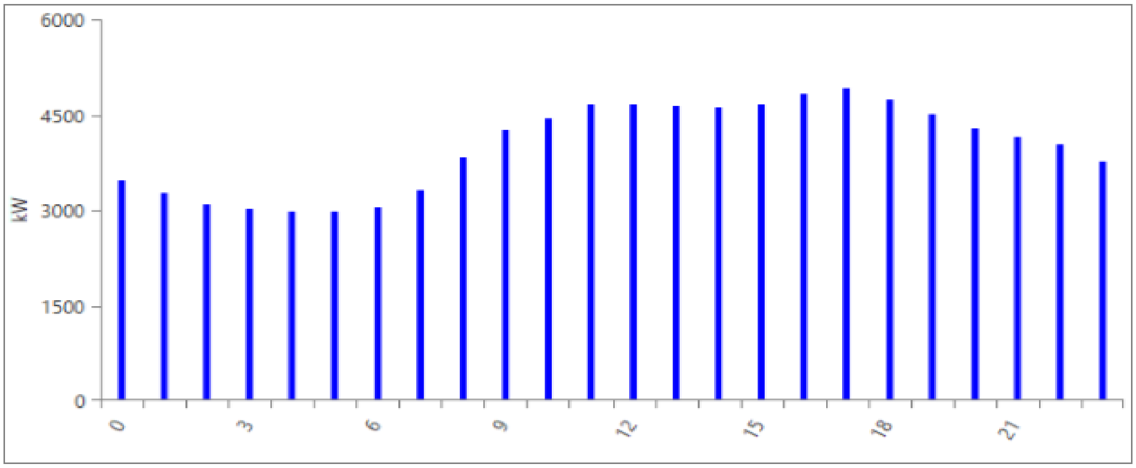

Figure 3: Iqaluit Average Daily Demand Curve Profile [14]

As shown above, the maximum demand occurs between 6:00pm and 7:00pm with a load just over 4.5 MW. Enercon produces 3 turbines capable of supplying this demand: E-70 2.3MW, E-82 2.35MW and the E-92 2.35MW turbine.

Iqaluit's marine ports are currently under construction and are expected to be done in 2020 [6]. The new ports have a wharf length of 100 meters and the maximum cargo load is limited to 40% of the wharf length by Nunavut regulation [15]. Assuming that if this project is approved, this process will take over a year and thus the port construction will be finished by this time. Due to the length of the rotor blades, the E-92 and E-82 2.35MW turbines could not be shipped by the NEAS to Iqaluit, leaving only the E-70 2.3MW turbine. As described above, the E-70 has proved to be reliable and consistent in Canada's northern climate.

The E-70 is available with 6 different hub heights of 57/64/75/85/98/114 meters. The cost of each hub height was not provided by Enercon but was provided by the WindPACT Design Cost and Scaling Model and therefore it was assumed that the cost of generating electricity compared to hub height, using this model, is consistent with Enercon's costs [16]. Using this analysis, the optimum hub height for a 70-meter diameter turbine is a 69-meter hub height and scaling this to a 71 meter diameter and the available hub heights for the E-70, a 75 meter hub height was selected.

3.2 Grid Connection and Energy Management

The Qulliq Energy Corporation (QEC) is the power utility for all of Nunavut and each municipality in Nunavut has its own respective electrical grid. To connect to the Iqaluit grid, a three-phase 25kV connection is required [14]. Enercon equips their gearless turbines with annular generators which are synchronous generators and has no need for a gearbox. Gearless systems are preferable as gearbox's lead to greater wear, more stress on the system, and an unnecessary moving part. The power output from these generators is not at the grid frequency or voltage level requires, therefore an AC-DC rectifier, a DC-link, inverter, filter, transformer, and control system are used to maintain reliability and grid integrity [17]. The control system used by Enercon is the SCADA remote terminal unit which is a closed-loop wind farm control system used to meet the specifications of the power utility.

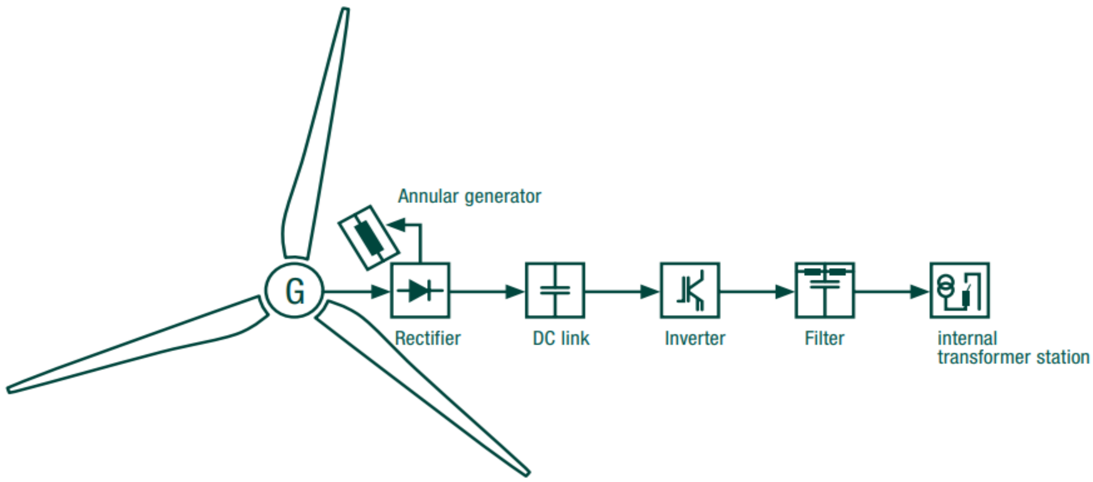

Figure 4: Grid Integration, Voltage and Frequency Regulation System [17]

As stated above, the turbine was fitted to the maximum load of Iqaluit to limit the amount of excess power produced, eliminating the need for energy storage. There is still the possibility for excess energy to be produced when the demand is below the amount of energy that the wind turbine is producing, therefore when this occurs the excess power will be used for Iqaluit's district heating (DH) system [18]. Power-to-heat technologies, specifically electrode boilers, for excess electricity management is a very efficient use of unwanted power [19]. Electrode boilers operate by using water as a resistor and running electricity through it which produces heat, boiling the water [19]. The boiler must be large enough to handle the maximum amount of power produced by the wind, therefore the CEJS 400 from CleaverBrooks was selected as it has a maximum power rating of 5.3 MW for 25 kV lines [15]. The QEC is working on a plan to upgrade their current DH system and therefore this system could easily be integrated into the new DH system [18]. When the wind is not producing enough power, which is the majority of the time, the existing diesel generators will be used. This is a simple wind-diesel hybrid system which has proven to be effective for many communities across the globe [20].

3.3 Site Selection

In considering different areas to place the two E-70 turbines, the main factors that limited the site is policy and cost. The first limiting policy is that there may not be any obstruction greater than 45 m tall within a 4-kilometer radius of the Iqaluit Airport [21]. Another factor considered was sound propagation but due to the first restriction, the sound of a wind turbine is not able to propagate the distance of an Iqaluit residence [24]. The issues that could potentially arise is if the farm is not in compliance with the CSA [24] and the wind turbine frequency were to cause any interruption with any navigational aid device such as RADAR as technically no turbine is allowed to be within an 80 km radius of a RADAR system which the Iqaluit Airport has [14]. An assumption was made that the wind turbines do not interfere with the RADAR system.

