The Nanortalik Energy System

Feasibility study of implementation of wind power in the Nanortalik energy system

In this analysis, the feasibility of implementing wind power into the Nanortalik energy system is investigated. The wind climate and present energy system is assessed, and a model is made where fuel cost savings are studied in relation to wind power implementation. The system is analyzed for economic viability.

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ABSTRACT

In this analysis the possibility of implementing wind power to the energy system in Nanortalik is investigated. This is done on the basis of received fuel consumption-, diesel powered electricity production and wind data from the 1601 met mast located on the peninsula east of Nanortalik city.

The main goal of the project is to determine whether implementation of a 1 MW WinWind wind turbine is economically feasible or not. The first part of the analysis includes a presentation of the current energy system in Nanortalik, where data regarding generator production and fuel consumption have been received through Nukissiorfiit. From the analysis of the present energy system, the peak electrical production has been found to be 819 kW, while the minimum production is equal to 243 kW. Over the studied period of 1 year the mean production was calculated to be 438 kW. In addition to the electric power production, a total of 1 021 MWh was generated by utilizing heat generated from the power producing units. The analysis further contain a wind resource assessment, which describes the relevant meteorological equipment and further includes sections regarding data processing and validation, time series analysis and implementation of the obtained wind data to WAsP. A mean wind speed of 5.81 m/s was found measured at 50 meter height, during the period of 26.06.2007 to 25.06.2010.

In WAsP the data is further utilized to calculate an annual energy production at two turbine sites in the vicinity of Nanortalik, where one is located close to the dump site on the peninsula east of Nanortalik city. The second turbine site is located on a hilltop approximately 3 km west of Nanortalik.

An annual energy production of 2.359 GWh is found for Turbine site 1 while the AEP is estimated to be 2.984 GWh for Turbine site 2, where the mean wind speed is estimated to be 7.31 m/s. The analysis furthermore consist of sections describing the grid connection of the wind turbine, as well as the construction parts where a thoroughly description of the road routing is implemented. An environmental impact assessment is also conducted together with description of the relevant legislation and regulations that must be followed in order to install a wind turbine in Greenland. A model which calculates the excess power production when operating a 1 MW wind turbine together with the three generators is developed and described. The calculations show that the total fuel cost savings for the respective turbine sites are equal to 3.04 million DKK and 3.68 million DKK yearly.
A socio-economic analysis concludes the report where it is found that implementation of a wind turbine at Turbine site 1 results in a positive NPV of 112 700 DKK. The project is thus marginally profitable. The alternative turbine site returns a negative NPV of 12.3 million DKK. This alternative is found unprofitable due to large expenses related to road construction. The conducted work shows that implementation of wind turbines in the Nanortalik system is viable, but a risky investment.

PREFACE

This study is the final result of the course 11427 Artic Technology at the Technical University of Denmark (DTU). The course counts for 15 ETCS, and extends over three semesters. The three semesters have consisted of general education regarding the Greenlandic society, a three weeks field trip to Greenland from the 31st of July to the 16th of August 2012 and the preparation of the final report.

The supervisors of the study have been Adriana Hudecz and Kasper Jakobsen (ARTEK), and we would like to thank them for good guidance and help throughout the project. Also, the help from the technical department of Kujalleq municipality and Nukissiorfiit's departments in Nanortalik and Qaqortoq have been helpful during the process – especially during the field trip to Greenland.

The project has lasted from January to December 2012, and the report was finalized and handed in at 03.12.2012.

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1 INTRODUCTION

Greenland is divided into four municipalities; Qaasuitsup, Qeqqata, Sermersooq and Kujalleq. The towns in Greenland are widely separated, and thus both of economical and practical reasons the respective towns are forced to function with individual power production/supply; hence there is no national grid in Greenland.

Figure 1 - The four municipalities of Greenland

The municipality in question in this analysis is Kujalleq, which is situated in South-Greenland. Kujalleq has a total population of 7 800 and an area of 53 000 km^2, which is approximately 19 % larger than Denmark. There are three towns in Kujalleq; Qaqortoq (3 129), Nasal (1 740) and Nanortalik (1 445), the number in brackets being inhabitants.

In this study the possibility of integrating wind power to the Nanortalik energy system is investigated - both technically and economically. The study is divided into two main parts:

- Wind resource estimation and a feasibility study of implementation of wind power into the system
- Development of a Matlab model of the energy system in order to analyse the resulting oil savings and carbondioxid reduction by implementation of wind power.

The wind resource estimation is based on four year time series of a 50 m meteorological mast and six years of data from a 10 m meteorological mast.

The feasibility study focuses around issues such as turbine siting, cost estimation and development of key financial figures to prove the viability of the project.

Development of the model for the energy system is based on the diesel generators, boilers, and wind turbine interactions, in order to calculate the benefits of wind power implementation. The study also involves study of the present energy system in collaboration with the local energy company, Nukissiorfiit, and meetings with the local authorities, constructions companies etc. to collect the required information.

2 THE NANORTALIK ENERGY SYSTEM

The overall conditions in Greenland are characterized by cold climate, remotely located communities and a poor transport system. This is also applicable to the town in question for this study – Nanortalik.

The Nanortalik energy system is supplied with energy from three main diesel generators, in addition to a peak load power plant consisting of two smaller diesel generators. In addition to supply electricity, the exhaust gas and heater water, which cools the generators, are part of the district heating system. The main power plant can be seen in Figure (2).

Figure 2 - Nukissiorfiit Nanortalik

In this chapter, the Nanortalik energy system is undergone. The chapter is initiated by presenting the present system, with both production and consumption statistics. It is finalized by discussing the efficiency of the power plant.

2.1 The Present Energy System

The key numbers (April 2011-April 2012) from Nanortalik's electricity- and district heating supply are given in Table (1):

Subject	*Unit*	*Figure*	*Unit*
Main power station	Generator 1	720[1]	kW
	Generator 2	540[1]	kW
	Generator 3	1 080	kW
Peak load power station	Generator 1	370	kW
	Generator 2	370	kW
Electrical production	Max prod. (08.12)	819	kW
	Min prod. (22.06)	243	kW
	Mean prod.	438	kW
Annual Electricity production		3 837	MWh
Heat production		1 021	MWh
Internal load[2]		168	MWh

Table 1 - Key figures for Nanortalik electricity- and district heating supply

The district heating supplies just a few residential buildings, whereas the rest of the city is supplied from local heating centrals within the buildings – mostly supplied from individual oil burners.

The power system is purely AC, where the transmission grid is operated at 6 kV and distribution grid at 400 V. As the power

1: The station was rebuilt in 2005/2006, thus replacing generator 1 and 2 from 620 kW each to 720 and 540 kW respectively

2: Based on figures received for 2010

systems in Greenland are isolated, resulting in rather small transmission distances, there is no use of higher operating voltage for the transmission grid. However, in case of substantial increase in transmission distance or consumption, the grid has been designed to be able to scale up the operational voltage to 10 kV, by only some minor measures. The electricity is, as mentioned, produced from three diesel generators located in the power station (See also Appendix A). The power station is operated by the national power company, Nukissiorfiit (Figure (2)).

The power station was rebuilt in 2005/2006, and in this period two of the generators were replaced, thus leaving the following three generators which are also used today:

- Man B&W Diesel BL23/30, power 1080kW (Installed 1989)
- Man B&W Diesel 8L16/24, power 720kW (Installed 2005)
- Man B&W Diesel 6L16/24, power 540kW (Installed 2005)

The power system also include an auxiliary peak load plant, located by the main station. It consists of two similar diesel generators from ECC Electric Construction and have a capacity of 370 kW each. The whole power plant gets its fuel from the tank farm located on the peninsula in the eastern part of the town.

Figure 3 - Man B&W Diesel BL23/30

The energy system supplies energy to several different customers, such as households, schools, heliport, shops and supermarkets. Previous years, a fish factory was

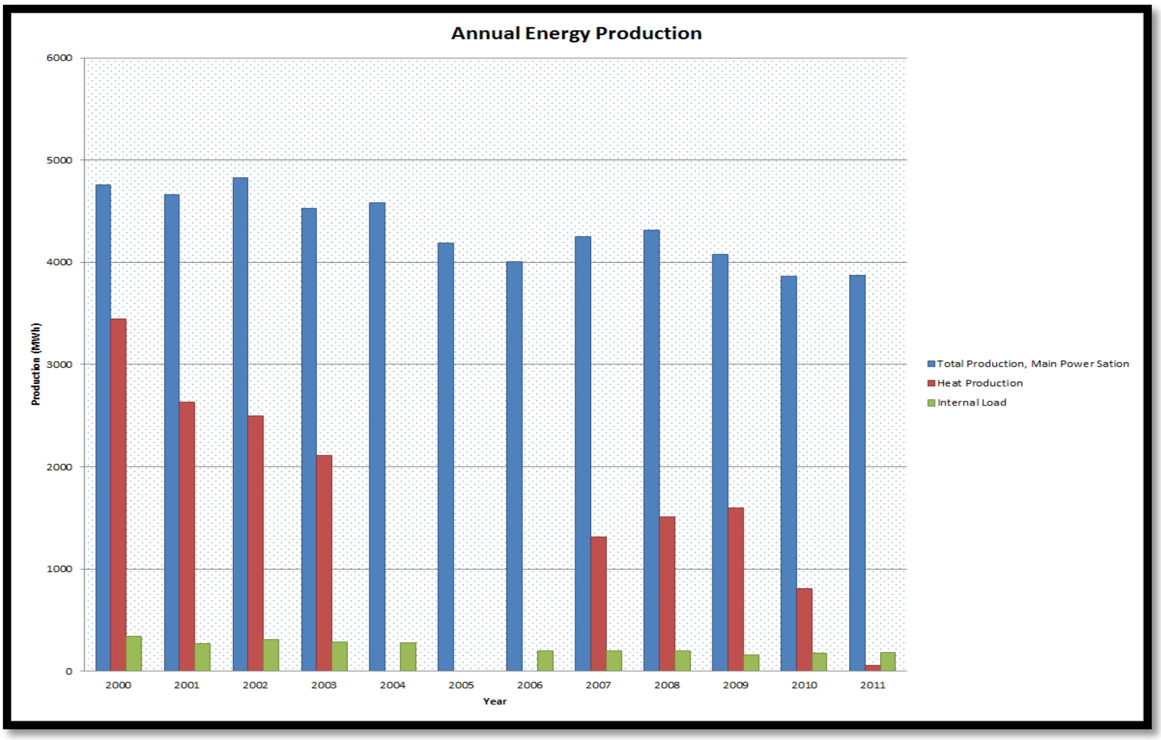

Figure 4 - Annual Energy Production and Internal Load

also on the customer list, but this industry was closed down for some years. However, in August 2012 the fish factory was re-opened which results in an increase in the energy consumption in the city. This is an important aspect in the operation of the energy system in Nanortalik in the future (Greenlanding Broadcasting Corporation, 2012).

2.2 *Energy Production*

In order to analyse the energy production of the Nanortalik energy system, data are provided from the national energy company of Greenland, Nukissiorfiit. Due to lack of consumption data, it is assumed that the energy produced equals the energy consumed. This introduces, however, a source of imprecision, since transmission losses are not included in the calculations. However, as the system, in general, is operating at low loading, the introduction of wind power will not lead to significant transmission losses (Nukissiorfiit, 2012).

In Figure (4), the total electricity production, heat generated from the generators and the internal load of the power plant from 2000 until 2011 is illustrated. As the the year of 2012 is not finished, the annual energy production can not be calculated for this year. It can be seen that there is a lack of data both for heat production (2004-2006) and internal load (2005). This is due to missing data in the time series received from Nukissiorfiit. In 2005, there are missing data for internal load in June, July and September. Data for the heat production are missing for November 2004 and from June 2005 until August 2006. Thus all of these years are omitted from the figure.

2.2.1 Total production

By analyzing the figure, it is seen that the total electricity production shows a slightly decreasing trend, which can be explained by the closure of the fish factory and a decreasing population. The population of Nanortalik has experienced a decrease during the last decade. The last peak was in 2003 with a population of 1 549 inhabitants (Statistics Greenland). The effect of the decrease in population can also be seen in the annual energy production presented in Figure (4).

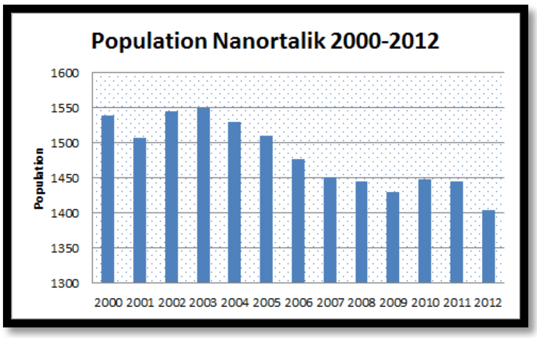

Figure 5 - Population Nanortalik 2000-2012 (Grønlands Statistik, 2012)

2.2.2 Heat production

The heat production is decreasing from 2000 until 2004, where three years without satisfactory data continues. The trend of the heat production can be explained by the same arguments as the ones for the total production. It is also worth noting that the heat production is absent at the same time as the renovation of the power plant took place. It is therefore a fair assumption that the district heating was either disconnected during the renovation or that it simply was not logged. From 2007 and onwards the heat production showed an increasing trend until 2010. This was explained by Nukissiorfiit by a damaged measurement instrument from the middle of 2010, from which it had been malfunctioning. Therefore, the decreasing trend experienced in 2010 and 2011 is not trustworthy, and a more likely assumption is that the increasing trend from the previous years is valid until a saturated condition is obtained.

2.2.3 Internal load

There are also missing data for the internal load during the summer of 2005 (June, July and September).

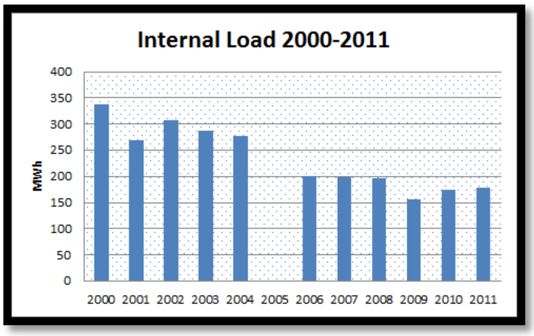

Figure 6 - Internal load 2000-2010

It can, however, be seen from Figure (6) that the internal load has been rather stable both periods from 2000 until the renovation in 2005 and also from 2006 until 2011. It is not found a direct relation between the internal load reduction and other parameters in the system, and the following explanations are therefore more or less qualified suggestions to what the reason could be. The reduction might be explained by the fact that the new generators are more efficient than the old ones – which also implies that the energy supplied to the district heating is reduced. It could also be caused by a reduced need of cooling on the newer generators.

2.2.4 Annual variation of the production

In order to elaborate the annual variation of the total energy production in Nanortalik, the last received data is put to use. The data stretches from April 2011 until April 2012, which serves as a reference year in this analysis. In order to obtain a satisfactory time series, several filtering measures are used. Invalid data are removed by means of validation routines conducted in Matlab. In most cases, the invalid measurements are

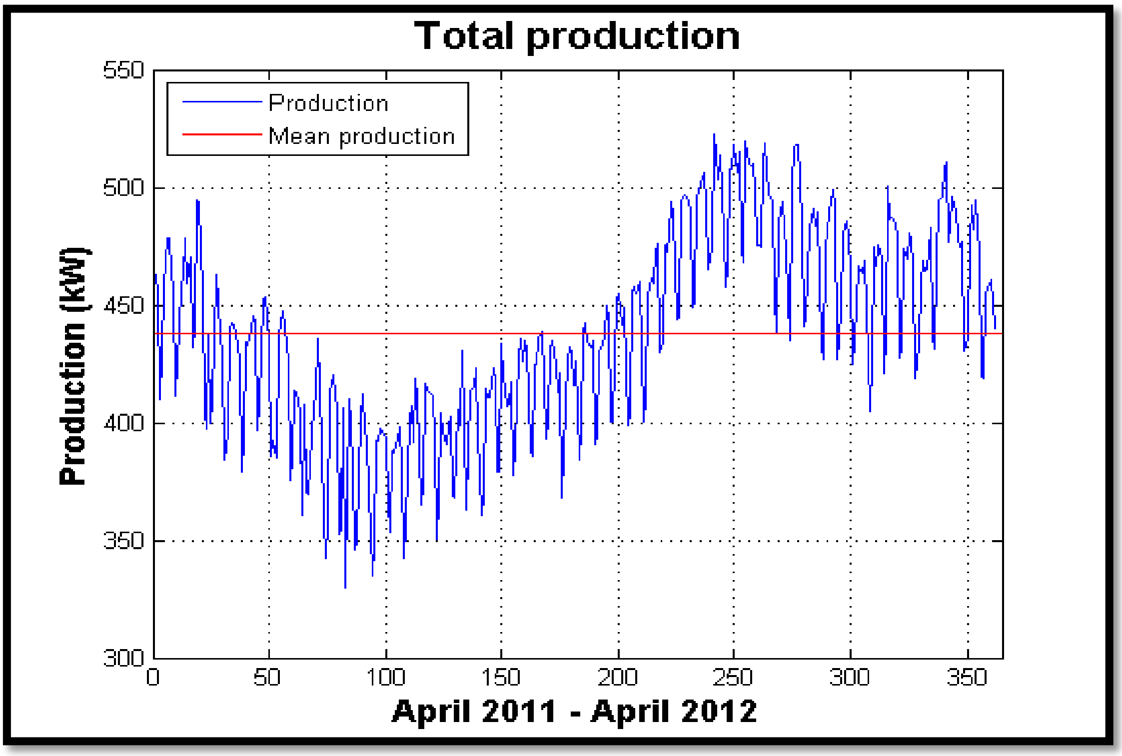

Figure 7 - Total production April 2011 - April 2012

replaced with the mean production. An alternative solution could be to replace the invalid data with the mean of the measurements before and after the erroneous measurement. This, however, requires a more complex Matlab script, and by assuming that the error associated with using the mean as a reference affects the result in a minimum manner, the error is found acceptable. The remaining plot of the annual variation is presented in Figure (7).

As can be seen from the figure, there are logical seasonal variation of the production within one year. The plot starts from the 1st of April 2011, and a decreasing trend is observed until the trends is increasing from around day 100 (middle of July).

The plot shows a somewhat linear increase from July until the peak production from day 250 to 280, corresponding to middle of December until middle of January. This has to be considered as a rather normal trend due to the climatological changes over the year. Finally, it is observed that the end of the plot has good correlation with the beginning of the plot, thus the April of 2011 corresponds well to the April of 2012.

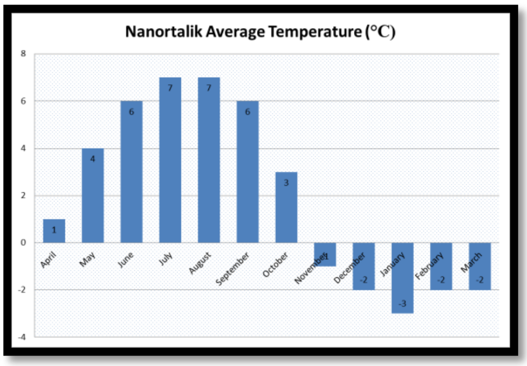

Figure 8 - Nanortalik Average Temperature (°C) ((Climate & Temperature))

The production ranges from a lower daily peak of 7.9 MWh in June to an upper peak of 12.5 MWh daily in the end of November. In order to validate the total production plot, the most relevant comparison is the temperature in Nanortalik. In Figure (8) the average temperature of one year is presented. It can be seen that the production correlates well with the temperature during the first half of the year (April to October). In the winter period, the overall correlation is also quite good, although the peak was expected some weeks later than experienced in Figure (7). This is due to annual variations of the climate.The conclusion is therefore that the annual production plot of 2011-2012 corresponds well with the reality.

2.2.5 Daily variation of the production

The daily variation of the energy production is investigated for both weekdays and weekends. The chosen days are Wednesdays and Sundays, respectively. In order to calculate the daily variation, the same time series as used in Figure (7), April 2011 until April 2012, is used. The mean of all hours are calculated, thus the plot represent the mean production each hour on Wednesday and Sunday. The plot illustrates a few important factors of the Nanortalik energy usage. It is observed that the minimum energy usage/production is between 04.00-05.00 in weekdays and at 06.00 in the weekends.

Weekdays

During weekdays the energy production increases rapidly between 07.00 and 09.00, where the slope somewhat flattens until the morning peak is reached at 12.00. This is reasonable since people wake up and start working during these hours. After lunch, the energy production starts decreasing until the afternoon low peak is reached between 15.00 and 16.00. Then the energy production starts increasing once the inhabitants are finished at work and the daily peak is reached at 18.00 with an hourly production of 683 kW. After this, the plot shows a decreasing trend until next morning.

Weekends
The variations during the weekends are quite similar to the ones during the weekdays, with the major exception being the magnitude of the production. The biggest difference is observed from 08.00 until 16.00, which is the work hours during the weekdays. The production is during these hours approximately 200 kW lower during the weekends. Otherwise, the variations are more or less the same during the week.

2.3 Frequency of the Power Levels

In order to better visualize the frequency of the different power levels, a cumulative distribution function proves good value. This curve illustrates the frequency of the different power levels, which is of interest since a similar curve can be made for the wind power production. Thus, a first impression of the influence that can be caused by implementation of wind power can be seen.

The curve is based upon data from April 2011 till April 2012, and due to the minimal amount of data used, there is attached some uncertainties to the estimation illustrated in the figure. The cdf of the power production is plotted in Figure (10). It can be seen that approximately 90 % of the power production levels are lower than 560 kW, which is of importance when implementing wind power into the system in terms of satisfying the grid quality requirements. Also, this figure gives a measure of the size of the potential wind turbine. A reasonable sized wind turbine for such a consumption is approximately 1 000 kW provided that it is designed for low wind speeds, as is the case for Nanortalik.

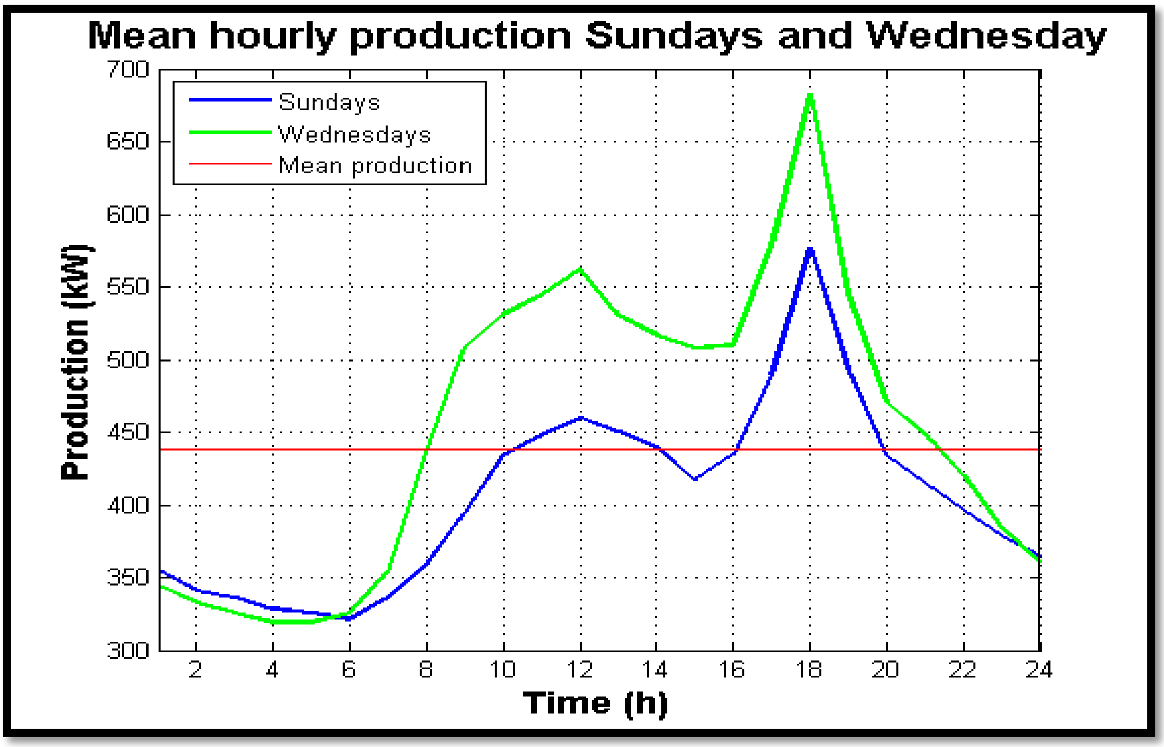

Figure 9 - Mean hourly production Sundays and Wednesdays

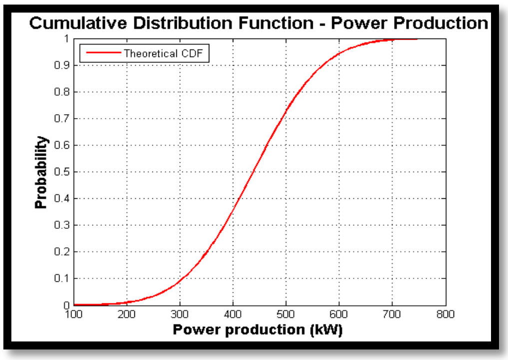

Figure 10 - Cumulative distribution function - Power production

2.4 *Oil Consumption*

The oil consumption data is received from Nukissiorfiit. In Figure (11), the total oil consumption from the power plant during the period 2000 to 2010 is presented. It is observed that the oil consumption is quite fluctuating over the period, varying between 90 000 and approximately 100 000 liters per year. Between 2001 and 2004 the oil consumption was rather stable, which correlates well with the energy production over the same period (See Figure (4)).

