Design, Performance, and Economic Evaluation of Grid-Connected Renewable Power Generation System for Iqaluit Community

by

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The above review committee determined that the Project is acceptable in form and content and that a satisfactory knowledge of the field was covered by the work submitted. A copy of the Certificate of Approval is available from the School of Graduate and Postdoctoral Studies.

ABSTRACT

The high demand for clean and green energy is due to the rise in global temperature as the climate is affected using fossil fuel for energy generation in the arctic region. Nunavut is rich in renewable resources like wind and solar, but almost 100% of their energy demand is met by diesel generators. Considering the soaring diesel prices, a hybrid wind power plant is proposed in this study and further compared to a similar size hybrid solar PV power plant. The hybrid wind power plant is the successor with lowest unit rate of 37.7₵/kWh and a payback period of 9.5years.

Keywords: wind energy, solar PV, carbon emission, northern territories

AUTHOR'S DECLARATION

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LIST OF ABBREVIATIONS AND SYMBOLS

HOMER	Hybrid Optimization of Multiple Energy Resources
RETScreen	Renewable-energy and Energy-efficiency Technology Screening software
RCEN	Canadian Environmental Network
CELA	Canadian Environmental Law Association
WWF	World Wildlife Fund
CERRC	Clean Energy for Rural and Remote Communities program
QEC	Qulliq Energy Corporation
AEF	Arctic Energy Fund
IPCC	Intergovernmental Panel on Climate Change Canada
US EPA	U.S. Environmental Protection Agency
EC	Environment Canada
LCOE	Levelized Cost of Electricity
NPC	Net Present Cost
IRR	Internal Rate of Return
ROE	Return on Equity
ARI	Arctic Research Institute
WTG	Wind Turbine Generator
tCO_2eq	Tonne of CO_2 Equivalent
AGL	Above Ground Level
ASL	Above Sea Level
GHG	Green House Gases

Chapter 1. Introduction

1.1 Problem Statement and Motivation

The Canadian government took some great initiatives upon signing the Paris agreement in 2015 and since then preserving the environment has been a priority. Canadian Environmental Network (RCEN), Canadian Environmental Law Association (CELA) and World Wildlife Fund (WWF) are some of the organizations that are working on the laws, policies, and direct project initiatives to tackle the climate change in Canada while the Clean Energy for Rural and Remote Communities program (CERRC) provides funding for renewable energy projects to the northern communities and a total of $300 million is made available until 2027 [1].

Based on the area, Nunavut is the largest in all provinces and territories in Canada, with a total population of 38,780 (2019), while the capital city is Iqaluit, which have a population of 7,740 (2016) with a growth rate of 2.5% [2]. With such low population and harsh weather conditions, it is economically and technically unviable to have a centralized grid. The current electrical distribution infrastructure in Nunavut is divided into three regions namely; Baffin, Kivalliq, and Kitikmeot region with 25 diesel powered genset plants of different capacities to provide a distributed and local power source to the 25 communities in all over Nunavut [3]. Iqaluit, which sits on the Baffin Island near the Frobisher Bay, makes it unique compared to other communities due to the availability of sea transportation. Iqaluit city have a peak load of 9,797KW and a total annual generation of 59,646MWh (2017) from its 6 number of gensets at the local power plant with a total installed capacity of 22,600 kW and an installed firm capacity of 17,600 kW [4]. Among these 6 genset almost 2 genset are running over their anticipated lifecycle. The remaining sets have completed nearly 50%-70% of their running hours, which indicates that the power plant is in a critical need of a retrofit. The local electrical utility company Qulliq Energy Corporation (QEC) applied in February 2021 for replacement of one of the genset with an estimated replacement cost of $8.415 million from the Arctic Energy Fund (AEF) over the period of two years (2022-2024). In this proposal, the customers will have to pay approximately 25% of the total project cost in terms of an increase in the electricity tariff with an average of 0.41 c/kWh with an amortization period of 27 years [5].

According to the Intergovernmental Panel on Climate Change Canada (IPCC-2006) the U.S. Environmental Protection Agency (US-EPA) states that an estimated 0.042 gal of diesel is consumed per kWh of energy generation and a total of 10.180 x10^{-3} metric tons of CO_2 per gallon of diesel is emitted [6]. Furthermore, an estimated 6.48 x10^{-4} metric tons of CO_2 is being offset per kWh of energy generated by a wind turbine (US-EPA, 2020). while an estimated 10.4 gCO_2 is emitted per kWh of power generated by a Solar PV power plant (2012) [7].

In this report, based on the weather data from the local airports and environment Canada engineering climate datasets [8], a wind energy power plant is proposed to cater the load at Iqaluit power plant by integrating the energy source to make use of the currently available genset and to avoid any unnecessary financial burden. Furthermore, the proposed system methodology will not only help in the reduction of CO_2 emissions but also reduce the cost of unit generated as wind energy systems are not steered by the fluctuation in the fuel prices, as evident the global fuel crises are affecting the electricity unit generation from non-renewable sources [9]. An alternative Solar PV power system is proposed but based on the key performance indicators like levelized cost of electricity (LCOE), Net Present Cost (NPC) and payback period the wind energy system with integration of genset for grid stabilization is more viable. A total of CAD$ 42.9 million is required to complete the project with an internal rate of return (IRR) of 10.1%, LCOE of 37.7 ₵/kWh and a payback period of 9.5 years.

The future work based on this report shall include the integration of battery backup systems to provide power grid integrity and stabilization with an effective techno-commercial proposal as it will reduce the CO_2 emissions further and completely avoid the use of fossil fuel in the drive to clean power generation.

1.2 Contribution

The contribution of this study is as follows:

1. An abundantly available wind resource is exploited to provide a stable and suitable size of hybrid wind power plant without any storage system with better LCOE than the current diesel genset power plant.
2. Comparable size wind and solar power plants are evaluated against diesel powered generators to provide a better alternative and to significantly minimize the carbon footprint.
3. The detailed wind assessment including system design, financial and economical constraints, evaluates this study as a base for a potential preliminary feasibility study.

1.3 Report Outline

The report is organized as follow:

Chapter 1 presented the problem statement and the motivation of this work, which is based on the global climate state and increasing fuel prices with high electricity rates for the Iqaluit community while the local renewable resources is provided as the viable solution to mitigate these problems.

Chapter 2 presents an overview of the relevant work previously published in the literature.

Chapter 3 presents the design and simulation basis of hybrid wind and genset power plant which is further compared to a hybrid solar and genset power plant providing the financial viability and cost analysis.

Chapter 4 presents the conclusion based on the simulation results while some key improvements are highlighted for the future works.

Chapter 2. Literature Review

2.1 Previous Case Studies

The Canadian government always advocated about the preservation of the northern territories in all regards, especially its environment and weather and for that reason the Arctic Research Institute (ARI) was established in 1964, which carried out extensive research in measuring wind and solar potential in Northern Canada [10]. With residential and commercial energy requirements major mining operations for diamond, gold and other precious commodities also have an excessive energy use. In Yukon and Northwest Territories (NWT), these requirements are fulfilled by hydroelectricity and a mix of other non-renewable sources [11]. While in Nunavut the only source of electricity is from the diesel generators as there is no centralized grid and almost all the communities have a decentralized energy network, as can be seen in Figure 2.1. Until 2016, multiple studies have been conducted for the assessment of renewable energy sources in the Nunavut region. The first ever renewable project having Solar PV System in combination with diesel generators will be installed in Kugluktuk [12].

Figure 2.1: Nunavut Electrical Infrastructure

In 2012, the Diavik mine located at Lac de Gras Island, NWT, added around 9.2 MW of clean wind energy. It consisted of 4 number of 2.3 MW with de-icing electric heaters in the blades of the wind turbines which amounted for around 10% of the mine total energy requirements. This was forecasted to produce 17 GWh/year with a total reduction of 10% in diesel consumption (YTD ~2 million Liters) in a total capital of $33 million [13].

This private project was the first step towards the integration of wind energy in the northern communities. Its aim was to reduce the dependency on fossil fuel and the reduction of GHGs. An evaluation between direct transmission lines, geothermal, nuclear, solar, and wind power system was performed, which resulted into selection of wind power system. As the transmission line project Capex was ROI prohibited, geothermal project had higher temperature differential requirements for its feasibility and the mine depth was not enough. Nuclear power plant option was ruled out based on the unavailability of the regulatory framework in the Northwest territories and this project was time sensitive while the solar power plant had a negative NPV due to its low penetration into the existing electrical network. While the wind power plant had a positive NPV and 8 years of a payback period.

This project took around 2 years (2010-2012) to commission since its inception. Due to proper project planning, selection of right vendors, system design based on real-time data and integration of almost every fault scenario resulted in a reduced number of issues during commissioning. In the latter stage of project life cycle several issues emerged, which includes selection of wrong lubricants unsuitable for temperatures below -30^{o}C for the turbines, and unheated enclosures for the electronics. The results of the project were eye opening as the wind turbine generators (WTGs) produced around 9.2% in the following year and around 7% more than the forecasted value with an average integration of 10.5% overall, while around 6% of carbon footprint (12,000 tCO_2eq) were reduced with an average of 25 years of plant life cycle [14].