When determining the cost associated with site selection, the two main components were road and power line construction. Road construction was determined to have a value of 500,000$/km and the power line costs were 250,000$/km given by the QEC [13]. This meant that the turbines should be kept as close to the city, without violating any regulations, as possible. There are plenty of regions capable of fitting the turbines, therefore existing road infrastructure should be used to reduce the amount of road construction.

Figure 5: Wind Farm Location

Figure 5 Depicts where the farm will be located, the distance from Iqaluit Airport (4 km), and the distance to the closest residence (2.11 km). The distance to the closest residence is also where the potential point of connection would be for the wind farm, therefore 2 km of power lines would be needed. Also shown in the map is the Iqaluit shooting range which is very close to the wind farm. There was no policy or legislation available specifying the required distance from a public building the plant must be built, therefore assuming that there is no required distance, the site is appropriate. This also allows for the road access to the shooting range to be used for turbine and building material transportation which reduces the road construction difference. The majority of the existing roads due permit for vehicle transport of the turbine components for the required crane and road requirements [22]. More road and infrastructure analysis need to be done on the ground to ensure that the roads would be able to sustain the weight of transportation. The distance of road construction would be reduced to approximately 350 meters which includes the connection to the Road to Nowhere (road to the shooting range) and the roads connecting the two turbines.

3.4 Comparison to Existing Generation

As previously stated, Nunavut is currently 100% diesel powered. Diesel power plants operate around 38% efficiency and since the Iqaluit facility is equipped with heat recovery technology for the DH system, the plant efficiency is raised by 9-12% [23]. The proposed wind farm operates at 17% efficiency, however; wind energy has zero-emissions and can produce the power for significantly cheaper than that of diesel. The environmental impacts need to be seriously considered along with the plant efficiency to make the right decision for Nunavut. This is mentioned later in the report under Economic Analysis.

3.5 Calculations

The wind data for the year was extracted from Environment Canada's website [10]. The data was selected from October 2017 to September 2018. The purpose of selecting this range is to obtain the maximum amount of data points possible with recent information. The location for the weather station where the data was recorded is the Iqaluit Airport with latitude 63°45'24.000" N longitude 68°33'22.000" W at an altitude of 33.5 metres.

The data points for the wind throughout the year were converted to the height of the hub of the turbine, 57 metres, using Equation 1.

$$u = u_r\left(\frac{Z}{Z_r}\right)^{\alpha} \tag{1}$$

Where:

- u is the wind speed (m/s) at the desired height z (m)
- u_r is the known wind speed (m/s) at the reference height Z_r (m)
- α is the wind profile coefficient

The new wind speeds were placed into bins in Microsoft Excel, and a histogram with frequencies at which each one occurs. The bins were selected up to 28 m/s because that is the cut-off speed of the selected wind turbine. The histogram is presented in Figure 6.

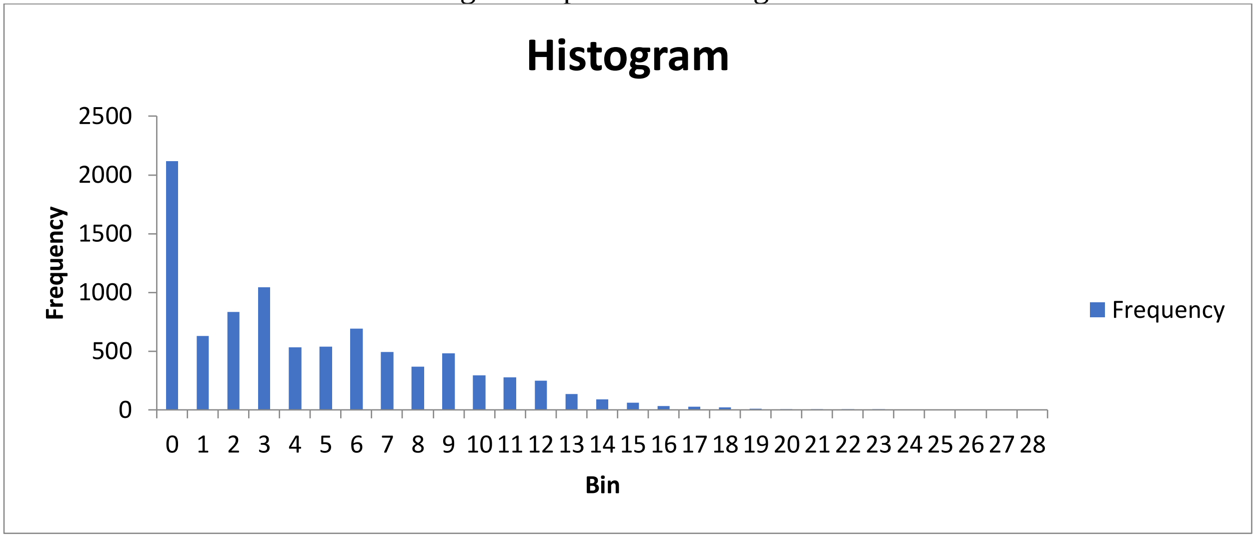

Figure 6

Once the bins were obtained the percentage time at which each wind speed occurs was calculated. This was done by summing the frequencies and later dividing by the total sum. Equation 2 describes how each one was calculated.

$$\%\,Time = \frac{Frequency\ @\ Wind\ Speed}{Total\ Sum\ of\ Frequencies} \tag{2}$$

After the percentage time of the year that each wind speed blows at is calculated, the probability density function (Weibull Function) is calculated using Equation 3.

$$p(u) = \left(\frac{k}{c}\right)\left(\frac{u}{c}\right)^{k-1} \exp\left[-\left(\frac{u}{c}\right)^{k}\right] \tag{3}$$

Where:
- p(u) is the probability
- k is the shape factor
- c is the scale factor

The shape factor is calculated using Equation 4

$$k = (\frac{\sigma}{u})^{-1.086} \tag{4}$$

Where:
σ is the standard deviation of the wind speeds (m/s)
u is the average wind speed (m/s)

The scale factor is calculated using Equation 5

$$c = \left(\frac{u}{\Gamma(1+\frac{1}{k})}\right) \tag{5}$$

Where:
Γ is the Gamma Function
u is the wind speed (m/s)
k is the shape factor

The percentage time was compared to the calculated statistical approximation, and the built-in Weibull Function in Microsoft Excel. Such comparison can be observed in Figure 7.

