Technical University of Denmark
Centre of Arctic Technology

Wind Energy Feasibility Report
Qaqortoq, Greenland

Panagiotis Vouterakos
111334

Supervisors:
Kasper Jakobsen
&
Martin O.L.Hansen

December 2012

Contents

1 Introduction

The present feasibility report was conducted in the context of DTU's course 'Arctic Technology 11427' and its purpose is to assist the govenment of Greenland and Kujalleq Municipality in southern Greenland in the assessment of wind energy as a potential option for integration to the current energy system of Qaqortoq, and possible future replacement of diesel generated electrical energy.

1.1 Background

The study is based on wind data retreived by Qaqortoq heliport station and telecommunication station owned by Asiaq GLV and DMI respectively. Electricity consumption data from hydro plant and diesel generators were retrieved by Nukissiorfiit, and the incinerator data from Kujalleq Municipality. The Municipality also provided useful information on the city infrastructure and future plans.

1.2 Qaqortoq

Qaqortoq is the 4th largest town in Greenland and it is part of the Kujalleq municipality. It has population of aprox. 3,300 inhabitants [3] and is the main center of primary and secondary education in South Greenland including a school of commerce, a folk high school, and a basic vocational school. Qaqortoq has a seaport located at the southern part of town and a heliport for transportation. Qaqortoq's primary economic activities are fish and shrimp processing, tanning, fur production, ship maintenance and trading of goods with nearby towns. The primary sources of income though are fishing, educational and administrative services with most of its production exported to Denmark.

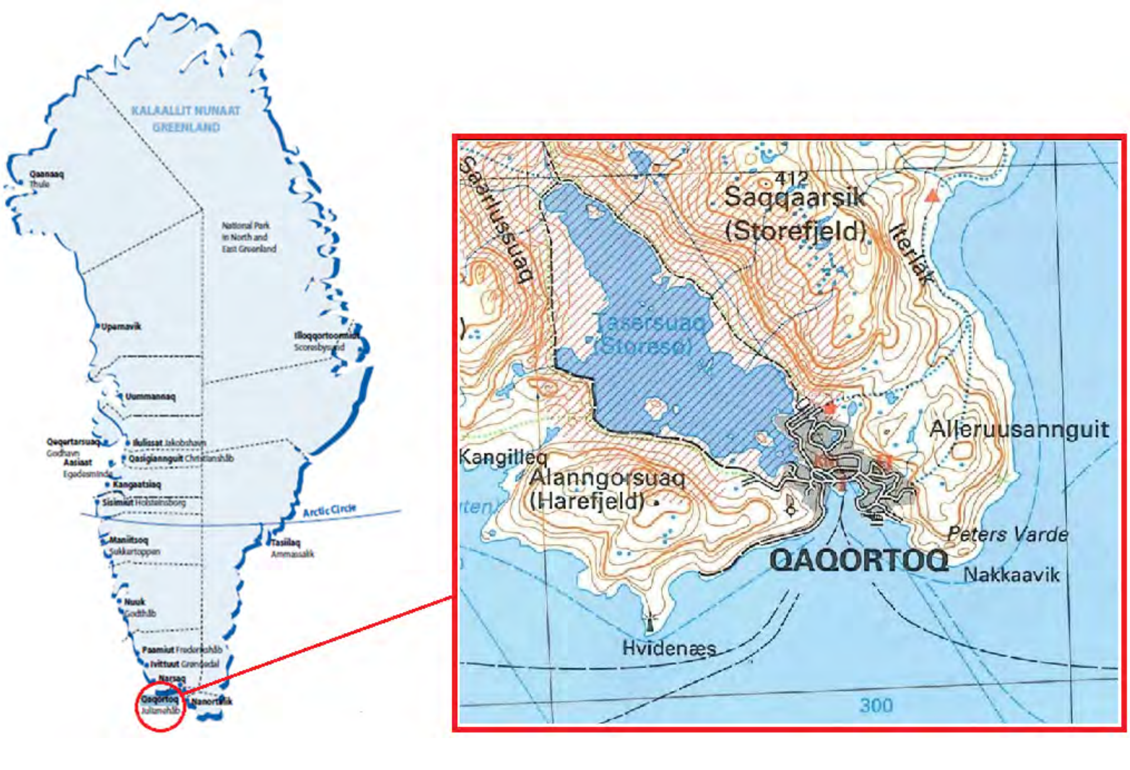

Figure 1: Map of Greenland and the location of Qaqortoq.

So far the main source of electricity comes from the hydro power plant which feeds both

Narsaq and Qaqortoq. However, it is common that the water level of the dam reaches the minimum level, creating the need to use the diesel generators to support the electrical grid at Qaqortoq. With the increasing growth of the population over the last few years, the demand for electricity has been increased. Additionally, an airport is planned to be built in the future, which will contribute to the demand for electricity. This broaches the topic of constructing a wind farm to compensate the energy needs of the population in Qaqartoq and also to reduce the cost of energy used.

1.3 Objective and scope of study

This feasibility report's scope and objectives are:

1. To analyse the data and estimate the mean wind speed and direction in the area.
2. Find potential sites to erect wind turbines
3. Analyse different case scenarios for wind turbine sitting location.
4. Description of the energy system.
5. Estimation of power production and fuel displacement through integration of wind energy.
6. Cost analysis which includes wind turbines, equipment, cranes, transportation, grid connection and
7. The feasibility study will also include a summary of the wind resource in Qaqortoq, IEC (International Electrotechnical Commission) classification of the chosen type wind turbine and assessment of the potential environmental impacts due to the wind turbines.

2 Wind Resource Assessment

A wind energy project is highly dependable on its economic revenue and thus when considering a wind farm development it is important to estimate the wind resource around the area of consideration. Several years of reliable wind data were available from 2 nearby met masts (meteorological masts) in Qaqortoq. Using 5 years of collected wind data (2006 to 2012) from a 10 meter cup anemometer meteorological mast from a heliport, a wind resource estimation and a feasibility study for wind energy in Qaqortoq is conducted.

As is the trend in wind energy industry, the software WAsP has been used to analyze and estimate the wind energy potential of the suggested wind farms. WAsP is a software program for predicting wind climates, wind resources and power productions from wind turbines and wind farms based on wind data measured at stations in the same region. The program includes a linear terrain flow model, a roughness change model and a model for sheltering obstacles.

2.1 Description of meteorological masts

As part of the visit/ fieldwork in Greenland, it was the physical inspection of the met masts. The two met masts consist of lattice masts with cylindrical booms, with the wind instruments placed at 10m height for DMI met mast and at 8m height for the Asiaq/GLV (at heliport) met mast. Wind vanes and anemometers are serviced every two years by changing their bearings and wind instruments are not calibrated according to IEC standards, therefore, the percentage of error in the data is unknown. Although the met masts appeared to be in good physical condition, it was noticed that many obstacles were around both DMI and Asiaq/GLV Qaqortoq met masts, which were simulated in WAsP. The met masts can be seen in the following figures where the relevant instruments have been highlighted.

Qaqortoq DMI met mast

Around the DMI met mast there is a 6m height satellite communication disk, a control room and a telecommunication mast, Fig. 2. Those obstacles confirm the wind distribution sudden fluctuations as seen in the wind roses and they were simulated in WAsP as blocks.

Figure 2: The10m meteorological mast next to Qaqortoq telecommunication base.

Qaqortoq heliport - Asiaq/GLV met mast

More specific, around the heliport met mast, Fig. 3, there is a helicopter warehouse, passenger waiting rooms and a block of buildings at north as seen in the panoramic picture in Fig. 20.

Figure 3: The 10m meteorological mast at Qaqortoq heliport.

A summary of errors in the set up of the met masts relevant with the quality of wind measurements were also observed during the vitit:

- Short booms of Qaqortoq helipad and Narsaq met masts can cause tower shadow effect, it is recommended to be over 3 mast side width for a lattice mast and over 6 mast diameters for a cylindrical mast.
- Other booms, such as the one in Qaqortoq Asiaq/GLV metmast, can create flow distortion.
- The actual place of each Qaqortoq met mast is very close to obstacles like buildings, other met masts, a satelite telecommunication disk that cause wind flow disturbance and turbulence.

All the above error factors have a significant influence on the wind measurements and on the net AEP (Annual Energy Production) of each site.