Since 2005, research regarding the wind energy potential is being carried by the Aurora Research Institute (ARI) at Inuvik, NWT [15]. In March 2012, the ARI team conducted a feasibility study for developing a wind energy generation system with a lower LCOE than the current diesel genset plants. Based on the wind speed data at 75m AGL (Above Ground Level) from three different sites located at (1) Inuvik airport (4.6 m/s), (2) Caribou Hills, 35km north of Inuvik (6.6 m/s) and (3) Storm Hills, 60km north of Inuvik (8.0 m/s) an initial wind project of adequate size around 1.5 MW to 1.8 MW was modelled. As this size of a project doesn't require much sophisticated power controls, which brought down the cost of the overall project. The project size was not cost-effective as compared to the diesel rates in 2012, so the team decided to increase the size of the project to 4MW which had a lower LCOE ($0.39 per kWh) which included the cost of the turbines, access roads, power lines and other ancillary items. While the initial model with 1.5MW to 1.8MW had an average LCOE of $0.73 per kWh which is almost double of the LCOE for 4MW wind power plant. This project was proposed to greatly reduce the NWT GHGs emissions as the local government has pledged to decrease the GHGs by 30% by the end of 2030 (6,000 tCO_2 annually) and around three million litres of diesel annually will be offset [16]. The excess wind energy can either be stored in a battery bank for the purpose of grid stabilization which can greatly increase the price of the proposed system, or the excess energy can be used to provide space heating which can displace gas or heating oil. It can also be stored as thermal energy in an electric thermal storage unit for later use of space heating, Figure 2.2 [17].

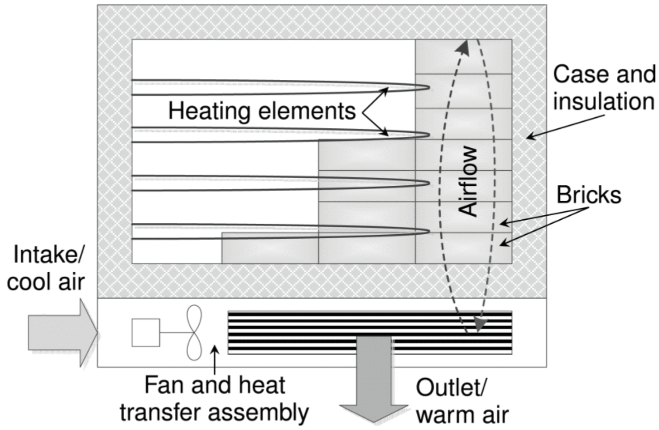

Figure 2.2: Electric Thermal Storage Unit Schematic for residential purposes

2.2 Feasibility Studies

In 2016, Qulliq Energy Corporation (QEC) issued the first RFP for potential of wind energy in Nunavut. JP Pinard Consulting won the bid to perform the feasibility study. This study included the optimal design of wind power plant for integration with the current Genset power plant for 25 different communities. Unlike Inuvik where the ARI team had been conducting studies to measure the weather data in such detail, the Nunavut communities only relied on the Environment Canada (EC) weather balloon stations. These stations were located at the local airports where the sensors are placed at a 10m AGL, which measured a wind speed of 7m/s (25 kph) such a windspeed at 10m indicates that Nunavut has a greater wind potential. Furthermore, they measured the wind speed at 25m and 57m height using the equation 2-1, which holds up to 100m AGL [18].

$$u_2 = u_1 \frac{\ln\left(\frac{z_2}{z_o}\right)}{\ln\left(\frac{z_1}{z_o}\right)}$$

Equation 2-1: Natural Log Law Equation

Where,

u_1 = Known wind speed at z_1

u_2 = required wind speed at height z_2

z_o = surface roughness (usually 1.4) unitless

z_1 = known height for u_1

z_2 = known height for u_2

Furthermore, in some communities the terrain is hilly with weather balloons located at heights. An average of 6.8 m/s windspeed at 100m AGL was calculated based on the data (2006-2015) from the 6 weather stations located at Iqaluit, Baker Lake, Cambridge Bay, Resolute, Coral Harbour and Hall Beach respectively. Information from the transport Canada and NAV Canada suggested that there should be no turbine placed in the 4km radius of the airport and no higher than 45m AGL, with airport NAVAIDS like Very high frequency Omnidirectional Radio Range (VOR) it is recommended to have a 15km in radius of clearance and an 80km clearance for RADARs. While a clearance for installation of a small turbines of 66m height AGL was received from the authorities.

A financial viability check was performed on RETScreen of proposed systems for all the 25 communities, 8 communities were ruled out based on the amortization period to be longer than the plant life that is 25 years. While 10 communities had a Return-on-Equity (ROE) lower than 8% threshold. The remaining 7 communities had a reasonable ROE, but Cambridge Bay community had a forecasted increase in load of around 70% which would suggest that a large turbine was needed which would affect the financial viability of the proposed system. The system proposed for Resolute Bay community had an uncertain installation site location which might increase the cost of installation and commissioning in the future. So based on the mentioned reasons these two locations were ruled out as well. The remaining 5 locations namely Iqaluit, Rankin Inlet, Baker Lake, Arviat and Sanikiluaq were further modelled in Hybrid Optimization of Multiple Energy Resources (HOMER). The total cost for large wind turbine generators with and without battery backup can range from $35.2 to $68.6 million with an LCOE between $0.15/kWh - $0.30/kWh with an ROI of 8.2% or more. While for projects with small wind turbines with and without battery backup can range from $4.2 to $10.5 million with an LCOE >$0.23/kWh, see table 2.2 [18].

Community	**System Size (kW)**	**Electricity Exported to grid (MWh)**	**hybrid System LCOE ($/kWh)**	**System Cost ($ Mil)**	**Payback Period (years)**	**ROI (%)**
Iqaluit	13800	12814	0.297	68.6	15.1	8.2
Rankin Inlet	2400	4736	0.291	26.7	16.9	7.3
Baker Lake	1600	2455	0.307	20.2	20.4	6.2
Arviat	2300	2653	0.319	19.6	22.2	5.7
Sanikiluaq	700	1008	0.340	10.5	>25 years	5.0

Table 2.1: Proposed system simulation summary (HOMER Model)

2.3 Current Situation

QEC published their corporate plan for 2021-2024, which is targeted at some maintenance and replacement work of the power plants. With an estimated 15,000 customers and approximately 76,000 KW capacity of diesel genset power plants in all over 25 different communities. The Iqaluit community have the highest load requirement of 9,960 KW, which is forecasted to be 10,572 KW by 2025. The expense over the period of 4 years until 2024 are estimated to be around $35 million divided into QEC departments and maintenance as well as upgradation projects in several communities [19]. Furthermore, an emergency required expense of $8.415 Million for the replacement of a Genset in Iqaluit power plant is incurred for which the responsible department has applied for the Arctic Energy Fund with a proposal that the cost will be split in a 75:25 [5]. AEF being responsible for the 75% and the customers will have to pay the remaining 25% over the period of the genset life cycle (27 years). The increase in the community-based rates will incur after the QEC first General Rate Application (GRA), which is expected to take place in the last quarter of the fiscal year 2023/24 [20]. The current domestic rate is 58.56 ₵/kWh, which will increase to 58.97 ₵/kWh an estimated 0.7% increase. Iqaluit power plant has a total of 6 diesel powered genset, 4 of which are installed in the years between 1992-2000 with a nameplate lifecycle hour of around 120,000 cycles. Two of these gensets are over their expected lifecycle which are of the highest capacity. Two new genset were installed in 2013 with a nameplate KW rating of 5000 KW each which brings the total plant capacity to 22,600 KW and an installed firm capacity (IFC) to 17,600 KW, which is ample for the forecasted load in 2025. While the decrease in IFC to 11,680 KW would result in downtime as it will not have enough capacity in case of generation shortages which would result in grid instability [5].

The previous wind assessments did not consider the replacement of diesel generators after the completion of their life cycle which greatly affects the LCOE of the system. The battery backup system includes an additional Operating and maintenance cost to the system. The case studies of previous projects in other territories and the wind assessment of Nunavut community with the current condition of the Iqaluit power plant shows that a hybrid system with enough wind potential to keep the grid stabilized and use the existing available gensets without the use of battery backup system would reduce the capital cost of the system and increase the annual generation with an offset in the carbon emissions as well.

Chapter 3. Objectives and Methodology

3.1 Objectives

The goal of this study is to design a hybrid power plant that will cater the load demand of the Iqaluit community by using the existing diesel-powered generators. There are several key objectives of this project that are listed below:

1. Using HOMER and RETScreen to design and simulate a Wind Power Plant for the Iqaluit community with an effective LCOE, ROI and CO_2 offset based on the latest weather data, load data, current electrical infrastructure, and fuel prices.
2. Provide a comparative analysis between the proposed wind power plant and a similar size solar PV power plant.
3. Provide a detailed cost analysis and timeline for the proposed wind power plant.

3.2 Methodology

To design such a hybrid power plant, we would need the following data:

1. Electrical load profile for the Iqaluit community.
2. Weather data for the installation site.
3. Installation site identification.
4. Power plant existing electric infrastructure.
5. Fuel prices and carbon emission data.
6. Wind turbine technical specifications and power curve.
7. Transportation method for all necessary equipment to the installation site.
8. Cost of all the required equipment, labour, material, Installation, and commissioning.
9. Financial Parameters.