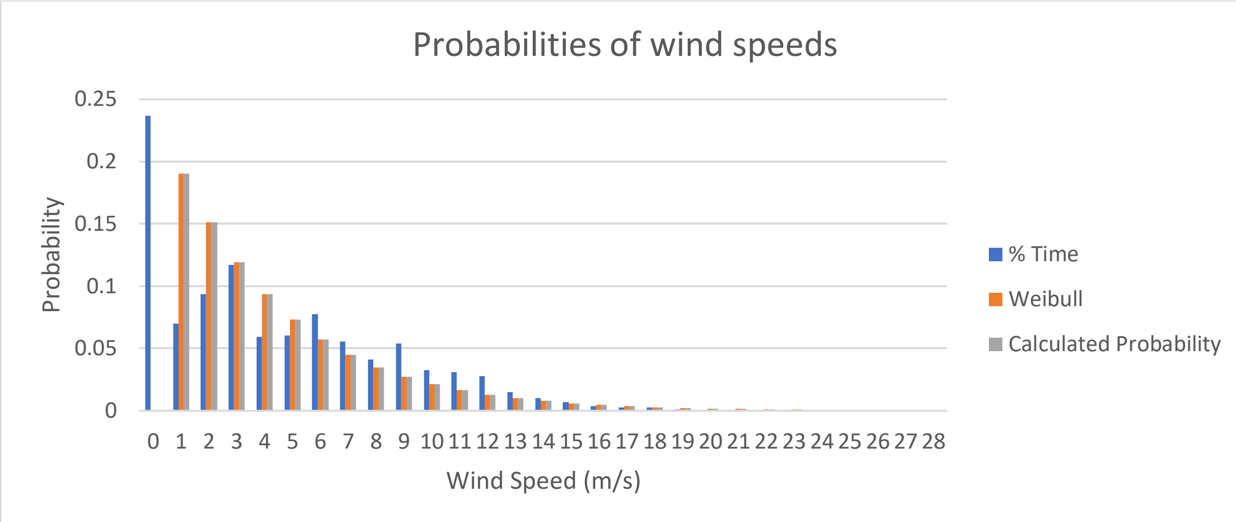

Figure 7

The average wind speed and the standard deviation were calculated using the built-in functions from Microsoft Excel.

The maximum wind power that can be extracted from the wind was calculated for each wind speed, assuming that density remains constant, using Equation 6.

$$P_{max} = \frac{1}{2}\rho A u^3 \tag{6}$$

Where:
P_{max} is power (Watts)
ρ is wind's density (1.225 kg/m^3)
A is area swept by the turbine (3959 m^2, as given by the manufacturer)
u is the wind speed

The maximum energy extracted out of the wind in a year is calculated using Equation 7.

$$E_{max} = P_{max} * 8760 \tag{7}$$

Where:
8760 is the number of hours in a year
E_{max} is energy (Watt-Hours)

The power extracted by the turbine is calculated using Equation 8.

$$P = P_{max} * C_p \tag{8}$$

Where:
C_p is the efficiency of the turbine at the wind speed (given by manufacturer, see Table 1)

P_{max} is power (Watts)
P is power (Watts)

Table 1: Cp Values for Wind Turbine E-70

Wind (m/s)	Power (kW)	CP	Wind (m/s)	Power (kW)	CP
0	0.0	0.00	19	2310.0	0.14
1	0.0	0.00	20	2310.0	0.12
2	2.0	0.10	21	2310.0	0.10
3	18.0	0.27	22	2310.0	0.09
4	56.0	0.36	23	2310.0	0.08
5	127.0	0.42	24	2310.0	0.07
6	240.0	0.46	25	2310.0	0.06
7	400.0	0.48	26	2310.0	0.05
8	626.0	0.50	27	2310.0	0.04
9	892.0	0.50	28	0.0	0.00
10	1223.0	0.50	29	0.0	0.00
11	1590.0	0.49	30	0.0	0.00
12	1900.0	0.45	31	0.0	0.00
13	2080.0	0.39	32	0.0	0.00
14	2230.0	0.34	33	0.0	0.00
15	2300.0	0.28	34	0.0	0.00
16	2310.0	0.23	35	0.0	0.00
17	2310.0	0.19	36	0.0	0.00
18	2310.0	0.16			

The energy extracted in the year is calculated by using Equation 9

$$E = P * 8760 \tag{9}$$

Where:
E is energy (Watt-Hours)
P is power (Watts)
8760 is hours in a year

The maximum energy and actual energy extracted are compared to each other and it can be observed in Figure 8.

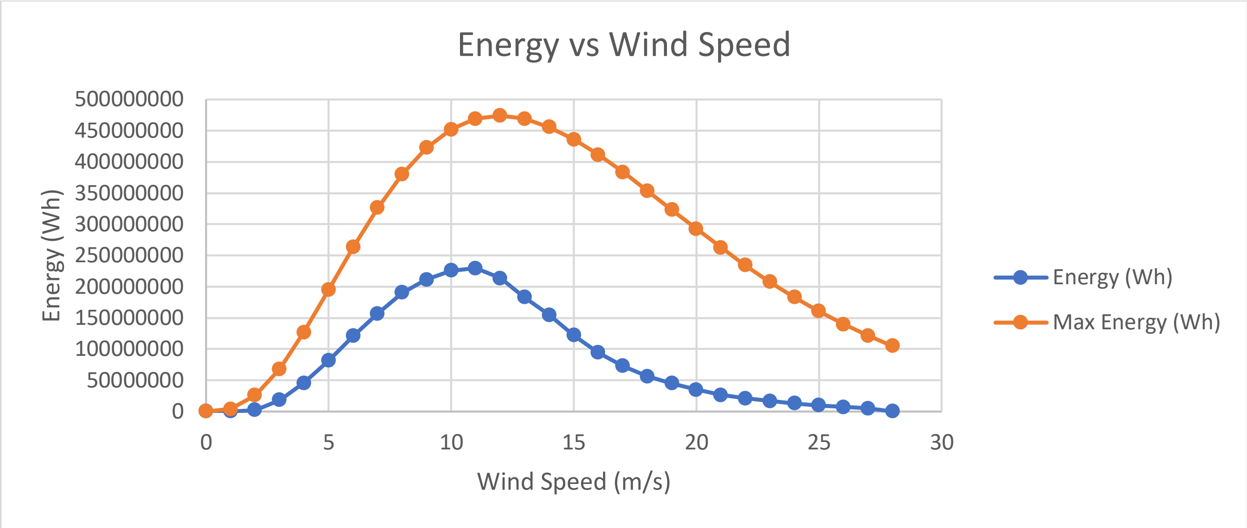

Figure 8

The sum of all the energies throughout the year yields 3,179.29 MWh.
The total energy theoretical throughout the year is 20,148 MWh.
The capacity factor is calculated using Equation 10.

$$CF = \frac{\sum E}{\sum E_{max}} \tag{10}$$

Where:
E_{max} is the rated power of the turbine multiplied by the hours of the year
The capacity factor for the wind farm using one wind turbine is 15.78%.
The same calculations were executed for different hub heights. Table 2 shows the different results at different heights.

Table 2: Results for Different Hub Heights (m)

Hub Height	Total Energy (MWh/year)	Capacity Factor
57	3179.29	15.78%
64	3333.62	16.55%
75	3462.08	17.18%
85	3592.74	17.83%
98	3763.36	18.68%
114	3793.20	18.83%

Figure 9 shows graphically the results from Table 2.