2.2 Observed wind climate

Wind data sets were collected from the 2 met masts in order to estimate the long term wind resource and AEP for the suggested sites [8]. An overview of the obtained data after quality inspection and validation can be seen in Table 1. Analysis of the wind data shows that the mean wind speed and direction at the Asiaq/GLV and DMI met mast is 2.97 m/s southwest and 4.37 m/s northwest respectively. However, as mentioned before the data are influenced by big obstacles around the met masts.A more detailed description of the wind resource and the Weibull distribution at the two met mast locations can be seen in figure 4.

Data set Qaqortoq	Frequency [minutes]	Elevation [m.a.s.l.]	Coordinates	Duration	Total span [years]	Recovery [%]
Asiaq/GLV (heliport)	10	18	N 60 42.941 W 46 01.880	1 Mar 2007 - 1 Mar 2012	6	93.78
Asiaq/GLV (heliport)	60		N 60 42.941 W 46 01.880	1 Jan 2004 - 31 Dec 2010	7	95.36
DMI (west)	60	32	N 60 42.928 W 46 02.617	1 Jan 2005 - 31 Dec 2010	6	99.87

Table 1: Wind data sets after review and validation.

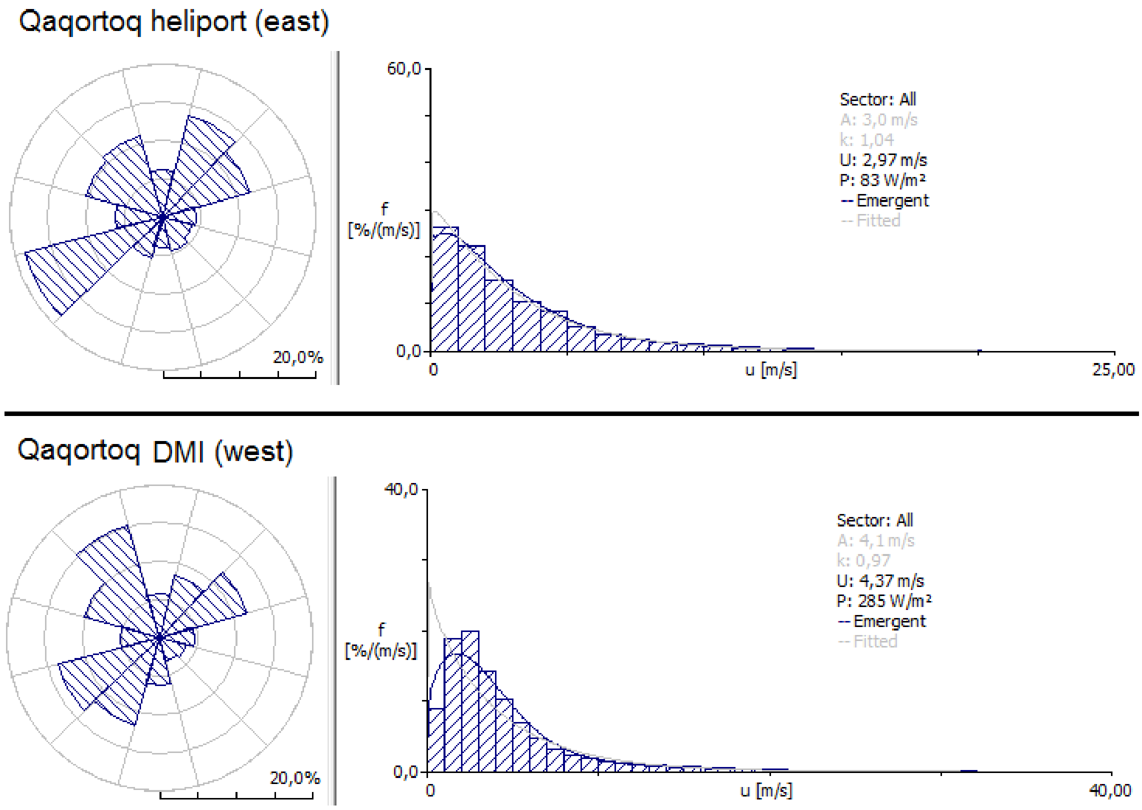

Figure 4: Wind rose and Weibull distribution at each met mast location.

2.3 Topographic inputs

A map of the area around Qaqortoq was created and imported to WAsP showing the elevation of the terrain and the roughness of the surface. The map covers an area of 25x38km^2 in order to include all the orographic variations and describe accuratelly the surface roughness at sufficient distance from the met masts, Fig. 5.

It was necessary to simulate all the buildings around both met masts in Qaqortoq as obstacles to further optimize the predicted wind climate. The terrain in the surrounding area of Qaqortoq is characterized by large open areas with some windbreaks mainly consisted of short bushes, grass and big rocks. As a rule of thumb, roughness changes at a distance of 100

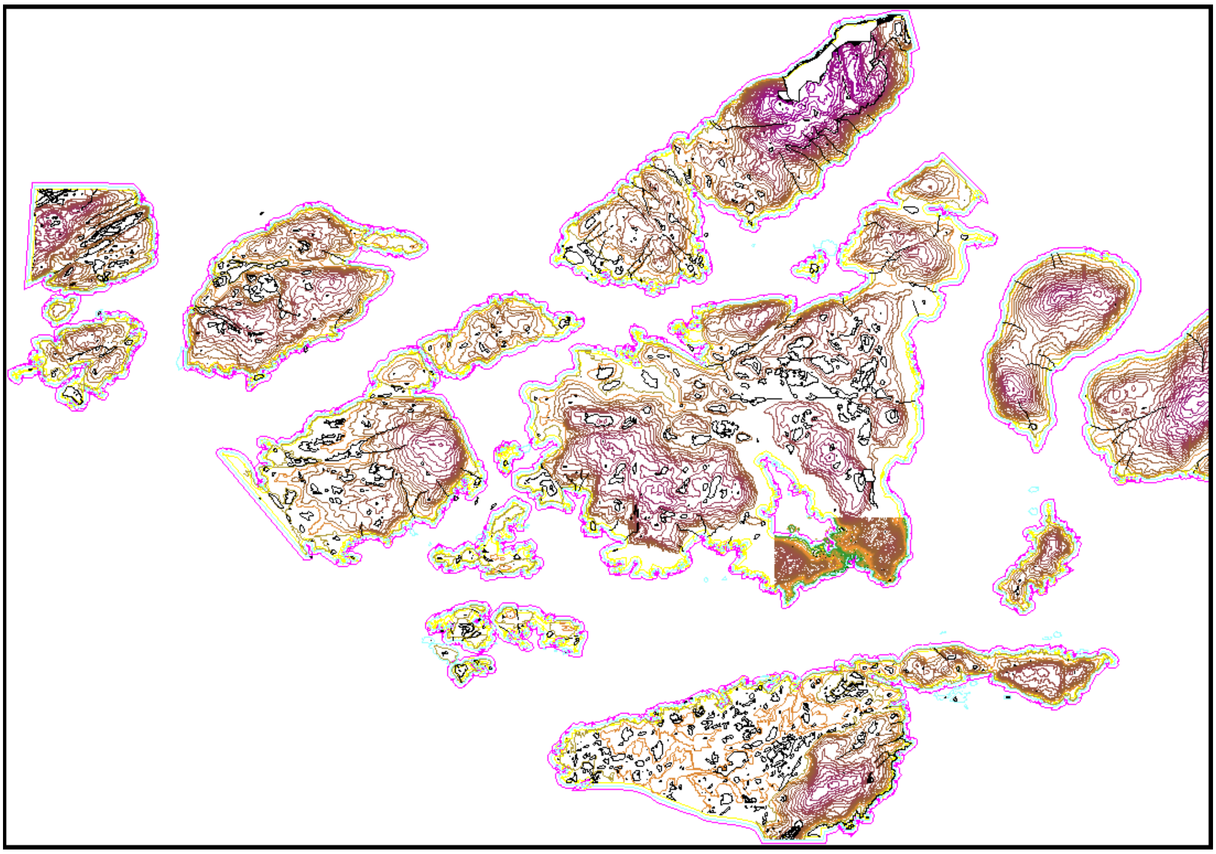

Figure 5: Roughness and orography vector map used in WAsP.

times the hub height of the wind turbine should be included in the map. In this report that the turbine hub height is 55m, an area of at least 5500km of well resolved information about roughness changes is required. This rule is based on the growth of the internal boundary layers. It is also important to mention that the snow cover in the area lasts for at least 5 months/year (November - March) [12] and therefore, it was necessary to import the mean annual roughness to WAsP. The roughness was set to 0.0245 in the farm lands, 0.25 in the city and 0.0001 for water, according to [7].