After this period the oil consumption shows a decreasing trend, which is reasonable due to the reasons presented earlier in this chapter. After a low level in 2006, the annual consumption has fluctuated quite much, reaching the lowest consumption of the decade in 2010 with a total of 85 000 liters. The same trend is experienced in the production data, although the difference is not that large as for the oil consumption. The reason for the low dump is that the heat production was lowered.

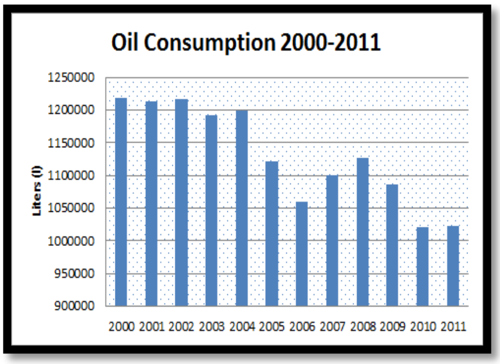

Figure 11 - Oil consumption 2000-2011

2.4.1 Annual variation of the oil consumption

The oil consumption is calculated on the basis of data received for the three generators from Nukissiorfiit. The data is filtered in the same manner as the production data and the separate consumption values are added into a total consumption for the whole power plant. The total consumption is then filtered for the last errors, and the result is presented in Figure (12). Without the filtering of the data some erroneous spikes, with several thousand liters in deviation, would appear in the plot.

The mean fuel consumption for one day is approximately 2 920 l during the period investigated, totaling at 1 056 000 l per year. As for Figure (12), the plot starts at 1st of April 2011 and finishes at 31st of March 2012. The fuel consumption shows similar trends as the production trend, which is reasonable. It is observed that the low peak is present in the middle of June, whereas the high peak is experienced in the middle of January. This is also reasonable, if compared both to the production trend and the temperature trends from Figure (8).

An interesting observation is the large increase in oil consumption over the last year, which is approximately 30 000 liters more than the previous year. Part of the reason is

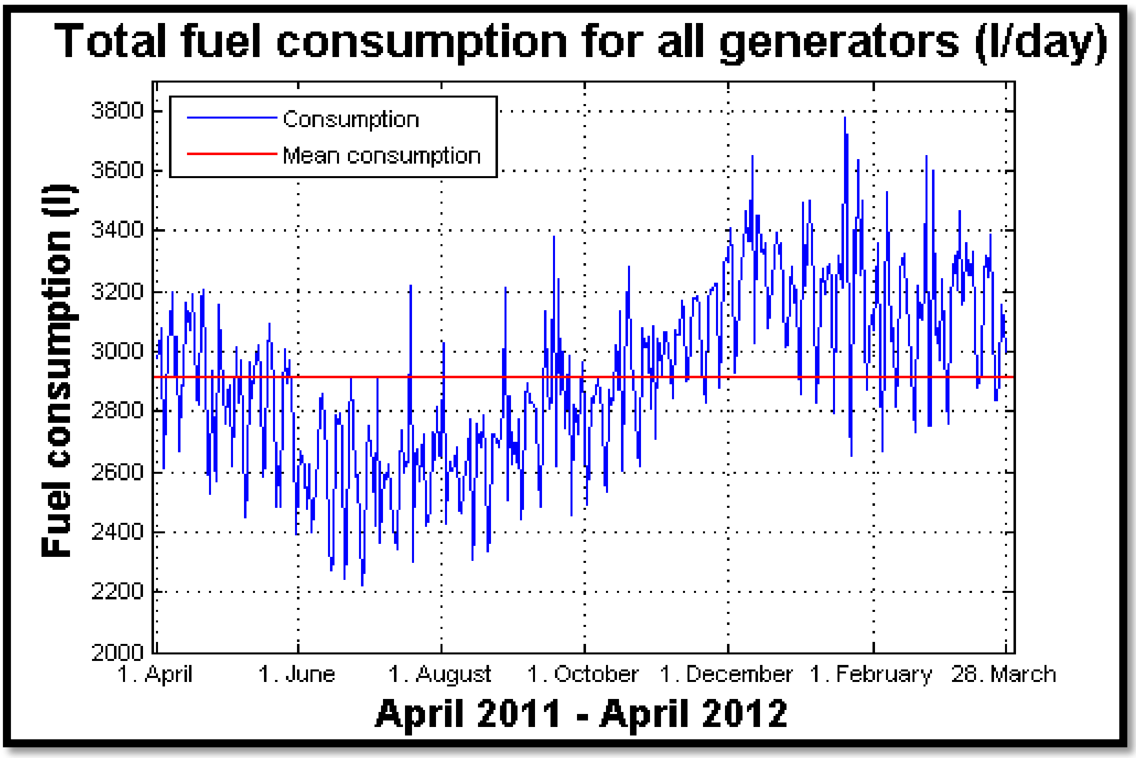

Figure 12 - Total fuel consumption for all generators (l/day)

the filtering process, where the invalid data is replaced with mean consumption data for the respective generators. The main reason of the increase in oil consumption is, however, that Nukissiorfiit had meter problems related to the oil consumption measurements in this period, and hence could the abnormalities be explained by erroneous measurements made by the meters.

Correlation between consumption and production data

In Figure (13) the correlation between the consumption and production trend is illustrated. The consumption data is adjusted to fit the production data by introducing a correlation factor. This is done by usage of the following relation throughout the oil consumption data series:

$$Adjusted\ Con = \frac{Con\ x\ mean(Prod)}{mean(Con)} \qquad \textbf{(1)}$$

Where:
Con = Oil consumption data
Prod = Production data

As can be seen from the figure, there are good correlation between the two curves. Several peaks are observed for the consumption compared to the production. The reason for this uncorrelation is due to problems with the measurement instruments for the oil consumption. The installed equipment is designed for large flows, thus the uncertainty of the measurement of the small flows in the Nanortalik energy systems are quite large. Nukissiorfiit informed that their best way of having control of the oil consumption was by control of oil bought and used, and how much energy that was produced.

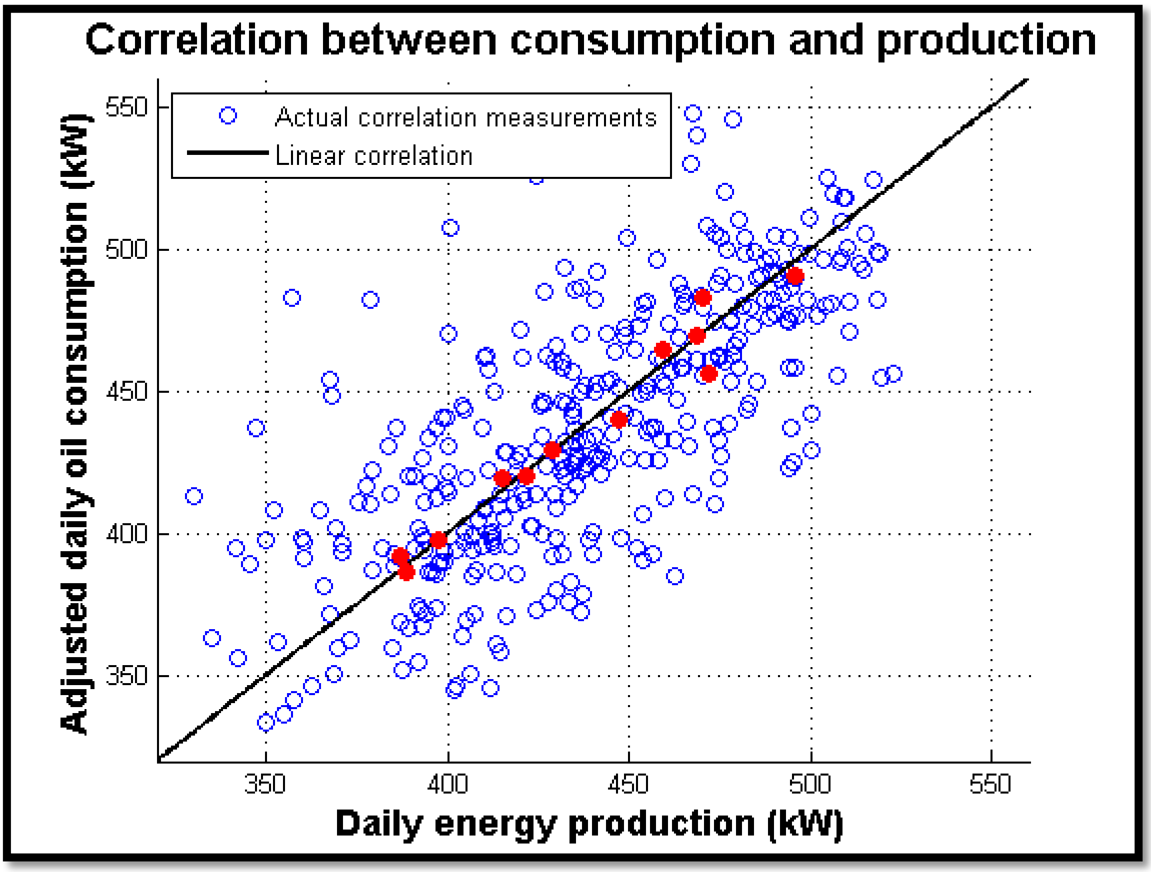

Figure 13 - Correlation between consumption and production data

2.5 *Efficiency of the Energy System*

A measurement used in the energy industry to calculate how efficiently a generator operates, is by usage of heat rate. It is expressed as the amount of heat energy required to produce (in Joules) a kilowatt-hour of energy. Operators of generating facilities can make reasonably accurate estimates of the amount of heat energy a given quantity of any type of fuel produces, so when this is compared to the actual energy produced by the generator, the resulting figure tells how efficiently the generator converts that fuel into electrical energy (Energy Vortex).

In this analysis it is chosen to calculate the efficiency of the generators by usage of the heat rate, which is derived from the produced energy, the consumed fuel, and the heat value and density of the fuel. These data are provided by Nukissiorfiit.

The overall thermal performance or energy efficiency for a power plant for a period can be defined as

$$\eta = \frac{E_{produced}}{Oil_{consumed}\ x\ HV\ x\ \rho}\ x\ 3\ 600 \qquad \textbf{(2)}$$

Where:
$E_{produced}$ = Produced energy (kWh)
$Oil_{consumed}$ = Consumed oil (m^3)
HV = Heating value (KJ/kg)
ρ = Fuel density (kg/m^3)
3 600 = The amount of KJ in 1 kWh

By usage of Equation (2), the efficiency of the total power plant can be calculated. The heat value used is 42 MJ/kg, whereas the fuel density used is 840 kg/m^3. Nukissiorfiit claims an electrical efficiency of 35-42 %. They also state that if heat generated from the generators is utilized, the efficiency increase to somewhere in the range of 60-90 % (Nukissiorfiit).

In Figure (14) the electrical efficiency between April 2011 and April 2012 is plotted. As can be seen there are rather large daily variations, with amplitudes greater than 15 %. By making monthly averages of the efficiencies, a more constant behavior is revealed. It is observed that the monthly fluctuations are rather small, within 2 %. It is therefore a fair assumption that the daily variations is due to whether the production is low enough to be covered by one generator only (including spinning reserves) or if another generator must be used – thus lowering the overall efficiency.

The mean efficiency of the power plant is 36.9 %, which fits well with the claim from Nukissiorfiit. By additional utilization of the generated heat from the generators (1 021 MWh), the total efficiency of the power plant is calculated to be 46.6 % - which is quite low compared to the claim from Nukissiorfiit. This results in 9.7 % higher total efficiency of the power plant, if the heat of the generators is included.

2.6 Control System

The energy system has a control system that automatically adjusts the voltage and frequency in order to maintain the desired 50 Hz frequency. In principle, if the load is reduced the frequency is increased and vice versa. However, the voltage depends on the

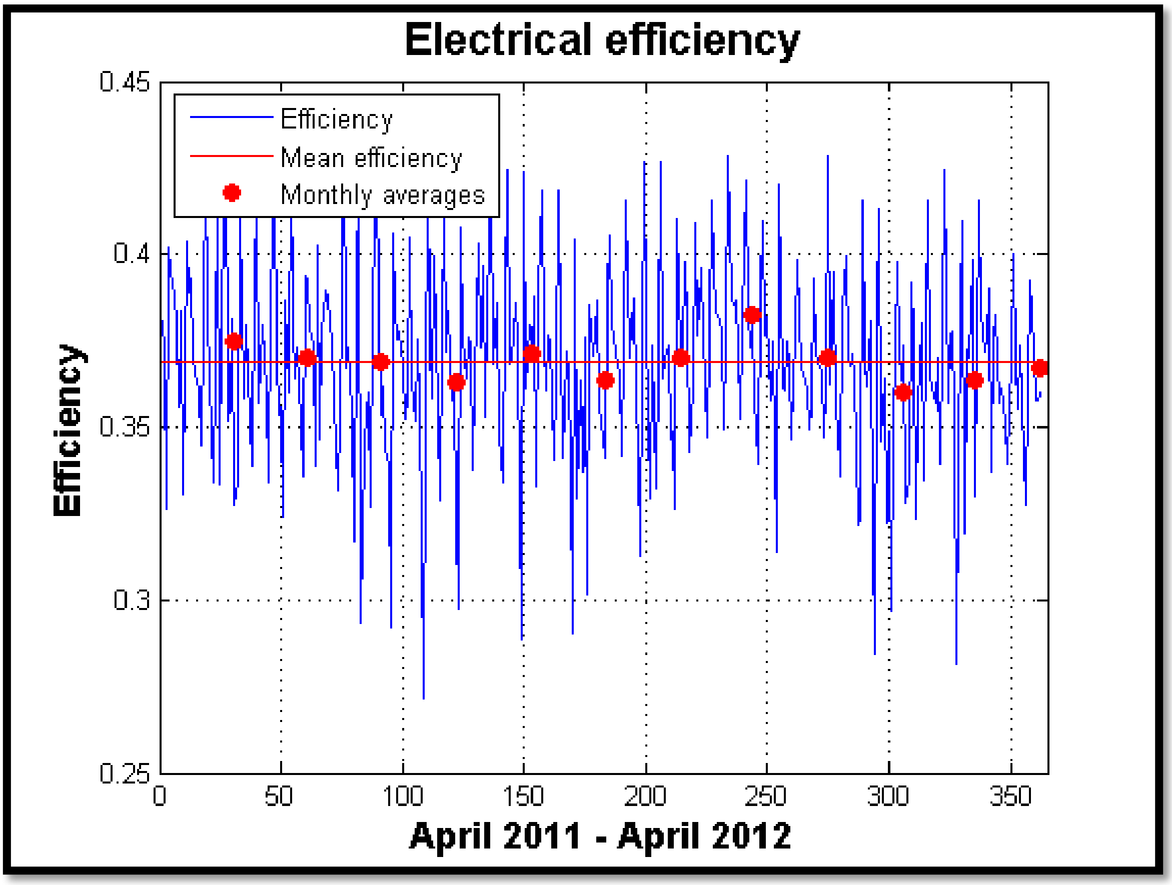

Figure 14 - Electrical efficiency of the Nanortalik energy system

change of load types and loading of overhead lines and cables. In both cases, control systems such as governors and Automatic Voltage Regulators (AVR) are utilized in order to maintain safe operation. Additionally, for small isolated grids two other factors are also considered more important than for “infinite systems”; hysteresis-adjustment and the spinning reserves.

2.6.1 Hysteresis adjustment

In Appendix (D) a screen dump from Nukissiorfiit showing the parameters of load and engine management is presented. There are especially two parameters that are interesting; the “Hystrese ved skift til lavere kapacitet” and “Effektreserve”. The first is a set point for how much the production must be lowered for a newly started generator to be shut down. Nukissiorfiit has chosen to operate with a hysteresis adjustment of 170 kW, meaning that the production must be 170 kW lower than the maximum production for one generator for the other to be shut down. By doing so, a situation where the second generator is turned on and off if the production is on the limit of the first generator, is avoided.

2.6.2 Spinning reserves

The system is designed with fixed spinning reserves for each hour of the day, as can be seen in Appendix (D). The fixed reserved can be changed by the operator of the system. The spinning reserve makes sure that the running production units are capable of handling a sudden increase in demand instantly, without the delay of starting a new generator.

The sum of the hysteresis adjustment and the spinning reserves function as a good protection for the energy demand in Nanortalik.

3 WIND RESOURCE ASSESSMENT

The wind resource in Nanortalik has been measured by a 50 meters met mast since June 26st 2007. The data used in this analysis stretches from that date till August 9th 2011, and from this time series three valid years are used – June 26th 2007 till June 26th 2010.

Figure 15 - 1601 Nanortalik 50 m met mast

The measurements have been carried out by Kjeller Vindteknikk AS (Kjeller Vindteknikk, 2011). It is worth noting that during the four years the equipment has not been subjected to revision, thus the bearings of the cup anemometers are most likely been worn out, which could imply that the cup anemometer is slowed down. This is part of the reason that only the first three years of data is used in this analysis.

The 1601 Nanortalik 50 meters met mast has been measuring wind speed at heights varying from 10 to 48.8 meters, in addition to wind direction and air temperature. The met mast has the following location:

1601 Nanortalik 50 m met mast	
UTM 23 Easting	487 462
UTM 23 Northing	6 667 438
Height (m.a.s.l.)	19
Start of measurement	25.06.2007
End of measurement	Running

Table 2 - 1601 Nanortalik 50 m met mast

The top mounted cup anemometers are mounted at a height of 48.8 m, and are of the types NRG 40 and Risø P2546A. The NRG 40 anemometer has not been functional since June 2009. NRG 40 anemometers have also been used for wind speed measurements at 30 and 10 m. Also a NRG HAE IceFree 3 was installed at 43.8 m to measure wind speed. The wind direction has been measured by a NRG 200P wind vane at 41.4 m, in addition to a NRG HVE IceFree 3 wind vane at 40.8 m.

The two anemometers at 48.8 m are mounted on a boom on opposite sides of the mast with a distance of approximately 1.5m from the mast and a height of 60 cm above the boom. There is also a lightning rod between the sensors. The configuration leads to an uncertainty of 1.5 % in the measured wind speed, according to Kjeller Vindteknikk AS.

The instruments installed on the met mast are presented in Table (3):

1601 Nanortalik 50 m met mast instruments			
WS	NRG 40	48.8 m	Top Sensor
WS	Risø P2546A	48.8 m	Top Sensor
WS	NRG 40	30 m	Wind shear
WS	NRG 40	10 m	Wind shear
WS	NRG HAE IceFree 3	43.8 m	Ice Free eq.
WD	NRG HVE IceFree 3	40.8 m	Ice Free eq.
WD	NRG 200P	41.4 m	Wind dir.
Air temp.	NRG 110S		Temp.

Table 3 - 1601 Nanortalik 50 m met mast instruments

The instruments used in this analysis are Risø P2546A (wind speed), NRG 200P (wind direction), NRG 40 at both 10 and 30 m (vertical wind profile) and NRG 110S (temperature).

3.1 Data Validation and Processing

The data validation is carried out by means of two main methods; manual and automated data screening. The first consists of two basic, but important verifications to assure that the collection of data has been carried out in a proper manner. This is done by verifying the data records and its time sequence.

Data records

The data records, hereinafter referred to as data recovery, concerns the totality of the times series. In this evaluation it is investigated how much data is missing and if the data recovery is adequately to represent a certain event, in this case the wind regime and its seasonal variation.

The data recovery is defined as the length of times series divided on the length of measurements corresponding to non-stop measuring. If the instrument has been without downtime and the processing is carried out without any rejection, the data recovery would be 100 %. Data recovery is expressed as

$$DR = 100 \times \frac{N_{valid}}{N} (\%) \qquad (3)$$

Where:
DR = the data recovery in percentage
N_{valid} = the number of valid records
N = the total number of possible records in the period

The pre-processed data recovery of the measurements is presented in Chapter (3.1.1).

Time sequence

The time sequence verification concerns the time and date stamp of the data. For instance, if the order of the measurements is not relative to time and date, the trend of the data will be differ significantly. This would cause major problems in the automated screening process. However, the time stamp is verified to be in order. Table (4) refers to a clip from the time series, where the time sequence is highlighted by the red box.

26.06.2007 00:00:00	3	0.5	4.1	1.4
26.06.2007 00:10:00	2.4	0.8	3.7	0.3
26.06.2007 00:20:00	2.1	0.7	3.7	0.7
26.06.2007 00:30:00	2.5	0.7	4.1	0.7

Table 4 - Time sequence clip from time series

Further on, the data validation is conducted by means of a Matlab script, which marks data of suspect appearance. This code carries out the automated screening and its basis is derived from three algorithmic tests: Range, relation and trend. These tests consist of statistical and metrological range limits, relation and trend behavior. It is worth noting that these tests are only referring to typical statistical behaviors at normal wind turbine sites. Deviations from the statistics will certainly occur, more or less dependent on factors such as the site's topography, climatology, atmospheric conditions etc. The test guidelines are also quite conservative, as it is easier to validate suspicious data than flagging non-suspicious data. Applied guideline is developed by AWS Truepower (AWS Truepower, 2010).

Due to statistical deviations from reality, further validation is needed to determine whether the suspect data is false negative or false positive. For instance, the wind speed may sometimes become larger than 30 m/s. A measure to validate such flagged data is to carry out an old-fashion visual inspection of the measurements. By inspecting both ahead and behind to the suspected event, one can rapidly get an impression of the spike's validity. By applying common sense and preferably several methods in the evaluation, the data recovery is held at a higher rate than by rejecting all suspected data. At the same time, the wind regime of the location is more correctly obtained, giving less uncertainty to the project's feasibility. Visual inspection after the automatic screening is also a good measure to pick up any false negatives measurements. False negatives are data that have been cleared by the screening process, but yet of invalid origin.

Note that the referring tests do not take into account incidents of ice accretion and shadow flickering.

3.1.1 1601 Nanortalik meteorological mast

The meteorological mast, which provides data for this analysis, contains a number of instruments. As mentioned, these instruments have not been reviewed during the measurement period, which implies a number of error sources which is described in the following sections. Table (5) presents an overview of the installed instruments on the 1601 Nanortalik meteorological mast.

Type	*Offset*	*Comments*
NRG 40 (48.8 m)	0.35	Not functional after June 2009. Utilized for vertical wind profile computation
Risø P2546A	0.35	**Utilized for wind speed profile**
NRG 40 (30 m)	1	Utilized for vertical wind profile computation
NRG 40 (10 m)	0	Utilized for vertical wind profile computation
NRG HAE IceFree 3	0	Not calibrated, hence inaccurate
NRG HVE IceFree 3	0.35	Not functional after April 2010 and low standard deviation values. Secondary reference
NRG 200P	0.35	**Utilized for wind directional profile**
NRG 110S	86.381	Utilized in air density computations

Table 5 - Measurement instruments at the meteorological station (Kjeller Vindteknikk, 2011)

Risø P2546A is used as reference for wind speeds, whereas NRG#200P is the reference for wind directional data. In addition to the measurements stated from Table (5), meas-

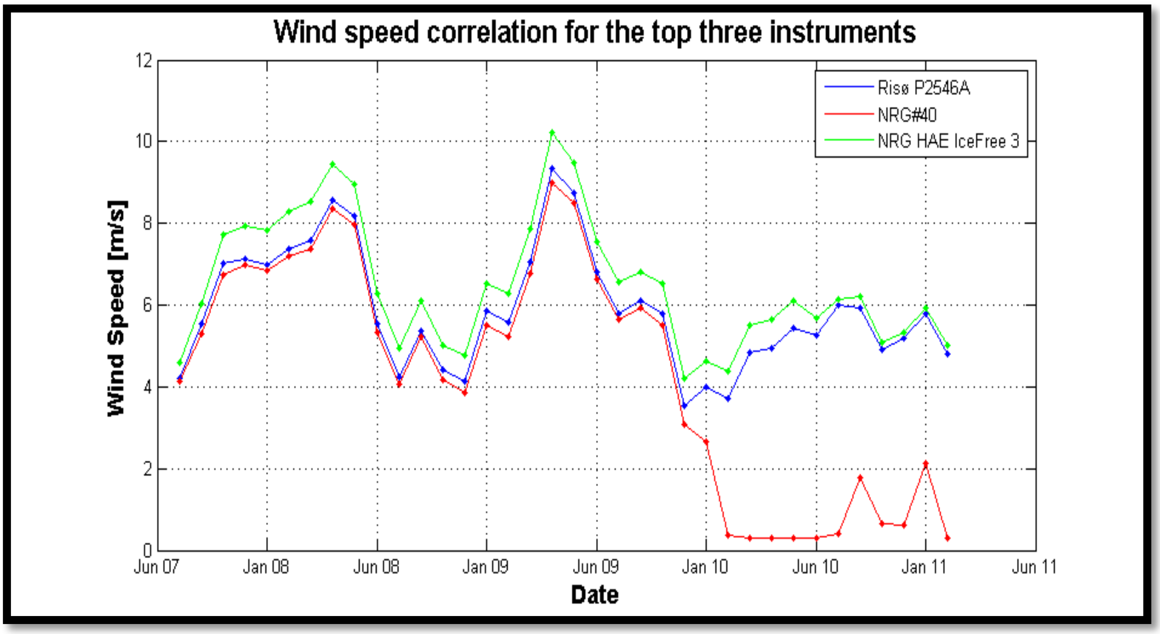

Figure 16 - Wind speeds of the top three instruments. The plotted wind speeds are measurements from the first three years, represented by monthly means

urements from the heliport in the town have been accessible. However, these are only used for some wind data verifications, e.g. abnormally high wind speeds, and pressure data. The top sensor at the heliport is mounted at 10 m, while the pressure data is only available in hourly resolution.