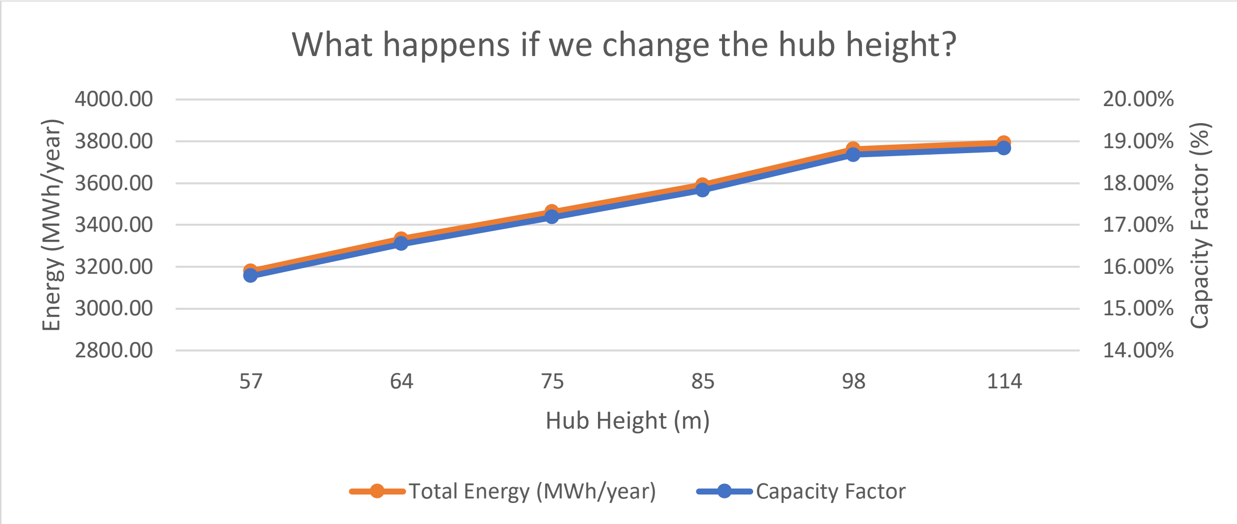
What happens if we change the hub height?
Energy (MWh/year)
4000.00
3800.00
3600.00
3400.00
3200.00
3000.00
2800.00
Capacity Factor (%)
20.00%
19.00%
18.00%
17.00%
16.00%
15.00%
14.00%
57
64
75
85
98
114
Hub Height (m)
Total Energy (MWh/year)
Capacity Factor

Figure 9

4.0 ECONOMIC ANALYSIS

In attempting to properly put together the economic analysis for this project, several factors had to be considered both for the current power generation system in Iqaluit and the proposed power plant. For the current power generation system in Iqaluit, these factors included the cost of purchasing the diesel needed to generate power, the average electricity cost in the province, per capita energy consumption and a number of others that will be explained further. Factors considered when analysing the proposed wind generation power plant includes the capital/initial costs, operation and maintenance costs, decommissioning costs and all relevant externalities that may become internalized. [26]

4.1 Capital / Initial Costs

The capital costs for these kinds of projects can be very expensive depending on the size of plant that is being built, this amount is realised by employing the industry standard methods of calculating capital cost which is in $/KW for power generation plant projects. This cost typically includes, the cost of the turbines, the materials needed to build the sub stations (if any), the transmission system to the power stations, the clearing of land, building of necessary roads leading to the site, labour cost for the initial building, etc.

There are very few wind energy projects in Canadas north, it was not easy trying to come up with exact costs, The companies that currently operate the two wind generation projects up north, Diavik Diamond mine and the Raglan mine didn’t exactly make it easy for specific prices and quotes to be acquired as a lot these are sealed due to NDAs, but after pulling information from various external resources, a reasonable set of costs was reached. Price forecasting Was challenging as a lot of the machinery and equipment used to build wind projects are foreign made, e.g. the Enercon turbine used in this project is a German made piece of machinery [27]. In this research, I have considered the inflation for costs obtained from previous years in order to give a somewhat more accurate figure of what the prices would look like.

The wind turbines, 2 of them cost about $5.75m each which is about $11.5 million. This cost included the transformer, blade heating, transporting it from purchase base to Montreal, the cost of cranes on site, the installation and commissioning. Energy storage suggested for the Enercon E70 was a 1MW & 1MWh battery system. The estimated all-in cost from 2016 was about $2.5m, which is about $3.45m in todays dollars. Large cranes and supporting cranes would be required, a 450 ton all terrain crane was recommended for this kind of project. The estimated rental cost for the machinery was a 4-month period came up to about $717k in todays dollars. Transport services involved ocean transport, freight rates to Iqaluit were rounded to be about $300/ton (2016). While their return was an estimated $250/ton. They came to a total of $229080 and $171120 in todays dollars. The roads and power lines needed to realise this project had to be delicately constructed. They will connect from the project site and the diesel power station to the local grid. A reasonable average of $500k/km for roads, with upgrades costing $250k/km was reached, summing up and including the distances, the total in todays dollars would be $2.5m and $1.3m. The Power line cost was placed at $250k/km which after calculating the distance resulted in a total of $1.725m today. A mandatory underground collector fee at $938k was also imposed. Other costs (in todays dollars) included a wind resource assessment, prefeasibility study cost, feasibility cost, utility interconnection, Geotech and foundation design, foundations, local equipment, site building, turbine assembly and supervision and others such as initial spare parts, insurance and overhead costs. A 10% contingency of $3.3m was also included. The total capital cost of the project came up to an estimated $38.6m @ $8401/KW [27].

4.2 Operation and Maintenance Costs

In North America, this is a rapidly growing industry, according to IHS market, “the O & M costs are going to see a near 40% rise by the next decade”, this is directly attributed to the slowly but steadily increasing demand for wind generation plants as well taking into consideration life cycle of the turbine and necessary upgrades that have to be made [28]. In North America, according to an average taken between 2014 and 2017, the average cost for O & M is upwards of $42,000/MW. O & M costs increase yearly at a slow rate and then rapidly usually around the 10th year of the turbines life, this is because at this point there needs to be a few major replacements and necessary upgrades made to the turbines [28].

O & M costs are typically what covers the land rent, insurance, admin fee, servicing of equipment, spare parts (replacement) and miscellaneous. The annual O & M costs for the proposed plant came down to $793k This was expected as we had to consider the location of the plant, which involved long distance travels from various areas where the spare parts, labour and technicians had to come from [27].

4.3 Feasibility Studies

The tables below illustrate some financial calculations involved in this research. The values seen are the current estimates for the building and operation of a 2-turbine wind power plant in Iqaluit. It was also assumed that QEC, the energy provider in Iqaluit will be responsible for bank rolling the project.

A sensitivity analysis had to be done using the cost of electricity in order to determine the feasibility of the project, while this project would be carried out with the intention of providing a solution to an energy problem, it is still economical attractive to see return on the project. The effective interest rate was assumed to be 8% [29], while the discount rate was assumed to be 6.5% [30]. The plant is to deliver 6922.8MWhe/year, we considered using the avg cost of wind energy in Ontario [31] of $0.1225/kwh which yielded an IRR of -0.7%. The NPV of the expenses was calculated in order to determine the NPV electricity cost and after calculations it was determined that with an NPV Elec cost of $0.19, the IRR will be -10% meaning, there will still be a loss on the return of investment.

REF	Cost of elec	IRR
ontario Avg wind	$0.12	-22.41%
Calc. NPEC	$0.19	-10%
Calc. Prop. Cost	$0.48	2.8%

Figure 10: Sensitivity Analysis to Determine Feasibility

Finally, considering the plant contribution to the grid is an estimated 17.54% (explained below) yearly, using the below calculation, we arrived at a proposed cost of electricity of \$0.48/kwh which yielded an IRR of %2.8.

$(0.1754) *(0.12) + (1-0.1754) *(0.56) = \$0.483/kwhe.$ (11)

Where 0.12 is the average cost of wind electricity in Ontario, (0.1754) is the percentage of energy the plant will contribute to the grid, (1-0.1754) is the diesel system contribution and 0.56 is the current cost of energy in Iqaluit.