2.4 Uncertainties

It is important to note that the predicted wind climate calculated by WAsP is only an estimation and that there are many uncertainties associated with it. The most relevant of these is:

- **Air Density** While the actual air density of the site is expected to be around 1.263 kg/m3, the value of 1.225 kg/m3 has been used for WAsP calculations, as the turbines power curve was not available for this value. As higher air density corresponds to higher power density, this means that the AEP is underestimated.

- **Surface Roughness** As estimating the surface roughness of the terrain is one of the most uncertain aspects of WAsP calculations, a sensitivity analysis will determine the impact of this uncertainty.

- **Contour Map** As the surrounding landscape can be characterized as complex, it is expected that any discrepancies between the resolution of the digital map and reality are corrected manually by the RIX and the WAsP similarity principle. A complex site map can be corrected by introducing the Δ RIX (Deviation of Ruggedness IndeX), which is the difference in RIX between a predicted site and a reference site. However, a correlation between met masts and turbine sites could not be achieved, resulting to a very high uncertainty from this topic.

- **Anemometer Calibration** Incorrectly calibrated anemometers can result in a basis in the data. Since the two met masts used are 10m high and the anemometer is known for not being calibrated to IEC standards, it has been assumed that the quality of the predicted wind climate data series are the main source of uncertainties.

Although six full years were available with a high data recovery rate, the fact that the anemometer was only at 10 meters high means that the measurements are highly influenced by local terrain effects (large obstacles). Before pursuing this project further it is recommended to attempt to obtain more wind data from higher points in a new met mast.

2.5 WAsP limitations

The main limitations of the WAsP flow model are three:

1. The atmosphere must be stable, meaning that the prevailing wind conditions must be near-neutral,
2. Mesoscale effects must be zero,
3. Orography must be gentle enough to prevent flow separation.

The two meteorological masts that were taken into consideration record data at height of 10m. Each met mast was later set as a reference point and cross predicted with the other. This method is important for the adjustment of the value of the heat flux and atmospheric stability. The next limitation regarding mesoscale effects cannot be met due to the large topographical effects in the area. Finally, the orographic profile of the area RIX is calculated by WAsP and it is within acceptable limits (around 10%).

2.6 Predicted wind climate

Using the six year of wind data and the vector map, a wind atlas was then generated by WAsP, Fig 6. This resource grid map shows the power density of wind in the area and it has been used as one of the criteria to choose the exact site location of each wind farm. The wind farms are two, the south and the north, a description of each one can be found later on the report. The reason for selecting a particular type of wind turbine is also explained in the relevant section. The AEP of the wind farms is presented in the table 2.

2.7 Icing incidents

According to Nukissiorfiit testimonies, one incident has been recorded where the high voltage cable had to be replaced because of icing. Furthermore, for icing events to occur some indications must be fulfilled [13].

1. The average annual temperature must less than 0°C. In Qaqortoq it is 1,7°C according to the data.
2. Icing event occur or have been noticed.
3. Temperature is below -20°C (operation min for the selected wind turbine is -30°C) for 9 or more days/year for min of 1h/day [14].

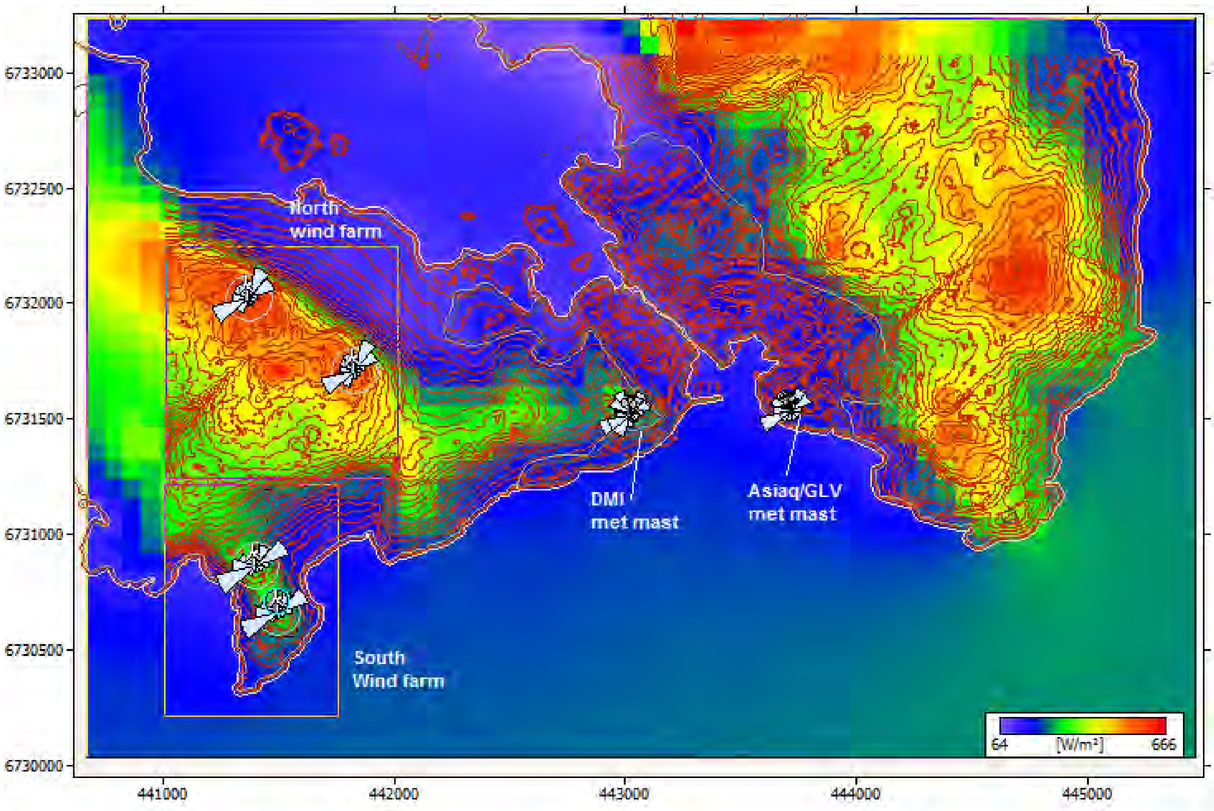

Figure 6: Power density resource grid.

Parameters	North wind farm	South wind farm
Net AEP $[GWh]$	8614	7074
Installed capacity $[MW]$	3.6	3.6
Type of turbine	Vestas V100-1.8	Vestas V100-1.8
Wake losses [%]	0.6	0.75
Full load hours	2393	1965
Capacity factor [%]	7.6	6.2

Table 2: AEP of the wind farms.

3 Environmental Impact Assessment

The purpose of an environmental impact assessment in the area of Qaqortoq is to identify and describe the influence that a wind farm project might have during the construction, operation and decommissioning phases on all affected parties in the area, such as human health, the environment, safety, local businesses, etc. The information contained within this section is courtesy of investigations carried out by NunaGIS.gl and based upon contacts from Kujalleq Municipality during the fieldwork phase in Qaqortoq on August 2012. According to the Kujalleq Municipality, every construction in Greenland must follow the Danish legislation. Therefore, before wind turbines can be installed in a rural zone, a permit is needed from the municipality. An application must be submitted first to the regional authority (Kujallek Municipality) using a specially designated area with wind resource. Application will determine whether that area is or will be appointed specifically for wind turbines in the city regional plan. The points that should be addressed are:

- the minimum distance from residential areas is respected.
- taking utmost account of and other interests associated with the use of the open country, including nature, landscape, cultural heritage regions and agriculture.
- the staging area is consistent with a specific designation in the regional plan.
- the interaction with other wind turbines are not apprehensive.

The step by step procedure is explained thoroughly in the Danish EIA manual [4] and an overview can be seen in the diagram in Fig. 7.