All these variables are further explained in detailed with the relevant data:

3.2.1 Electrical Load Profile

The available data from Qulliq Energy Corporation (QEC) only have the annual generation and a peak load in kWh for 2020 and further forecasted until the year 2030, See table 3.1 [4]. From table 3.2, Due to the unavailability of daily load profile for Iqaluit a synthesized load profile was created from the Yukon hourly load profile. The Yukon electric utility by the name of "Yukon Energy" has installed a monitoring system which shows a summary of electricity consumption and generation from different sources mainly hydro and thermal. It is the only electric utility infrastructure with such monitoring equipment in the north with the same weather conditions and that is why it is selected for building a synthetic load profile for the Iqaluit community.

The synthetic load profile in HOMER is based on the daily average demand and a peak load in kW, while a day-to-day and hourly randomness variable is required to create a realistic load profile since the original load data doesn't have a min, max and average value for each day. A 2% hourly and a 5% day-to-day randomness value is selected in this simulation. But due to these variables the magnitude of the load profile changes while the shape of the load profile remains the same. To scale the synthetic load profile a scaling value is required which was estimated based on the average daily peak load throughout the year. A scaling value of 165,811.6 kWh/day was estimated and further applied in HOMER to adjust to the desired annual demand.

A total of 60,521,234 kWh/yr A.C load was considered for the simulation in the HOMER. The simulator scales the load profile based on the annual A.C demand and maps an hourly load profile with an average demand value, minimum value, and maximum value in kWh, a timeseries graph of the A.C load served throughout the year has been shown in figure 3.1.

Year	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Installed Firm Capacity (kW)	17600	17600	17600	17600	17600	17600	17600	17600	17600	17600	17600
Peak Load (kW)	10087	9960	10093	10230	10387	10572	10654	10807	10958	11107	11259
Annual Generation (GWh)	59.03	60.35	61.13	61.77	62.71	63.53	64.35	65.24	66.10	66.98	67.89

Table 3.1: Iqaluit Yearly Load Profile Summary

Month	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Avg. Monthly Load (GWh)	33.00	33.47	37.45	44.31	47.26	48.87	48.58	44.73	47.21	41.43	38.79	34.21
Peak Load (MW)	1100	1116	1248	1477	1575	1629	1619	1491	1574	1381	1293	1140

Table 3.2: Yukon Load Profile Summary

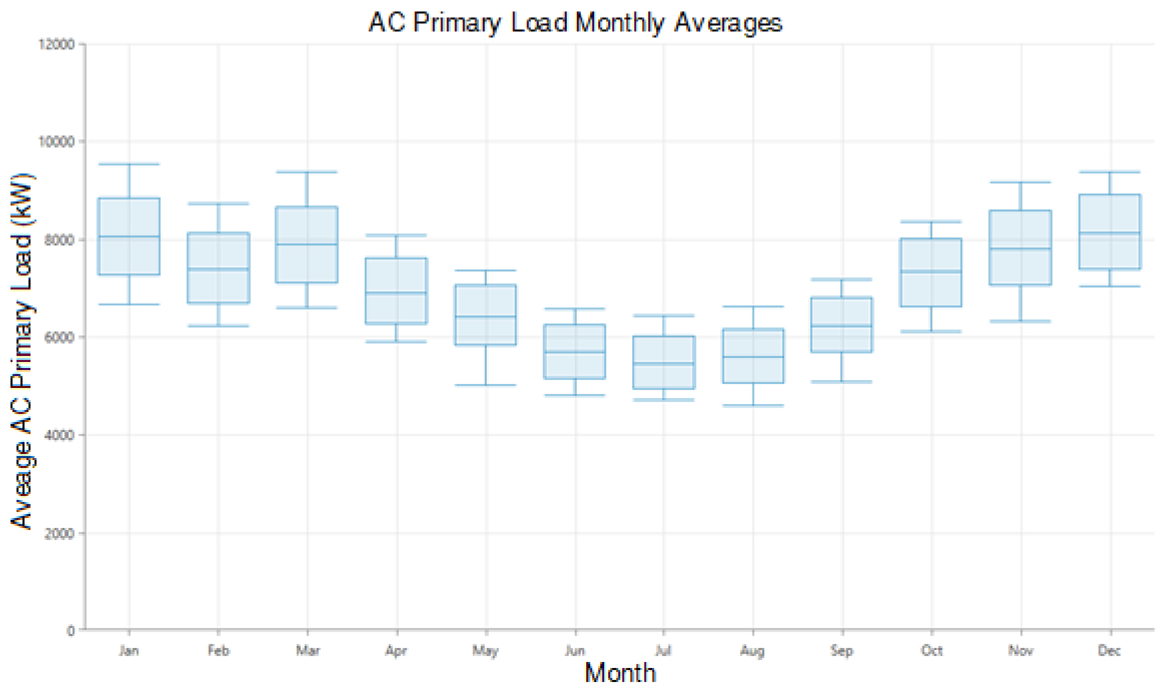

Figure 3.1: Monthly Averages of A.C load over one year

From figure 3.1, it can be observed that the peak demand for Iqaluit is high in December as it has a fairly cold weather condition, and the maximum demand comes from space heating appliances. While in summer the use of space heating is limited to the night-time. That is why there is a variation in the winter and summer load profile. The peak load served is estimated to be 9.8MW.

3.2.2 Weather data

There are multiple sources available to collect the weather data for the simulation model. For this study, the weather data including wind speed in m/s, wind direction, temperature and humidity are considered and is collected from Canadian Weather Energy and Engineering Datasets (CWEEDS) and compared to the meteorological data available in HOMER and RETScreen. The data from CWEEDS is based on the ground weather station located at the Iqaluit airport at 10m AGL while it also utilizes the data from National Aeronautics and Space Administration (NASA) meteorological satellites as is the case for HOMER [21].

Based on this information, no local ground data was available at heights higher than 10m AGL while datasets for past 25 years from 2022 was collected from the NASA meteorological satellite data and compared with a synthesized data calculated using the natural log law equation at a height of 75m AGL, which showed a similar average value for the entire year meaning that the built-in weather data source in HOMER can be used for simulation.

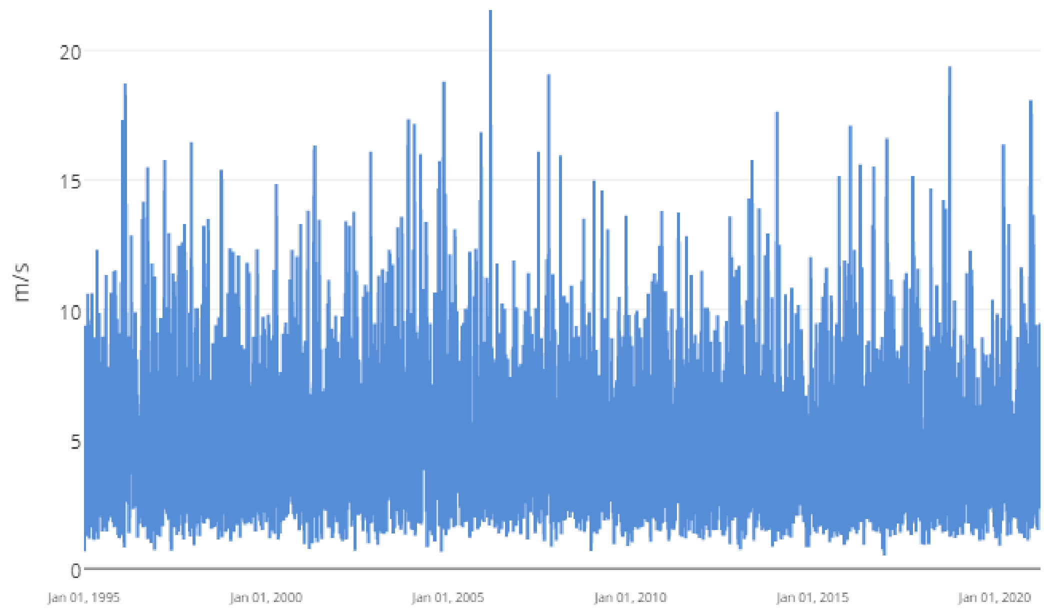

Figure 3.2: Windspeed profile at 10m AGL (1995-2020)

From figure 3.2, It is evident that rare wind spikes have been observed over the 25 years period where the windspeed is estimated to be over 18m/s while the average windspeed is estimated to be ~6m/s. The Weibull distribution of the windspeed and its frequency also shows that the windspeed at 6m/s has a higher frequency throughout the year, see figure 3.3.