Given values	amount	unit	annual energy output	6922.8528	Mwhe
installed capacity	4.6	MW	annual O&M	793500	per year
capital cost	8401	per kW	annual revenue @ Proposed cos	$3,343,737.90	per year
gas price	0.07597	per kWh	discount rate	6.5	%
expected capacity factor	80	%	total Cash flow (profit)	$2,550,237.90	
O & Maintenance cost	793500	per yr,per kw			
plant efficiency	17.18	%			
project length	20	years			
effective interest rate	8	%	Net present elec cost	$0.19	per kwh
Proposed elec cost	0.483	$			

year	initial cost	Operating cost	total expenses	total revenue	total cash flow	for IRR
0	38644600	0	38644600	0	38644600	-38644600
1	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
2	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
3	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
4	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
5	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
6	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
7	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
8	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
9	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
10	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
11	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
12	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
13	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
14	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
15	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
16	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
17	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
18	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
19	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90
20	0	793500	793500	$3,343,737.90	$2,550,237.90	$2,550,237.90

NPV-EXPENESES	$26,016,822.74	NPV @ proposed elec cost	$43,351,912.97
NP ELEC COST	0.187905358	IRR @ CAN AVG - (PROP COST)	2.80%
IRR @ calc. NP ELEC	-10%	Payback	15.2
IRR @ NP ONT price	-22.41%		

Figure 11: The price yearly cash flows and parameters selected for calculation

From the figure above, while the initial capital is quite significant, the succeeding cash flows are also very good. The project would have a yearly cash flow (after taking out O&M) of \$2.5m, with an NPV of \$43.3m and a payback period of 15.2 years.

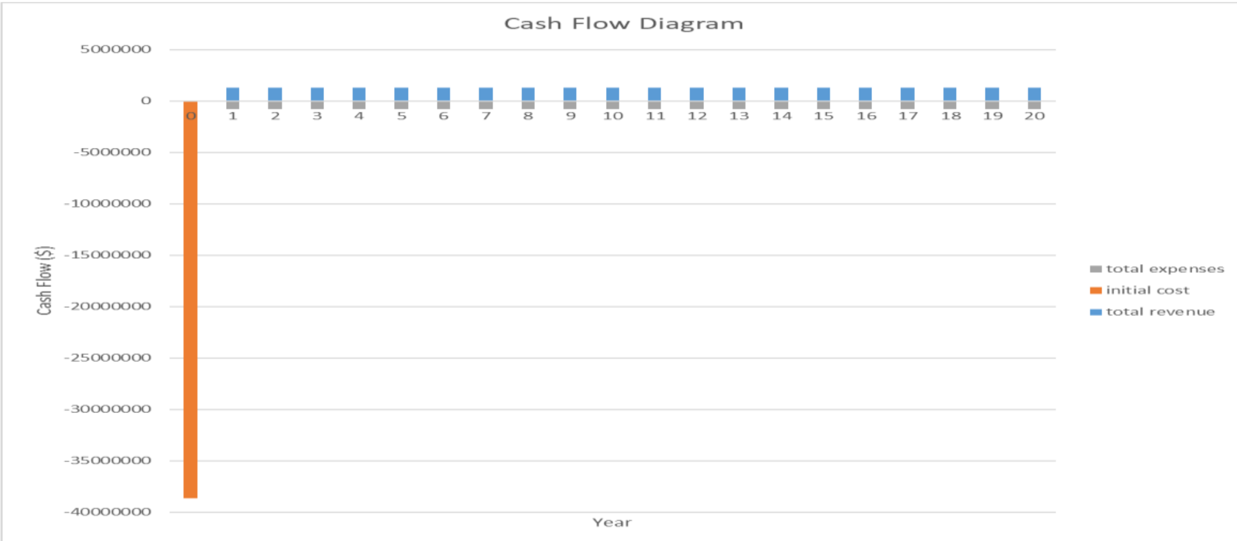

Figure 12**:** Cash flow over the lifetime of plant.

The Per Capita energy consumption in Iqaluit was 5.1MWhe as of 2017, with a population of 7740[32], the energy consumption was an approximate 40000MWhe [33]. The installation of a 2-turbine plant would lift a %17.54 weight off the diesel consumption and cost in the area. In 2017, the estimated amount spent on diesel by the GN (Government of Nunavut) was about $29.6m. The proposed plant would relieve the government of about $5.2m of the current yearly diesel expense, reducing it to about $24.4m yearly, 5.2 m over 20 years is $104m, thus increasing the viability of the proposed project.

This project not only being self-sufficient in terms of generating enough revenue to operate and maintain itself as well as generate profit, will also be cutting the government's current diesel expenditure by a significant amount over its lifetime.

The project is economically feasible.

4.4 Decommissioning Costs

Decommissioning happens when the wind farms power is ceased, and the site is either dismantled or repowered. Repowering involves the equipment being replaced or upgraded with more advanced and efficient technology in order to prolong the lifespan of the plant [34]. Typically, we would need to consider the local requirements for decommissioning the project but seeing as Nunavut has no regulations for wind power generation or its decommissioning, it is hard to get an estimate as to what that would cost. Places like Quebec require a specific amount to be set aside by the company after 10 years of the plant's life for decommissioning. Also, the only ever decommissioned wind farm in Canada is the Cowley ridge farm, while they employed the method of decommissioning for resale [35], no known money values were specifically mentioned. Generally, in the US, it costs an average of 200,000 (cad$260000) to decommission a wind turbine. [36] so we are looking at a minimum of $520000 for the decommissioning of both wind turbines.

4.5 Externalities That May be Internalised

Wind power generation has the lowest impact out there on the environment, including on water consumption and shouldn't be a major concern for the environment. It is going to reduce the already ridiculous amount of CO2 emissions in the area.

Advantages of the project

- Unlimited, "free", renewable source of energy [37]
- areas become more accessible due to construction of roads and substations
- more employment opportunities for the locals of the area
- increase in economic growth as new infrastructure and developments start to flood the area
- reduction in the cost of energy
- reduction in the overall carbon footprint pf the area

5.0 ENVIROMENTAL IMPACT ASSESMENT

Nunavut is a territory in northern Canada, it is made of 25 remote communities that depend primarily on imported diesel for their energy production. Nunavut's electricity demand has by 21% between 2005 and 2015, where the annual electricity consumption reached 5.2 megawatts hour [38]. In 2016, a signification portion of Nunavut's installed electricity generation capacity was powered by diesel fuel [38]. Greenhouses gases emission in Nunavut has been related to energy generation. In fact, greenhouse emissions have increased by 62% between 2000 and 2015 with a total average of 626 thousand tonnes of CO_2 annually and 17.2 tonnes per capita [38].

The international Panel on Climate Change claims that although Nunavut does not emit large quantities of greenhouse gases, it is particularly vulnerable to climate change impacts [39]. And according to Environment and Climate Change Canada, climate change has altered ice conditions, permafrost and precipitation patterns in Nunavut [39]. Its research data indicates that the average temperature increased by 2.7°C between 1948 and 2016 and that the warming trend is to be expected [39].