3.1.1.1 Wind speed

Figure (16) clearly identifies and verifies the issue regarding the NRG#40 (48.8 m) instrument. After June 2009 the instrument stopped working. The ice-free instrument seems to be overly sensitive and do not correlate well with the two other instruments, hence the Risø P2546 A is selected as the primary reference for wind speeds at the site. Another obvious issue regarding the ice-free instrument is that it is mounted 8 meters below the two other instruments, which implies that it would be more reasonable if it measured lower wind speed compared to the other two. This is partly caused by not calibrating the instrument. The NRG#40 instruments are utilized for computation of vertical wind profile. Due to absence of instrument revision, only the first year have been utilized for this purpose. The measurement quality has gradually become poorer, especially for the cheap NRG instruments. Figure (17) illustrates the relation of wind speed in terms of height at the meteorological station. These anemometers are mounted to measure the wind shear, which are used to estimate the wind speeds at turbine height. In Chapter (3.7), the vertical wind profile is computed.

The meteorological mast at the heliport has undergone a correlation study in the same manner as the instruments at the 1601 mast. The heliport data has been filtered, but only by removing the flagged error values. From Figure (18) it can be seen that the correlation is a bit off compared to the wind speed correlation plot of the NRG#40 at same height. From June 2007 to November 2007, the measurements seem to follow the same pattern, whereas a discrepancy occurs December 2007. After this the trend of the mean values are the same until May 2008.

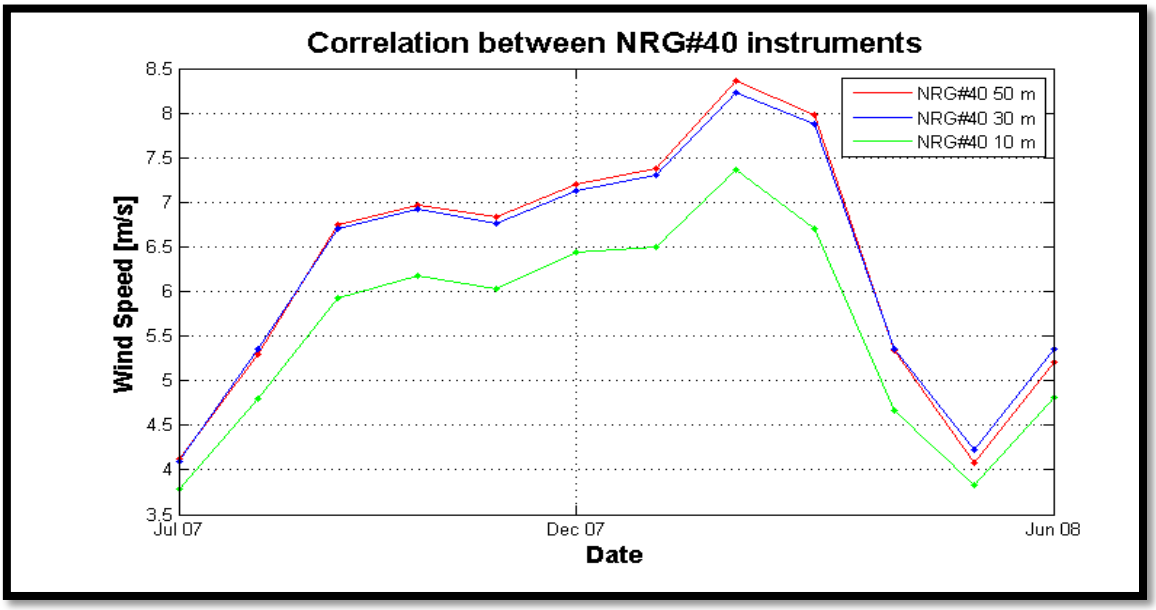

Figure 17 - Wind speeds at three different heights. The plotted measurements are from the first year and in monthly averages

Over the 1 year period, the averaged wind speeds at the heliport are measured to be substantially lower than measured by NRG#40 cup at 1601 mast. The linear distance between the two masts are approximately 500 meters, which means that the two masts should correlate to some extent - which they do. Factors such as roughness changes, local obstacles, height to sea-level and calibration are probably the reasons for the large difference in mean speed values.

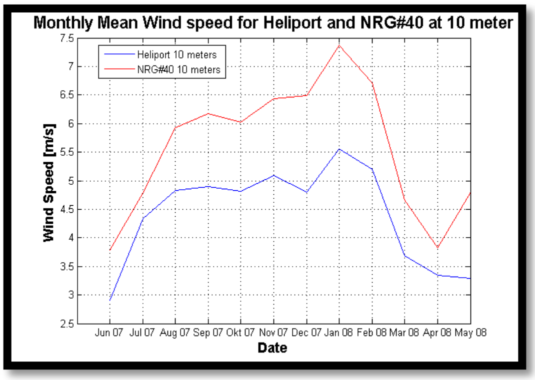

Figure 18 - Correlation between monthly averaged wind speed at the heliport and the utilized meteorological station (1601)

3.1.1.2 Wind direction

Figure (19) illustrates that the wind directional measurements of the two wind vanes are correlating quite well. However, the plot also verifies that the ice-free wind vane stopped working around March 2010.

By taking a closer look at the wind vane data by means of standard deviation values, the correlation becomes more absent. Figure (20) clearly illustrates that the 200#P wind vane is more sensitive to directional changes.

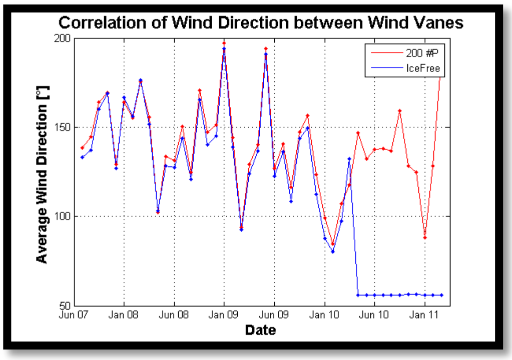

Figure 19 - Wind direction measurements from the two wind vanes. Plotted period is of approximately four years and measurements are presented in monthly averages

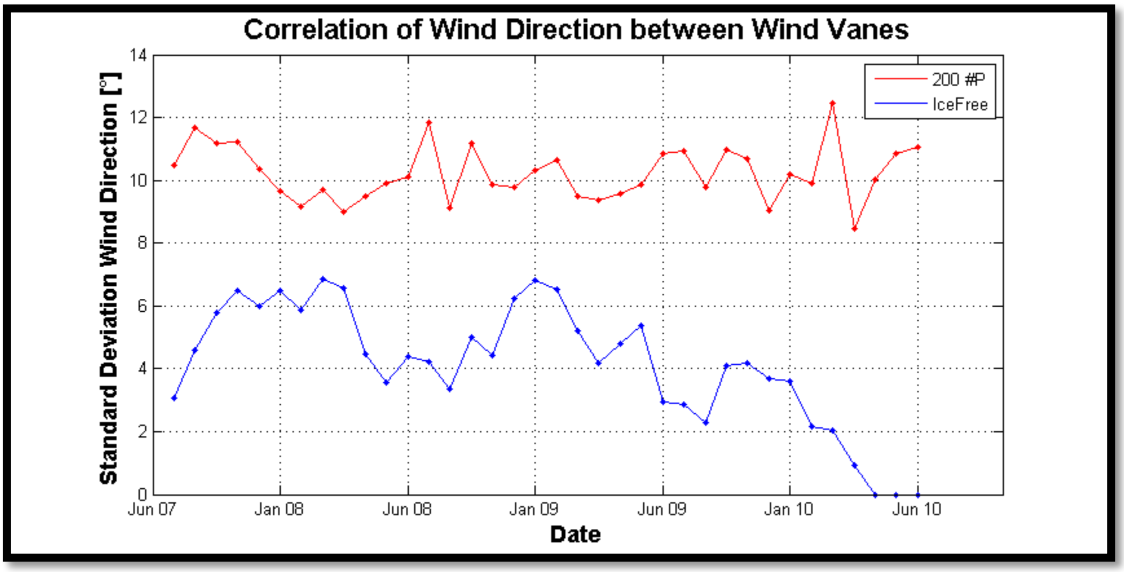

Figure 20 - Standard deviation of wind direction from both wind vanes. The plot illustrates the corresponding values for the first three years and measurements are presented in monthly averages

For this study, the Risø 200#P wind vane is selected as primary reference.

Pre-processed wind climate

The data recovery for the fourth year is poor, hence this year is disregarded. Low data recovery data does not describe the real wind regime and its seasonal variation.

3.1.2 Range Tests

The range tests are the most used validation tests, and consist of upper and lower limiting values of different measures of the measured data. In Table (7) the range tests used in this analysis is shown. The limits of each range test must be set so they include nearly (but not absolutely) all of the expected values for the site.

Not all the presented range tests are carried out. Atmospheric stability analysis has not been an objective; hence measurements of solar radiation, differential temperature and vertical wind speed have not been of interest. Such measurements have also not been carried out at the measurement station. For similar reasons (bad quality and lack of measurements) several relational and trend tests have not been performed.

Furthermore complementary annotation of tests and approaches are presented for the tests where this is considered a necessity.

Year	*2007/2008*	*2008/2009*	*2009/2010*	*2010/2011*	***2007-2010***
Parameter					
Mean Wind Speed [m/s]	6.46	6.10	5.03	5.86	**5.86**
Standard Deviation Wind Speed [m/s]	0.87	0.82	0.67	0.77	**0.79**
Data Recovery [%]	99.3	100.0	99.3	68.3	**99.5**

Table 6 - Data results before screening and processing

Sample Parameter	AWS Validation Criteria	Validation Criteria	Number of Suspected Data
Wind Speed: Horizontal			
Average	Offset < Avg. < 30 m/s	Offset < Avg. < 30 m/s	366
Standard Deviation	0 < Std. Dev. < 3 m/s	0 < Std. Dev. < 3 m/s	1911
Maximum Gust	Offset < Max < 35 m/s	Offset < Max < 35 m/s	138
Wind Direction			
Average	0° < Avg. < 360°		0
Standard Deviation	3° < Std. Dev. < 75°	1° < Std. Dev. < 75° *	1848
Maximum Gust	0° < Max. ≤ 360°	0° < Max. ≤ 360°	0
Temperature	Varies seasonally		
Typical Range	-35° < Avg. < 35°C	-35° < Avg. < 35°C	0
Solar Radiation	Varies seasonally		
Typical Range	Offset < Avg. < 1200 W/m2	-	-
Wind Speed: Vertical	Varies with terrain		
Average **(S/C)	Offset < Avg. < ± (2/4) m/s	-	-
Standard Deviation	Offset < Std. Dev. < ± (1/2) m/s	-	-
Maximum Gust	Offset < Max < ± (3/6) m/s	-	-
Barometric Pressure	Optional: Sea Level Shown		
Average	94 kPa < Avg. < 106 kPa	94 kPa < Avg. < 106 kPa	289
Differential Temperature	Optional		
Average Difference	> 1.0° C (daytime)	-	-
Average Difference	< 1.0° C (overnight)	-	-
TOTAL			**4552**

Table 7 - Range tests and corresponding criteria and suspicions

3.1.2.1 Average wind speed (Horizontal)

The first part of the range check is to validate the range of the measured horizontal wind speeds. However, initially during a wind data validation, the time series is plotted and a rapid visual validation is performed, to reveal possible abnormal behaviors.

The minimum measured wind speed in the time series is 0.2 m/s, whereas the maximum is measured at 30 m/s. The Risø anemometer is, however, calibrated to an offset value of 0.27 (Risø National Laboratory). In Table (7) it is specified that the average wind speed should be in the range between offset value and 30 m/s. There is one spike at 30 m/s, being the maximum wind speed measured.

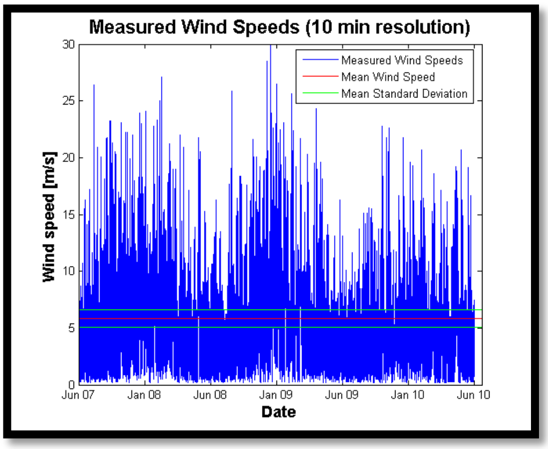

Figure 21 - Average wind speeds for the first three years

By visual inspection, this spike, as well as other, seems to be real. This is on the basis that ambient measurements follows, hence it is a trend. However, the lower level should not be accounting for values lower than or equally to the offset value; hence these data are given an error code 995.

3.1.2.2 Standard deviation of wind speed (Horizontal)

The range of the horizontal wind speed standard deviation measurements is specified in Table (7) to be larger than zero, but less than three. The data set has suspect measurements in both ends of the range, illustrated by Figure (22). The red dotted line indicates independent measurements with standard deviation equal to zero, whereas the blue dotted line is the distribution of standard deviation measurements equal three or more. The featured and conservative range is applied, and such erroneous are marked as 999.

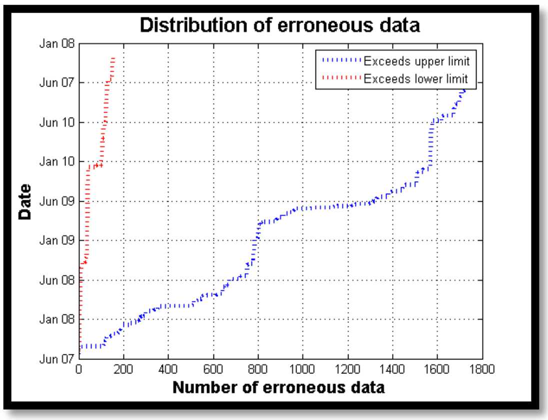

Figure 22 - Suspected standard deviations of horizontal wind speed distributions in the time series. The first three years are utilized

A large number of abnormally high measurements of wind speed standard deviation might be an indication of a turbulent wind regime; hence cases of flattening of the corresponding distribution (blue dotted line) might be sign of a high turbulent period. The area surrounding the meteorological mast is known to be characterized by turbulence, due to the large mountain in the eastern direction. However measurement on turbulence, e.g. by a sonic anemometer, is not provided; hence the AWS guideline has been utilized.

3.1.2.3 Maximum gust wind speed (Horizontal)

In both ends of the range stated for gust speeds there are suspicious measurements. Most of the measurements exceeding the limits are gathered. Ambient measurements of the spikes are showing a trend, making the suspicious peaks more reasonable. The maximum wind speed is measured equal to 40 m/s, being a realistic obtainable speed. In order to assure whether there was a storm during the periods of suspicious gust, a cross-checking with the heliport have been carried out. The heliport only contains 10 minutes average data for wind speed at 10 meter height, which have been used in the validity assessment. The mean values are high, usually 20 m/s or more during the suspected time period, indicating period of strong winds. Therefore, no invalid measurements in terms of horizontal gust wind speed are found. On the other hand, there are several logged data of gust measurements below the offset value. These measurements are discarded and marked as 998.

High gust speeds December 8th 2008
34.8 m/s
35 m/s
37.3 m/s
36.3 m/s
37 m/s
35.7 m/s
35 m/s
34.1 m/s
34.5 m/s
35 m/s
36.7 m/s
35.4 m/s
36 m/s

Table 8 - High gust speeds. Excerpt from the time series on December 8th 2008 refers to ambient verification of exceeding measurements and indication of a strong wind period

3.1.2.4 Standard deviation of wind direction

This test proved hard to apply to the measurements, and required a more thorough assessment. Application of statistical «best-practice» would in this case reject 11.16 % of the data. The main issue and misleading is regarding the test's lower limit, as such flagging might be an indication of icing events. Being a site in Greenland, this is not an indicator to ignore. The test is therefore carried out in conjunction with icing.

To evaluate the risk of icing accretion on the measurement instrument and thus the data's validity, the wind vane measurements are investigated. The wind vane is known to be the weaker link in terms of icing accretion, as the direction of the wind speed do not change as much as the wind speed itself (Alaska Energy Authority, 2006). Although data are considered suspicious by statistical models, they may still be of valid origin. In order to avoid deleting such data and keep the recovery rate at an adequate ratio, and thus to best describe the wind regime, several inspections and relations have been carried out. A case of icing is more likely to be of affection for more than 10 minutes, thus several continuous 10 minute averages would be assumed to be affected and reflect an incident. First of all, the measurements are collected by means of two wind vanes, where one of them is ice-free. However, the ice-free wind vane stopped working approximately in March 2010. In order to determine the lower value of standard deviation of the wind direction, investigation of the relation between the measurements from these two vanes to find cases where they are not correlated have been carried out. The lower validation criteria for the wind direction are either 1 or 3°, according to Table (7). For high values of the lower limit (3°), the measurements of the two wind vanes seem to correlate for most of the suspected data. For lower limits (1°), the vanes seem to be less correlated. Small changes in the wind direction are obviously possible within a 10 minutes

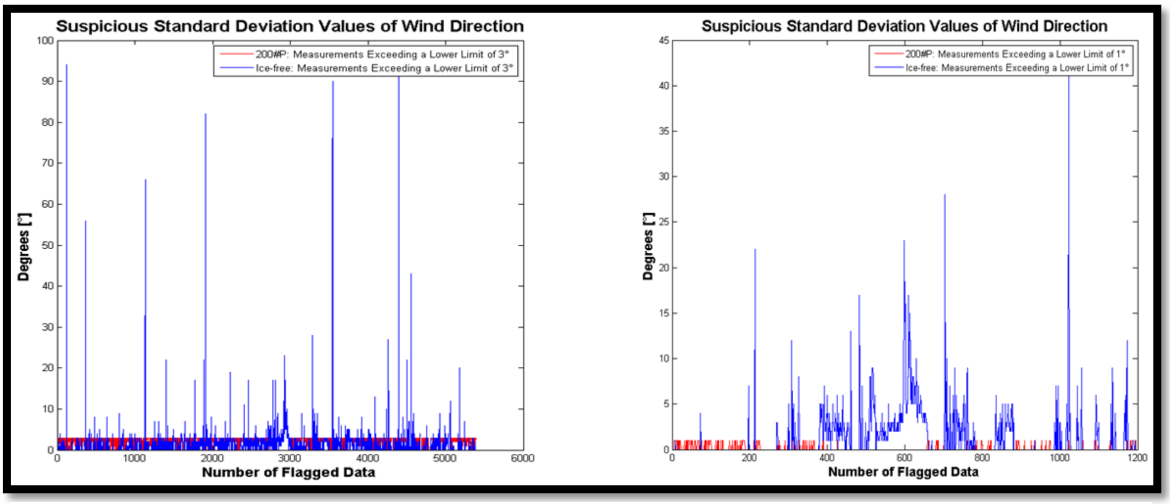

Figure 23 - a) Correlation between the two wind vanes for values of standard deviations of wind direction below 3 m/s. As the ice-free instrument cannot suspect risk of ice accretion, the suspected measurements are referred to by the 200#P wind vane. b) Correlation between the two wind vanes for values of standard deviations of wind direction below 1 m/s. As the ice-free instrument cannot suspect risk of ice accretion, the suspected measurements are referred to by the 200#P wind vane

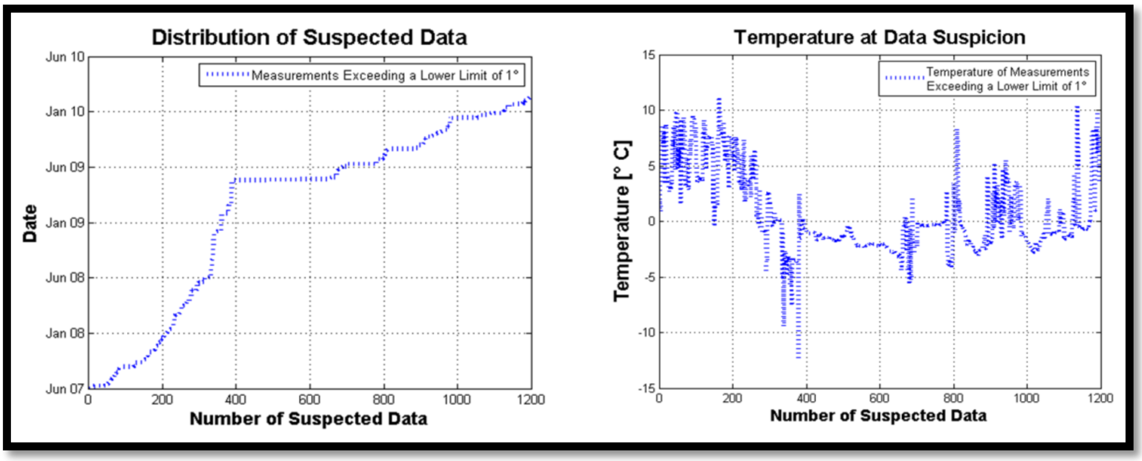

Figure 24 - a) Distribution in time of standard deviation values of wind direction below 1°. b) Temperature for measurements with standard deviation of wind direction below 1°

average, hence other parameters needs to be taken into account in the assessment of data validation with respect to risk of ice accretion. The second parameter of interest is the temperature. Icing events are usually flagged when the standard deviation recorded by the direction vanes is zero or near zero, and the temperature is near or below freezing. This is a conservative approach since direction vanes tend to freeze before anemometers do. During periods of detectable icing, it is unwise to rely on anemometer data even if the anemometers indicate speeds above the offset, since they may be slowed by moderate ice accumulation (AWS Truepower, 2010). Figure (25) gives an idea of ice accretion probability with respect to temperature.

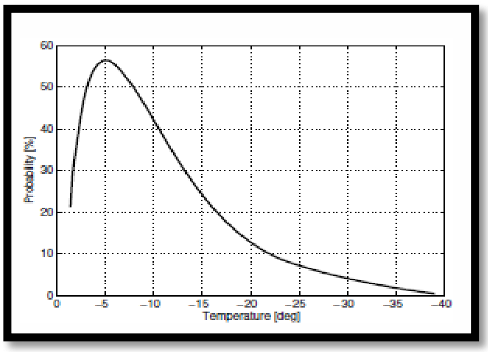

Figure 25 - Probability of ice occurrence versus temperature (Branlard, 2010)

In this analysis, the 10 minute resolution data has been utilized. Possible invalid flagging are thus likely to occur, as ice accretion will be a case for continuous measurements. Cases of continuity and temperature relation for suspected data is clearly visualized by studying the parallels between the plots in Figure (24). By taking a closer look at these plots; flagged data often appoints to low temperatures. Especially in the cases of longer continuity, the risk of icing is assumed to be high. Therefore, all data suspected at temperatures below zero degrees are marked as 994. Note that the temperature measurements are known to include some uncertainties, estimated to be ± 2° C. This uncertainty is assumed to even out the bundled errorBy straightforward application of the parameter reference given by the range test, the consequence would be an inadequate recovery rate. Such act would be considered as waste of good and useful data. It might also be crucial in estimation of the wind regime, and would certainly involve great uncertainty of the project's feasibility. By adopting several methods in this assessment, the error rate of the standard deviation of the wind direction have been reduced from 11.16 % to 1.18 %.