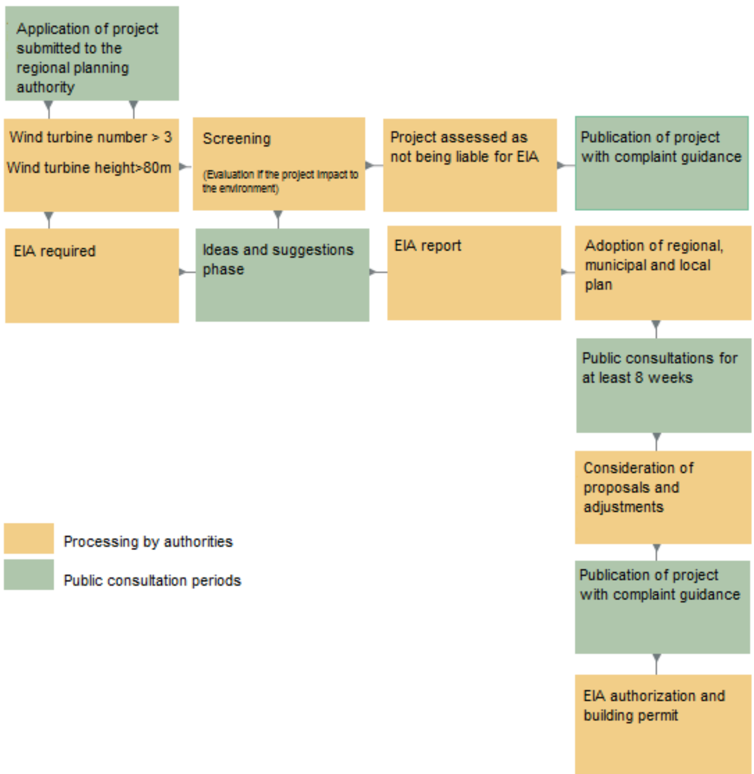

Figure 7: EIA procedure in Denmark. [4]

The outcome of the energy system calculations shows that the total input of wind power in Qaqortoq cannot exceed 3.8MW. This number can be achieved by two wind turbines with less than 80m hub height, Table. 7. Therefore, the regional planning authority could evaluate this project during screening as not liable for an EIA. Screening is an administrative process in which the project assessed in relation to a number of fixed criteria and the results are published. The screening criteria include:

- the size of the project,
- the environmental sensitivity of geographical areas that may be affected,
- the extent of the impact (geographical and scope of people affected) and
- the duration, frequency and reversibility.

In brief, all the important issues regarding the impact of a wind energy project should be addressed in the EIA section.

3.1 Aviation

So far the main means of transport from and to Qaqortoq is by air, with a helicopter. The helipad is mainly used to transport passengers with flights scheduled 4 times per day. The helicopter routes can be seen in Fig. 8, but pilots assured that those routes can be subjected to changes when the weather is foggy or windy.

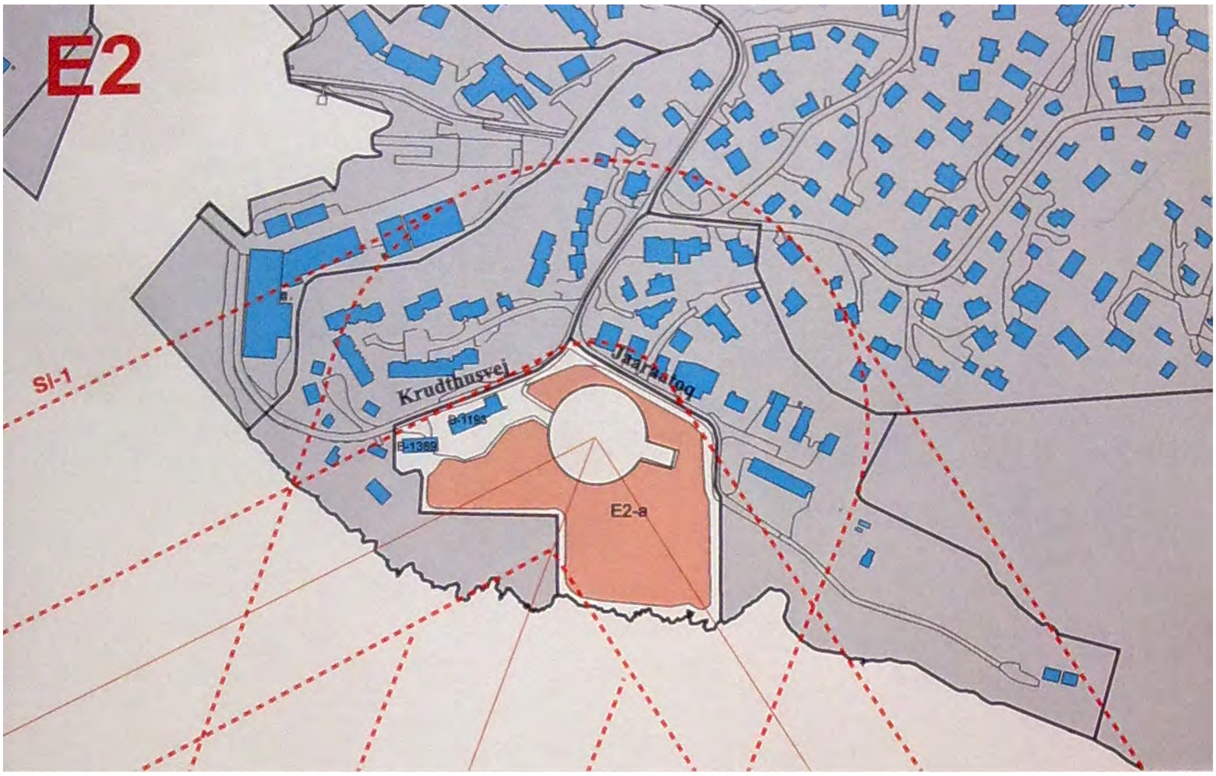

Figure 8: Helicopter routes when approaching the helipad.

Moreover, there is a Municipality plan to build an airport in the near future at one of the 5 suggested sites seen in figure 9.

The most feasible options to develope a wind farm without compromizing aviation safety is in the location around Alanngorsuaq area located at the west side of Qaqortoq. More precisely the cape at the southern part would be the safest option because it is located far from the helipad and the potential airports, it is relatively lower in height and wind turbines with the right light marking would be easily distinguished by pilots.

Figure 9: Planning of future developments in Qaqortoq.

3.2 Development and restricted zones

Kujalleq Municipality provided a map, Fig. 10, with areas of future development. Both wind farm locations need infrastructure for opening roads to access each site. The "north site" requires the biggest investment as there is not a service road around and the nearest road is the one that goes around the lake. The "south site" location is more attractive because it is located close to the damn site road which can be extended to the site without that large road construction. The climate of Qaqortoq could be concidered mild compared to other Greenlandic cities. The snow cover during winter last from early November to late April with maximum height of 1m. Those conditions are suitable for constructing such project.

3.3 Flaura and fauna

According to NunaGIS.gl there is hardly any endangered species inhabits the area of the two potential sites. The categories of species included in the endangered and relisted spieces map, Fig.16 (Appentix), are plants, birds, fish, seals and other mammals.