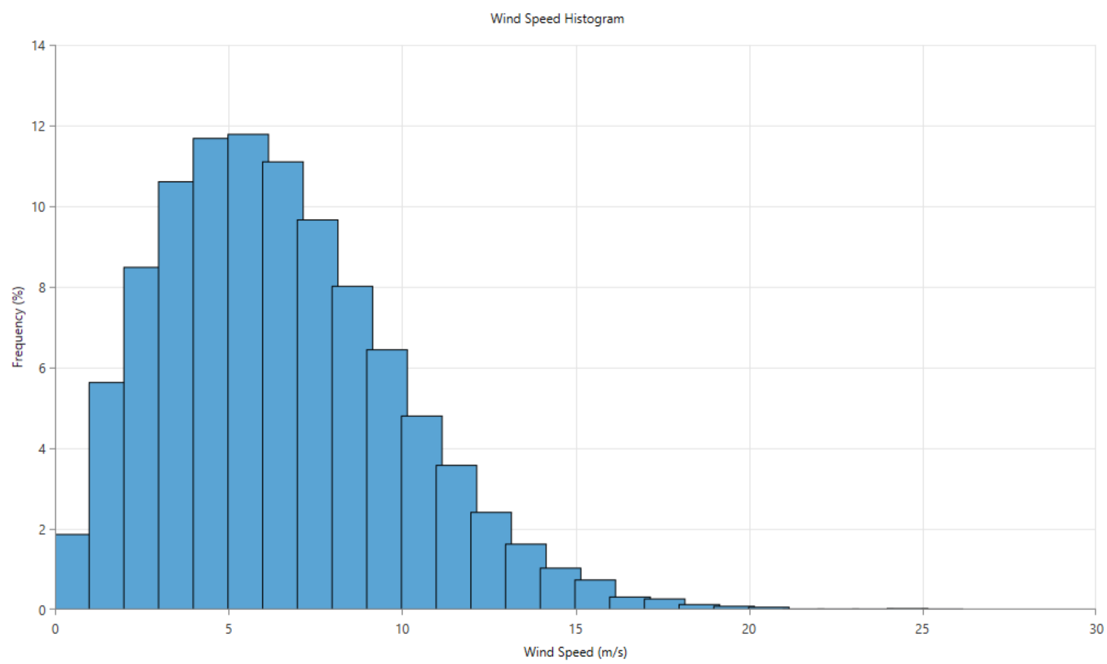

Figure 3.3: Weibull distribution of Windspeed vs frequency

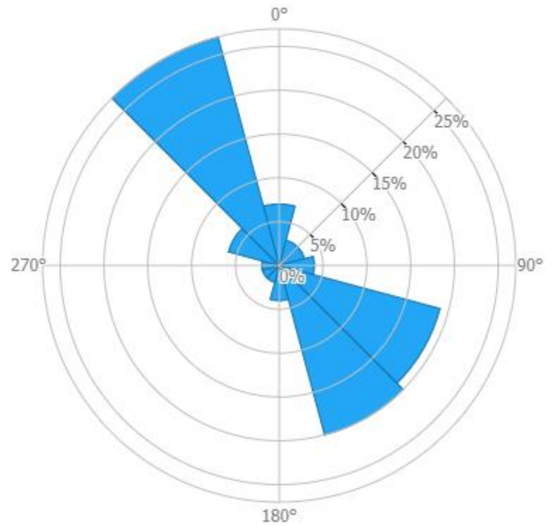

Figure 3.4: Wind direction Frequency Rose

From figure 3.4, we can see that the wind direction is more towards the north-west and the south-east, which is due to the locality of the Iqaluit city as it is to the north of the Frobisher Bay. So, both simulators HOMER and RETScreen have the same weather data input from the NASA meteorological satellites which is being used for the simulations in this study.

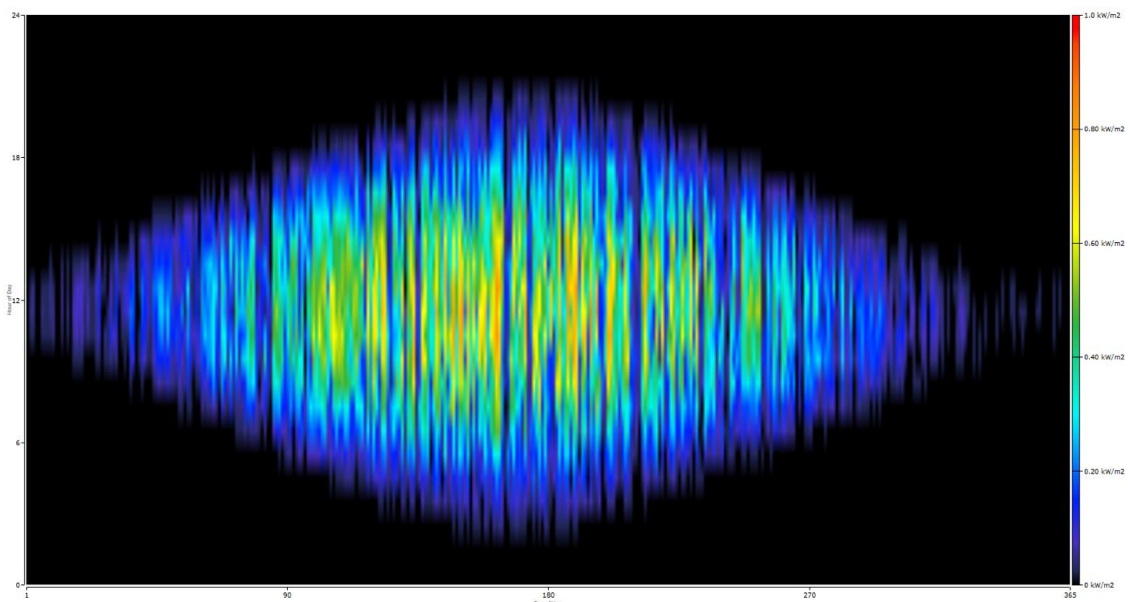

Figure 3.5: Iqaluit Yearly Solar GHI Profile DMap

In figure 3.5, a Data Map (DMap) is plotted which shows the annual solar GHI with days plotted on the x-axis while the hours throughout the day on the y-axis. The darker colors show a lower or unavailability of Solar Irradiance while a brighter color shows a higher GHI value based on the color legend with kW/m2 values plotted on the right of the DMap. We can see that the Global Horizontal Solar irradiance (GHI) in Iqaluit is around 400 W/m2 to 600 W/m2, which is a good amount of GHI to generate around 80-85% of power output from a 21% efficiency PV panel. While the GHI from the DMap we can see that solar irradiance is abundantly available in summer but it's almost around 100 W/m2 in winter which significantly reduces the efficiency of a Solar power plant.

3.2.3 Installation Site

The wind turbines in any project are usually placed not far from the city due to reasons such as its economical if its closer to the local grid. It would have short lengths of access roads and transmission lines. It is also easier to find the workforces in the nearby community for the installation, operations, and maintenance of the wind turbine power plant. While all these reasons are compelling for the selection of a site near the community but due to presence of the local airport it is always advised to keep a measured safe distance for the wind turbines to not interfere with the navigation aid equipment at the airport. Based on the information obtained from the local airport for the wind assessment by J.P Pinard Consulting [18], it is advised to have at least 4km of a safe distance where the allowed height of the turbine hub was estimated to be ~66m if the wind turbines were to be placed in under 4km of a radius of the airport.

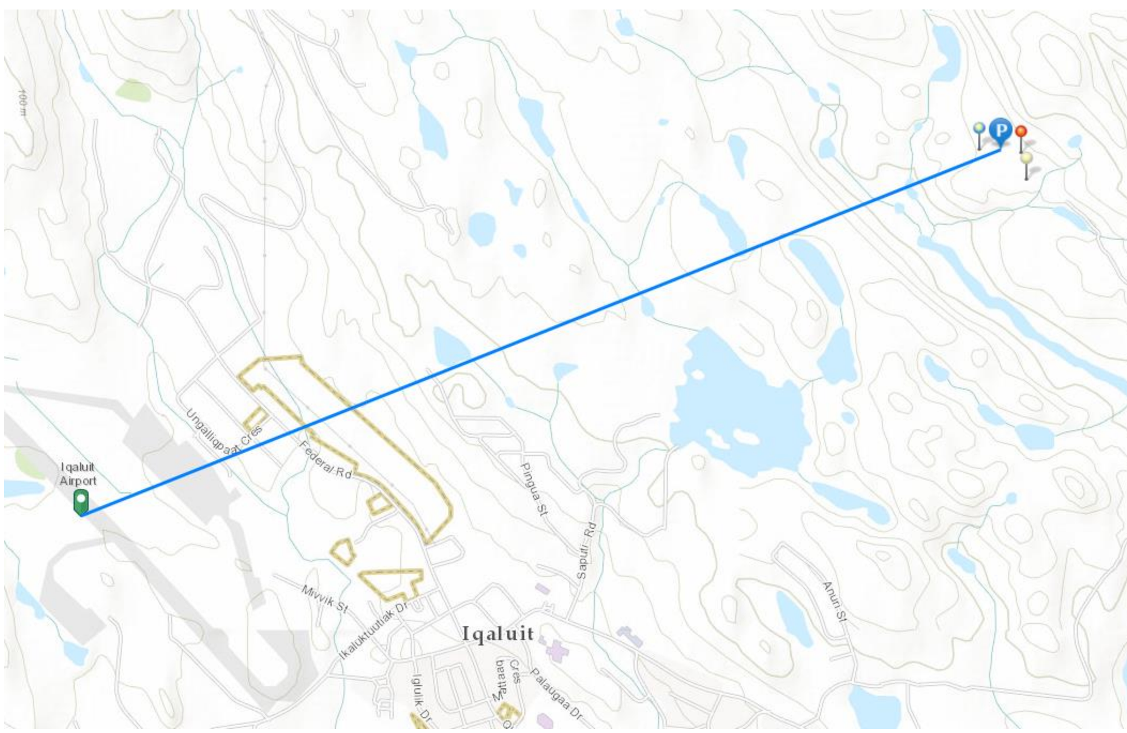

Figure 3.6: WTG location and distance from the airport

From figure 3.6, The site selection process for wind turbines took into consideration the height from sea level, access to the community, accessible transportation route for the installation and the flora and fauna in the specific location.