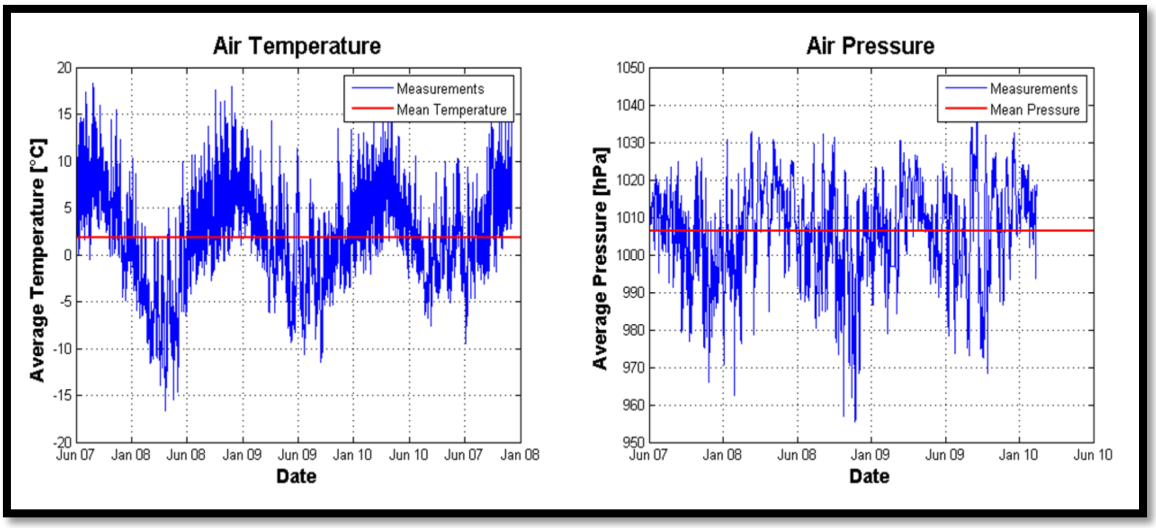

Figure 26 – a) Temperature measurements (10 min average) for the first three years. b) Pressure measurements (60 min average) for the first three years

3.1.2.5 Temperature and barometric pressure

At the meteorological station, the pressure has not been measured. Pressure measurements from the heliport have therefore been utilized. These measurements are carried out in hourly resolution, while the temperatures are in 10 minute resolution.

Pressure and temperature data are mainly of interest regarding air density calculations, used to determine the wind power density at the site. However, as WAsP only can utilize one value of air density for such computation, a few errors make insignificant impact. Rejection of wind data would thus be reckless. Instead, such suspicions are treated otherwise.The temperature measurements are well within the given range, whereas there are some pressure errors. These errors are set to mean pressure, but could also be calculated by measurements in the cloce vicinity of the erroneous ones. The temperatures also seem to be normally distributed with respect to the seasonal changes in Greenland (Hub Pages, 2011). Temperature and pressure are respectively illustrated in Figure (26).

The pressure time series proved several invalid measurements. Several negative values were found, which is physically not attainable. However, neither the range of temperature or pressure data are processed at this point, but rather dealt with in conjunction with calculations of air density. Information relating to the processing of such errors is given in Chapter (3.8).

3.1.2.6 Correlation between measured temperature

The temperature has been measured at both the 1601 Nanortalik met mast and the Nanortalik Heliport met mast. By using the data from June 2007 till June 2009, the following plot of the temperatures have been obtained:

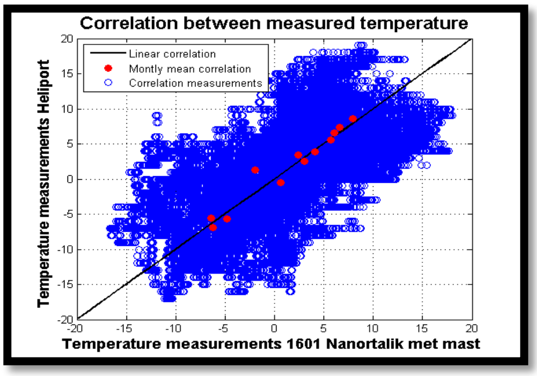

Figure 27 - Comparison of the hourly temperatures between the 1601 Nanortalik met mast and the Nanortalik Heliport met mast from June 2007 till June 2009

The measurements for the Nanortalik Heliport met mast is recorded every hour, whereas the 1601 Nanortalik met mast records the measurements every 10 minutes. Thus, averages of each hour are made to be able to compare the two time series. As can be seen from the figure, the correlation between the two measurement series is acceptable as they show similar trends over the years. Some deviations are, however, observed from the monthly averages. This could be due to different measuring heights (minor effects), different local influences and different configurations of the measuring devices. The conclusion is that the measured temperature at the Heliport site can be used for the air density calculation.

The deviation could be within reasonable values, considering that there are several uncertainties associated with this correlation plot; stretching from local meteorological conditions, wrongly calibrated measurement equipment toinstrument quality and condition.

3.1.3 Relational Tests

The relational tests are based on expected physical relationships between various parameters. In Table (9), the relational tests used in this analysis are shown. Relational checks should ensure that physically improbable situations are not reported in the data without verification. By use of the recommended criterion given in Table (9), 1 156 data, equivalent to approximately 1 %, are found to be suspicious of relation. However, as both the gust and average wind speeds have through other validation tests been processed, the conservative range is extended. Allowing a maximum ratio of three, appoints and rejects only ap-

Sample Parameter	*AWS Validation Criteria*	*Validation Criteria*	*Number of Suspected Data*
Wind Speed			
Max Gust vs. Average	Max Gust ≤ 2.5 x Avg.	Max Gust ≤ 3 x Avg.	1156
60 m / 40 m Average Difference	≤ 3 m/s	-	-
60 m / 40 m Daily Max Difference	≤ 5 m/s	-	-
60 m / 25 m Average Difference	≤ 5 m/s	-	-
60 m / 25 m Daily Max Difference	≤ 8 m/s	-	-
Wind Speed: Same Height		-	-
Average Difference	≤ 0.5 m/s	-	-
Maximum Difference	≤ 3.0 m/s	-	-
Wind Direction		-	-
60 m / 25 m Average Difference	≤ 20°	-	-
Wind Shear	Varies with terrain	-	-
60 m / 25 m Average	$-0.05 < \alpha < 0.45$	-	-
TOTAL			**1156**

Table 9 - Relational tests and corresponding criteria and suspicions

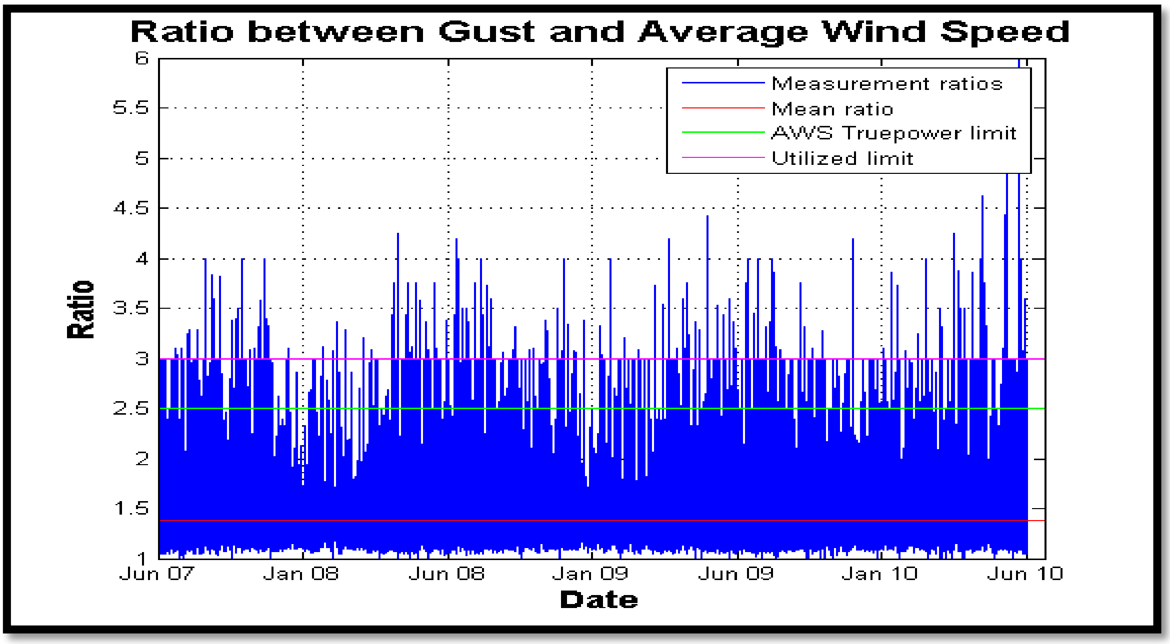

Figure 28 - Ratio between measurement of gust and average wind speeds

proximately a seventh of the primarily suspected data. Such exceeding events are categorized and marked by 997.

3.1.4 Trend Tests

The trend tests are based on the rate of change in a value over time. In Table (11) the trend test criteria are listed.

3.1.4.1 Average wind speed average: 1-hour change

By applying the AWS Truepower's solicitation forth in Table (11), 3.1 % of the data was found out of trend and should therefore be rejected. In order to maintain an adequate recovery rate of the data, the concervative hourly wind speed change of < 5 m/s needed to be modified.

Further research proved the average wind speed trend test to be far too conservative for this site, hence two modifications of the detection loop was carried out. Primarily, the time of the wind speed comparison was changed to be within two ten-minute averages. Furthermore, the allowed derivative was changed to twice the given value, 10 m/s, in accordance wih the supervisor of the project (Jakobsen K. R., 11427 Arctic Technology , 2012). Such a test practice refers only to one suspect measurement throughout the whole time series, which are marked as 996.

3.1.4.2 Temperature average and barometric pressure average

For the same reason as stated in the range test, invalid temperature and pressure data do not affect the data processing carried out in this chapter. Although, the suspicious measurements presented by this test are taken into account in computation of air density and wind power density.By automatic screening, 215 temperature measurements have been flagged due to untrendy behavior. On the other hand, there are no new exceedances with respect to pressure. These suspicions are the same erroneous pressure measurements discovered and presented in the range test.

3.1.5 Summary

By combining AWS Truepower's data validation routine with some site customized modifications, the final discarded data are presented in Table (10). Note that samplings related to temperature and pressure are not discarded, but rather processed by other means.

Sample Parameter	*AWS Validation Criteria*	*Validation Criteria*	*Number of Suspected Data*
Wind Speed Average	All sensor types		
1-Hour Change	< 5.0 m/s	< 10.0 m/s *	1
Temperature Average			
1-Hour Change	≤ 5°C	≤ 5°C	215
Barometric Pressure Average	Optional		
3-Hour Change	≤ 1 kPa	≤ 1 kPa	93
Differential Temperature	Optional		
3-Hour Change	Changes sign twice	-	-
TOTAL			**309**

Table 11 - Trend tests and corresponding criteria and suspicions

Sample Parameter	*Number of rejected Data*	*Erroneous Data Share [%]*	*Erroneous Data Distribution [%]*	*Code*	*Rejection Criteria*
Range tests					
Wind Speed: Average	366	0,23	6,7	995	Invalid (below offset value)
Wind Speed: Standard Deviation	1911	1,22	35,3	999	Abnormal behavior (unknown event)
Wind Speed: Maximum Gust	138	0,09	2,6	998	Invalid (below offset value)
Wind Direction: Standard Deviation	1848	1,18	34,1	994	Risk of ice accretion and abnormally high value
Relational tests					
Wind Speed: Max Gust vs. Average	1156	0,74	21,3	997	Abnormal behavior (unknown event)
Trend tests					
Wind Speed (Avg.): 1-Hour Change	1	0,00	0	996	Abnormal behavior (unknown event)
TOTAL	**5420**	**3,45**	**100**		

Table 10 - Algorithmic tests and related data rejection

Year	*2007/2008*	*2008/2009*	*2009/2010*	***2007-2010***
Parameter				
Mean Wind Speed [m/s]	6,40	5,99	5,06	**5,81**
Standard Deviation Wind Speed [m/s]	0,84	0,79	0,66	**0,76**
Data Recovery [%]	95,1	97,2	97,3	**96,5**

Table 12 - Measured data after screening and processing

3.1.5.1 Post-processed wind climate

"The observed wind climate (OWC) should represent as closely as possible the long-term wind climate at anemometer height at the position of the meteorological mast. Therefore, an integer number of full years must be used when calculating the OWC, in order to avoid any seasonal bias. For the same reason, the data recovery rate must be quite high (> 90-95%) and any missing observations should preferably be distributed randomly over the entire period" (Mortensen, Planning and Development of Wind Farms: Wind Resource Assessment and Siting, 2011). In this analysis the Nanortalik wind regime is described by usage of three years of measurements where all have fulfilled the minimum required recovery rate. The distributions of the rejected data are illustrated in Figure (29).

The rejected data are randomly distributed throughout the three-year time series. At the most, the screening rejects a few hours of continuous data, which is far from the recommended limit of approximately 14 days (Berg, 45701 Introduction to Micro Meteorology for Wind Energy, 2011).

3.1.6 Summary of Data Validation and Processing

In Chapter (3.11) the mean wind speeds for another measurement mast, located in Nanortalik from 1960 till 1984 (in addition to one measurement in 2006) is evaluated. There are found large fluctuations in the mean wind speed from year to year, with a span of 2 m/s. Taken into account that the equipment back then did not have the same

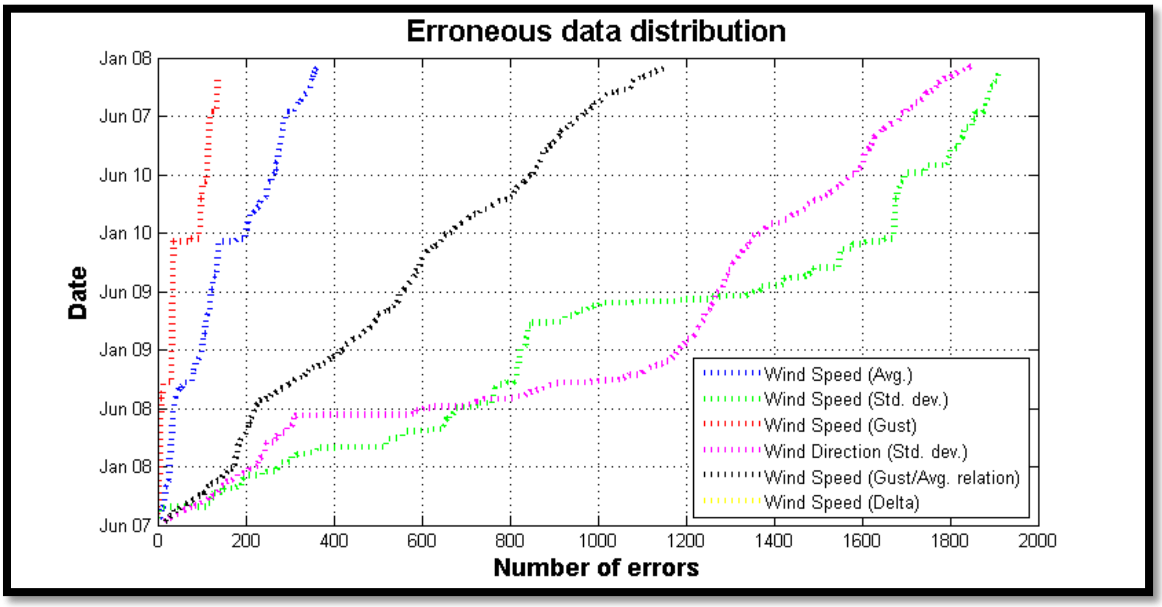

Figure 29 - Rejected data distribution for algorithmic tests

accuracy as the ones used in the recent years, the measurements still prove that large variation exists in Nanortalik on an annual basis. It is nevertheless seen that the mean of the long term prediction is approximately 5.5 m/s at 10 m height. The reference site, described in Chapter (3.4), proved a mean wind speed at 10 m height at the Heliport Weather station equal to 4.55 m/s for the same time period as the measurements from the 1601 Nanortalik meteorological mast were conducted. By evaluating the annular mean wind speed from 2007 till 2010, a periodical mean is found equal to 4.43 m/s (see Table (13) for the Heliport site. As can be seen, there is a difference in the two mean wind speeds, which is due to the years of measurements used. In Table (13), the raw data from the Heliport Weather Station is used to get an overview of the wind climate, without processing the data through a validation script. In Chapter (3.4), the heliport data is processed; hence a more correct wind speed is obtained. The raw data nevertheless proves valuable to assess the annual variation of the wind speed, as a large difference is found for the year 2009-2010.

Wind Speed Measurements – Heliport Weather Station		
Measurement year (June to June)	**Mean wind speed (m/s)**	**Change from mean wind speed**
2007 to 2008	4.39	0.9 %
2008 to 2009	4.61	4.1 %
2009 to 2010	3.91	**11.7 %**
2010 to 2011	4.79	8.1 %
Mean period	**4.43**	

Table 13 - Wind Speed Measurements – Heliport Weather Station (Pre-processing of data)

The same comparison can be made for the wind speed measurements at the 1601 Nanortalik meteorological mast. Considering that the filtering routine performed in this analysis did not approve the measurements for the last year (2010-2011), the report from Kjeller Vindteknikk is utilized. The measurements obtained in that report are presented in Table (14).

Wind Speed Measurements – 1601 Nanortalik Meteorological mast		
Measurement year (June to June)	Mean wind speed (m/s)	Change from mean wind speed
2007 to 2008	6.50	8.1 %
2008 to 2009	6.16	2.5 %
2009 to 2010	5.05	**15.9 %**
2010 to 2011	6.34	5.4 %
Mean period	**6.01**	

Table 14 - Wind Speed Measurements – 1601 Nanortalik Meteorological mast (Kjeller Vindteknikk)

By comparing Table (13) and Table (14) it is observed that the by far largest difference is found for the measurement during the year from 2009 to 2010 with 15.9 % difference for the mean wind speed for the period. It is therefore reasonable to conclude that this specific year is not representable for the 20 year wind regime in Nanortalik, as the low wind year (2009 to 2010) contributes in a negative manner.
Therefore, the mean wind speed of 5.81 m/s used in this analysis is conservative, which implies that the annual energy production calculated in Chapter (4) also is conservative. This also affects the total economy of the project in a negative manner. The mean wind speed is regardless used throughout this analysis.

3.2 Generalised Wind Climate

By usage of WAsP software (Technical University of Denmark, 2012) a generalised wind climate, or wind atlas, of Nanortalik can be created, which contains wind speed and direction data in the region. WAsP predictions are based on the *observed wind climate* at the met. station site; i.e. time-series of measured wind speeds and directions over one or several years that have been binned into intervals of wind direction (the wind rose) and wind speed (the histograms). Therefore, the quality of the measurement data has direct implications for the quality of the WAsP predictions of wind climate. The quality of the data was validated in the filtering process described in section (3.1). In order to obtain the generalized wind climate, two inputs must be applied:

- Observed Wind Climate
- Met. station site description

The observed wind climate is created from the wind data provided by the met mast described in the previous section. As described, the met mast has functioned without supervision during the period, resulting in several periods with incorrect readings. Therefore the data needs to be filtered for abnormal variations in the wind behavior. The outcome of the filtering process is a three years time series stretching from June 2007 till June 2010.

In addition to the observed wind climate, a site description of the meteorological station needs to be performed, and potential obstacles need to be taken into account before a complete wind atlas is created. As can be seen in Figure (35), there are some buildings in the vicinity of the met mast which could affect the readings. Thus, these obstacles needs to be included in the wind atlas created in WAsP. In the following, the different aspects of the creation of the wind atlas are undergone.

3.2.1 Observed Wind Climate

The observed wind climate of Nanortalik is presented in Figures (30) to (34), representing the Weibull distribution and Wind Rose of the region. Both of them are calculated in

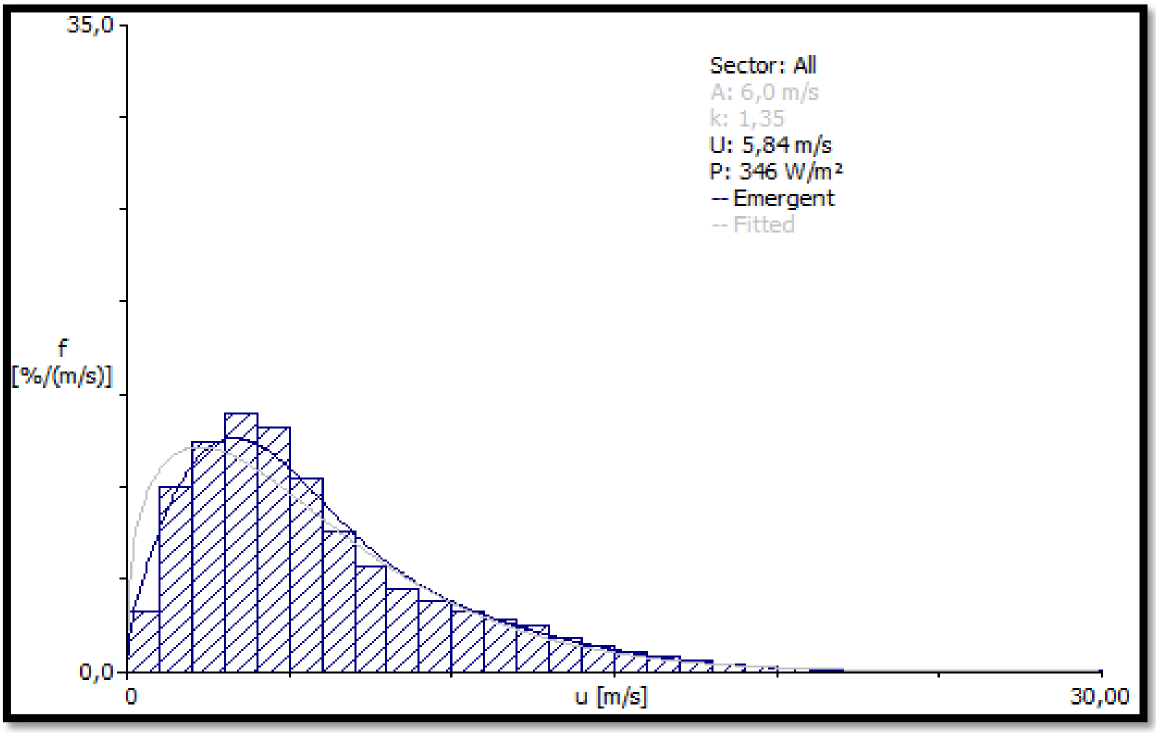

Figure 30 - Weibull distribution 1601 Nanortalik met mast (WAsP)

the WAsP software and compared by using Matlab. As can be seen from the figures, the wind direction is primarily situated from north, with Sector 2 (15-45°) as the major contributor with a frequency of 26.4 %. The calculated mean wind speed of the region is **5.81 m/s**. This corresponds well to the mean wind speed calculated in a wind analysis made by Kjeller Vindteknikk AS (Kjeller Vindteknikk, 2011), where the result was 6.01 m/s. The difference is due to different years of data used and different filtering methods of the data. In the next sections, the Weibull distribution and Wind Rose are undergone and validated. The Weibull distribution is a probability density function calculating the possibility for the different wind speeds to occur. In order to correct for a local siting, a scaling factor A and a shape factor k is implemented in the probability density function. The general Weibull distribution is presented in Equation (4):

$$Weibull\ pdf(V_0) = k\frac{{V_0}^{k-1}}{A^k}\exp\left(-\left(\frac{V_0}{A}\right)^k\right) \quad \textbf{(4)}$$

To calculate the A and k parameters of the Weibull distribution, the first and second moments (the equations for the mean (μ_x) and the variance ($\sigma^2{}_x$) of the wind data series) are utilized are used.

$$\mu_x = A\Gamma\left(1+\frac{1}{k}\right) \quad \textbf{(5)}$$

$$\sigma^2{}_x = A^2\left(\Gamma\left(1+\frac{2}{k}\right) - \Gamma^2\left(1+\frac{1}{k}\right)\right) \quad \textbf{(6)}$$

The gamma function, Γ(x), is defined as

$$\Gamma(x) = \int_0^\infty t^{x-1}\, e^{-t}\, dt \quad \textbf{(7)}$$

In order to set up two useful functions with the two unknown parameters, both (5) and (6) are put equal to zero. The function for Γ (7) is implemented in (5) and (6), and also (6) is reorganized in such a way that there is only one unknown, k. This is done by replacing the unknown A in (6) with a function made for A in (5).