The energy generation and consumption patterns in Nunavut has been the leading causes of pollution and climate change in the area. The pollution is not limited to electricity generation emissions but to transportation imposed by the remoteness of Nunavut communities require diesel imports in bulk, which has a significant contribution to greenhouse gas emissions and can cause severe damages to the environment if accidents happen like spills [39].

Electricity demand and consumption is projected to grow for all Nunavut's communities. In Iqaluit for instance, the electricity load was estimated to near 57,000 MWh in 2014, it is estimated to increase by 3-4% annually due territorial and federal government driven projects as well as exploration activities in the mining sector in addition to population grown and new housing [40]. Iqaluit community has witnessed a rapid increase of 149.1 tonnes annually in emission between 2009 and 2013 totaling to 493,813 tonnes of CO_2 equivalent of which, 116,000 tonnes were related to electricity generation [40].

The wind farm project is intended to be integrated into the existing diesel-powered installation to relieve the load on the grid and decrease the greenhouse gases emissions as well as improve the air quality and ease the impact on the surrounding environment. The wind turbines are to be installed on the north-west side of the community and will be connected to the grid through power lines. Although the project benefits seem appealing, the installations do not come without consequences on the environment, including the population, the fauna, the flora and land stability.

5.1 Life Cycle Assessment

A crucial part of the feasibility study of the wind farm project is the environmental impact assessment. The life cycle assessment is a vital tool to assess the environmental effects of the electricity generation in the for of a cradle to grave analysis. It examines the energy and material flows including raw material extraction, processing and manufacturing, transportation, implementation, maintenance as well as recycling [41] options as shown in the figure 12 below.

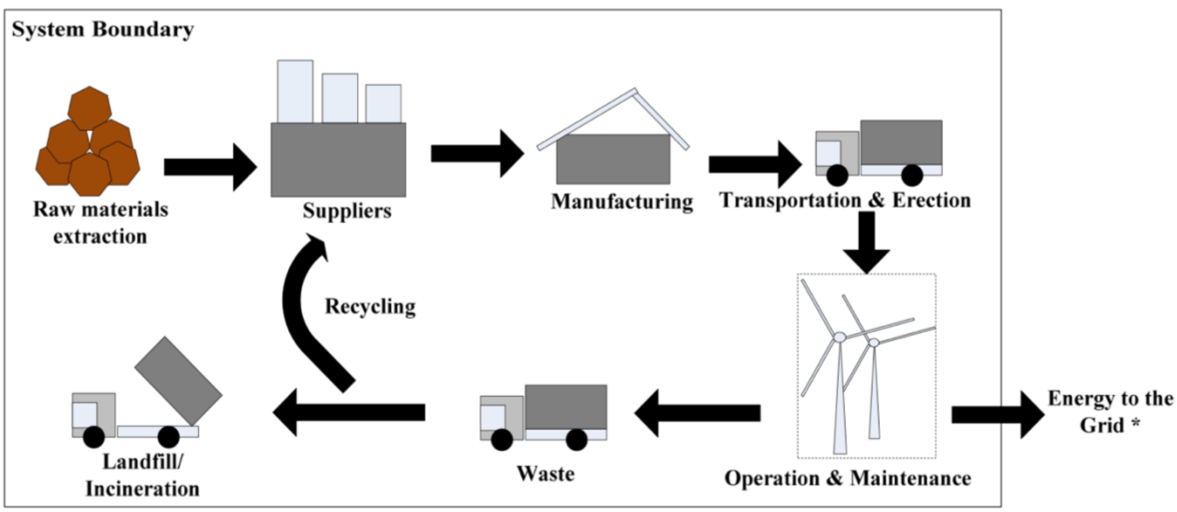

Figure 33: Scope of life Cycle Analysis [41].

For the life cycle analysis to be conducted, the-cradle-to-grave processes had to be decomposed into four major stages; construction, transportation, operation and maintenance, and end of life treatment [41].

- The Construction phase comprises raw material extraction, manufacturing of wind turbine components and assembly, foundation as well as grid connection cables. This phase produces the portion of greenhouse gas emissions as raw material extraction and production, such as, aluminum, steel and concrete are energy intensive and account for about 1400 tonnes of CO_2 per wind turbine [42].

- The transportation phase includes, transport raw material for manufacturing as well as transport of wind turbine parts to the erection site and operation and during operation and maintenance. This phase don not have a significant contribution to greenhouse gases emissions and are predicted to generate around 18 tonnes of CO_2 per wind turbine [42].
- Operation and maintenance include regular oil change and lubrication as well as part change in case of malfunction. It sums up the monitoring the proper functioning of the wind farm. It does not account for a noticeable portion of CO_2 emissions and is predicted to generate about 12 tonnes.
- The end of life phase takes into account dismantling of wind turbines when they are out of service as well as transport to disposal site and landfills. The emission generated during this stage is estimated to be about 13 tonnes of CO_2 per wind turbine [42]. The life cycle analysis considers the possibility of material recycling in order to reduce the environmental impact of the construction phase [43].

Figure 14 below summarizes the contribution of the important life cycle phases in terms of greenhouse gases emission.

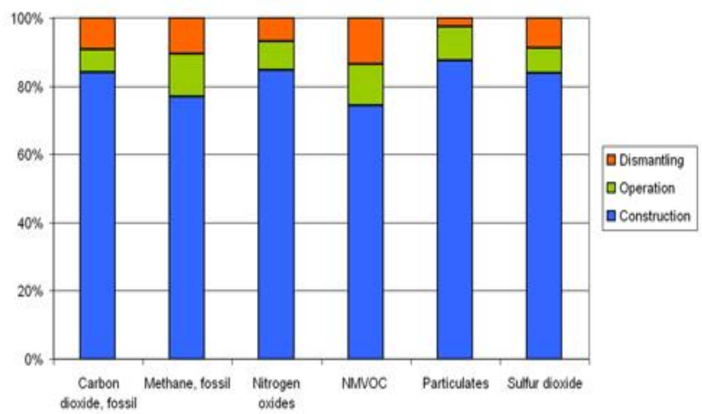

Figure 14: Life Cycle stages contribution in terms of greenhouse gas emissions [42].

The total CO_2 equivalent emissions are estimated to be 1500 tonnes per turbine comprising all the life cycle stages and without considering material recycling. However, if recycling is used it would have a negative contribution to the greenhouse gas emissions and thereby reduce the overall impact on the environment. Recycling is estimated to have net reduction of 500 tonnes of CO_2 during the life cycle of wind turbines [41]. Figure 14 below illustrate the difference between the two scenarios in which landfill and recycling end of life are considered in term of energy generated as well as CO_2 emissions [41].