The selected site is in the north-east of the Iqaluit community (63.767, -68.479) within reach of the locals with a total distance of around 4km as specified by a blue line from the airport. While there are no direct access roads to the wind turbines site an estimated 5km of access road will be constructed. To provide connectivity between the local power grid and the specified installation site.

The same location will be utilized for the solar PV power plant as there's not much flat ground space available near the Iqaluit power plant.

3.2.4 Local Grid infrastructure

From table 3.3, The local electric grid for Iqaluit community comprises of multiple diesel powered gensets only. A local distribution network is established to provide power to the community throughout the year. From the list of the available gensets it is evident that some of the gensets needs a replacement based on their engine lifecycle hours. Almost half of the gensets are installed before the year 2000 while only 2 gensets are new and of higher capacity of 5000kW each. While the QEC engineering department has put an application to replace the G4 genset with a new same capacity genset the remaining 2 genset (G1 and G2) are still expected to be operational. The total plant capacity is 22,600 kW based on gensets rating.

Unit	kW	Engine Hours	Year Installed	Engine Life Cycle
G3	2000	87175	1996	100000
G1	3000	119593	1993	120000
G4	3300	141806	1992	120000
G2	4300	150427	2000	120000
G7	5000	29933	2013	120000
G8	5000	32590	2013	120000

Table 3.3: Iqaluit Power Plant Genset Lineup

3.2.5 Fuel Price

The fuel prices are all-time high due to the recent pandemic and the current geopolitical situation which have limited the trade routes and thus increased the prices of all the commodities of daily life. Furthermore, the fuel prices are higher than usual for the northern communities based on the limited number and seasonal transportation options. Due to the extreme weather conditions fuel for the diesel gensets is transported in the summer when the transportation routes are open, and the fuel is then stored for the coming winter season as there is no available transportation method. The current consumer price index is all time high since January 1983 [22] at 7.7%. This includes the gas prices as well at a $2.28/L of diesel which for reference was $1.31/L in 2021. This indicates that the LCOE for Iqaluit increase as it is majorly dependent on diesel prices for its power generation. The QEC posted an official summary for the 2022/2023 general rate application

(GRA) for all the communities in Nunavut. A total of $51.5 million is proposed for the fuel costs as the fuel expense has increased over the years by $2.7 million year-over-year. The GRA proposes that a 5.1% increase in the unit price shall recover the shortfall. A 50% subsidy in unit price for first 700 units in the summer season and a 50% subsidy in unit price for the first 1000 units in the winter season keeps the unit price at around 58.56 ₵/kWh which will increase to 58.97 ₵/kWh based on the GRA 2023/2024. Keeping in view that the unit price in Nunavut is higher than any other territory due to the extensive dependency on diesel powered generators.

3.2.6 Carbon Emissions

The current genset lineup in Iqaluit power plant have a total of 22,600 kW capacity while the annual load demand is around diesel consumption of around ~59,000 MWh/yr [5]. Based on the fuel price from 2021 i.e., 1.31/L and the total fuel costs of $51.5 million which was proposed in the GRA 2023/2024 a total of around 16 million litres of diesel is being consumed each year which have a negative effect on the environment and the global temperature rise. According to the US-EPA a total of 2.68 tCO_2 per litre of diesel is being emitted which amounts to a total of ~43,000 tCO_2 annually, which can be offset by installing renewable energy sources like wind and solar.

3.2.7 Wind Turbine Generator

There is a variety of wind turbines ranging from 5kW to >3MW depending on the vendor and type of wind turbine. There are various turbine technologies available to better suit the needs of the project. As this project is in the Northern Canada region where extreme winter conditions are recorded so a normal day turbine will not a suitable choice. Based on the location and weather conditions a 75m hub height, gearless and variable speed wind turbine is selected. The blades of the wind turbine are fabricated from Glass Reinforced Plastic GRP epoxy resin, which is a type of fibre glass that have a more flexible characteristic rather than being rigid. It can come with a fitting of electric heating element for de-icing, which is a potential requirement for a wind turbine in temperatures like -38^{o}C or lower which can cause ice to accumulate on the turbine blades. It is necessary as the wind turbines have a nameplate lifetime of 20-25 years. The icing of the blades increases the drag on the pressure side of the blade and decreased the lift of the blades which can cause the turbine to halt [23].

From figure 3.7, it can be observed that the cut-off for this specific wind turbine is 3m/s and the generation stabilizes at 15m/s. The energy generation can go up to 2,300 kWh in peak wind speeds, but the penetration of wind energy is set in the design to a maximum of 33% which doesn’t affect the grid stabilization requirement as well. Higher penetration levels can be achieved by using a storage system with a converter to provide a stable power output from the wind turbines.

Wind speed m/s	Power curve data kW	Energy curve data MWh
0	0	
1	0	
2	2	
3	18	442
4	56	1,178
5	127	2,351
6	240	3,855
7	400	5,504
8	626	7,136
9	892	8,651
10	1,223	9,998
11	1,590	11,154
12	1,900	12,107
13	2,080	12,854
14	2,230	13,401
15	2,300	13,761
16	2,310	
17	2,310	
18	2,310	
19	2,310	
20	2,310	
21	2,310	
22	2,310	
23	2,310	
24	2,310	
25	2,310	
26	2,310	
27	2,310	
28	2,310	
29	2,310	
30	2,310	

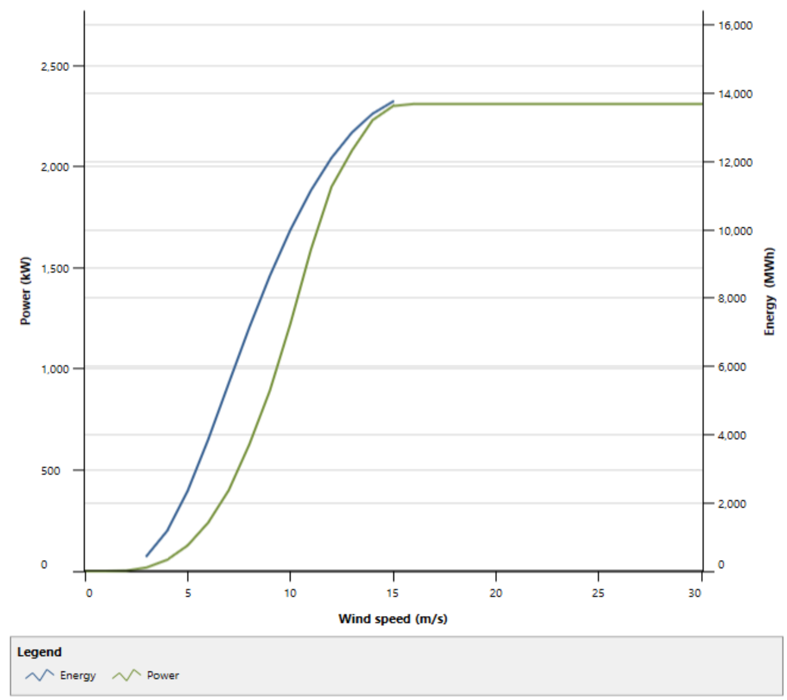

Figure 3.7: Wind Turbine Efficiency Curve

3.2.8 Solar PV Panel

The recent advancements in the Solar cell technology offers an efficiency of around 20.9% of commercially available PV Panels with a nameplate rating of bifacial 650 Wattage, with Mono-crystalline half cut cells to fully utilize the panel area and increase the aperture area of the panel. In figure 3.8, the I-V curve shows that the PV panel amperage will decrease significantly based on the decrease in the GHI and the voltage will be affected based on the temperature. An operating temperature of -25^{o}C to +40^{o}C with a temperature coefficient value of -0.34 % / °C in Pmax is provided, which will significantly reduce the power output at around 3.4% per 10^{o}C drop in temperature below the operating temperature.

These panels can be used with a fixed, single, or dual-axis tilt mounting frame to increase to fully utilize the sun hours in that region. Due to the extreme weather conditions the PV panels will require a significant amount of maintenance effort as the ice will accumulate over time and the active methods for de-icing of the PV panels are not that effective. A Solar PV plant of size in MWs usually requires a tractor with a plow to remove the snow usually daily in a winter weather condition like in Iqaluit. Also, the Solar PV Panel depends on the sun hours and a clear weather throughout the day.