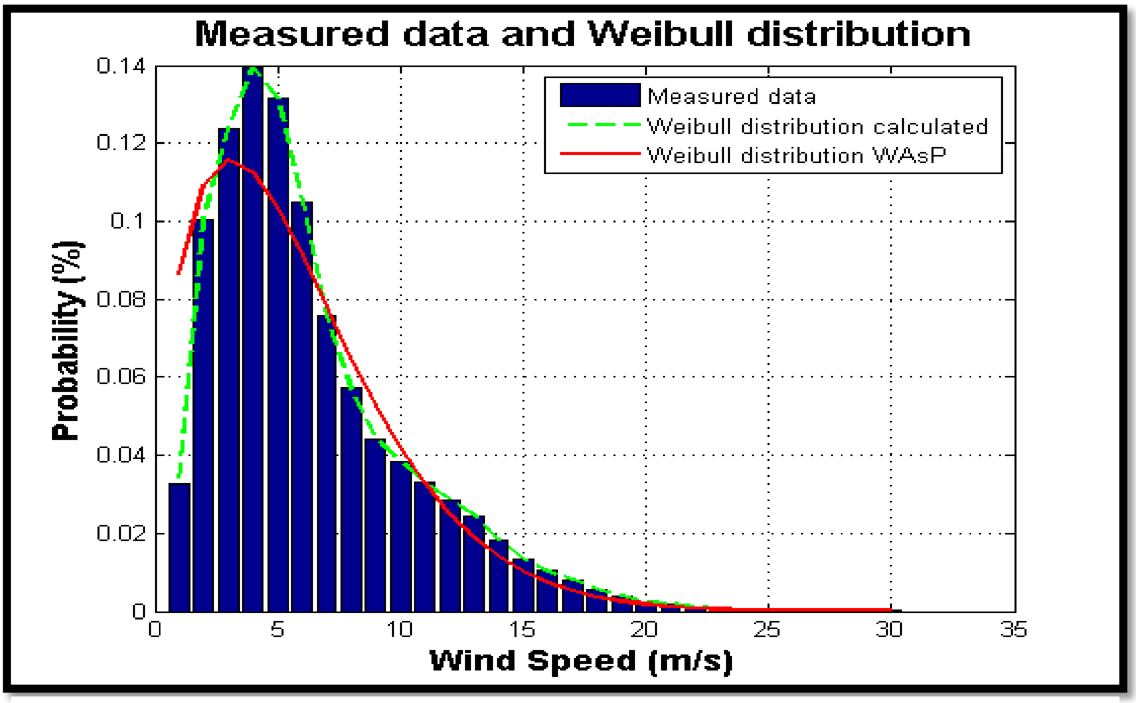

Figure 31 - Weibull distribution 1601 Nanortalik met mast

In Matlab the function "fsolve" is utilized to iteratively solve these two equations with the two unknown parameters, A and k. Matlab uses iteration between the two functions to find the values that gives a solution, based on a guess which is put into the function. The optimized values for the parameters A and k for 1601 Nanortalik are:

- **A = 6.44**
- **K = 1.50**

For most wind conditions, the k value range from 1.5 to 3.0 (K. Ulgen, 2002). The calculated value at 1.50 is therefore considered to be relatively small, and proves a quite spread wind regime. The A value is also within the range of expectancy, due to the fact that 62.9 % of the wind speeds are below this speed (Norges Miljøvernforbund, 2009).

The Weibull distribution of 1601 Nanortalik met mast is presented in Figure (31) where the red line is the simulated Weibull distribution created from the WAsP software and the dotted green line is the calculated distribution by usage of Matlab.
As can be seen from the figure, the calculated and WAsP simulated Weibull distributions are slightly uncorrelated. This is due to different Weibull parameters. The Weibull parameters obtained in WAsP are:

- **A = 6.0**
- **K = 1.35**

The reason for this uncorrelation is due to that the applied software, WAsP, is based on an emergent distribution, whereas the Matlab script calculates the combined Weibull distribution. At WAsP FAQ site the following explanation is found (Technical University of Denmark, 2010):

"In WAsP 8 and later versions, wind farm and single-turbine productions are based on the so-called emergent distribution (see the definition below), and consequently this distribution is the standard total or all-sector distribution referred to.

This is a change from WAsP 7 and earlier versions, where the so-called combined Weibull distribution was the standard all-sector distribution used for production calculations. The use of the emergent all-sector distribution for production calculations has been found to be more accurate – the reason for using the combined distribution in previous WAsP versions was mostly historical (low computer speed).

In most cases, the difference is practically of no importance, but in cases of large sector-wise variations in the wind speed distributions, the difference in calculated production may be non-negligible (up to 5% has been encountered).

Definitions of all sector wind speed distributions
All-sector wind distributions are sometimes also referred to as 'stacked', 'total' or 'omni-directional'.

- ***Fitted Weibull distribution*** *Weibull distribution fitted to an all-sector (stacked) wind speed histogram. Used only in connection with the observed wind climate, i.e. the *.tab and *.owc files.*

- ***Emergent distribution*** *The weighted sum of the Weibull distribution values from all the direction sectors. In general, this distribution is NOT a Weibull distribution; e.g. it could be bi-modal in case of two dominant sectors with very different mean speeds. Used in connec-*

tion with regional (wind atlas) as well as predicted wind climates.

- ***Combined Weibull distribution*** *The Weibull distribution matching the mean speed and power density (1st and 3rd moments) with the weighted sum of the sector-wise mean speeds and power densities, respectively. The combined Weibull distribution has the same mean speed and power density as the emergent distribution. Used in connection with regional as well as predicted wind climates."*

The Weibull distribution is useful in the calculations of the energy production from the wind turbine(s), and is therefore often applied in system analysis of wind power integration.

Another method to describe the wind speed distribution is by usage of a cumulative density function (CDF). This function describes the probability a wind speed with a given probability distribution has to be found at a value less than or equal to a given wind speed. Intuitively, it is the "area so far" function of the probability function. The CDF of the wind climate of 1601 Nanortalik met mast is presented in Figure (32).

From the CDF it is observed that the most likely wind speed range is from 0-7 m/s, as this range is present 70 % of the time. Wind speeds above this range are of course present during the year, but the vast majority is defined as low speed wind. This implies that a low speed wind turbine must be used in this system, as is further undergone in Chapter (4).

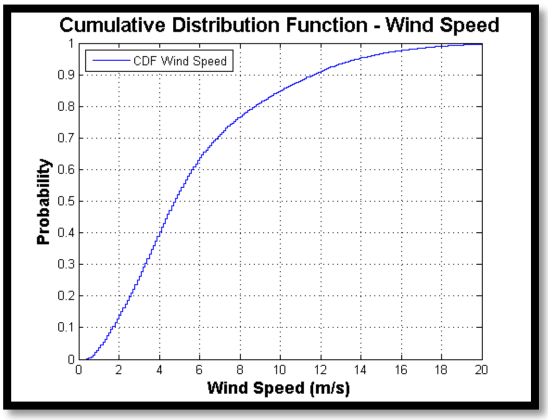

Figure 32 - Cumulative distribution function - Wind Speed

3.2.1.1 Wind Rose

The wind rose gives a succinct view of how wind speed and direction are typically distributed at a particular location. Presented in a circular format, the wind rose shows the frequency of winds blowing from particular directions. The wind roses presented in Figure (33) and (34) are both divided into twelve sectors, each representing 30°.

In order to validate the WAsP calculated wind rose (Figure (34)), the wind rose is also calculated by usage of Matlab (Figure (33)). The wind roses are identical in both shape and magnitude, thus both validates each other.

From the wind roses it is observed that the majority of the wind is directed from northeast (Sector 2). The frequency of wind coming from this sector is 26.4 %, whereas the second highest frequency is found in sector 1 (12.2 %). By also including that 11.8 % of the wind is coming from sector 12, the total amount of wind coming from north is 50.4 %. This is a number of great importance in the determination of the location of the wind turbine(s), both in terms of avoiding turbulence and to avoid obstacles in this direction.

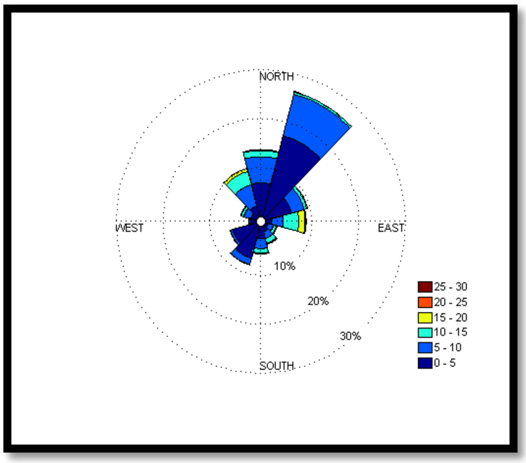

Figure 33 - Wind Rose 1601 Nanortalik met mast (Matlab)

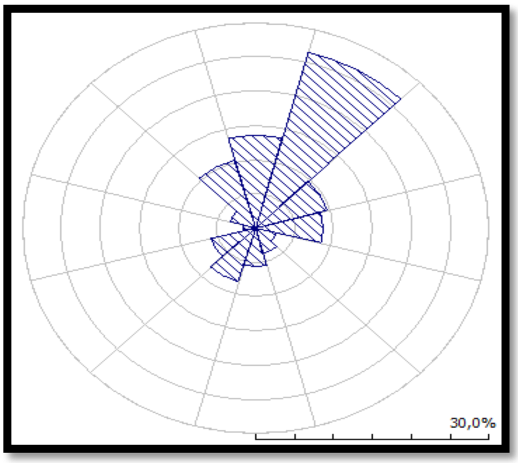

Figure 34 - Wind Rose 1601 Nanortalik met mast (WAsP)

Even more information can be found by the sector wise distribution by listing the mean wind speed, k-factor, A-factor, power density and frequency (see Table (15)). All of these are gathered from the WAsP software:

Sector	*μ*	*k*	*A*	*Power density (W/m²)*	*Freq. (%)*
1	5.5	1.62	6.1	247	13.5
2	4.4	2.06	5.0	98	26.6
3	4.7	1.35	5.1	201	9.6
4	10.9	2.69	12.3	1 193	8.7
5	8.6	2.40	9.7	637	2.8
6	7.9	2.00	8.9	574	3.8
7	6.4	1.59	7.1	398	5.7
8	3.5	1.87	4.0	56	8.2
9	3.2	1.73	3.5	43	5.9
10	3.3	0.93	3.2	163	1.7
11	7.0	1.86	7.9	436	3.4
12	8.4	2.18	9.5	639	10.2
Mean fitted	5.54	1.35	6.0	334	
Mean source data	5.81			333	

Table 15 - Sector wise wind climate 1601 Nanortalik met mast

The values in Table (15) correspond to the wind rose in Figure (34). As can be seen from the table, there are large differences between the sectors. The sector with the highest frequency (sector 2) has one of the lowest mean wind speeds, thus also one of the lowest power densities (98 W/m^2).

Figure 35 - Map of the obstacles close to the 1601 Nanortalik met mast

The sector with the highest power density is sector 4, with a mean wind speed of 10.9 m/s and a power density of 1 193 W/m^2. The large differences between the different sectors are due to the terrain of the area. As can be seen in Figure (37), there are several geographical factors that have large influence on the wind, with the fjord located to northeast and the mountain located to east as the major contributors.

3.2.2 Meteorological Station site description

If obstacles are present near the possible site or the meteorological mast, these obstacles needs to be modeled in WAsP because of their influence of the collected wind data. The obstacles could for example be terrain features such as houses, walls, shelter belts, a group of threes etc.

From (Mortensen, Wind Resource Assessment and Siting, 2011) the following definition of an obstacle is found:

- If the site (anemometer, turbine hub or other calculation point) is closer to an obstacle than about 50 obstacle heights (*H*) and its height lower than about 3 obstacle heights – then treat it as a sheltering obstacle and use the shelter model.

- If the site is further away then 50*H* and/or higher than 3*H*, then treat the feature as a roughness element, i.e. adding to the general roughness of the terrain.

For the area surrounding the meteorological mast, there are four obstacles/ obstacle groups that could affect the measurements, and that therefore needs to be included in the generalized wind climate. These are presented in following map, taken from the WAsP simulation:

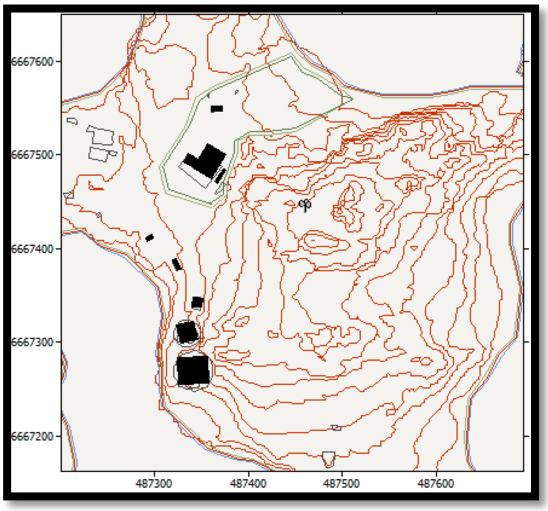

Figure 36 - Obstacles close to the 1601 Nanortalik met mast

After modeling the obstacles close to the met mast, the generalized wind climate was simulated without giving any change. This is probably due to the height of the met mast at this location. On this basis the obstables further away are neglected.

Even though the obstacles most likely are too far and/or too small to affect the result, they are included in the generalized wind climate to make it as precise as possible.

3.3 Topographical Inputs

The topographical inputs to WAsP are given in the *vector map*. The vector map is created in the WAsP Map Editor, and contains information regarding height contours, roughness change and obstacles if present. The height contours are described by an elevation map, whereas a land cover map contains the roughness length of the area.

3.3.1 Elevation Map

As mentioned, the elevation map contains the height contours of the terrain. From (Mortensen, Wind Resource Assessment and Siting, 2011) it is given that the elevation map should extend *"at least 2-3 times the horizontal scale of significant orographic features from any site, being either met mast, reference site, turbine site or resource grid point"*. A widely used rule for the minimum extent of the map is 100 x height of the measuring device or hub height of turbine. In this analysis the size of the quadratic map is 19 km^2, thus the general rule is satisfied.

As the accuracy and detail of the elevation map are most critical close to the site, different resolutions are used for the areas within the map. The map is built with a base of a height curve map with a resolution of 25 meters. Then a height contour map with a resolution of 10 meters is put on top, resulting in an increased resolution of the height contours at and around the site. In addition two maps of 2 meters and 0.5 meters resolution with a size of 2.5 km^2 are implemented. This results in a quite exact orography at and around the site. Finally a map of the buildings in Nanortalik, provided by the local municipality, is utilized to implement roughness and sheltering obstacles close to the site.

3.3.2 Land Cover Map

The land cover map contains the roughness length of the area. The roughness length is a classification of the land cover, where different classes are designated by a specified roughness length value, z_0. In Table (16), typical roughness length values are shown:

z_0 m	Terrain
1.00	city
0.80	forest
0.50	suburbs
0.30	shelter belts
0.20	many trees and/or bushes
0.10	farmland with closed appearance
0.05	farmland with open appearance
0.03	farmland with very few buildings / tress
0.02	airport areas with buildings and trees
0.01	airport runway areas
0.008	mown grass
0.005	bare soil (smooth)
0.001	snow surfaces
0.0003	sand surfaces (smooth)
0.0001	water areas (lakes, fjords, open sea)

Table 16 - Roughness length for different terrain types (Berg & Mann, Introduction to Micro Meteorology for Wind Energy, 2011)

Nanortalik is surrounded by fjords and mountains with close to no vegetation. The town consists of a residential area with a small density of small buildings. Map of the town and the surroundings is given in Figure (37). Based on the map and the roughness table, three general roughness lengths are used in the land cover map:

Terrain	*Roughness length (z_0)*
Water surfaces	0 m
Mountainous areas	0.03 m
Nanortalik town	0.3 m

Table 17 - Roughness lengths used in the land cover map

The sea and fjords are given a roughness length of 0 meters in WAsP which is the value for water in WAsP. For the mountains and hilly landscape around the city of Nanortalik a roughness value of 0.03 is given. This is the same roughness height as for farmland with very few buildings or trees (Berg & Mann, Introduction to Micro Meteorology for Wind Energy, 2011). Due to the low density of buildings and that the buildings are small; a roughness value of

Figure 37 - Nanortalik

0.3 is given for the city of Nanortalik. All the roughness heights have also been on-site evaluated and validated.

3.3.3 Obstacles

As described in section (3.2.2), if obstacles are present near the possible site or the meteorological mast, these obstacles needs to be modeled in WAsP. The obstacles close to the meteorological mast (which is also the area of the potential wind turbine site) are described in the mentioned section. As another meteorological mast has been used as a reference site, also obstacles from this site have been included in the land cover map. These obstacles are described in Section (3.4).

3.3.4 Vector map of Nanortalik

In Figure (38) the computed map of the Nanortalik area is visualized. This is the map implemented in WAsP with height contours, roughness lengths and obstacles.

The city of Nanortalik and one of the possible turbine sites are located within the square in the middle of the map. It is worth mentioning that the surroundings are heavily influenced by mountainous terrain. It is also worth mentioning that all the main wind directions, concentrated around sector 1 (north) is totally or partially influenced by land, and hence a relatively large roughness length and mountainous terrain.

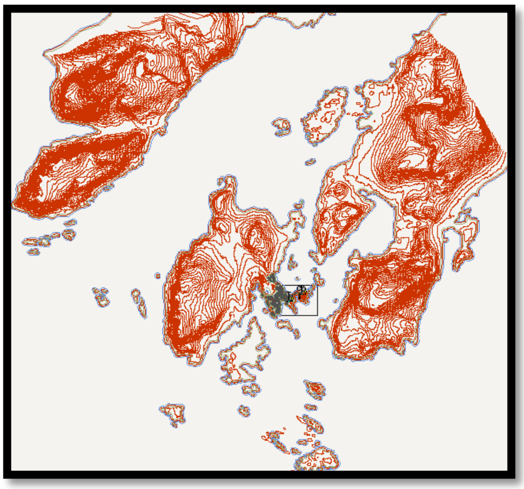

Figure 38 - Vector map of Nanortalik

This is based on the rule of thumb that states that the roughness change impact reaches measuring height in a distance of 100 x measuring height. This corresponds to a distance of 5 kilometers from the meteorological mast. As can be seen on Figure (38) it is only the southern directions that are influenced by water only. In Figure (39), the square in the middle of the vector map in Figure (38) is zoomed in:

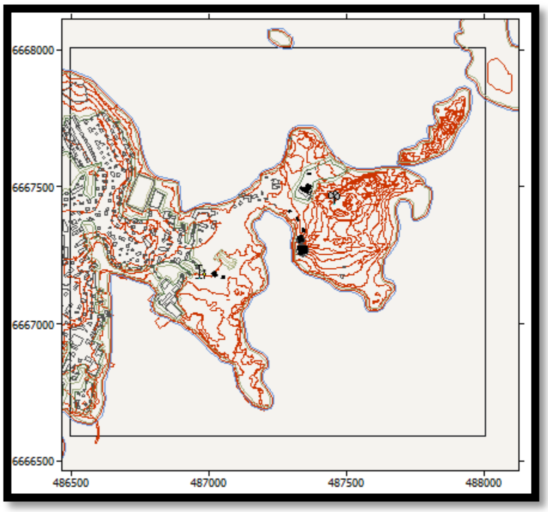

Figure 39 - Vector map Nanortalik town

3.4 Reference Site

In order to validate the data obtained from the 1601 Nanortalik met mast, reference wind measurements from the met mast located at Nanortalik Heliport is used. The met mast is located approximately 600 m southwest of the 1601 Nanortalik met mast, and there are available measurements from August 2006 until February 2011. The data consists of 10 min average measurements of both wind speed and direction at 10 m, in addition to hourly measurements of humidity and pressure.

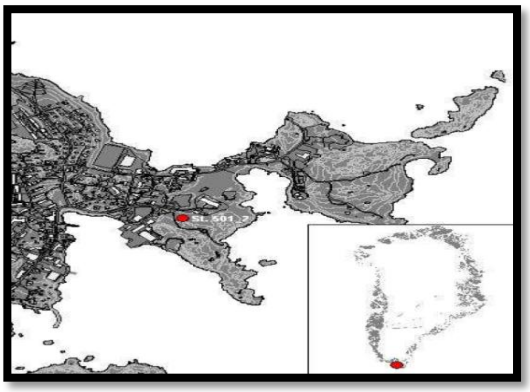

Figure 40 - Nanortalik Heliport Climate Station (Asiaq, 2008)

The met mast has the following location:

Nanortalik Heliport Climate Station	
UTM 23 Easting	486 978
UTM 23 Northing	6 667 149
Height (m.a.s.l.)	3.34
Start of measurement	13.05.2001
End of measurement	Running

Table 18 - Nanortalik Heliport Climate Station

There are several instruments installed on the climate station. The ones used in this analysis are the 10 min mean wind speed (WS1600), 10 min mean wind direction (WD1600), the pressure (QFF1000) and the air temperature (AT1203).

The WS1600 and WD1600 at 10m are mounted on a boom on opposite sides of the mast. The distance between the two equipment's is not given, neither is the height above the boom. The used instruments installed on the met mast are presented in Table (19):

Nanortalik Heliport Climate Station instruments			
Quantity	**Device**	**Height**	**Type**
WS	WS1600	10 m	Top Sensor
WD	WD1600	10 m	Wind dir.
Air temp.	AT1203	2 m	Temp.
Air press.	QFE1000	2 m	Pressure

Table 19 – Nanortalik Heliport Climate Station instruments

The met mast is seen in Figure (41):

Figure 41 - The Nanortalik Heliport met mast

3.4.1 Filtering the Meteorological Data

The filtering of the meteorological data from the Nanortalik Heliport Climate Station proved to be more challenging than for the 1601 Nanortalik met mast. The number of pressure and temperature data did not match the number of wind speed and directional data, due to different sampling frequencies. Filtering was thus applied without taking temperature and pressure into account. No standard deviation and gust measurements are measured at the heliport mast either, which reduces the functions of the filtering script drastically. All test including standard deviation, maximum gust, temperature and pressure is removed, which induces a higher uncertainty regarding the heliport data. 90.3 % of the removed data were due to invalid spikes, whereas the other 9.7 % were removed due to a high difference between one measurement and the next. A mean wind speed of 4.55 m/s was found with a data recovery of 97.05 %. By also inspecting the time series visually, the data has been accepted as valid and useable for the reference site.

3.4.2 Generalised Wind Climate

As described in section (3.2), the general wind climate of the Heliport site can be created by means of the observed wind climate and a site description of the meteorological station. The outcome of the filtering process described in section (3.4.1) was almost 4 years of consecutive data. The data used is, reasonably, for the same time as the one used for the 1601 Nanortalik met mast – June 2007 till June 2010.

Also a site description of the meteorological station at the Heliport needs to be performed, and potential obstacles need to be taken into account before a complete wind atlas is created. As can be seen in Figure (41), there are some buildings in the vicinity of the met mast which could affect the readings. Thus, these obstacles needs to be included in the wind atlas created in WAsP. In the following, the different aspects of the creation of the wind atlas for the Heliport site are undergone.

3.4.2.1 Observed Wind Climate

The observed wind climate of the Heliport site is presented in Figures (42-44), showing the Weibull distribution and Wind Rose as calculated in both WAsP software and Matlab for validation. It is observed that the vast majority of the wind is coming from north, with Sector 1 (345-15°) as the main contributor with a frequency of 22.1 %. The calculated mean wind speed at 10 m at the Heliport site is **4.55 m/s**. The wind speed at 10 m is also measured by the 1601 Nanortalik met mast, but the data from this anemometer is not considered good enough to be used due to instrument deficiencies, thus the mean wind speed cannot be compared.

3.4.2.1.1 Weibull distribution

The simulated Weibull distribution of Nanortalik Heliport met mast is presented in Figure (44), created from the WAsP software. The Weibull parameters obtained in WAsP are:

- **A = 4.7**
- **K = 1.29**

The CDF of the wind climate of the Nanortalik Heliport met mast is presented in Figure (42).

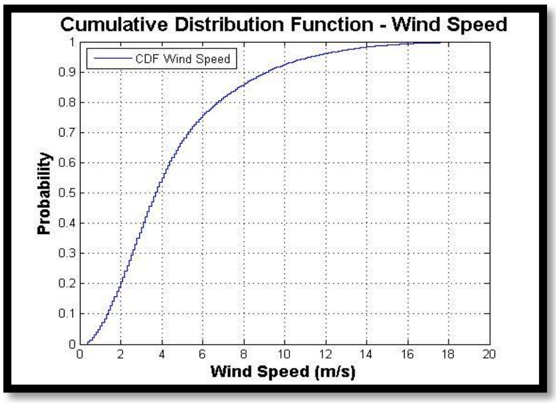

Figure 42 - Cumulative Distribution Function - Nanortalik Heliport site

From the CDF it is observed that the most likely wind speed range is from 0-5 m/s, as this range is covering 70 % of the wind occurences.