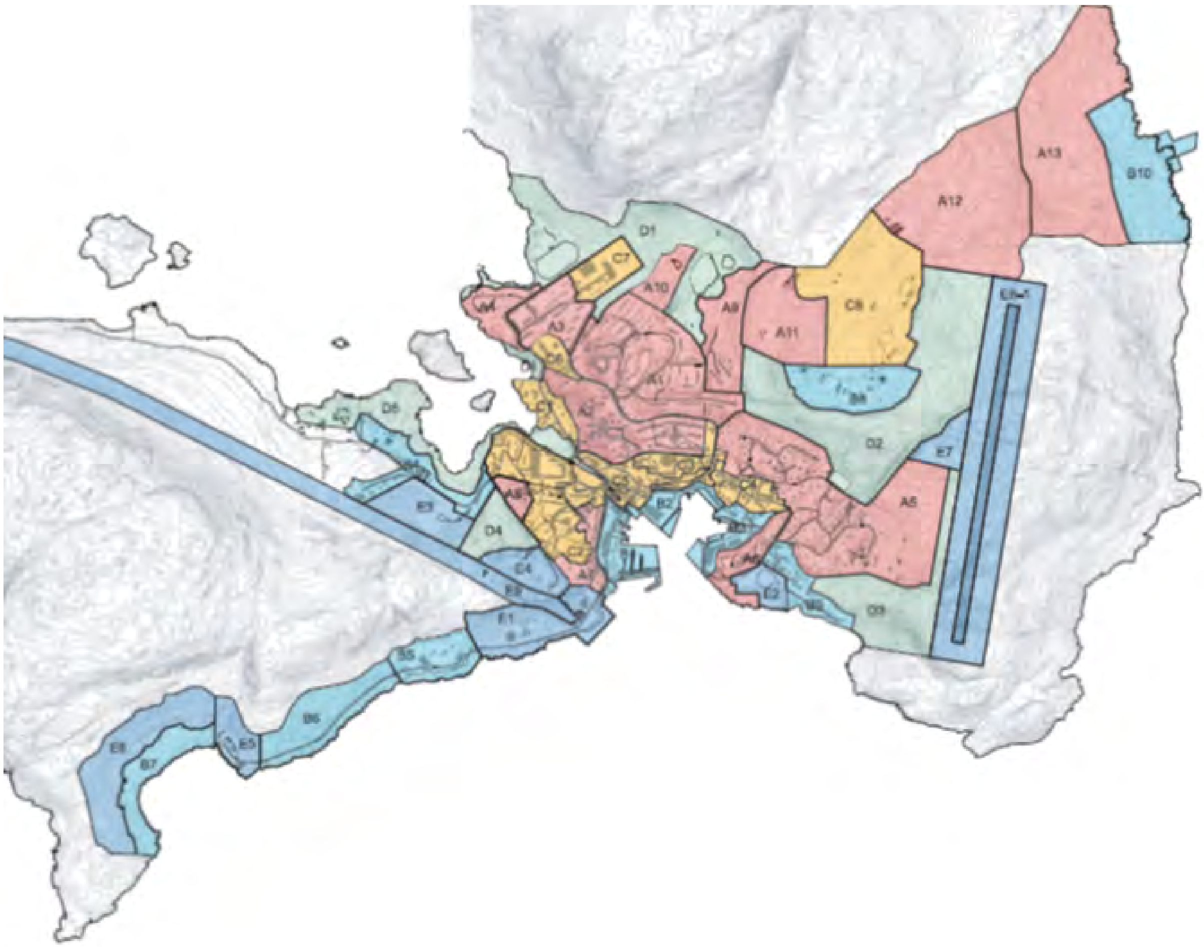

Figure 10: Developments zones in Qaqortoq.

3.4 Visual impact

The south site is highly unlikable to cause shadow flicker to any part of the city during low sun or light reflections from the blades rotating in sunny weather. A photo has been edited illustrating the south wind farm which is approx. 2,400m from the closest residential point.

On the other hand, the north site is quite closer to the city boundaries and shadow flicker or light reflections from the blades might occur during sunset and sunrise in a clear sky day. Further investigation should be done in case of the selection of this wind farm site since the visual aspect for this site is a major drawback.

3.5 Noise

Noise limits in Denmark have been set to 45dB(A) for residential areas and 40dB(A) for rural areas. Both sites are located over 300m away from the outskirts of Qaqortoq where the noise is below 40dB(A) [4].

3.6 Other issues

Water reservoir

The area around the lake must remain unaffected by the construction of the two suggested wind farms. Any necessary road widening in case of construction of north site should be handled with extra care and debris should disposed to the damp site by trucks.

Fishing

The proposed wind farm is not expected to cause noticeable disturbances to fishery business even during construction of "south site" as there is not a particular fishing interest around that area.

Radar and communication

The north site of suggested wind farm is located 200m away from the telecommunication tower, therefore further research for possible interference should be carried out if this site is selected.

3.7 Decommissioning

The wind turbines in the farm are expected to have a service life of at least 20 years and at the end of their life period they must be decommissioned. It is expected that at this time the turbines will be either sold to steel market companies or be recycled. Regarding the foundations it is suggested to be left at the site in order to repower the wind farm.

4 Site Assessment

Kujalleq Municipalitys future plans for Qaqortoq include an airport and new building zones north east of the city current map. As a consequence a new road to the airport should be built and possible rebuilt of the existing road network. From the map in figure 9 it can be observed that only a few sites are capable of developing a wind farm project and they are described in this section.

4.1 Descripion of the wind farm, design and layout

Two sites have been considered most capable of supporting a wind farm project without being subjected in prohibited areas. Both sites are located at the west side of Qaqortoq and from now on they will be referred as north and south site. The choice for those sites has been made after the EIA in collaboration with the planning and development manager from the municipality.

4.1.1 North site wind farm

The north site is located about 1200 m northwest of Qaqortoq's city boundary on a 200m height plateau with low plantation and granite rock terrain. At this area there is also a telecommunication tower (coordinates 441502, 6731700), Fig.11. The wind turbines have been placed north and east of the tower at 10 rotor diameters apart from each other and from the tower. The site is also approx. 2km from PCC at the main substation and the terrain to in between is suitable for laying an on-ground cable. This site has one of the region's best wind resources with annual mean wind speed 5,66 m/s and net AEP=8614GWh. Access to the north site is by foot or helicopter and therefore a road should be developed to transport all the wind turbine components.

Figure 11: Telecommunication tower close to the north wind farm site.

4.1.2 South site wind farm

The south site is also situated to the west side of Qaqortoq in a rocky slope to the cape next to the coast line, Fig.12. The area foreseen for the construction of the wind farm is covered with short plantation (grass, bushes) and large areas of uncovered rocky terrain.

Figure 12: Illustrated wind farm "south site" as seen from a point north of the damp site.

The site is approx. 1500m from PCC and 500m from the dump site where a paved road coming from the city ends. A road construction of 900m is necessary to be built in order to access the wind cite from the damp. The south site offers some financial advantages, such as lower infrastructure cost. The two wind turbines have been placed 4 rotor diameters apart and they can easily accessed by foot or boat. The wind resource in this site has annual mean wind speed 4,67 m/s and net AEP=6951GWh. The Danish wind energy recommends as a rule of thumb, turbines in wind parks to be spaced somewhere between 5 and 9 rotor diameters apart in the prevailing wind direction and between 3 and 5 diameters apart in the direction perpendicular to the prevailing winds. This requirement is covered by both sites.

4.2 IEC Classification

The International Electrotechnical Commission (IEC) provides standards for all kinds of electrical equipment. Among these is the IEC 61400-1 standard for wind turbine safety which is used by wind analysts as guidance for wind turbine micro-siting. This standard covers topics like structural integrity, turbine control, electrical safety, and environmental conditions.In this report the discussion is about the wind-related aspects. The IEC classification also provide a standard to the manufacturers in order to classify wind turbines within the limits of extreme wind and turbulence intensity. The latest edition IEC 61400-1 ed.3 is used in this report and it is described by the following Figure 13.

For both wind farm sites, the choice of suitable wind turbine is made upon the 50 year extreme wind U_{ref} and the assumed turbulence intensity I_{ref} for the wind turbine hub height $z_{hub} = 80m$. The turbulence intensity could only be calculated to the met mast site at the heliport and it cannot be transferred to characterize another site (not available turbulence data).

Wind turbine class		I	II	III	S
V_{ref}	(m/s)	50	42,5	37,5	Values
A	I_{ref} (-)	0,16			specified
B	I_{ref} (-)	0,14			by the
C	I_{ref} (-)	0,12			designer

Figure 13: The IEC 61400-1 Ed.3 classification system.

In order to ensure that the siting of the turbines, is within the accepted standards as depicted from the IEC 61400-1, the wind resource engineers need to assess the following parameters:

- the 50-years extreme wind is lower than U_{ref}
- The turbulence intensity must be lower than I_{ref} in a range between 0.6 U_{ref} to cut-out

4.2.1 50 Year Extreme Winds

The extreme wind conditions determined at the two sites fit the class III for wind turbine reference, since the extreme wind for the sites is below 37.5 m/s (34m/s for the 1 hour data). However according to a DMI report [15] the maximum recorded 10 minute wind speed is 41,7 (18/3/1997) which sets the wind turbine class at II. The uncertainty here is huge (20 %) and might be due to equipment calibration differences, development of the area around the met mast, etc.

4.2.2 Turbulence Intensity

The effective turbulence intensity must be lower than the representative turbulence intensity within a range from 0.6 times the rated velocity to the cut-out velocity. The turbulence intensity can be calculated using:

$$I_u(z) = \frac{\sigma_u}{U(z)} \tag{1}$$

where σ_u is the standard deviation of the horizontal wind fluctuation. For turbulence in flow over flat terrain with uniform roughness length z_0 (homogeneous conditions).

Because of lack of turbulence intensity data, these values could not be calculated, however as a result of a meeting with Air Greenland flight engineers and pilots, a turbulence chart was observed indicating high frequency events throughout the year in the heliport area. Therefore, in this report a high turbulence/ low wind speed wind turbine must be chosen. This class is covered by IIA standards according to IEC 61400-1 ed.3.

4.3 Selection of suitable wind turbines

The choice of suitable wind turbines for Qaqortoq has been made with respect to the wind potential of each site, the grid capacity and the total energy consumption of the city. The peculiarity of the two sites of high turbulence and low wind speed, urges the use of a class IIA wind turbine, a turbine class that most manufacturers can provide. A wind turbine model that fulfills all the required parameters for the site locations, such as the IEC IIA wind class, extreme low temperature operation, and relative compact design for transportation and low infrastructure development cost is the Vestas V100 1.8MW. The fact that this turbine can operate in very low temperatures and maximize the energy production at low wind speeds due to the 100m blade design make it ideal for a south Greenland location such as Qaqortoq. A pair of this wind turbine is suggested to cover 3,6MW of electric energy in Qaqortoq. The main features of the turbine are listed to Table 3.