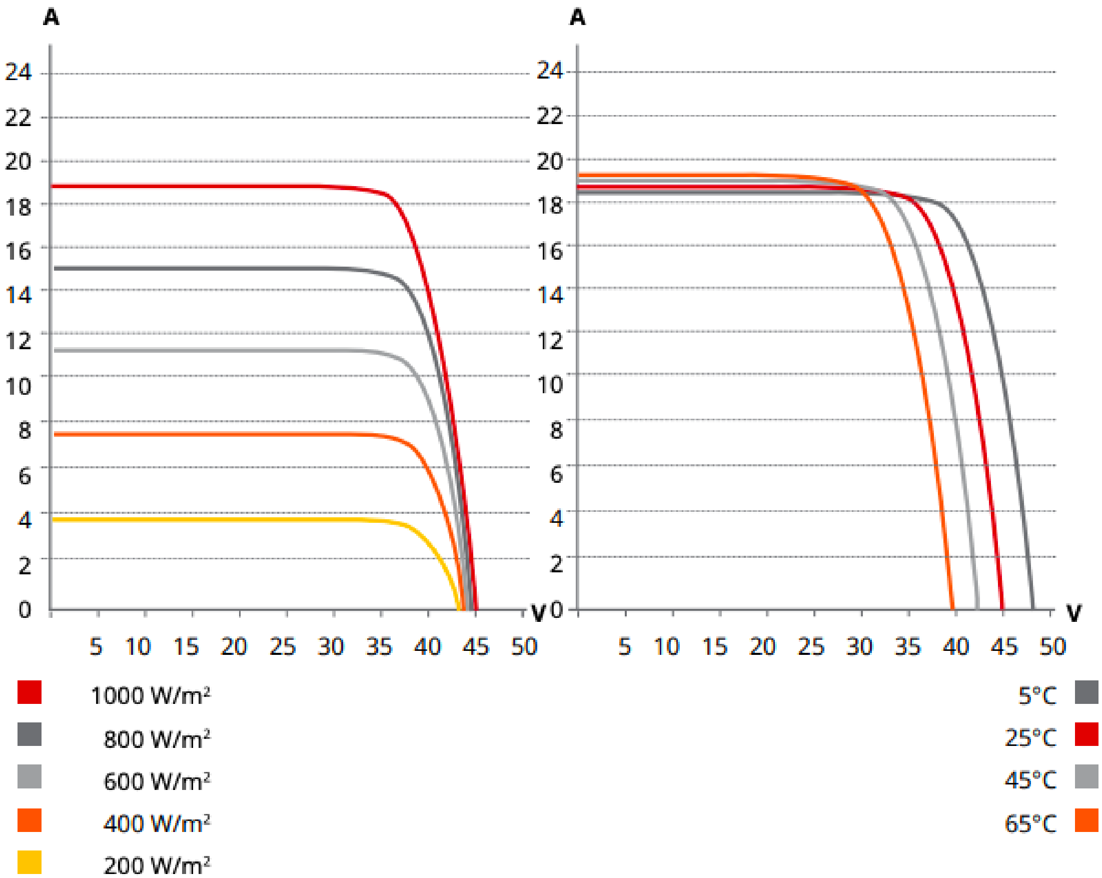

Figure 3.8: Solar PV Module I-V Curve

3.2.9 Equipment Transportation and Costs

The economics of the project requires the detailed costing for each system design which shall have the costing details for the following items:

a. Costs of the feasibility study for the concept design of the wind power plant.
b. Development costs for the detailed work based on the feasibility study.
c. Engineering costs for designing the construction and tender documents of the proposed wind power plant.
d. Costs for the estimated equipment based on the tender documents, which includes:
a. Wind turbines.
b. Solar PV Panels and Inverters.
c. Access roads.
d. Transmission lines.
e. Substation.
f. Site and Crane Pad Construction.
g. Utility Interconnection.
h. Spare parts.
e. Installation costs of the equipment.
f. Transportation costs.

g. Training and commissioning costs.
h. Project management costs.
i. Material Testing costs.

Such a detail cost analysis is always based on the material supply and installation quotations from several vendors, which was out of scope of this project. So, the costs of the designed system are based on a previous study in 2016 by J.P Pinard Consulting [18]. The Canadian dollar depreciation rate is considered and further applied to evaluate a project cost per item for installation in 2022. Where the Canadian dollar with a conversion rate of CAD$ 1.25 equivalent to USD$ 1.00 in 2016 is evaluated at CAD$ 1.29 against USD$ 1.00. This evaluation increased the overall prices by 3.1%.

3.2.10 Financial Parameters

The financial parameters include the fuel cost escalation rate, inflation rate, discount rate, project life cycle. While the Consumer Price Index (CPI) is around 7.7% for the current year and it's been increasing at a rate of 1.4% since May 2022. Based on this the price for diesel have been increasing, which is taken as CAD$ 2.28/litre for the simulation.

There are several key indicators that can tell us if the designed project is financially and technically viable over its lifetime. In this simulation we will consider the Internal Rate of Return (IRR), which calculates the rate at which the Net Present Value (NPV) of the project is equal to zero meaning at which rate the project will pay off its capital. From previous case studies the viable IRR is >5%. While a higher Return on Investment ROI is preferred over other designs as it will generate a positive cash flow after paying of its debt. Finally, the Levelized Cost of Electricity (LCOE) which is essentially the unit rate per kWh produced, a LCOE lower than 58.97 ₵/kWh is preferred as this is the QEC GRA rate for the upcoming fiscal year.

Based on these parameters the hybrid wind and diesel genset power plant will be designed to provide a viable solution for the next 25 years. While a Solar PV and genset hybrid system of the same size will be designed for a comparative analysis.

3.3 System Design

The proposed renewable systems involve a hybrid wind and genset power plant which will be designed in HOMER and RETScreen while the hybrid solar PV and genset power plant will be designed in HOMER only with the base system as existing gensets only with only the 3300kW genset to be replaced.

3.3.1 Hybrid Wind and Diesel Genset Power Plant

The hybrid wind and genset system shall be designed in HOMER with set parameters. The same system shall also be designed in RETScreen while keeping the losses and design parameters the same. Only the output of the simulation will be different based on the same input design parameters.

3.3.1.1 System Architecture

The system design parameters are based on the information provided earlier in this chapter. Furthermore, the system architecture (see figure 3.9) is defined below:

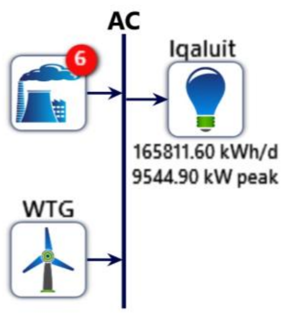

Figure 3.9: Hybrid Wind and Diesel Genset Power Plant Architecture

From table 3.4, there are 6 diesel generators of different sizes ranging from 2000KW to 5000KW. While a maximum of 3 number of wind turbines of 2.3MW each are used to keep the project capital cost low and provide a nominal renewable penetration at around 30% or below to keep the electric grid stabilized without a battery backup system.

Component	Name	Size	Unit
Generator #1	Genset (2000KW)	2,000	kW
Generator #2	Genset (5000KW)	4,000	kW
Generator #3	Genset (5000KW)	5,000	kW
Generator #4	Genset (3000KW)	3,000	kW
Generator #5	Genset (3300KW)	3,300	kW
Generator #6	Genset (4300KW)	4,300	kW
Wind turbine	Enercon E-70 [2.3MW]	3	ea.

Table 3.4: Hybrid Wind and Diesel Genset Power Plant Summary

3.3.1.2 Diesel Generator Parameters

From table 3.5, the diesel gensets have different capacities and hence different fuel requirement for the industry standard loading of 100%, 75% and 50%. The fuel type for all the generators is Diesel (#2 oil) as it is widely used in the industry for such size gensets. The information from QEC for the gensets didn't provide a detailed fuel consumption chart for each generator. So, a relevant size and specification model was selected from several manufacturers to create an average fuel consumption chart for each genset, as shown in table 2. HOMER creates a slope intercept for the fuel consumption of a genset based on the standard loading consumption values, so the variable loading operation can accurately correlate with the fuel usage. Also, there is no maintenance downtime or scheduled operating time defined for the simulation. The available loading capacity is estimated to be around 70% to avoid any mechanical fatigue and account for the performance losses as well. While the operating cost for the genset is calculated based on the annual estimated fuel consumption for the genset and then taking a nominal maintenance and operating cost of 3% for the year based on that value which is further divided by the hours of operation for the year.

Name	Capacity (KW)	Capacity Available (%)	Fuel Req. at full capacity (litre)	Fuel Req. at 75% Capacity (litre)	Fuel Req. at 50% Capacity (litre)	O&M Cost ($/hr)	Life Cycle (hrs)
G3	2000	70	541	402	280	5.71	100000
G7	5000	70	845	597	410	14.27	120000
G8	5000	70	845	597	410	14.27	120000
G1	3000	70	640	448	313	8.56	120000
G4	3300	70	660	462	323	9.42	120000
G2	4300	70	720	504	352	12.27	120000

Table 3.5: Genset Parameters

3.3.1.3 Wind Turbine Parameters

The selected wind turbine has a 75m hub height, 71m rotor diameter, swept area of 3,959m2 and a total of 3 blades. The total losses factor amounts to 20% with a breakdown given below:

RETScreen	HOMER	Loss Value
Availability	Availability	5%
Array Losses	Environmental	4
	Wake Effects	2.9
Airfoil	Turbine Performance	4
Miscellaneous	Electrical	3
	Curtailment	3

Table 3.6: Wind Turbine Losses

In RETScreen the losses are all summed while in HOMER the losses are combined multiplicatively. The losses factors are based on the equipment manufacturer provided information, weather data and wind direction, see table 3.6. Also based on previous research studies and wind assessments for the cold climate conditions. The wind turbine availability is 95% throughout its lifetime while the array losses which includes the effects of multiple wind turbines on each other as one turbine close to the other might disturb the wind distribution which have a negative impact in performance called the wake effect. The airfoil losses include the impact of icing on the wind turbine as ice accumulation can decrease the radial velocity of the blades. Finally, the electrical and curtailment losses include the I^2R losses in the electric cables and further conversion losses to maintain desired synchronized grid frequency.