3.4.2.2 Wind Rose

The wind rose for the Nanortalik Heliport site is presented in Figure (43):

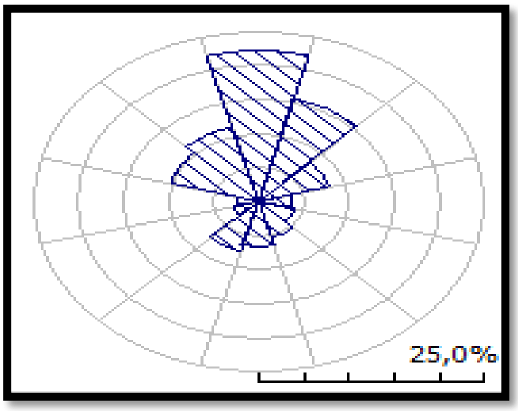

Figure 43 - Wind Rose for Nanortalik Heliport met mast (WAsP)

From the wind roses it is observed that the majority of the wind is directed directly from north (Sector 1). This frequency of wind coming from this sector is 22.1 %, whereas the second highest frequency is found in Sector 2 (15.6 %). By also including that 11.4 % of the wind is coming from sector 12, the total amount of wind coming from north is 49.1 %.

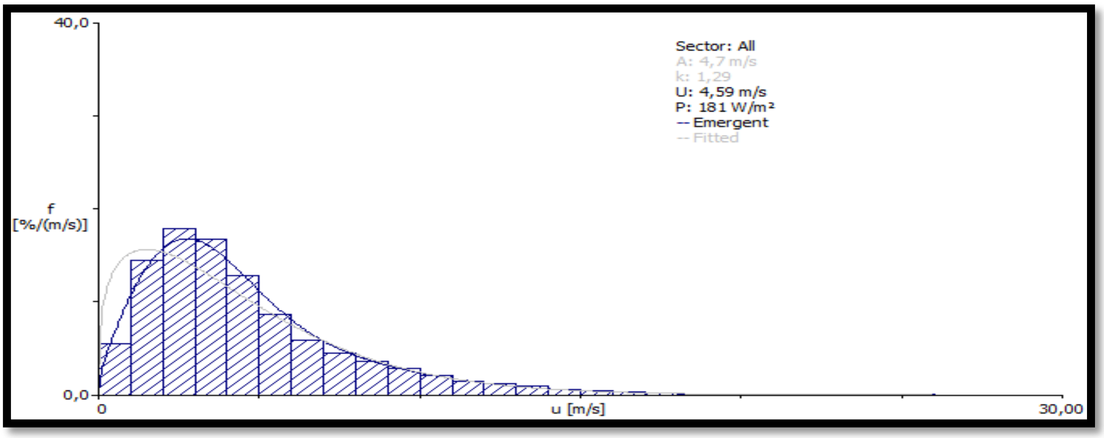

Figure 44 - Weibull distribution for Nanortalik Heliport met mast (WAsP)

3.4.2.3 Heliport Weather Station site description

For the area surrounding the Nanortalik Heliport, there are eight obstacles/ obstacle groups that could affect the measurements, and that therefore needs to be included in the generalized wind climate. The rest of the settlements are treated as a roughness within the city. The obstacles are presented in following map, taken from the WAsP simulation:

Figure 45 - Obstacles close to the Nanortalik Heliport met mast

In Figure (46) a map of the area close to the met mast is shown with the met mast and obstacles outlined:

Figure 46 - Map of the obstacles close to the Nanortalik Heliport met mast

Even though the obstacles most likely are too far and/or too small to affect the result, they are included in the generalized wind climate to make it as precise as possible.

3.5 *Terrain Evaluation of the Two Measurement Stations*

The two meteorological stations used in this analysis have different terrain, as visualized in Figure (39) – the vector map of Nanortalik town. There are different roughness effects, different obstacle effects and different orographic effect that affects the measurements. In this section all of these are undergone, and the section is finalized with a comparison of the power density of the two measurement sites.

3.5.1 Roughness effects

The roughness evaluation of the area is described in Section (3.3.2), thus only the effects of the roughness length chosen is discussed. The roughness effects of the two sites are visualized in Figure (47), where the effect of roughness is visualized by the red color on the roughness rose.

From the figure it can be seen that the Heliport site is far more affected by the surrounding roughness than the 1601 Nanortalik met mast. This is reasonable due to several reasons. The Heliport site is located next to the settlement, which represents a significant roughness change in the terrain. Another important factor is that the Heliport met mast is measuring at a height of 10 meters, whereas the 1601 Nanortalik met mast measures at 48.8 meters. Therefore, the effect of roughness change is dramatically reduced for the 1601 Nanortalik met mast site. It is observed that the sector with the highest roughness effect is located in northwest direction, the same direction as the settlement is located.

Figure 47 - Roughness effect at the two measurement sites

3.5.2 Obstacle effects

In the previous sections the obstacles that could affect the measurement readings were identified and included in the WAsP project, both for the Heliport site and the 1601 Nanortalik site. The computed effect of the obstacles is visualized in Figure (48):

Figure 48 - Obstacle effect at the two measurement sites

As mentioned in the previous sections, the effect of the obstacles is expected to be low.

In the calculation made in WAsP, the effects on the 1601 Nanortalik site is zero, whereas the effects on the Heliport site is limited to two buildings located north of the Heliport mast. This is mostly due to the low height of the Heliport mast. If not considered in the calculations, the influence of the obstacles could have an influence of the wind farm calculations.

3.5.3 Orographic effects

Orographic elements such as hills, valleys, cliffs, escarpments and ridges exert an additional influence on the wind. Near the summit or crest of these features the wind will accelerate whereas near the foot and in valleys it will decelerate. The orographic effects on the measurement sites are presented in Figure (49):

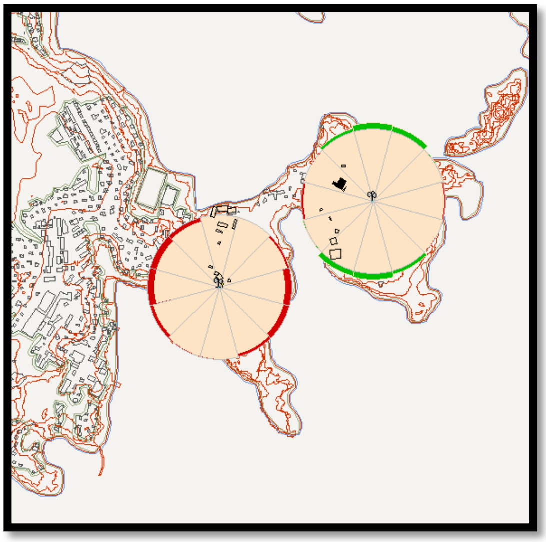

Figure 49 - Orographic effect at the two measurement sites

The orography have different effect on the two sites, where the Heliport site experiences a deceleration and the 1601 Nanortalik site experiences an acceleration. The deceleration effects for the Heliport site is situated from east and west, indicating that the met mast is located at a lower altitude than the surroundings to the west and east.

The 1601 Nanortalik site experiences the opposite effect, since it is located at a local peak.

3.5.4 Power density

The three factors that affect the wind mentioned in the preceding sections are all affecting the power density in the different sectors around the measurement sites. Whether the total effect is high or low is best visualized by investigating the power density distribution of the two sites, as shown in Figure (50):

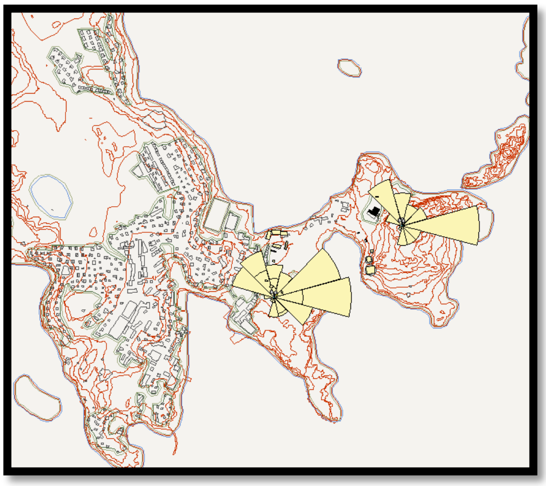

Figure 50 - Power density at the two measurement sites

As can be seen from the figure, there are some differences between the power densities of the two sites. The easterly wind direction is the dominant at both sides, but at the Heliport site it is situated more in a northerly direction than at the 1601 Nanortalik site. This is most likely due to the orographic effect, which has a deceleration effect from the westerly direction.

It is also observed that a higher power density is experienced from northwest at the Heliport site.

Altogether, the power density of the two sites is quite similar.

3.6 Wind Resource at Nanortalik

The wind resource at and around Nanortalik is characterized by north to north-easterly and north to north-westerly wind. South of Greenland, and hence Nanortalik, is located at the polar front between the dominating westerly wind in the south and the polar easterlies in the north. At Figure (51) the wind regimes are shown, note that the south of Greenland is at approximately 60° N (National snow and ice data center).

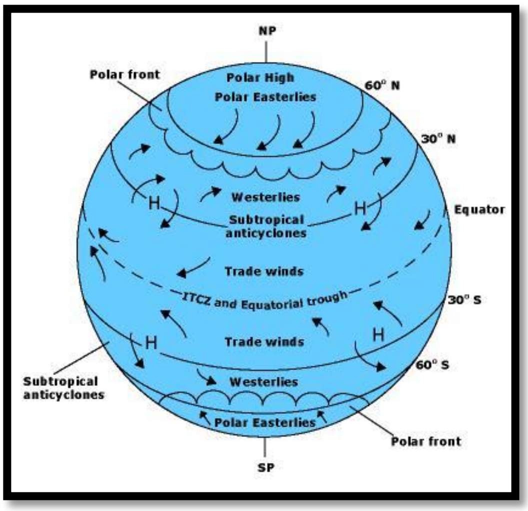

Figure 51 - Wind regimes

These two phenomenons's, which are based on the Coriolis Effect and pressure, characterize the main wind direction on specific latitudes. Because of the hilly terrain west from Nanortalik and sea dominated terrain north of Nanortalik, it is the polar easterlies that have the dominating effect. This is due to the katabatic wind coming from the inland ice, which has a higher air density and is influenced by gravity, resulting in a higher power density. The measurements have the same result as expected from the theory.

The overall main wind direction is north to north-east with a frequency of 26.4 %. This direction, however, has a low mean wind speed of only 4.55 m/s. In terms of higher mean wind speed, the north and north to north-west are of interest with 6.3 and 8.9 m/s in terms of mean wind speed, respectively. These two directions also have approximately 12 % frequency.

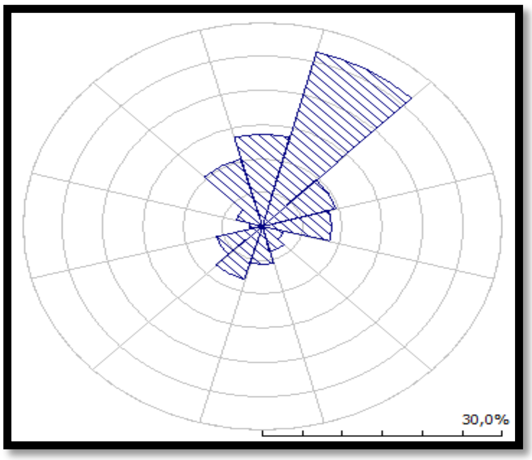

Figure 52 - Wind rose of Nanortalik

The overall mean wind speed at Nanortalik is **5.81 m/s**, which corresponds to **345 W/m^2** in power density. This is clearly a low wind site, but modern IEC class III turbines are becoming increasingly efficient at extracting energy at low wind speeds (Kjeller Vindteknikk, 2011). Figure (52) shows the wind rose for Nanortalik.

3.6.1 Resource Grid

The resource grid represents the wind climate for small fractions of the map for which predicted wind climate data are calculated. The points are regularly spaced and are arranged into rows and columns, and by usage of this tool the pattern of wind climate for the area is revealed. All the fractions have the same height a.g.l.
For each fraction in the map, WAsP is able to calculate several data which can be displayed in the resource grid. Three of them are:

- The elevation
- The mean wind speed
- The mean power density

One of the most interesting data to be displayed for this chapter is the mean wind speed, and this is also the data displayed in Figure (53). The colors on the figure represent different velocities for the different fractions, stretching from 3 m/s for the blue areas to 10 m/s for the red areas. As can be seen, the most promising wind speeds are located west of the town close to the hillside by the sea. However these wind speeds are not ΔRIX corrected, and hence calculated with some uncertainties attached. This is because the WAsP software is based on a linear flow model, whereas the area contains highly complex terrain. This leads to an overestimation in the software due to its inability to calculate the flow distortion.

3.7 Vertical Wind Profile

The modeled data in WAsP can be validated by utilizing data from three anemometers placed in different heights, z, in the meteorological mast. For the vertical wind profile calculations, data from the following equipment is used:

Instrument	*Type*	*Height*
NRG 40	WS	10 m
NRG 40	WS	30 m
NRG 40	WS	48.8 m
NRG 200P	WD	41.4 m

Table 20 - Instrument list for vertical wind profile

The NRG#40 instruments are utilized to calculate the vertical wind profile. Since no instrument revision has been undergone and considering the issues regarding the NRG cups long-term measurement quality, only the first year of measurements has been utilized, ranging from June 2007 to end of May 2008.

3.7.1 Calculated wind profile

Two methods have been utilized to calculate the wind profile:

1. Method based on Kjeller Vindteknikk report, the IEC power law (Kjeller Vindteknikk, 2011).

2. Method based on the logarithmic velocity profile, the log-law (Berg & Mann, Introduction to Micro Meteorology for Wind Energy, 2011).

Both methods can be used to predict the vertical wind profile at reasonable accuracy in neutral atmospheric conditions. In this study, the wind speeds below 4.1 m/s have

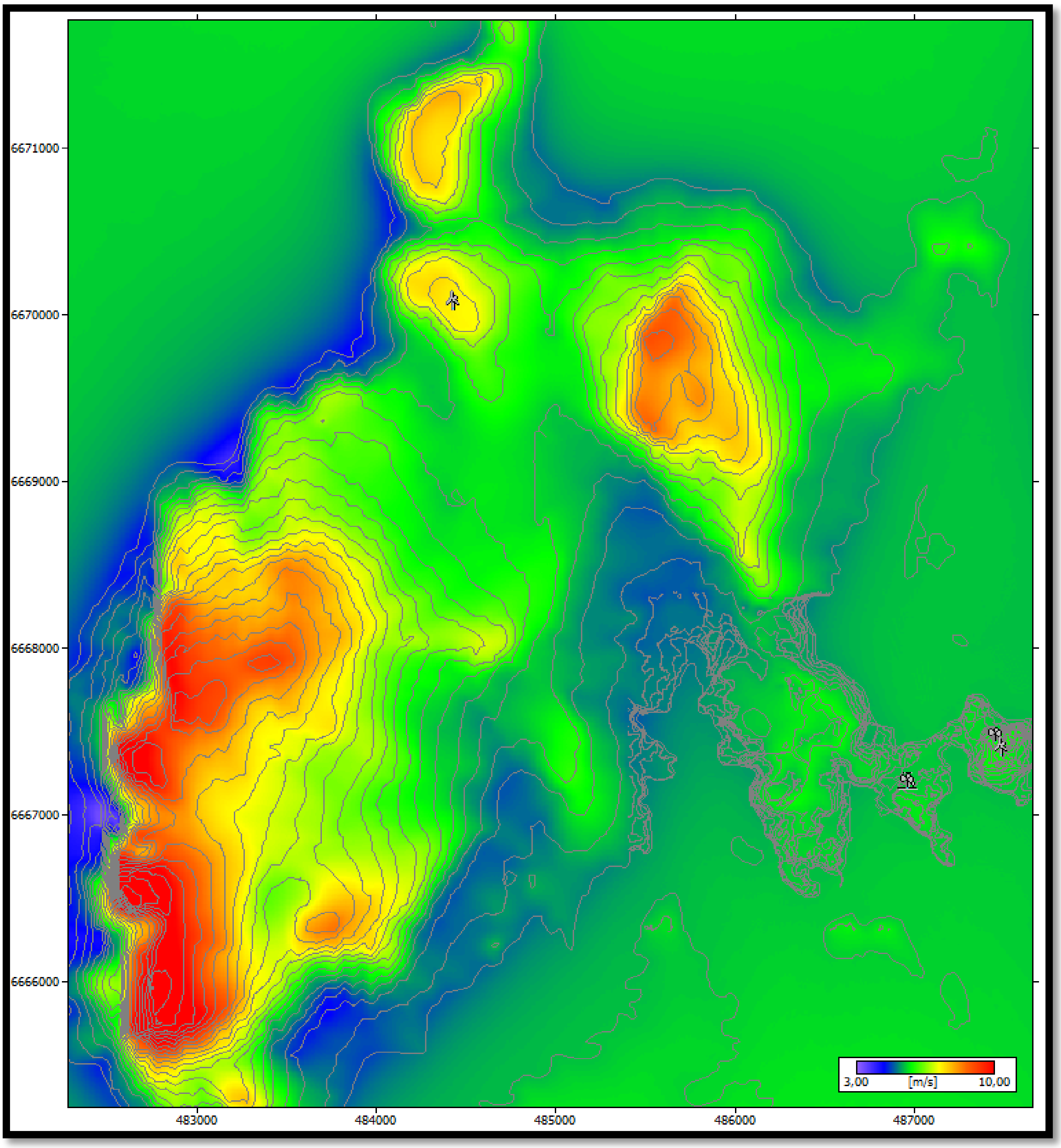

Figure 53 - Resource Grid for Nanortalik (Blue represents 3 m/s and red 10 m/s)

been removed to obtain the required atmospheric conditions (Jakobsen K. , 2012). The NRG#40 anemometers are also known for inaccurate measurements of lower wind speeds, according to Kjeller Vindteknikk (Kjeller Vindteknikk, 2011).

3.7.1.1 IEC Power Law

The idea is to use measurements from two or more heights along the mast, to calculate the wind profile for the site. This method requires data of mean wind speed at different height levels, as well as directional data if the sector-wise distribution is wanted. The method can also be used if the mean wind speed is known in only one height, by using approximated alpha values.

The vertical wind profile can be calculated by the following equation:

$$U(z) = U(z_r)\, x \left(\frac{Z}{Z_r}\right)^{\alpha} \qquad \textbf{(8)}$$

Where:
U(Z) is the calculated mean wind speed, at a given height, Z
$U(Z_r)$ is the mean wind speed at a reference height, Z_r.
Z is the wanted height.
Z_r is the reference height.

Alpha, α, is the wind shear coefficient, which can be found by rearranging Equation (9):

$$\alpha = \frac{\log\left(\frac{U(Z_1)}{U(Z_2)}\right)}{\log\left(\frac{Z_2}{Z_1}\right)} \qquad \textbf{(9)}$$

Where:
$U(Z_1)$ is the calculated mean wind speed, at the instruments height, Z_1
$U(Z_2)$ is the calculated mean wind speed, at the instruments height, Z_2
Z_1 and Z_2 is the respective instruments heights.

The wind shear coefficient is calculated to be 0.086 which is an acceptable value, although the empirically derived value for neutral conditions are approximately 1/7 = 0.143. Figure (54) presents the vertical wind profile for the 1601 meteorological mast location by use of the IEC power law method. The calculated mean values at height 10m, 30m and 48.8m have been plotted on top of the graph. There is a fairly good correlation between the points and the curved graph, meaning that the graph gives a rather good approximation of the actual wind speeds at the given height range.

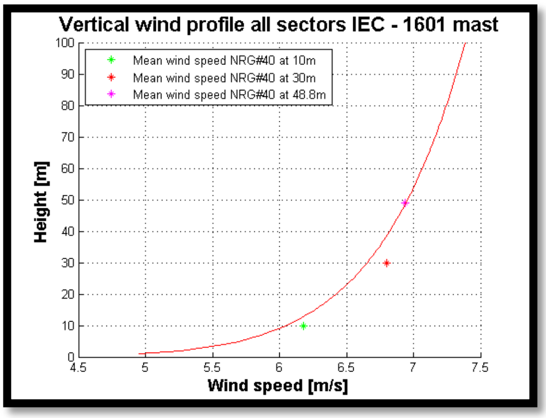

Figure 54 - Vertical wind profile all sectors at 1601 mast - IEC Power Law method

3.7.1.2 Sector-wise vertical wind speed profile

The wind speed data have been divided into 12 sectors, where each sector covers 30 degrees.

The surrounding area consists of a variety of landscape classifications. Some steep mountains are located west of the prospected wind farm site, as well as the town of Nanortalik. In the north there is a mixture of sea and more gradual inclining terrain. In the east there is mountainous terrain, as well as an approximately 1 kilometer wide fjord dividing the mountainous area with the prospected site. The southern part is mostly dominated by sea. To take each sector roughness into account, the log-law is utilized.

Figure 55 - Nanortalik and surrounding area

3.7.1.3 The log-law method

The logarithmic velocity profile is given by the log-law shown in Equation (10):

$$U(z) = \frac{u_*}{K}\ x\ log\ \left(\frac{Z}{Z_0}\right) \qquad \textbf{(10)}$$

Where:
U(Z) is the calculated mean wind speed, at height, Z.
U_* is the friction velocity.
Z is the wanted height.
Z_0 is the roughness length representing the on site terrain type.
K is the von Kármán constant.

The constant, K, is a dimensionless constant describing the logarithmic velocity profile of a turbulent fluid flow, and is set to 0.4 in this analysis. The friction velocity is derived from Equation (11):

$$u_* = \frac{U(z)\ x\ k}{\log(\frac{Z}{z_0})} \qquad \textbf{(11)}$$

A friction velocity is calculated for each sector, and is further utilized to obtain the vertical wind profile. Figure (56) presents the vertical wind profile in sector 1 using the log-law method. The calculated mean wind speeds fits the profile reasonably well. See Appendix (B) plots of sector 2 to 12.

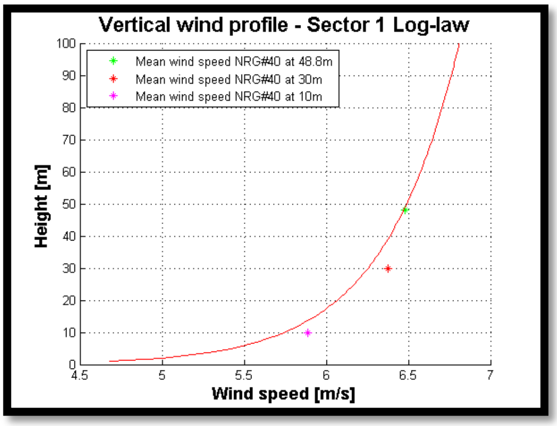

Figure 56 - Vertical wind profile sector 1, 1601 mast

3.7.2 Investigation of roughness lengths

To compute the vertical wind profile, by use of the log-law, all 12 sectors must be assigned with a roughness length, z_0, in order to calculate the velocity profile in all directional sectors. Table (16) shows roughness length values with the corresponding terrain characteristics. The table is adapted from the European Wind Atlas (1989) and is found in the "Introduction to Micro-meteorology" course-notes (Berg & Mann, Introduction to Micro Meteorology for Wind Energy, 2011). The following section presents the different sectors response to the assigned roughness lengths.

Sector 1:
The three mean wind speed points fits well with the profile, for a roughness length of z_0 = 0.0004, which is representable of the sea roughness length (0.000 in WAsP).

Sector 2:
The overall best fit is obtained by utilizing the same roughness length as sector 1, z_0 = 0.0004. The 30 meter mean wind speed value is although somewhat off. This can be due to that an overall average roughness is assigned to the section, which fits better to the 10 and 48.8 meter results. Both flow separation and wind shear phenomenon's can have impacted the 30 meter anemometer.

Sector 3:
This sector responds well to a roughness length of z_0 = 0.0005, which is in between smooth sand surface and snow surface. The plotted 30 meter mean wind speed is although somewhat off.

Sector 4:
With a roughness length at z_0 = 0.0004, which is the same as in sector 1 and 2 a good fit is obtained for all points.

Sector 5:
The two calculated mean values for the 48.8 and 30 meter measurements respond well to a higher roughness length, z_0 = 0.2 meter. Meanwhile, the 10 meter mean value misses by more than 1.3 m/s. By adjusting the roughness length down to a value close to sea, the 10 meter mean value fits better, and so does the 48.8 m. This can show that there are some incorrelations between the measurement instruments, or as explained above, the averaged roughness for the whole sector does not fit with all heights.

Sector 6:
The mean wind speed values respond well to an assigned roughness of z_0 = 0.005, which is characterized as bare soil.

Sector 7:
The fitting experiences the same event as in sector 5, where the two top anemometers fit well with the wind profile, while the 10 meter instrument is somewhat off.

Sector 8:
The same applies to this sector. Higher roughness length seems to fit the 30 meter instrument, while lower fits the 10 meter instrument. With an applied roughness length of z_0 = 0.02, which is characterized as airway with few buildings and trees, the points fit is okay.