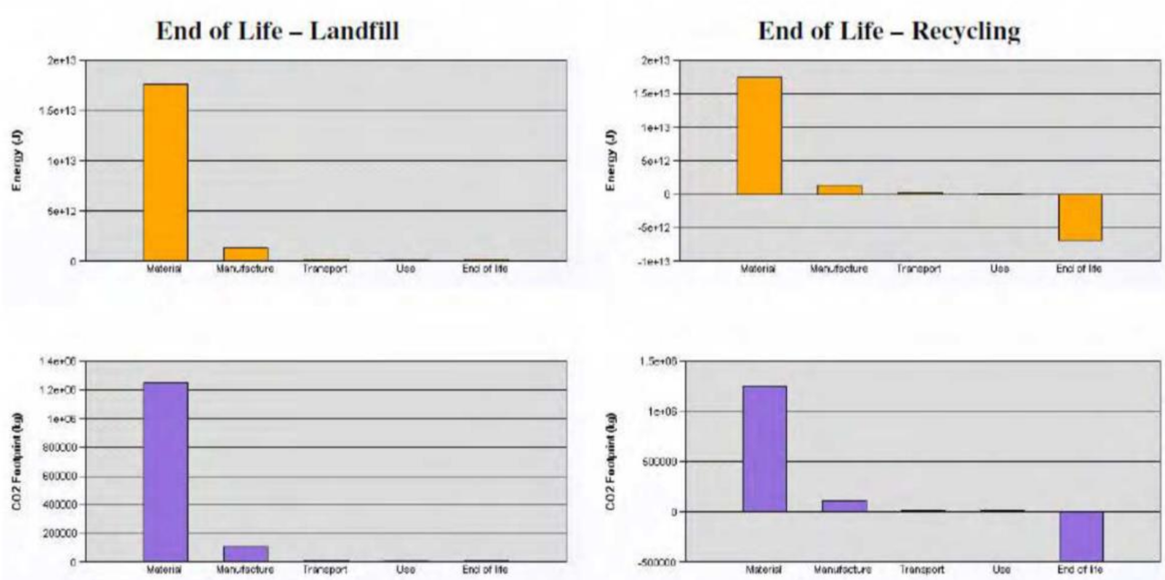

Figure 15: Life Cycle energy and emissions assessment with and without recycling [41].

The life cycle assessment for the Iqaluit installation was conducted based on an existing model that analyzed the life cycle of a 2MW wind turbine [40]. It was concluded that the construction phase contributes to 80% of the total emissions and that includes raw material extraction, manufacturing of the wind turbines (tower, blades, generator…), foundation as well as power grid connection cables. The other phases; transportation, maintenance, waste disposal, do not have a significant impact on the environment compared to the impact of the whole project. The total greenhouse gas emissions resulting from all the process are estimated to nearly 1500 tonnes of CO_2 equivalent per wind turbine. However, the end of life stage is estimated to have negative contribution to greenhouse gases emission and would result in a net reduction of 55% in the overall project's predicted emissions.

The results obtained from the life cycle analysis of wind turbine indicate that although wind turbines life cycle have an impact on the environment in terms of emissions, it does not compare to the effects of fossil fuel-based electricity generation. Moreover, material recycling has the potential to significantly reduce the environmental impact. The results put emphasis on the importance of sustainable design and sustainable manufacturing in the early stages of the project installation.

5.2 Local Environmental Impact

The wind power plant consists of two wind turbines of type Enercon E-70 [43] installed close to existing roads to minimize transportation and maintenance access cost. The power plant total area to be used would be mainly for wind turbines and transmission power lines.

Iqaluit surrounding land consist tundra; rocky land covered with small shrubs, mosses and grasses. It is covered in snow and ice during winter and in summer the ground below the surface remains frozen [44]. The land disturbance would be limited to excavation and minor access roads, initially made out of gravel, to wind turbines. The installations would not disturb any waterways since they are none in the vicinity.

The main concern with wind power plants is its potential impact on local bird species. In fact, few bird species live in Iqaluit region all year long, the majority are migratory. it likely that migration pattern and bird habit would be disturbed near the wind turbines, however, the proposed installation is relatively small compared to the surrounding and it is very unlikely to noticeable impact. The same prediction can be applied to terrestrial native mammals, like arctic foxes, bears and caribous. Nonetheless, the power company in charge of the installation would collaborate with the local agencies to ensure that the project installation is in accordance with standards for animal habit protection and avoid any ecological disturbances.

In Conclusion, the proposed installation has the potential to improve the air quality of Iqaluit region. It is projected to result in a 17.25 % reduction in greenhouse emissions, which is equivalent to 3 tonnes of CO_2 per capita on an annual basis, including transportation. In addition, it will reduce transportation related contamination as well as accidents such as oil spills.

6.0 IMPLEMENTATION ISSUES

The proposed installation is base in Iqaluit which is part of the Arctic region. Arctic regions lay on top of a layer of permafrost which is very sensitive to temperature change. In fact, Iqaluit has been trying to mitigate the effects of permafrost thaw due increase in temperature resulting from climate change. Permafrost thaw affects the stability and the sustainability of built structures and can make it subject to collapse [45]. Wind turbines installed in Iqaluit region could be affected by permafrost thaw rendering them instable and affecting thereby their well operation and performance. Therefore, close attention should be paid to the wind turbine foundation and regular maintenance should be provided. These requirements may pose a issue as they potentially increase the maintenance costs and decrease the overall efficiency of the installation.

Wind power generation plants, especially smaller plants like ours tend to be very capital intensive. Not a lot of governments are willing to let go of lump sums of money in one go for projects like these, private investors also tend to shy away because the projects tend to pose some serious financial risks if not handled very carefully.

Other implementation issues directly relate to the community response to the proposed project. A lot of people in various communities have raised their concerns about wind turbines being installed in their areas. Their reasons being, the large turbines have visual effects on the beautiful scenery of nature [37], the noise that the wind turbines produce causes serious discomfort to a lot of people and the significant amount of land that these projects tend to consume. But, in this very scenario, the people of Iqaluit stand to gain a lot from the implementation of this power plant, ranging from the potential reduction in cost of electricity, increase in employment opportunities, potential economic growth and urban developments that will follow the construction of this plant. When it's all tabled out, the Pros outweigh the Cons, but it wouldn't be a surprise if the community altogether refuse the project for the above-mentioned reasons.

7.0 DISCUSSION

The proposed wind power plant in the Iqaluit area was found to be technically feasible. The wind turbine selected for Iqaluit was the Enercon-E70 2.3MW turbine. This turbine was selected due to its ability to operate in such low temperatures (up to -40^{o}C) and Enercon's experience in Northern Canada. Iqaluit has high average winds which suggest a great potential for wind power generation [14]. The E-70 2.3MW turbine was sized for Iqaluit using its low cut-in wind speed of 2 m/s, its smaller blade diameter to lower costs, and matching the peak load of Iqaluit's electrical demand. The hub height of 75 m was selected using the relationship between the levelized cost of electricity and the height of the turbine [21]. The wind farm proposed consists of two wind turbines would be able to provide a total power of 6922.8 MWh/yr which would reduce the load of power production by diesel by 17.5%.

The results show that for one wind turbine installed in Iqaluit at a hub height of 75 meters it is possible to get 3462.08 MWh/year and the peak power is 57.444 kW. This value of energy is considering that the wind turbine operates all day the 365 days of the year, which is not a completely true assumption since the turbine might be brought to a stop when there is no need for its power, because we are not storing the extra power. The capacity factor related to this hub height is of 17.18%. The overall efficiency of the farm with one turbine is poor, considering that average wind farms around the world operate at efficiencies around 27%-29%. The calculation of capacity factor was simplified in order to make it applicable for all year long, factors as environmental phenomena wasn't considered in the calculations. For example, at extremely cold temperatures that Iqaluit gets at some parts of the year; the formation of ice is possible in the blades which would decrease the overall of the turbine. When there are storms the wind speeds increase exponentially and it would be dangerous for the turbine operating under these conditions. This could be also a factor to consider for the overall capacity factor being so low. The data in general seems flawed, since in the literature it is shown that the average velocities in the area are larger than 4.05 m/s.