3.3.1.4 System Cost

The cost of this proposed system is based on the breakdown and exchange rates as discussed earlier.

	Item description	**Unit**	**Qty**	**Amount**	**Total**
1	Wind assessment and engineers report	Ea.	1	$ 1,236,000	$ 1,236,000
2	Permits	Ea.	1	$ 206,000	$ 206,000
3	Wind Turbine with all necessary equipment	Ea.	3	$ 4,789,853	$ 14,369,558
4	Access Roads	Ea.	5	$ 1,127,403	$ 5,637,015
5	Transmission Lines	Ea.	8	$ 453,643	$ 3,629,144
6	Substation	Ea.	1	$ 1,031,007	$ 1,031,007
8	Utility Interconnection	Ea.	1	$ 1,031,008	$ 1,031,008
9	Installation	Ea.	1	$ 2,355,852	$ 2,355,852
10	Transportation	Ea.	1	$ 618,604	$ 618,604
				Sub total	**$ 30,114,188**
			Contingency	10%	$ 3,011,419
11	Training and commissioning	Ea.	1	$ 515,504	$ 515,504
12	Project management	Ea.	1	$ 869,399	$ 869,399
				Total	**$ 34,510,510**

Table 3.7: Wind Turbine System Capital Cost Summary

From table 3.7, we can see that 3 number of wind turbine are being considered for the RETScreen model with a total of 6.9MW capacity. While an access road of 5km is required from the project site to the QEC power plant. The transmission lines both overhead and underground are considered, where overhead is from the wind turbine power plant to the QEC power plant and the underground lines will be between wind turbines which comes to a total of 8 km, as each turbine is almost 1km away from each other and a 5km to the QEC power plant. The substation will be required to provide for the monitoring and control of the wind turbine power plant, where the staff will look after the generation performance and maintenance works.

The QEC provided team will be interconnecting the wind power plant to the QEC power plant with the help of the contractor hired for works. A contingency reserve of 10% is required for a project with such high risk as the contractor will not be able to provide a replacement for equipment on urgent basis keeping in view the location and transportation routes for the project. There is only one genset to be procured and installed i.e., genset with a capacity of 3300 KW for a capital cost of CAD$ 8.4 while the existing equipment will be used. A replacement cost of all the generators is calculated based on the cost for generator replacement provided by QEC in its application [5]. A per MW cost is estimated to be CAD$ 2,550.

3.3.1.5 Constraints

The Wind energy penetration in the design is kept at 30% as HOMER gave a grid instability warning above this level of wind penetration. So only a 30% power supply will be from the wind turbines in terms of the total power generation. This will be achieved by reducing the speed of the wind turbine to produce less power or by adding a battery backup system which will significantly increase the initial capital of the project further increasing the LCOE and IRR than the required value.

3.3.1.6 Results

The HOMER simulator evaluated this proposed system based on its iterative method for all constraints and a combination of different genset output with different fuel consumption and wind turbine output and the best possible combination resulted with a 10.1% IRR while a payback period of 9.53 years and an LCOE of 37.7 ₵/kWh. The payback period is calculated by dividing the total capital of the system ($) by the annualized energy units generated (kWh/yr) to get the number of years for the installed system to return the initial capital. While the LCOE ($/kWh) is calculated using the equation 3-1:

$$LCOE = \frac{C_{ann,tot}}{E_{served}}$$

Equation 3-1: Levelized Cost of Electricity

Where,
$C_{ann,tot}$ = total annualized cost of the system ($/yr)
E_{served} = total electrical load served (kWh/yr)

A total capital of CAD$ 42.9 million is needed for its design, procurement, installation, and commissioning.

While the RETScreen model have an NPC of CAD$ -781 million with a negative IRR and a LCOE of 1.65 $/kWh. This is due to the reason that it predicted the annual fuel costs to be CAD$ 56.9 million with no salvage return as well. From table 3.8, A total of CAD$ 53.1 million is needed for its operations for 25 years with a Net Present Cost (NPC) of CAD$ 928 million. Throughout this period multiple genset will be replaced as they complete their lifecycle and further give a salvage value is calculated for the gensets using equation 3-2 a total of CAD$ 65.7 million salvage value is estimated which is subtracted from the total NPC. While a total of CAD$ 805 million has been used for fuel.

$$S = C_{rep} \times \frac{R_{rem}}{R_{comp}}$$

Equation 3-2: Salvage Value of Component

$$R_{rem} = R_{comp} - (R_{proj} - R_{rep})$$

Equation 3-3: Remaining Lifetime of Component

$$R_{rep} = R_{comp} \times \left(\frac{R_{proj}}{R_{comp}}\right)$$

Equation 3-4: Replacement Lifetime of Component

Where,
S – is the salvage value
C_{rep} – replacement Cost
R_{comp} – Component lifetime
R_{proj} – Project lifetime
R_{rem} – Remaining lifetime of the Component at the end of the project

In table 3.9, a breakdown of the total generation from each unit over 25 years is given where the 5MW genset have the highest production of 15.35 GWh/yr with a total share of 22.6% among all the gensets while 2MW genset has been barely used. While the wind turbines have a total production of 18 GWh/yr with a total share of 26.6% which is below the 30% penetration limit. The wind turbines have a mean output of 2MW with a rated capacity of 6.9MW and a capacity factor of 29.9%. A total fuel consumption was around 8.68 million litres with an average daily consumption of 23,795 L/day. While a total of 22.7 $MtCO_2$/yr was produced.

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Enercon E-70 [2.3MW]	$34.5M	$35.1M	$0.00	$0.00	$0.00	$69.6M
Genset (2000KW)	$0.00	$121,152	$0.00	-$10.6M	$12.1M	$1.62M
Genset (3000KW)	$0.00	$2.64M	$13.3M	-$7.64M	$99.2M	$107M
Genset (3300KW)	$8.42M	$2.94M	$14.5M	-$8.06M	$103M	$121M
Genset (4300KW)	$0.00	$4.37M	$17.7M	-$4.60M	$129M	$146M
Genset (5000KW)	$0.00	$3.60M	$25.0M	-$21.6M	$206M	$213M
Genset (5000KW)	$0.00	$4.37M	$22.3M	-$13.2M	$256M	$269M
System	**$42.9M**	**$53.1M**	**$92.8M**	**-$65.7M**	**$805M**	**$928M**

Table 3.8: Breakdown of Net Present Cost of Hybrid Wind and Genset Power Plant

Component	Production (kWh/yr)	Percent
Genset (2000KW)	417,600	0.614
Genset (5000KW)	12,733,022	18.7
Genset (5000KW)	15,353,599	22.6
Genset (3000KW)	5,700,000	8.38
Genset (3300KW)	6,337,650	9.31
Genset (4300KW)	9,417,000	13.8
Enercon E-70 [2.3MW]	18,098,957	26.6
Total	68,057,828	100

Table 3.9: Production Summary of Hybrid Wind and Genset Power Plant

From figure 3.10, we can see the diesel consumption of all the gensets is averaged monthly. Where the consumption is lower in the summer season, decreasing from April until September. While in winter the consumption is the highest with a peak at 1700 L/hr. This is due to the wind energy penetration. As in summer the wind speed is higher which favors the wind turbines rather than the icy winter weather.

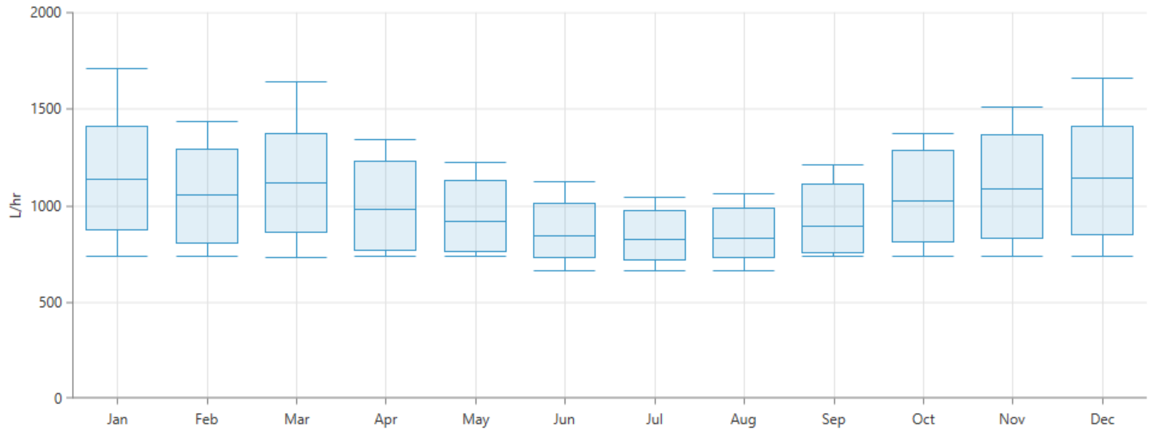

Figure 3.10: Monthly Average Diesel Consumption

3.3.2 Hybrid Solar PV and Diesel Genset Power Plant

The hybrid solar PV and genset system shall be designed in HOMER with set parameters.

3.3.2.1 System Architecture

This proposed system has the same genset configuration but instead of wind turbines it has a Flat Plate Solar PV modules with inverters, see figure 3.11. From table 3.10, a total of 7MW solar PV panels are used with a 2.3MW solar converter with the current diesel generators lineup.