Sector 9:
The two top mean values responds well to a low roughness length at z_0 = 0.00005, while the 10 meter mean value is off.

Sector 10:
The same roughness as in sector 9 applies quite well to all points, giving a good total fit for all mean values.

Sector 11:
The three mean values matches the vertical wind profile quite well by use of a low roughness length, z_0 = 0.00005 m.

Sector 12:
A low roughness length also applies to sector 12, with z_0 = 0.000004 m. The top and bottom mean wind speed values match the vertical wind profile well, while the 30 meter results are a bit off.

According to these test results, most of the sectors are mainly impacted by sea roughness, while sector 5, 6, 7 and 8 seems to be impacted by land roughness levels. None of the applied roughness lengths exceeded 0.2 meters, which seems low in the seemingly rugged landscape surrounding the prospected wind farm area. The uncertainty regarding the calculated vertical wind profile is high, since modifications have been done to the wind data in terms of filtering, to try to obtain the most atmospheric neutral conditions as possible. The results still give an acceptable indication of the wind speeds at the respective height levels.

3.8 Climatological Inputs

Wind speed and direction measurements at 48.8 meters are used, which is the highest anemometer in the meteorological mast. These measurements are not as affected by obstacles as the measurements at a lower height, and are the measurements closest to the turbine hub height. In order to get the best approximation, the conditions around the meteorological mast have to be as equal the actual conditions as possible. The data used in WAsP are influenced by these conditions, so in order to minimize the uncertainty the conditions need to be well computed. WAsP also calculates the difference in height by extrapolation, so less extrapolation results in less uncertainty. This is also the reason why the measurements are used from the height closest to the hub height.

In this analysis a standard air density cannot be used due to the arctic conditions in Nanortalik. The air density is mostly affected by ambient temperature and its changes. By applying the standard air density, is the same as assuming a normalized sea level pressure (101.325 kPa) and standard temperature (15° C) according to ISA (International Standard Atmosphere). Such an approximation might not involve to large uncertainties for some wind farm sites; hence temperature and pressure are chosen not to be measured. However, in Nanortalik the climate differs greatly from the standardized assumptions, e.g. by a long-term average temperature at 2 °C (Nanortalik climate). This long-term prognosis fits well to the measured temperatures between year 2007 and 2010, with a deviation of 0.15 °C.

Figure 57 - Temperature measurement instrument (AWS Truepower, 2010)

By usage of the "Air density calculator" in WAsP, the air density at a temperature of 2° C at an altitude of 10 is calculated to 1.281 kg/m^3. However, both the temperature and barometric pressure have been measured on-site and can thus be computed manually. At 1601 meteorological station only temperatures have been measured. As both the 1601 and heliport mast are located at approximated sea level and the two locations being close to each other, the barometric pressure measurements from heliport have been utilized in the computation of air density at 1601. In this approach the *ideal gas law* have been utilized, which is derived by Equation (12). This approach is assumed to be a good approximation, however does not take the air's relative humidity into account.

$$\rho = \frac{P}{RT} \qquad (12)$$

Where:
ρ= Air density (kg/m^3)
P = Mean pressure (Pa)
R= Specific gas constant (8.3145 $m^3Pa/molK$)
T = Mean temperature (K)

Note that the pressure measurements at heliport are carried out in hourly resolution, while the temperatures are in 10 minute resolution. This is the reason to utilize the temperature measurements at 1601 instead of the heliport's. The temperature deviates to a larger extent than pressure within an hour and has thus larger impact in the wind resource estimation. In order to not waste the high resolution temperature data, the barometric pressure is assumed to be at constant value for the whole hour. The resulting air densities in time are illustrated by Figure (58).

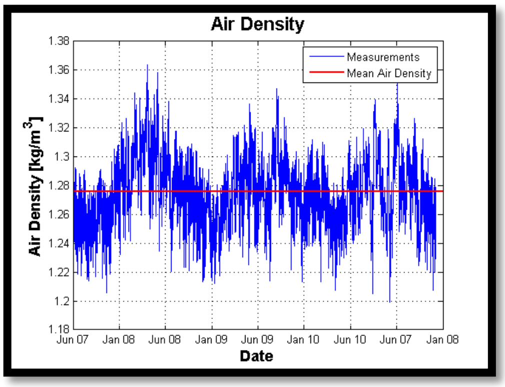

Figure 58 - Air density from June 2007 to June 2010 (filtered)

Figure (58) was initially affected by invalid measurements, mainly by negative-spiked pressures values. The range test carried out in terms of data validation refers to all the temperature data being within reasonable range. Some hourly temperature changes within an hour have been flagged, but these measurements are treated as they have the same temperature as its previous measurement. This is assumed to be a good approximation in order to obtain good wind resource estimation. However, this is no reason for the negative computed air densities. This is due to some errors in the pressure measuring. For these cases, the air densities are selected to be equal the average air density.

Figure 59 - Barometric pressure measurement instrument (AWS Truepower, 2010)

The mean pressure measured at the Nanortalik Heliport met mast is 101.325 Pa, whereas the mean temperature is 1.8 ° C (274.95 K). Based on the measurements, the mean air density of Nanortalik Heliport site is 1.27 kg/m^3.

Result comparison and difference between the three above-mentioned approaches in determining the air density is given in Table (21):

	Magnitude	*Unit*
Default	1.225	kg/m^3
WAsP	1.281	kg/m^3
Measured	1.27	kg/m^3
Difference (Default vs Measured)	4	%

Table 21 - Difference between default, WAsP estimated and measured air density

The temperature change corresponding to change in altitude, unless there are any special local climatic phenomenons. An increase in altitude of 100 meter is normally equivalent to a drop of 0.65 °C. Note that correction with respect to altitude has not been carried, as the met mast is approximated to be at sea level. The air density is implemented in WAsP and the power curves of the turbine generators are corrected. A higher air density results in a higher power density and hence increase in output power, thus the power output is sensitive to air density, in this case giving approximately 4 % additional production estimate compared to applying the standard value. Note that the power curve has to be site specific in terms of actual air density.

3.9 Wind Power Density

"Wind power density (WPD) is defined as the flux of kinetic energy in the wind per unit cross-sectional area. Combining the site's wind speed distribution with air density, it provides an indication of the wind energy production potential of the site" (AWS Truepower, 2010) . In descriptions of geographical variation and energy potential, the WPD is often used as such reference in preference of a mean wind speed (Hughes, 2000). The reason for this is because the power density value is a truer indication of a site's wind energy potential (AWS Scientific, Inc., 1997).

The wind power density is, however not single-handedly, a direct determination of cost efficiency of harvesting the wind at a site. A normal categorizing and initial guidance in regional selection of a wind farm in terms of WPD and corresponding production estimate is (Renewable Energy Science and Technology):

- Poor: < 150 Watt/m^2
- Good: 250 ~ 350 Watt/m^2
- Excellent: > 350 Watt/m^2

Note that additionally other factors needs to be taken into assessment, such as local topography, turbulence intensity etc. In case of too high turbulence, the turbine must pitch out to lower the strain, hence loss of production. The WPD is calculated in the following way:

$$WPD = \frac{1}{2N}\sum_{i=1}^{N} \rho_i v_i^3 \; (W/m^2) \qquad \textbf{(13)}$$

Where:
N = the number of records in the period
ρ = the air density (kg/m^3)
v_i^3 = the cube of the ith wind speed for record i (m/s)

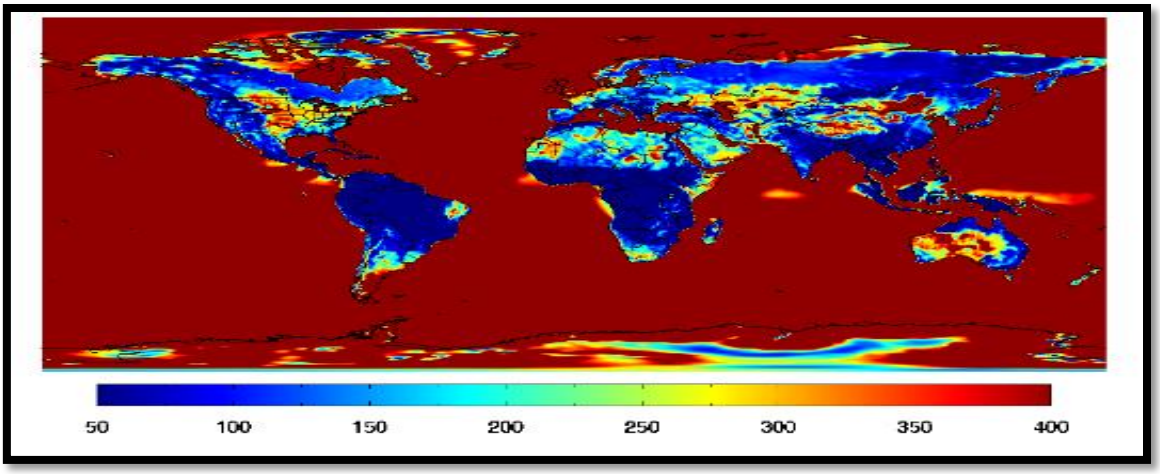

Figure 60 - Annual mean wind power density at 50 meter above the surface (W/m2) (Renewable Energy Science and Technology)

Note that in order to obtain the most accurate estimate of WPD, the high resolution data should be utilized directly into the equation, e.g. do not compute the average air density and WPD for the measurement period, but utilize the 10 minute averages. The pressure is as known not provided in such resolution; this matter is derived in Chapter (3.8).

By applying lower resolutions in this computation will result in an attenuation of the normal variability. A true WPD is a few percentages greater due to use of 10 min averages (Wind resource handbook).

In the utilized approach of computation of the WPD have included the following variables:

- Temperature
- Pressure
- Wind speed

These variables may differ depending on choice of method for estimation of air density and WPD. Based on Figure (60), the WPD level in Southern-Greenland should in general be good.

By computation a WPD value for every 10 minute measurement throughout the three-year period, the mean value at measurement height (48.8 m) at the 1601 mast is 346.2 W/m^2. Figure (61) illustrates the WPD distribution for this period.

By supplying the three-yearly mean air density into WAsP, the WAsP computed WPD at same height has been verified. The WAsP WPD prediction is 346 W/m^2, hence the two estimations are within a good margin of each other, by only a deviation of 0.06 %.

Normally the WPD value is more or less assumed to be proportional to the energy yield at given site, however in comparison of some wind farms this has proved not to be the case. There are of course other factors involved, as mentioned above. Another factor that has been shown to be of importance is the shape factor of the Weibull distribution. A long Weibull tale would result in a high WPD estimate; however for wind speeds above cut-off the turbine will

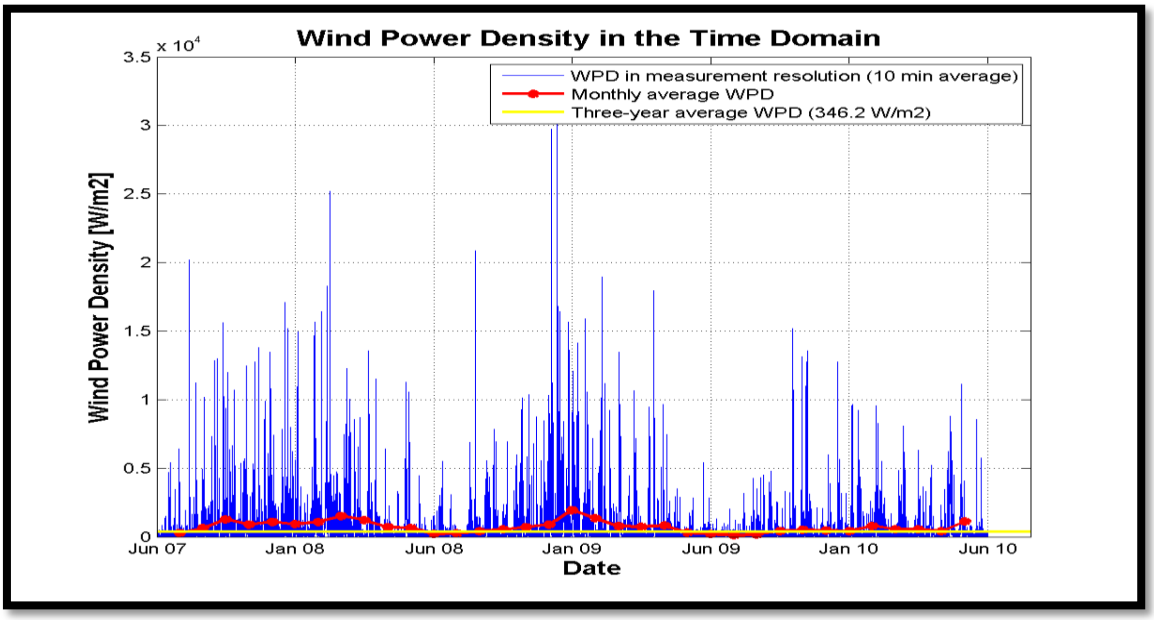

Figure 61 - Wind power densities represented by means of different resolutions

not produce electricity (Mortensen, Wind power density vs energy yield, 2009). In order to avoid this issue and to give a more realistic estimate in terms of production, a suggestion could be to not include wind speeds out of normal production range for wind turbines in the computation of WPD and multiply the resulting value with the corresponding production rate. By production rate, the frequency of wind within production is being referred. However, such approach has not been utilized, mainly due to comparison and verification of WAsP estimate and to keep a standard to evaluate the site categorization by means of projects economical appeal.

3.9.1 Classification

In describing an area, the wind power density have been pointed out to be a better reference than the wind speed, however "wind class" ranking is a more normal referral (Hughes, 2000). This way of site discussion makes the wind resource versatile to relate to. The various wind classes by means of wind speed and WPD ranges are presented by Table (22).

As the measurements and computation of WPD is based on 48.8 m, the 50 m values are utilized in the ranking of wind resource at the 1601 mast. By means of the WPD, the measurement station is located in a wind power class 3, meaning a WPD in the range from 300 to 400 W/m^2. "Grid cells designated as Class 4 or greater are generally considered to be suitable for most wind turbine applications. Class 3 areas are suitable for wind energy development using tall (e.g., 50 m hub height) turbines. Class 2 areas are marginal and Class 1 areas are unsuitable for wind energy development" (AWS Scientific, Inc., 1997).

However by means of wind speed, a general rule of thumb is that the mean wind speed at 80 m above ground level is required to be greater than 6.5 m/s, else the site is of no interest for utility-scale wind projects (AWS Truepower, 2010). The post-processed mean at site is computed to be 5.8131 m/s. This emphasizes the weakness of utilization of mean wind as reference for wind farms and would normally resulted in rejection of the project, as the 1601 mast in this perspective is located in a weak Class 2 area instead of an averaged Class 3 area.

	30 m (98 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density (W/m²)	Wind Speed m/s (mph)	Wind Power Density (W/m²)	Wind Speed m/s (mph)
1	≤160	≤5.1 (11.4)	≤200	≤5.6 (12.5)
2	≤240	≤5.9 (13.2)	≤300	≤6.4 (14.3)
3	≤320	≤6.5 (14.6)	≤400	≤7.0 (15.7)
4	≤400	≤7.0 (15.7)	≤500	≤7.5 (16.8)
5	≤480	≤7.4 (16.6)	≤600	≤8.0 (17.9)
6	≤640	≤8.2 (18.3)	≤800	≤8.8 (19.7)
7	≤1600	≤11.0 (24.7)	≤2000	≤11.9 (26.6)

Table 22 - Classes of wind power density (AWS Scientific, Inc., 1997)

3.10 Annual Variability

Annual variability is very important to assess when a long term prediction shall be calculated. The annual variability has an influence on the calculated uncertainty of the long term prediction, which will be calculated later in this chapter. Three years of data have been utilized in this analysis.

Yearly mean wind speed [m/s]	
2007-2008	6.36
2008-2009	6.02
2009-2010	5.06
Total	5.81

Table 23 - Yearly mean wind speed

The different yearly mean wind speeds is shown in Table (23). The annual mean wind speed is presented together with the total mean wind speed over the three years. It is obvious that the wind varies both within one year and over three years, which is why there are uncertainties related to a long term prediction.

With use of three years instead of one year, the variability in the mean wind speed is reduced. This is of great importance when calculating a long term prediction. With only one year of data the energy production can deviate with as much as 20 % for a low-wind site (Wind Energy - The Facts Part 1). With use of several years, this deviation reduces and a more reliable and realistic wind climate is calculated. Figure (62) shows the variation over the three years in terms of wind speed. As can be seen the wind is clearly lower during the summer period (in the middle of the plot). This is

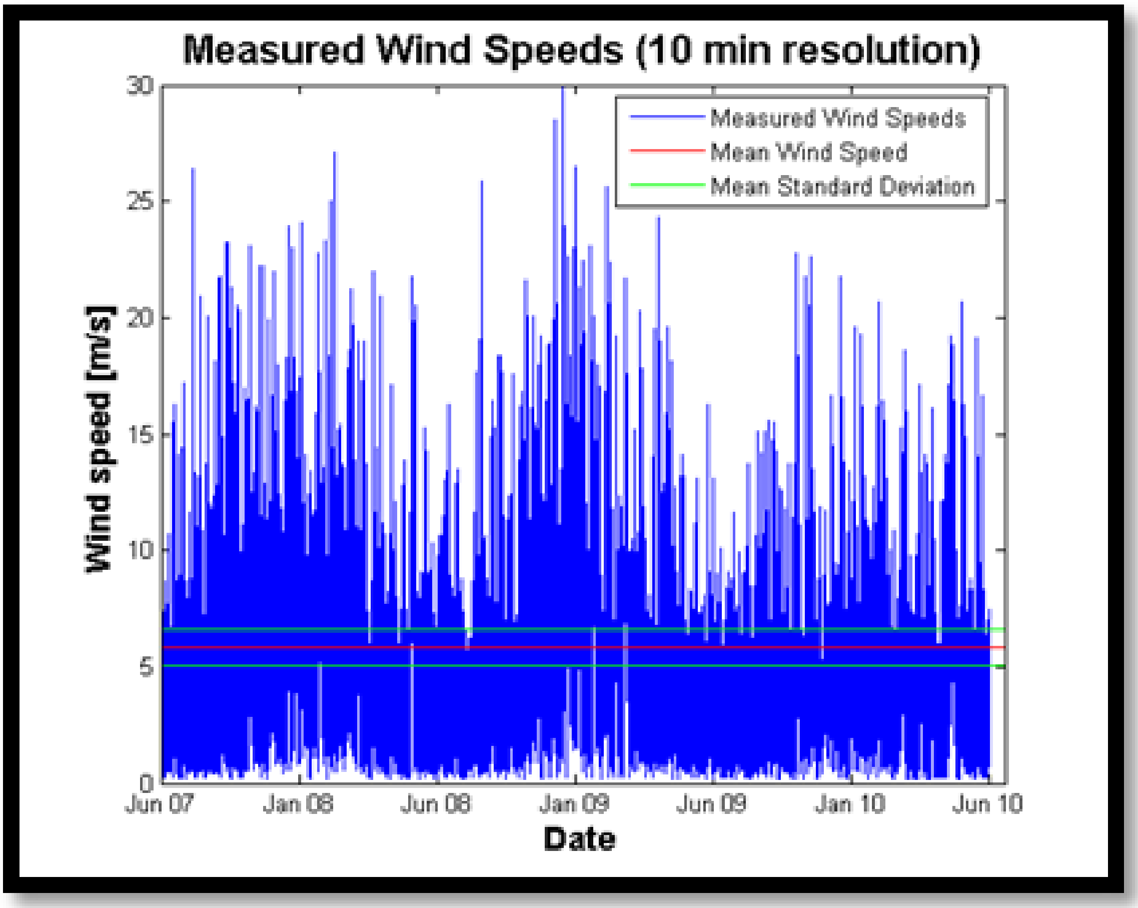

Figure 62 - Measured wind speeds June 2007 - June 2010

expected due to seasonal variations, but the mean wind speed in the first year is also higher than the second, which can be related to yearly variations. The red line in the plot is the overall mean wind speed over two years.

In order to validate the calculated wind climate for Nanortalik, a long term prediction has to be taken into account. Data for three years has been used in the calculations in WAsP which is acceptable. Data from three different heights and anemometers on the meteorological mast are validated in order to get a better picture of the wind resource. In addition to this a reference site is used to calculate the wind profile to verify the results in WAsP. Due to no availability of wind data records at a long term reference station, only on-site wind data will be used, and hence the reference site is also characterized as on-site measurements as well. In many cases it is better to use 3 or 4 years of on-site data to predict the long term wind resource instead of calculating a long term correction. This is due to the uncertainties when implementing the long term correction. On this basis no long term correction will be calculated. In this case only three years of proper data is available and thus applied. This is certainly a contribution to the uncertainty of production in terms of a 20 year period.

When evaluating the total uncertainty of the calculated wind climate, the uncertainty of the measurements themselves needs to be evaluated. In addition also the length of the data period needs to be assessed, as there are uncertainties related to the length of the time series. The root square sum of these uncertainties is the total uncertainty (Kjeller Vindteknikk, 2011).

The measurements have an uncertainty of 2 % which is related to calibration of the anemometers, the configuration of the anemometers and the long term mean wind speed calculation (Kjeller Vindteknikk, 2011). The uncertainty related to the length of the period is found to be 6 % for one year and then decreasing as the square root of the number of years (EWEA, 2004). In this case the uncertainty related to the length then becomes approximately 3.46 % (6 % / $\sqrt{3}$). Table (24) shows the total uncertainty of the calculated wind climate.

	Length of period [years]	*Uncertainty regarding measurements*	*Uncertainty regarding length of time series*	*Total uncertainty*
Measured data	3	2 %	3.46 %	**4.0 %**

Table 24 - Uncertainties of long term prediction

A total uncertainty of 4.0 % has been found, which means that there is only a 4.0 % chance that the wind climate will differ from the computed, over longer time periods.

3.11 Long Term Prediction

The long term prediction of the wind climate at Nanortalik is based on the report “Weather and climate data from Greenland 1958-2010” (Ministry of Climate and Energy, 2011). This report, and its attached data files, presents the Greenlandic weather and climate data that is accessible to the public, and contains of 81 weather stations. In this analysis the 04283 Nanortalik weather station is used (see Figure 63).

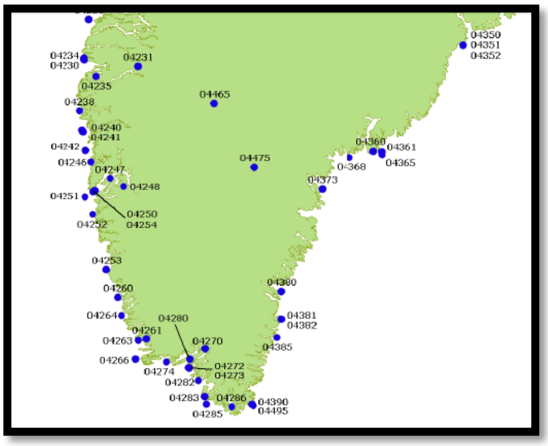

Figure 63 - Southern Greenland with station positions

The weather station has the following properties:

Owner	DMI
Time of operation	02.01.1961 – 31.10. 1985
Latitude N	60 deg 08 min
Longitude W	45 deg 13 min
Elevation	21 m.a.s.l
Height of met mast	10 m

Table 25 - Properties of the Nanortalik weather station

As can be seen from the table, there are wind data from 24 years of wind data in the data series, thus a good picture of the expected long term wind regime can be provided from the data. In Figure (64) and (65), the location of the weather station is visualized.

Figure 64 - Foundation of the 04283 Nanortalik Weather Station

Figure 65 - View towards the drinking water supply from the 04283 Nanortalik Weather Station

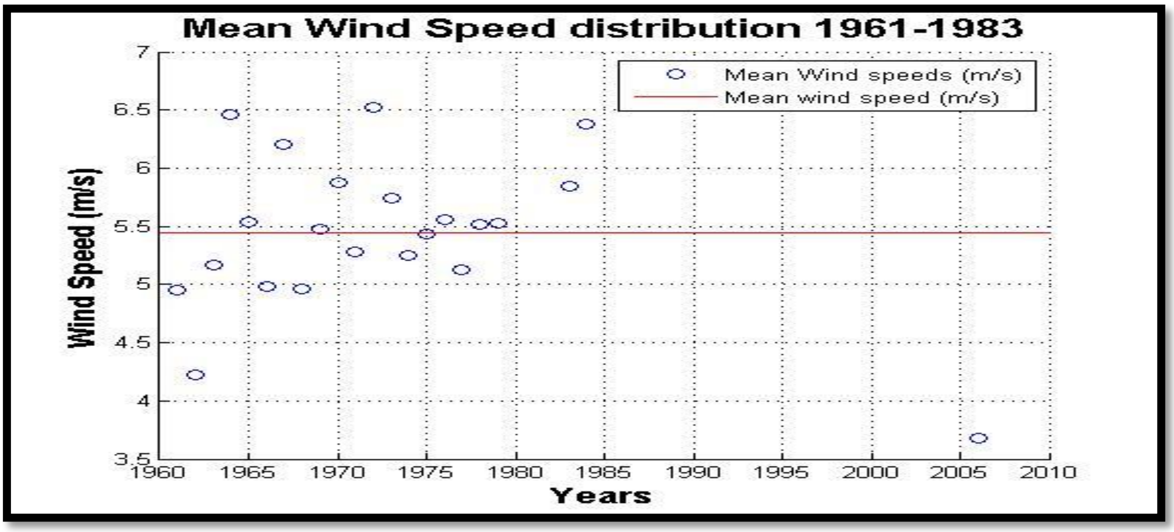

Figure 66 - Mean Wind Speed distribution 1961-1983

The data series is analysed and a total mean wind speed is calculated, proving a mean wind speed of 5.44 m/s at 10 m. The value for the heliport site is 4.7 m/s. The best way to assess this further is to study the annual variation of the mean wind speed. This variation is presented in Figure (66).