The site selected had to meet several specifications due to policy, road and power line construction, and several other factors mentioned in the technical analysis section. The site for the 2 E-70 turbines is slightly northeast of the center of the village. The airport restrictions and sound propagation were the main factors in having it this distance from the village. The site is just over 4 km from the airport and very close in proximity to the Iqaluit shooting range since there are already roads built up until the range, this lowers the capital cost. Another reason as to why it is just over the 4km airport restriction is to reduce the length of power lines installed. Approximately 2 km of power lines will need to be installed for grid connection. The Enercon turbines are equipped with closed-loop control at the point of connection using there SCADA-RTU-C and SCADA-FCU wind farm regulators. If the demand of Iqaluit were to rise and another turbine was needed, the region has a significant amount of space to accommodate this.

According to the economic analysis, however, the initial cost is very high, and the return is low. The economic cash flow in Figure 10 shows that the project would start to make profits at the beginning of year 23, which is very long considering that the proposed project's length is 25 years and investors usually want it to be seven years or less. The plant delivers an actual amount of 6922.8 MWhe. After calculating the NPEC, which resulted in a value of \$0.19 and the IRR found was -10%, which means the project is infeasible project. The annual energy consumption of Nunavut per capita was found to be 5.1MWh in 2017. There is a population of 7440 people as of 2017 and the energy consumption would be approximately 39474 MWhe [32]. The installation of a 2-turbine plant would lift a 17.54% weight off the diesel consumption and cost in the province. This would help reduce a cost of about 6 million for a 29 million electricity production cost. In 2017, the amount of diesel the GN (Government of Nunavut) purchased was around 215 million litres of diesel [33], with an average global price of \$2.595 per gallon which is about \$0.6855 per litre of diesel [34]. The GN spent over \$147m on diesel, excluding import costs and any subsidies granted by the government. The proposed plant would relieve the government of 5% of the current diesel expense, reducing it to about \$140 million yearly. Thus, this would not be a viable option for reducing electricity costs or removing burden on diesel expenses for the government.

Since the project shows a payback period within the life of the project, despite the negative net present value, it is still worth implementing under the following conditions: government subsidies are available, or a carbon cap and trade system is implemented, initial, and maintenance costs of wind power plants significantly decrease (which is reasonable to assume with emerging technologies that would cut down construction costs and various components costs or if the project was to use recycled material. Innovative technologies could also allow to reduce losses and increase power efficiency) and/or electricity prices continue to rise well above the inflation rate. That leads to the conclusion that the proposed project should be put on hold until those conditions are met.

With the proposed project about 3 tonnes of CO_2 equivalent per capita can be reduced. Greenhouses gases emission in Nunavut has been related to energy generation. In fact, greenhouse emissions have increased by 62% between 2000 and 2015 with a total average of 626 thousand tonnes of CO_2 annually and 17.2 tonnes per capita [38]. The international Panel on Climate Change claims that although Nunavut does not emit large quantities of greenhouse gases, it is particularly vulnerable to climate change impacts [39]. And according to Environment and Climate Change Canada, climate change has altered ice conditions, permafrost and precipitation patterns in Nunavut [40]. Its research data indicates that the average temperature increased by 2.7C between 1948 and 2016 and that the warming trend is to be expected [41].

As mentioned in the environmental analysis Iqaluit has recently had a rapid increase of 149.1 tonnes of emission between 2009 and 2013 and 116,000 tonnes of the emissions were due to electricity generation [12]. Iqaluit's community is mostly diesel powered and the proposed wind power plant would help in the fight against climate change since it is a renewable and clean source of energy. It can relieve the load on the diesel-powered grid which can help decrease the greenhouse gases emissions. The air quality in Iqaluit by the removal of short-lived climate pollutants can help decrease disease and improve the health of the people living in the community. Farmers, graziers and fishermen have the best chance to feed the world, and our industries have the best opportunities for sustainable growth and new green markets. Increasing greenhouse gases can lead to extremes in our weather and changing the long-term climate. Strong radiation inversion with the low temperatures with bad air quality can create a negative impact for people with heart disease or lung disease. Moreover, in this particular case, it could potentially reduce the load on the two main diesel power plant operating in the region and generating a total of 4.6 MW which would help reduce greenhouse gas emissions. In the environmental assessment a life cycle analysis was conducted it was found that the carbon footprint is about 1400 tonne per wind turbine. Construction accounts for 80% of the total emissions, it includes raw material extraction, manufacturing of the wind turbine as well as foundation and grid connection cables. The other stages do not have a significant impact on the environment. At the end of the wind turbines life cycle, it can have a negative contribution to the CO2 emission, but if recycling is used then it will reduce the emissions of manufacturing the wind turbine by 55%.

For the implementation of the proposed project from the environmental point of view the main drawback can potential impact local bird species in Iqaluit. Due to the very low temperature ranging between -30 to -40 degrees there are only a few bird species that live in Iqaluit and they mostly migrate to other locations. The wind turbines can cause a disturbance in migration patterns and also bird habitats. The proposed wind farm only consists of 2 turbines which will be installed in a small area and this would not cause a major impact. The animals which live in Iqaluit are terrestrial native mammals, like arctic foxes, bears and caribous. The wind farm installed would most likely be closed off to avoid the interaction between the animals and the wind turbines. One would ensure that the project installation will protect the animal habit avoid any ecological disturbances.

Another implementation issue could be Iqaluit's land. Iqaluit consists of rocky land covered with small shrubs, mosses and grasses. It is covered in snow and ice during winter and in summer the ground below the surface remains frozen. For the installation of the wind turbine it is required to dig deep into the land in permafrost. Arctic regions lay above a layer of permafrost that is very sensitive to temperature change. This can pose a danger since the wind turbine may not be stable. This means the wind turbine can requires extra maintenance which can increase the maintenance cost and reduce efficiency. Also, many people would be concerned that the large turbines would not look aesthetically pleasing and it can also be very noisy. Another issue would be from a economical point of view the government does not provide any subsidies or incentives regarding the use of clean energy.

This project was considered because the area appears to be a great fit for a wind farm. The quantity of the available wind resource, available farmland to place turbines, and diesel power plants as a backup for when wind power is not available suggests that this project is a good idea to implement in Iqaluit. Iqaluit only source of power comes from diesel and providing a renewable resource can help reduce the load of expenses for electricity generation. In economic analysis this project is feasible without significant government subsidies but pushing for subsidies can help reduce the payback period of 15 years. Also, incentives provided by the government can encourage Iqaluit's community to use renewable resources.

8.0 CONCLUSION

In conclusion this project is technically feasible because the wind farm chosen has the maximum capacity to provide 6922.8 MWhr/yr of power to Iqaluit. This would help reduce the load of diesel power generation by 17.54 percent which is approximately 6 million dollars of the 29 million they spend annually. It is also economically feasible since the payback period was found to be 15 years for a 20-year project and the IRR found is 2.8% on the payback. Therefore, it is profitable. It is environmentally feasible due to the reduction of about 3 tonnes of greenhouse gases per capita which reduces the city's carbon footprint. Considering all these factors it is worth implementing this project. Some future recommendations would be push for government incentives to help with the project feasibility economically. Also, in the future we can scale up the windfarm to help further reduce the load of electricity production by diesel.

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