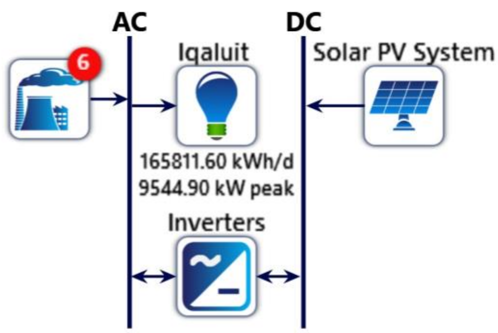

Figure 3.11: Hybrid Solar PV and Diesel Genset Power Plant Architecture

Component	Name	Size	Unit
Generator #1	Genset (2000KW)	1,000	kW
Generator #2	Genset (5000KW)	5,000	kW
Generator #3	Genset (5000KW)	5,000	kW
Generator #4	Genset (3000KW)	3,000	kW
Generator #5	Genset (3300KW)	3,300	kW
Generator #6	Genset (4300KW)	4,300	kW
PV	CS7N-650MB	7,000	kW
Inverter	Inverter	2,333	kW

Table 3.10: System Architecture of Hybrid Solar PV and Genset Power Plant

3.3.2.2 Solar PV and Inverter Parameters

A total of 7MW of Solar PV modules with the highest efficiency of 20.9% and a rated nameplate wattage of 650Watt were used for this simulation. A derating factor of 80% for 25 years has been used which is the manufacturer required value. A temperature coefficient of -0.34%/^{o}C with a nominal operating temperature of -25^{o}C to +40^{o}C. Fixed tilt mounting was considered and an >98% efficiency multiple MPPT Grid-Tied inverters are used.

3.3.2.3 System Cost

The cost of a per kW of Solar PV is estimated to be CAD$ 2,000/kW from multiple case studies, which includes the engineering, procurement, installation, and commissioning costs [12]. A project specific cost is only available through a quote from a vendor and a contractor for a complete system installation which was out of the scope of this project. So, the cost per kW is estimated by dividing the total cost of the Kugluktuk solar PV project estimated CAD$ 2,500/kW has been assumed which includes the complete cost of engineering till commissioning with an added cost of transportation to Iqaluit from Quebec and a contingency of 10% as well.

3.3.2.4 Constraints

This system has the same constraint of 30% renewable penetration in the overall system power production. While no battery backup system is added as this system is grid-tied.

3.3.2.5 Results

The total NPC for this proposed Solar PV system is CAD$ 1.04B with an IRR of 2.3% and a payback period of 13.5 years while the LCOE is 42.4 ₵/kWh.

From table 3.11, a total capital of CAD$ 36.9 million is needed for this project. An operating cost of CAD$ 53.5 million is required over the course of 25 years while multiple gensets will be replaced and the converter will be replaced as well. The fuel resources will be around CAD$ 920 million for all the gensets with a salvage return of CAD$ 61.3 million.

Name	Capital	Operating	Replacement	Salvage	Resource	Total
CS7N-650MB	$27.3M	$33.3M	$0.00	$0.00	$0.00	$60.6M
Generic large, free converter	$1.17M	$1.42M	$2.35M	-$2.10M	$0.00	$2.84M
Genset (2000KW)	$0.00	$230,235	$0.00	-$9.19M	$11.5M	$2.56M
Genset (3000KW)	$0.00	$2.29M	$14.5M	-$11.6M	$85.7M	$90.9M
Genset (3300KW)	$8.42M	$3.11M	$14.1M	-$6.22M	$109M	$129M
Genset (4300KW)	$0.00	$4.16M	$18.1M	-$6.91M	$122M	$138M
Genset (5000KW)	$0.00	$5.08M	$20.6M	-$5.35M	$375M	$395M
Genset (5000KW)	$0.00	$3.75M	$24.4M	-$19.9M	$216M	$225M
System	$36.9M	$53.3M	$94.0M	-$61.3M	$920M	$1.04B

Table 3.11: Breakdown of Net Present Cost of Hybrid Solar PV & Genset Power Plant

Component	Production (kWh/yr)	Percent
CS7N-650MB	6,826,219	10.7
Genset (2000KW)	396,800	0.619
Genset (5000KW)	23,315,074	36.4
Genset (5000KW)	12,940,000	20.2
Genset (3000KW)	4,926,000	7.69
Genset (3300KW)	6,698,175	10.5
Genset (4300KW)	8,963,350	14.0
Total	64,065,618	100

Table 3.12: Production Summary of Hybrid Solar PV and Genset Power Plant

From table 3.12, we can see that the genset with 5MW capacity has the highest production of 36.4% with a total of 23.3 GWh/yr while a 10.7% Solar PV penetration is estimated with a total of 6.8 GWh/yr. The Solar PV system has a mean power output of 779 kW with a daily mean output of 18.7 MWh/day. A total of 9.92 million litres of diesel will be consumed throughout 25 years which amounts to a total of 25.9 MtCO_2/yr.

3.4 Comparative Analysis

From Table 3.13, it is evident that based on the capital cost the genset only system is more feasible as it is almost 80% less in capital cost than the hybrid wind and genset system and around 77% less than the hybrid solar PV and genset system. But the NPC of the systems suggest that hybrid wind system is around 15% less in cost than the base system and hybrid solar PV system throughout its system lifecycle.

While the Operational costs (OPEX) for the hybrid wind and genset system is 19% less in cost than the base system, while the hybrid solar PV system is only 8% less than the base system. That is due to the maintenance cost of gensets while the wind penetration is almost three times more than the solar PV system which increases the load on the gensets in the hybrid solar PV and genset system thus increasing the OPEX.

The LCOE is the resultant of CAPEX, OPEX and the annual power generation which gives a better overview of which system is better in the long term. The LCOE for hybrid wind and genset system is only 37.7 ₵/kWh which is almost 36% less than the base system and 11% less than hybrid solar PV system.

Furthermore, the CO_2 emissions are based on the usage of the gensets where the hybrid solar PV and genset system have lower solar PV penetration which resulted in higher usage of the gensets thus the CO_2 emissions are higher for that proposed system while for hybrid wind and genset system is around 21% lower than the base system.

	Base System (Genset Only)	Proposed System (Wind and Genset)	Proposed System (Solar PV and Genset)
Net Present Cost	$ 1,090,000,000	$ 28,000,000	$ 1,040,000,000
CAPEX	$ 8,420,000	$ 42,900,000	$ 36,900,000
OPEX	$ 26,900,000	$ 21,800,000	$ 24,800,000
LCOE (per kWh)	$ 0.585	$ 0.377	$ 0.424
CO2 Emitted (kg/yr)	28,869,570	22,732,950	25,980,160
Fuel Consumption (L/yr)	11,034,010	8,684,998	9,926,495

Table 3.13: Simulation Results for all Systems

Chapter 4. Conclusion

4.1 Conclusion

In this study, a hybrid wind and genset power plant was designed based on the weather data from multiple resources including local airports, CWEEDS, and NASA meteorological satellite. Load data was synthesized from Yukon load data for Iqaluit based on its population and further adjusted and scaled using HOMER software. The system architecture included the existing gensets with 6.9MW wind capacity without a battery backup system.

A similar size hybrid solar PV power plant with existing gensets was designed with 7MW of solar PV panels, 2.3MW of converter and no battery backup system. A comparative analysis was further carried out between the wind and solar PV hybrid power plants which was then compared to the base system with existing genset only and a replacement of G4 genset which is already proposed by QEC.

The system design based on the input parameters for both the hybrid systems resulted in an LCOE lower than the base system LCOE with a reduced CO_2 emission and lower fuel consumption. The comparative analysis shows that the hybrid wind power plant will have three times more renewable penetration with a CAPEX of only CAD$ 42.9 million. This makes the wind with genset power plant more feasible in terms of installation, operation, maintenance, fuel consumption and CO_2 emissions. Thus, the study concludes that QEC should proceed with the hybrid wind power plant, which will have an IIR of 10.1% and a payback period of 9.5 years. Where the wind power plant will further generate free electricity for 15.5 years and will reduce the carbon footprint by 21%.

This project by QEC will be the first wind power plant of this scale in all the 25 communities in Nunavut. It will also play an important role in the future of energy and environment preservation in the region while significantly increasing the trust in the local government. As it has both an economical and environmental view for the future of these communities.

4.2 Recommendations and Future Work

There are a few important recommendations which will further enhance the local grid in Iqaluit, these are:

1. This project is scalable if the wind power penetration in the local grid is increased. The LCOE will be reduced based on the project CAPEX and OPEX.
2. The proposed hybrid power plant relies on a synthetic weather and load data, which might not fully reflect the practical installed system. QEC should gather wind data at higher altitudes and monitor the load data which will make the initial wind assessment study more reliable.
3. A sensitivity analysis of the project based on different capacities of Solar PV and Wind power plants will help in electricity price forecasting for increasing load conditions.

4. The increasing renewable power would require a battery backup system that will be used for grid stabilization. Newer technologies in battery systems include Supercapacitor battery banks for grids that includes a housing with cooling or heating system to keep a nominal operating temperature for the battery backup system. These batteries have charging cycles estimated to be more than 1 million as per manufacturer provided specifications [24]. Although the prices are currently high per kWh, but it will decrease in the future as the demand grows because many utilities around the world are favoring it among other battery technologies.

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