Wind turbine	Vestas 100
Rated power [MW]	1.8
Power regulation	Pitch regulated with variable speed
Rotor diameter [m]	100
Blade length [m]	49
Hub height [m]	80
Wind class	IIA, IIIA, S
Operating temperature	-30°C - 40°C

Table 3: Wind turbine characteristics.

The Vestas V100-1.8MW is a doubly fed induction wind turbine generator (DFIG) that complies with all the grid regulations and it is equipped with the VCS (Vestas Converter System), which ensures a constant and consistent output to the grid. Along with the turbines pitch control, VCS also ensures energy optimization, low-noise operation and reduced load on the gearbox and other key components. The turbines grid compliance system provides sufficient active and reactive power regulation to maintain grid stability as well as fault ride-through capabilities in the event of a grid disturbance.

5 Grid Connection

Most remote communities in Greenland, such as Qaqortoq, operate on hydro or diesel generators. An integration of a wind power plant to the grid would assist or substitute on the electrical energy production from the existing diesel generators. The problem with diesel generators is that they are cheap to buy, but the cost of maintenance and operation is quite high. The electrical company Nukissiorfiit, a government owned company, is the owner and responsible of the grid control, operation and maintenance in Greenland and consequently responsible for a future wind farm connected to the grid in Qaqortoq. Qaqortoq is primary electrical supplied by two generators from Qorlortorsuaq hydro plan through a 70km long, 60kV transmission line which delivers to the city substation where it is transformed to 10kV.

The main hardware elements of a typical wind farm grid connection are the following:

- Wind turbine generator, transformer and switchgear
- Internal wind farm cabling to substation
- Wind farm transformer
- Substation: switchgear and transformer
- Ground cables to point of common coupling (PCC)

5.1 Point of common connection

Grid connection distance is a critical issue for any wind farm, however both sites are located within 3km of a strong point of connection (POC) meaning that the voltage is height and the load center is close enough. The north site is closer to th 60kV line, while the south site is closer to the main substation where the high voltage grid of 10 kV starts.

For insuring a strong point of connection, it is necessary to calculate the grid operator regulation, r. This indicator is dependent on the wind farm capacity (3,6 MW) and the short circuit power of the electric power system and should be in a specific range:

$$0.02\% < r = \frac{\text{Wind farm capacity}}{S_n} < 0.2\% \tag{2}$$

The peculiarity of Qaqortoq energy system must be fully studied before any wind farm grid connection.

5.2 Cable routing

The point of common connection (PCC) of the wind turbines to the site follows the formation of one straight line. In each site the line meet in PCC and then it heads straight to the POC at the main 10 kV substation. The type of line from the wind site to the substation can be ground based since the cable cost per meter is less expensive then the air based lines.

5.3 Grid codes

Any location in Greenland has it's own unique grid capacity and because of that there is not a fixed reference of grid codes. However, it is relevant to mention what are the main topics that a grid code covers for Denmark although the grid in Europe is different than the grid in Greenland. The Danish TSO Energinet.dk is the publisher of the grid code in Denmark, which is a booklet Technical regulation 3.2.5 for wind power plants with a power output greater than 11 kW that contains specific information about the following topics:

- voltage and frequency tolerance,
- voltage quality
- active and reactive power control and
- behavior during grid faults.

6 Energy System

6.1 System overview

A description of the Kujalleq municipality total electrical load was conducted that includes consumption for the public buildings (school, town hall, etc.), street lighting, district heating as well as other private loads energized by the public network. Three sets of electric load data were received from the municipality and Nukissiorfiit, the hydroelectric generation, electric boiler consumption and incinerator data gathered at Table 4. An other dataset was also provided with the heat production for 2011 and 2012. Because the hydroelectric data received from Nukissiorfiit were only for 10 months it was more representative to compare for this period. It is safe to assume that the electricity production from the two hydroplant generators cannot be controlled from Qaqortoq and therefore the production should be consumed. Nukissiorfiit has two main diesel generators for Qaqortoq, each 1.88 MW, Fig.18, and 4 backup diesel generators 1.125MW each, Fig.19, that all can be fully controlled. Additionally, there are also two 1.2MW electric boilers and one private 300kW oil boiler that cn be seen in the energy system overview in figure 14.

Data set	Duration [minutes]	Total series [months]	Power consumption [kWh]	Max day consumption [kWh]
Hydropower electricity usage	6 Jul 2011 30 Apr 2012	10	17529735	4909
Boiler Electcit consumtion	6 Jul 2011 - 30 Apr 2012	10	4525	1201
Inciterator electricity consumption	6 Jul 2011 - 30 Apr 2012	10	132521	5112

Table 4: Qaqortoq electriity production overview for 10 months.

The main supply of electrical energy in Qaqortoq is from the hydropower plant at Qorlortorsuaq Dam which has 2 Francis 3.8MW generators (total electricity production is 7.6 MW) operated by Nukissiorfiit [6]. The hydropower plant generators delivera total of 25.8 GWh in the months, out of which 8.273GWh are consumed in Narsaq. It is important to mention that the hydropower plant energizes, in order of importance, first the main electrical system and heating boiler in Narsaq and then the electrical system and boilers in Qaqortoq. During winter months both hydro generators work while the diesel generators in Qaqortoq are in standby. The diesel generators were mainly used before 2008 because that year the hydroplant was ready to operate.The overview of the system can be seen in figure 14.

6.2 System Evaluation with Wind Energy

From the above data it can be concluded that there are numerous options to integrate wind power to the local grid and at the same time reduce the work load of diesel generators and incinerator or substitute them. The question that arises is what combination diesel generators and incinerator should be implemented to safely disconnect them and at the same time satisfy the power demand. Then, a cost analysis model should be made to ensure that the wind-diesel combination is profitable for the municipality.

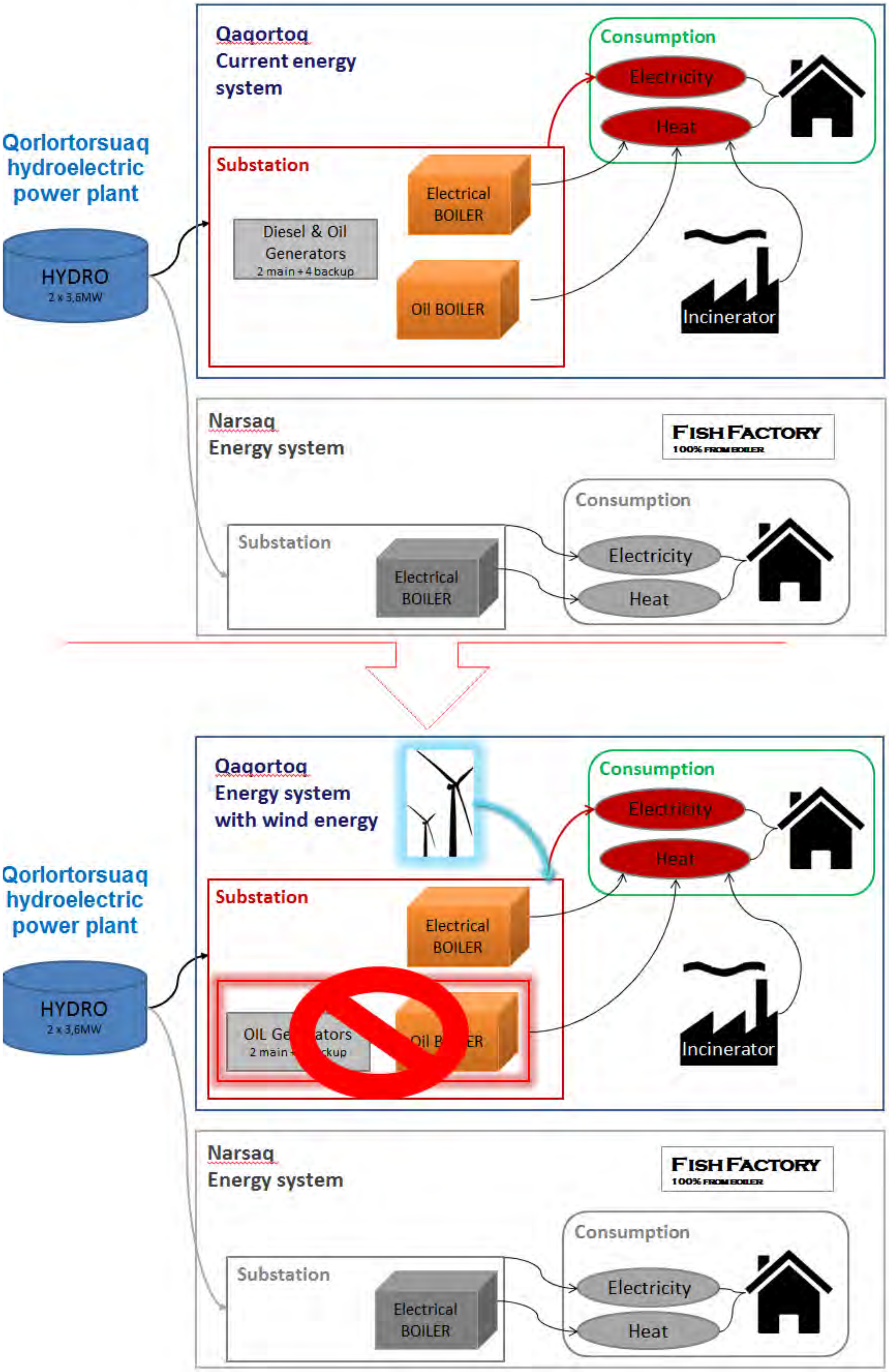

Figure 14: The current energy system and the suggested with 3.6MW wind energy.

7 Cost and Investment Models

In this report, the economic analysis that is being carried out consists of a private economic evaluation for the most prevalent site locations which is the south wind farm site. Up until this report was conducted there were not any wind farms developed in order to get familiar on the costs that a wind project might have. Therefore, because of the peculiarities of Greenland such as the distance from wind turbine manufacture locations and high cost of materials, it was more appropriate to calculate the suggested wing farm as a European offshore project. The inputs for the financial study of Qaqortoq south wind farm are the following:

- The economic report presented is a private economic analysis.
- The AEP and capacity come as a result of the WAsP calculations for the wind farm and it is 7074kWh/year.
- The discount rate is 7.5% per year.
- The AEP used in the economic calculations takes into account all losses.
- The individual cost of the grid connection consists mainly of the cable purchase and installation cost which is equal to 120 Euro/m (information was given by Kujalleq Municipality). The calculation of the grid connection cable length comprises the distance from the PCC and the distance between the turbines.
- To account for the cost of wind turbines, the rule of thumb is used 1000000 Euro/MW.
- The cost of electric energy is 37 Euro/kWh, the heat production cost is 110 Euro/kWh and the fuel cost is 63 Euro/MWh.[16]

7.1 Discount rate

The discount rate primarily depends on three factors: time preference, risk, and inflation. The time preference factor varies from changes of stock and government bond prices and the inflation rates vary from year to year. Risk primarily deals with the investors view of the project. Some examples which influence the risk percentage are the credibility and feasibility of the project, the reliability of the wind turbines used, the experience and the track record of the developer, and other uncertainties of the project. An important risk factor is also the project timing. In the time gap between the power purchasing agreement and the moment the wind farm is fully operational and starts producing electricity, the prices of investments (for example, prices of steel and cement) and the interest rate may change, thus increasing the risk rate [9].

For the south wind farm project a discount rate of 7.5% has been used as this is recommended by the EWEA economic report [10]. It has to be mentioned though that this rate is for European sites, so an unknown uncertainty might be included here.

7.2 Simplified Economic Analysis

The purpose of conducting a simplified economic analysis is to provide a quick, basic estimate of the feasibility of a wind farm. The two simplified economic analysis methods used are the simple payback period analysis and the cost of energy analysis [11]. The simple payback period analysis calculates the number of years it takes for the cumulative savings to exceed the initial capital investments (without taking into consideration the discount rate). The payback period equals the installed capital cost divided by the average annual energy price return. For the Qaqortoq south wind farm the simple payback period is 56 years. This payback period off course makes the wind project unprofitable. (the Excel sheet used is attached on Campusnet in the file of the report)

The cost of energy is defined as the amount of money it would take for the wind farm to produce one unit of energy, taking into account the initial capital investments, discount rate, annual operations and maintenance costs and the AEP of the wind farm. To calculate this value, one must account the initial capital cost with the inflation into a total cost over the lifetime of the wind farm (20 years) and then divide this value by the AEP of the wind farm. For the Qaqortoq south wind farm this was calculated to be 353.7 Euro/kWh which again is a very high price making the project unprofitable.

7.3 Expenditures

Capital expenditure (CAPEX) is defined as the initial investment in a project. A wind farm project is a capital-intensive investment in comparison to more common fuel energy technologies. The initial capital investment for the Qaqortoq south farm project is described in figure 15 and the components of the capital expenditures along with the percentage of each component are shown in Table 5.

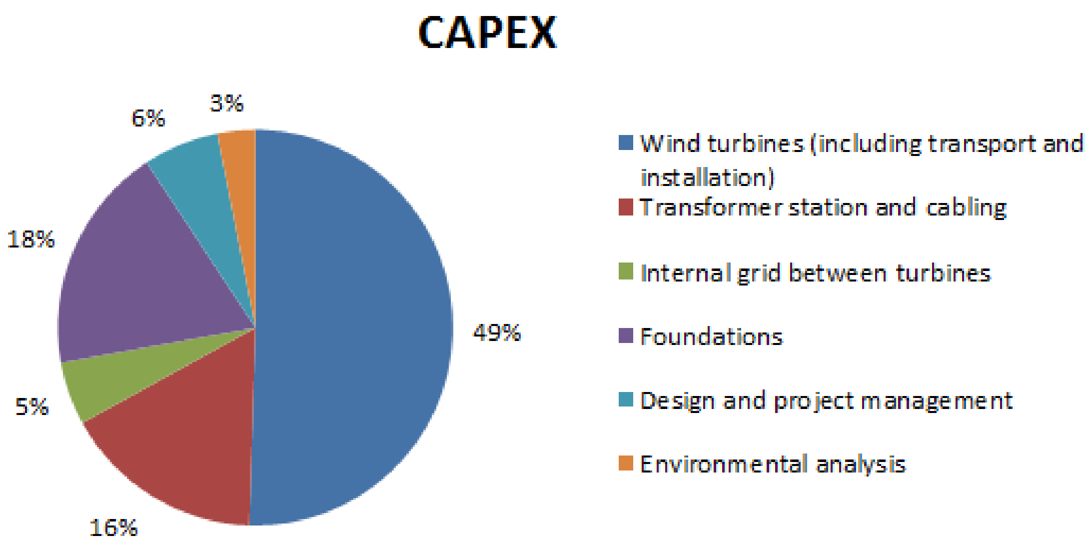

Figure 15: CAPEX expenditures.

Components	Share [%]	Expenditures [Euro]
Wind turbines (including transport and installation)	49	7.203.000,00
Transformation station and cabling	16	2.352.000,00
Internal grid between turbines	5	735.000,00
Foundations	18	2.646.000,00
Design and project managemen	6	882.000,00
Environmental analysis	3	441.000,00
Other costs	3	441.000,00
Total Initial Investments	100	14.700.000,00

Table 5: Estimated CAPEX components.

Operational expenditure (OPEX) are the long term costs associated with a project. These constitute of insurance, regular maintenance, repair, spare parts, and administration of the wind farm. The operational expenditure might be higher than average operation and maintenance costs compared to other wind farms because south wind farm location in Qaqortoq is very remote. The operation and maintenance cost of the wind farm per MW used in the calculations is for offshore wind farms, 0.018 Euro/kWh. [10]

Thus, the calculated operational expenditure cost in present value for the south wind farm is 1.298 Euro in total for 20 years. The total expenditure (CAPEX + OPEX) is 14.701.298 Euro.

Due to lack of time to analyse if a wind power plant can replace the diesel fueled generators a further study should be done, all data series can be provided after request.

8 Conclusion

The purpose of this report was to make an analysis of the wind climate of Qaqortoq and the area around it, find potential locations with good AEP for implementing wind farms, describe the grid and the energy system of the city, conduct an EIA and finally to do a cost analysis for such a project.

The wind resource assessment showed that the five year mean wind speed from the two met masts was 2,97 m/s and 4,37 m/s including many uncertainties. Most of those uncertainties were discovered at the sites inspection during the trip in Greenland on August 2012. Those include the very low met mast height and the large obstacle around them and also the unknown calibration method used (more uncertainties are mentioned in the relevant section). The power density was then calculated for the area around Qaqortoq and two locations were chosen taking into account the EIA and the suggestions of Kujalleq municipality's planning office. The two wind farm sites have different AEP, and although the north site can produce more energy (AEP=8614 GWh), the south site is more preferable (AEP=7074 GWh) because it is closer to the main road and thus requires less infrastructure cost. A small description of the grid and the energy system is also made, however any integration of wind power will require an thorough grid and energy system analysis. A simple cost analysis was conducted for south wind farm site that showed that the payback period is very long (56 years), way beyond the 20 years suggested lifespan.

Because of the uncertainties the results in this report might highly differ from the actual conditions and therefore it is suggested to all interested parties as a short term solution to install a 50 m met mast (like the one in Narsarsuaq) in the area of the north wind farm site. That way after a year there should be a much more accurate wind climate for the area. Also, because most cities in Greenland are in very remote locations, a special care should be taken when analysing the grid and the energy system, as there are not any grid codes or guidelines for each particular city.

With all of this in mind it is the conclusion of this report that at the moment a wind farm is not recommended to be built in the Qaqortoq area.

References

[1] Nyserda Wind Resource Assessment Handbook, New York State Energy Research and Development Authority 10.30, 2010

[2] Wind turbines Part 12-1: Power Performance Measurements of Electricity Producing Wind Turbines IEC 61400-12-1:2005, CENELEC, 2006

[3] http://www.qaqortoq.gl/, 9/2012

[4] Moller og Gronborg AS, Carl Bro As, VINDMOLLER PA LAND DREJEBOG FOR VVM, ISBN 87-7323 042 1, 2002

[5] Technical regulation 3.2.5 for wind power plants with a power output greater than 11 kW version 4.1, Energinet.dk, 2010

[6] QORLORTORSUAQ Hydroelectric Project-7.5MW, Verkis.is, 2010

[7] Jacob Berg, Jakob Mann and Morten Nielsen, Notes for DTU course 46100: Introduction to micro meteorology for wind energy, DTU Wind Energy E-0009 (EN), ISBN 978-87-92898-15-5, 2012

[8] Laust Boas, Peter Riddersholm Wang, Technical report 11-15, Weather and climate data from Greenland 1958-2010, DMI, 2010

[9] Costs and Prices. Rep. Vol. 2. European Wind Energy Association, Wind Energy - The Facts.

[10] S. Krohn, The Economics of Wind Energy, European Wind Energy Association, 2009

[11] J. Manwell, Wind Energy Explained: Theory, Design and Application, John Wiley and Sons, 2009

[12] John Cappelen, Edward Hanna, RECENT CLIMATE OF SOUTHERN GREENLAND, Danish Meteorological Institute, Copenhagen, Denmark, Institute of Marine Studies, University of Plymouth, 2001

[13] W.Jowitt, A Study of Methods of Determining the Icing Potential of Cold Climates for Wind Energy, Technical University of Denmark, 2012

[14] S. Baars et al., GL Wind Technical Note 067, Certification of Wind Turbines for Extreme Temperatures, Germanischer Lloyd Industrial Services GmbH, 2011

[15] Cappelen J., et al, Technical report 00-18, The observed climate of Greenland, 1958-99, DANISH METEOROLOGICAL INSTITUTE, 2001

[16] Ataatsimoortumik aningaasartuutit, Enhedsomkostninger, Nukissiorfiit, 2010

8.1 Appentix

Figure 16: Red listed and endangered species map by nunagis.gl. There is none.

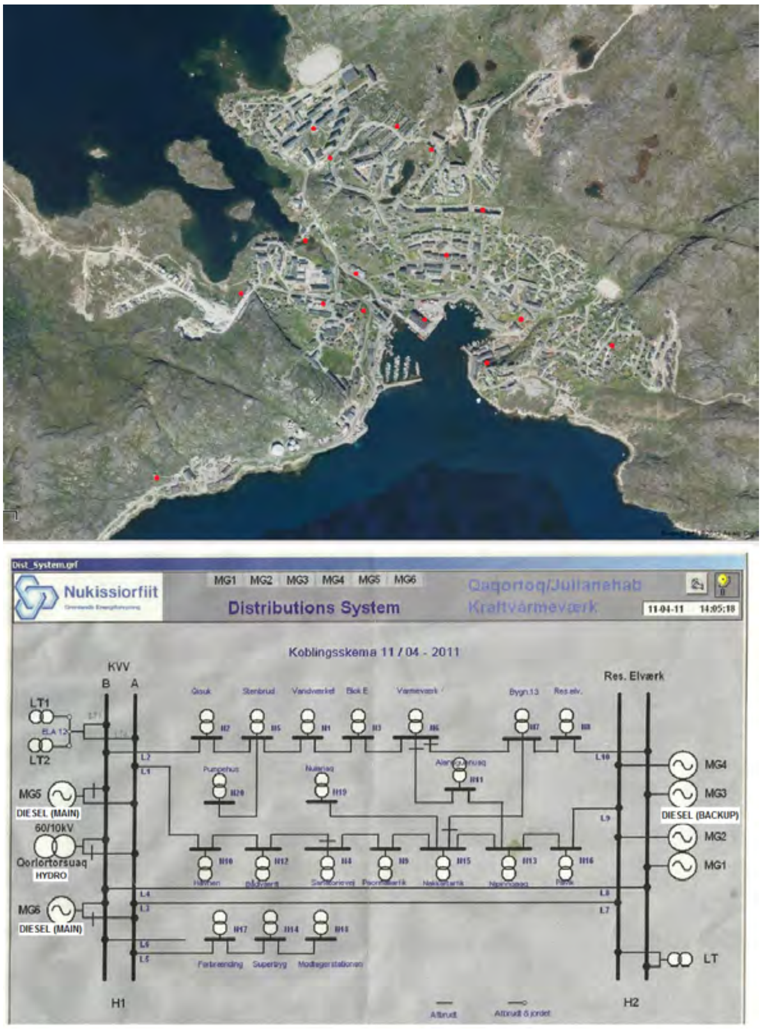

Figure 17: Qaqortoq distribution system.

Figure 18: One of the two main diesel generators.

Figure 19: Three of the four backup diesel generators.

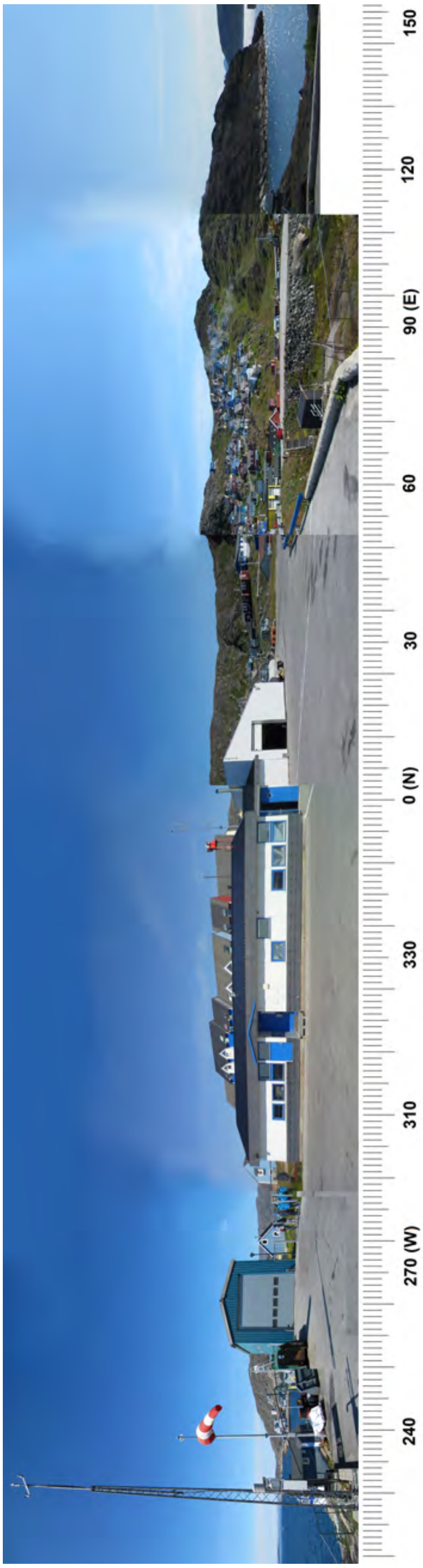

Figure 20: Topography and obstacles around the heliport met mast.