As can be seen, the distribution is rather scattered, varying from 4 m/s to 6.5 m/s. The reason for this and the reason for the difference between this weather station and the one at the heliport consist of several factors. First and foremost, they are located at different locations with different surroundings, where the heliport station is influenced by the large mountain in east, this station is affected by other mountains. Since the mean wind direction is easterly, the first mentioned has largest influence. In addition, the heliport station is influenced by many obstacles, which has a large influence on the measurements.

The mean wind speed distribution shown in Figure (66) also implies further uncertainties as the measurements do not cover the same measurement period as the Heliport data; hence a direct correlation over the same time period is not possible.

In addition, the equipment on the weather stations are not revised as often as they should, resulting in unreliable measurement. The conclusion is therefore that the measurements have a reasonable correlation.

4 PRESENTATION OF SITES

Two potential locations are assessed for the wind turbine in this analysis, mainly based on the wind climate, but also on the accessibility of the transport and difficulties regarding wind turbine erection.

By studying the wind resource map (See Figure (53)), several areas with considerably better wind resources are observed. During the field trip to Nanortalik, all of these locations have been investigated, with regards to transportation in particular, but also EIA issues like noise and visual impact. The mountainous area southwest on the island has by far the highest wind speeds, and also the mountain north of the town has higher wind speeds than the chosen sites. These have not been chosen due to accessibility. As illustrated in Figure (67), the wind turbines are located in two quite different areas; Turbine site 1 in the town and Turbine site 2 in the hilly area northwest of the town. The first have been chosen due to its easy accessibility and because the area is low work intensive in terms of the mounting process. The second turbine site is chosen based on its relatively high wind speed, seemingly easy road construction and low turbulence.

In this section, the two chosen sites are further undergone with respect to the wind resource and the main challenges at the sites. Also, the sites have been validated according the the IEC 61400-1 standard in addition to a general site assessment.

4.1 Turbine site 1

Turbine site 1 is located approximately 1 km from the centre of Nanortalik, and approximately 300 m from the nearest habitation. The site is situated 100 meters south of the 1601 Nanortalik met mast described in the previous chapter. In Table (26), the main figures of the site are presented:

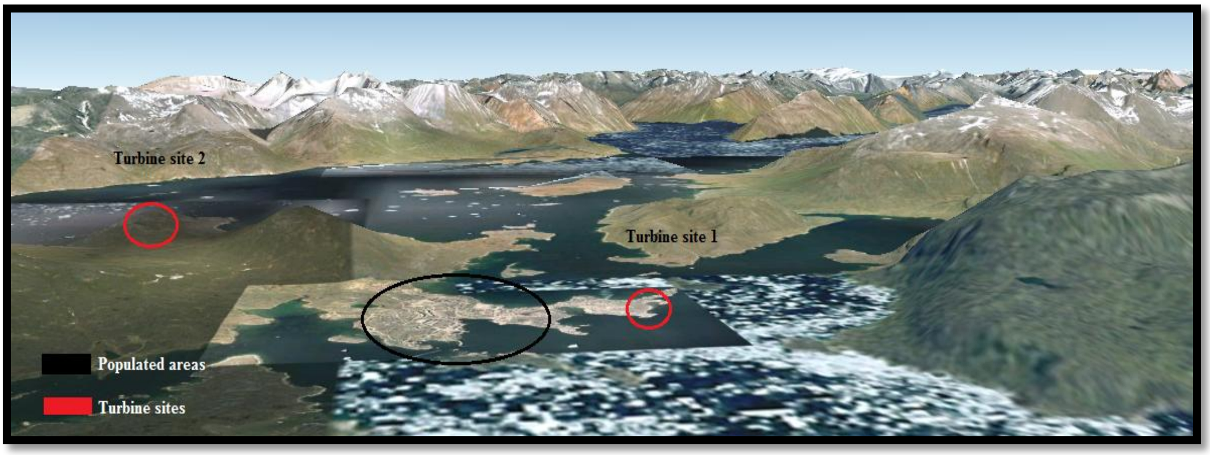

Figure 67 - Potential turbine locations

Turbine site 1	
Longitude	487 492
Latitude	6 667 363
Mean wind speed (50 m)	5.81 m/s
Power density (50 m)	345 W/m^2
Main challenges	Turbulence and distance to nearest habitation

Table 26 - Main figures of Turbine site 1

There are two main challenges connected to the erection of a wind turbine at this location; possibly high levels of turbulence intensity, due to complex terrain in east, and the short distance to the nearest residential building.

4.1.1 Wind resource

The wind resource at the site is rather low, with a mean wind speed of 5.81 m/s at 50 meters height. Considering the power in the wind, given by the following equation,

$$P = \frac{1}{2}\ x\ A\ x\ \rho\ x\ V^3 \qquad \textbf{(14)}$$

Where:
P = Power in the wind (W)
A = Swept area of the rotor blade (m^2)
ρ = Air density (kg/m^3)
V = Velocity of the wind (m/s)

it is easily seen that such a low wind speed (compared to 7.27 m/s for Turbine site 2 at 50 meter hub height) has a big influence on the power production – and finally the fuel savings.

4.1.2 Turbulence intensity

The flow towards a wind turbine is essentially turbulent, with wind speed variations originating from production of turbulent kinetic energy due to surface roughness. This occurs in combination with production or destruction of turbulent kinetic energy due to atmospheric stability. Upon approaching a wind turbine, the wind speed decreases and the turbulence increases in anticipation of the flow distorting and energy extracting object. In this analysis, the atmospheric stability is not considered, however, the orography of the area surrounding Turbine site 1, is of particular interest.

The mechanical loading of the components of a wind turbine, like the blades or the shaft, originates from aerodynamic forces on the rotor blades. Turbulence therefore causes variations in the mechanical loading; in other words: it causes damaging fatigue loads. To date fatigue loading is considered as the primary factor which determines the life time of a wind turbine, and several methods for designing a turbine, for a given life time, exist (Brand, Peinke, & Mann, 2005). As can be seen from Figure (69), a 600 meters high mountain is located approximately 2 km east of the turbine site. As can be seen from the WAsP Engineering calculations, it is the wind from this direction that provides the highest turbulence intensity levels. In Chapter (4.3) the turbulence intensity is assessed in the IEC Classification.

Figure 68 - 1601 Nanortalik met mast with the 600 meters mountain in the background

Figure 69 - Turbine site 2 located at the middle peak. To the left is the drinking water supply for Nanortalik

4.1.3 Noise issues

Being situated only 300 meters from the nearest habitant, the noise from the turbine could be a potential problem. The problem is further enhanced by the lack of vegetation in the area, which serves as a noise reduction during moderate to high wind speeds. In consultancy with the Kujalleq municipality, it is in this analysis used Danish regulations regarding tolerated noise level, and this matter is discussed in Chapter (9).

4.2 Turbine site 2

Turbine site 2 is located 4 km from the centre of Nanortalik, in a northwest direction. The location, being in the other end of the island, is advantageous in terms of noise issues and also proves far higher wind speeds. In Table (27), the main figures of the site are presented:

Turbine site 2	
Longitude	484 434
Latitude	6 670 034
Mean wind speed (50 m)	7.27 m/s
Power density (50 m)	702 W/m^2
Main challenges	Road construction

Table 27 - Main figures of Turbine site 2

Being situated over 4 km from the population, noise is not considered an issue. It is seen that in the westerly regions of Nanortalik a relatively high peak is located. This could imply some turbulence at the turbine site, since the site is located at a lower altitude. By evaluating the wind rose for Nanortalik, it is noted that the majority of the wind will avoid the peak, thus remain unaffected. In the further work on this project, it would be interesting to do a more thorough investigation of the turbulence in the area, to verify whether the turbulence poses a threat to the turbine. The simulations performed in this analysis proved an acceptable turbulence intensity level, although WAT simulations resulted in exceedance of the maximum allowable effective turbulence intensity distribution, which is discussed in Chapter (4.4.4).

4.2.1 Wind resource

The wind resource at Turbine site 2 is considerable higher than at site 1, with a mean wind speed of 7.27 m/s at 50 meters height. Thus, the potential fuel saving by locating the wind turbine at Turbine site 2 is far greater than at Turbine site 1.

4.2.2 Road construction

The road leading from the town to the erection site will add much higher road construction cost to the project, and thus whether the cost of energy will be higher or lower than the alternative is primary a matter of both the length and complexity of the road. All of this is thoroughly discussed in Chapter (7).

4.3 IEC Classification

The IEC Classification is simulated by use of WAsP Engineering and the Wind Farm Assessment Tool (WAT) software. WAT takes into account the wind regime calculated in the WAsP Climate Analyst, the terrain and the turbine location and heights. The simulations return key parameters related to the IEC classification of wind turbines.

In IEC 61400-1, the wind turbines are divided into three turbine classes, I, II and III, according to a reference wind V_{ref} of 50 m/s, 47.5 m/s and 37.5 m/s respectively. There are also three turbulence categories in the classification system, A, B and C, which are defined by the reference turbulence intensity I_{ref}. The categories are 16 %, 14 % and 12 % respectively. In Table (28), the IEC 61400-1 classification system is presented:

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

Table 28 - The IEC 61400-1 classification system

4.3.1 Extreme Wind

V_{ref} is the maximum extreme wind speed for the different wind turbine classes. The extreme winds have the strength to totally destroy a wind turbine, having 10 minute averages as high as 40-60 m/s, with even larger wind gusts. They rarely occur, and might not occur at all within a wind turbines life time, but it is important to have an idea of how high the wind speeds statistically can be at a site to assure that the wind turbine can withstand it. Statistical methods are developed so that these average extreme winds can be estimated relatively precisely. This is of course without the influence of the global warming, which in time can affect and possible change the climate. In "Introduction to Micrometeorology for Wind Energy" (Berg & Mann, Introduction to Micro Meteorology for Wind Energy, 2011), the following definition of extreme wind is found:

" By the extreme wind, U50, we define the 10 minute average wind, U, which on average exceeds some threshold value corresponding to U50, one time during a period of 50 years. The extreme wind, U50, is thus the largest wind one can expect within 50 years."

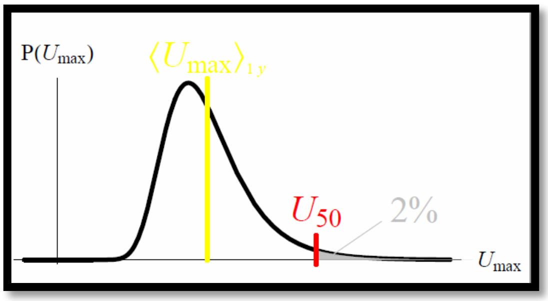

Figure 70 - Definition of the extreme wind,

U50, based on yearly maxima (Berg & Mann, Introduction to Micro Meteorology for Wind Energy, 2011)

The extreme wind is calculated by utilization of the Gumbel distribution.

The Gumbel distribution is used in probability theory and statistics to model the distribution of the maximum of a number of samples, for example a wind distribution at a site. The Gumbel distribution is given in Equation (15):

$$F_X(x) = \exp\left(-\exp\left(-\frac{x-\beta}{\alpha}\right)\right) \qquad \textbf{(15)}$$

Where α and β are two free parameters, from which the extreme wind is determined by using equation (16):

The method is based on order statistics where all the yearly peak wind speeds are arranged in ascending order (in this case only 3 years). Then a linear regression is made, thus creating a fitted straight line. By choosing the desired cumulative probability (0.98), the extreme wind is found.

$$U_T = \alpha \log T + \beta \qquad \textbf{(16)}$$

U_T is the extreme wind estimated within T years, and the most common value for T is 50 – thus this value is also used in this analysis.

By using statistics of yearly maximum wind speeds, there are several methods to estimate U50. The one used in WAsP Engineering is by assigning a cumulative probability F_i to each X_i, given by the following equation:

$$F_i = \frac{i}{N+1} \qquad \textbf{(17)}$$

The cumulative probability is plotted as a function of the measurements in the following way:

- X-axis = X_i
- Y-axis = -log (-log (F_i))

The α- and β-parameters are found by making a linear regression of the points created, thus making a fitted straight line. Then the probability of a U50 extreme wind to occur, which is 0.98, is calculated and plotted as –log(-log(F_i)). The point where the fitted straight line and the probability line crosses shows the U50 extreme wind on the x-axis. According to (Berg & Mann, Introduction to Micro Meteorology for Wind Energy, 2011), the method systematically overestimates the value of α and β, resulting in a too high estimate of the extreme wind, U50.

There are two other methods to estimate the extreme wind from the Gumbel distribution – the WAsP Weibull method and the PWM (Probability Weighted Moment) method. There are large uncertainties attached to the extreme wind calculation, and further work on the project could involve other methods of predicting the extreme wind.

In the IEC classification and site assessment, a WAsP/WEng file of the WinWind WWD-1 turbine is created based on received documentation from the manufacturer. An additional wind turbine, Vestas V44, is chosen as an alternative turbine to the WinWind WWD-1 turbine.

4.3.1.1 Turbine site 1

The simulation proves an extreme wind speed varying between **38.70 ± 8.94 m/s** for the V44 turbine and **41.05 ± 9.62 m/s** for the WWD-1. With such an extreme wind speed, an IEC II turbine can handle the wind regime according to the standard. Taking into account the uncertainties with the calculation, an IEC I turbine would be a safer choice.

Extreme wind	*Turbine site 1*
WWD-1 at 70 m a.g.l.	41.1 ± 9.6 m/s
V44 at 40.5 m a.g.l.	38.7 ± 8.9 m/s

Table 29 - Extreme wind results for Turbine site 1

4.3.1.2 Turbine site 2

For the second turbine site, the simulation gives an extreme wind varying between **49.7 ± 10.6 m/s** and **50.9 ± 10.9 m/s** for the respective turbines, thus an IEC I turbine is required for the site for a hub height of 40.5 meters, while a special class turbine is needed for a hub height of 70 meters.

Extreme wind	*Turbine site 2*
WWD_1 at 70 m a.g.l.	50.9 ± 10.9 m/s
V44 at 40.5 m a.g.l.	49.7 ± 10.6 m/s

Table 30 - Extreme wind results for Turbine site 2

4.3.2 Turbulence Intensity

The turbulence intensity is crucial to investigate, due to its relation to induced fatigue load on the main components of the wind turbine. The turbulence intensity quantifies how much the wind speed varies within typically 10 minutes, and is calculated from Equation (18):

$$I_u(z) = \frac{\sigma_u}{U(z)} \qquad \textbf{(18)}$$

Where:
I = Turbulence intensity
σ = Standard deviation of wind speed
U = Wind speed

The mean wind speed, U (z), for the two sites is:

- **Turbine site 1:** 5.81 m/s
- **Turbine site 2:** 7.31 m/s

The turbulence intensity in the natural atmosphere is dependent on the surface roughness and the wind velocity. For the longitudinal component, u, the standard deviation is approximately constant with height, thus the turbulence intensity decreases with height and velocity. In calculations of the turbulence intensity one can use a rule of thumb to simplify the calculation. The following equation can be used for neutral conditions in flat terrain to calculate the standard deviation of the turbulence velocity fluctuation:

$$\sigma_u = Au_\star \qquad \textbf{(19)}$$

A is dependent on the roughness length, whereas the frictional velocity is mean values at given sites, respective to the different sectors and their frequency.

4.3.2.1 Turbine site 1

The simulation of turbulence intensity proves that the highest turbulence intensity at 40.5 m a.g.l. comes from the sector in east, with a magnitude of 15.5 %. It seems likely that this is the sector with the highest turbulence, as the mountain just east of the site is characterized by a steep slope leading to the site. At 70 m a.g.l. the highest turbulence intensity is 13.9 % coming from the same sector. The mean turbulence intensity from all directions is simulated to be 11.5 % for the lowest hub height, while it is 10.2 % for the highest hub height. An IEC B turbine is thus required for this site at a hub height of 70 m a.g.l, when considering turbulence intensity.

I_{ref}	*Turbine site 1*
WWD-1 at 70 m a.g.l.	13.9 %
V44 at 40.5 m a.g.l.	15.5 %

Table 31 - Turbulence Intensity for Turbine site 1

4.3.2.2 Turbine site 2

On Turbine site 2 the turbulence intensities are considerably lower. The site has a mean turbulence intensity of 6.7 % and 6.1 % for the respective hub heights of 40.5 and 70 m a.g.l. The maximum simulated TI for the lowest hub height is equal to 9.5 % coming from the 150 degrees sector, while for the highest hub height the result is 8.9 % from the same sector.

I_{ref}	*Turbine site 2*
WWD-1 at 70 m a.g.l.	8.9 %
V44 at 40.5 m a.g.l.	9.5 %

Table 32 - Turbulence Intensity for Turbine site 2

An IEC C turbine is appropriate according to the turbulence levels at Turbine site 2.

4.3.3 IEC Classification

The site-specific calculated turbulence intensities and extreme wind speeds, for Turbine site 1, correspond to a wind turbine class C, which has a referred turbulence intensity of 16 %.This result in an IIA wind turbine, due to the site conditions and stated assumptions. In order to reduce the risk of extra maintenance costs and production loss, the IEC standards have to be satisfied:

Turbine class	
Turbine site 1	IEC IIA
Turbine site 2	IEC I C/S

Table 33 - IEC Classification of the two sites

4.4 Site Assessment

Besides the turbine classification, the IEC 61400-1 standard includes a protocol for site assessment. The theories for the different criteria are sited from the help function in WAT. The site assessment criteria are

- Extreme wind speed
- Maximum flow inclination
- Allowable wind shear
- Allowable turbulence intensity
- Allowable wind-speed distribution
- Complex terrain
- Air density
- Extreme wind speed based on 3-sec periods

4.4.1 Extreme wind speed

"The fifty-year extreme wind speed at turbine hub height must not exceed the reference wind speed V_{ref} of the certificate. The reference wind depends on the turbine class".

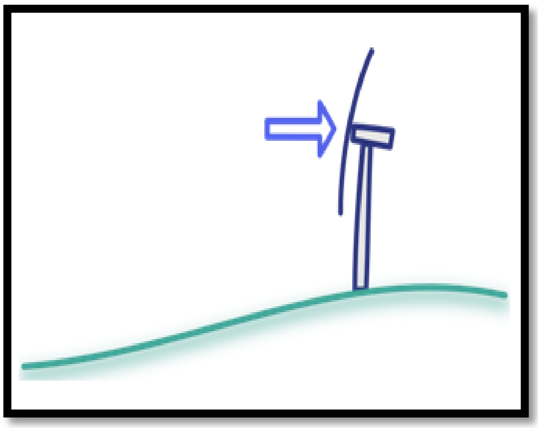

Figure 71 - Extreme wind speed (Risø DTU)

4.4.1.1 Turbine site 1

The highest estimated extreme wind for the site is **38.7 m/s** and **41.1 m/s** depending on hub height, which is less than the allowed value according to the turbine specifications (41.5 m/s).

4.4.1.2 Turbine site 2

The highest estimated extreme wind for the site is **49.7 m/s** and **50.9 m/s** depending on hub height. In this case a class I turbine is needed at 40.5 meter hub height, while a special class turbine (S) is needed at 70 m a.g.l.

4.4.2 Maximum flow inclination

"For turbine class I, II, III, the flow inclination must not exceed ± 8° for any wind direction. The manufacture may specify an alternative limit for a class S turbine".

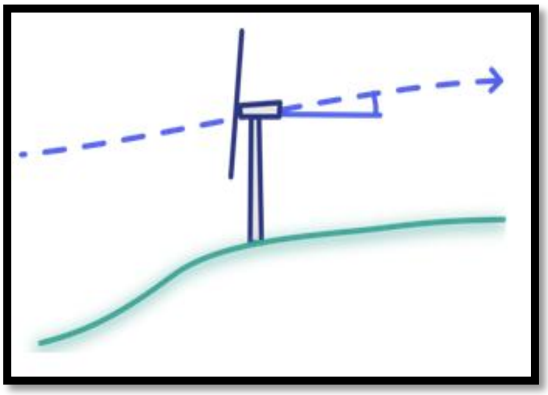

Figure 72 - Maximum flow inclination (Risø DTU National Laboratory for Sustainable Energy, 2011)

4.4.2.1 Turbine site 1

The highest estimated flow inclination for the 40.5 m a.g.l. hub height is **0.838°** while the maximum is **0.428°** at a hub height of 70 m a.g.l, which is well inside the maximum flow inclination requirements.

4.4.2.2 Turbine site 2

For Turbine site 2, the highest estimated flow inclination for the 40.5 m a.g.l. hub height is **2.09°** while the maximum is **2.509°** at a hub height of 70 m a.g.l. Although the flow inclination is a bit higher at this site, it is still inside the requirements for all turbine classes.

4.4.3 Allowable wind shear

Wind shear is a change of wind speed or direction with height. This is critical to assess, as large wind shears lead to an uneven load distribution on the turbine blades, which may result in fatigue damage. As stated in the Site Assessment in the IEC 61400-1, the averaged wind shear exponent for all directions must be lower than 0.2. According to the standard, higher values will result in fatigue damage. With ultimate loads the wind shear coefficient is 0.11. To

avoid blade-tower interaction the wind shear has to be positive.
"The site average vertical wind shear at hub height must neither be negative or to steep. IEC 61400-1 express these conditions as 0<α< 0.2, where α is the exponent of a power law approximation near hub height."

The wind shear exponent is calculated by utilizing Equation (20):

$$\alpha = \frac{\log\left(\frac{mean(WS)}{Uhub}\right)}{\log\left(\frac{Z_{mast}}{Z_{turb}}\right)} \qquad \textbf{(20)}$$

Where:
α = Wind shear
WS = Wind speed
Z_{mast} = Height of met mast
Z_{turb} = Height of wind turbine
U_{hub} = Wind speed at hub height

Wind speed at hub height can thus be calculated by the following equation:

$$Uhub = \left(\frac{\mathrm{Uf_w}}{\mathrm{kappa}}\right) * \log\left(\frac{\mathrm{Z_{turb}}}{\mathrm{z0_w}}\right) \qquad \textbf{(21)}$$

Where:
Uf_w = Friction velocity
Kappa = Von Karman constant (0.4)
$z0_w$ = Roughness length of surroundings

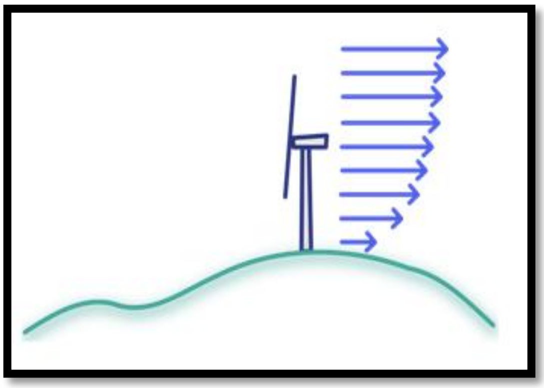

Figure 73 - Allowable wind shear (Risø DTU National Laboratory for Sustainable Energy, 2011)

4.4.3.1 Turbine site 1

For the lowest hub height the average shear is maximally **0.138**. While for the 70 m a.g.l. hub height the maximum average shear is **0.115**. The average shear values for all sectors are 0.118 and 0.100 for the respective heights.

Wind shear coefficient, α	*Turbine site 1*
WWD-1 at 70 m a.g.l.	0.115
V44 at 40.5 m a.g.l.	0.138

Table 34 - Wind shear coefficient for Turbine site 1

4.4.3.2 Turbine site 2

Turbine site 2 proves to have lower vertical wind shear values, with maximum values of **0.105** for 40.5 m a.g.l. and **0.089** for 70 m a.g.l. The average wind shear values for all sectors are equal to 0.063 and 0.024 for the respective hub heights.

Wind shear coefficient, α	*Turbine site 2*
WWD-1 at 70 m a.g.l.	0.089
V44 at 40.5 m a.g.l.	0.105

Table 35 - Wind shear coefficient for Turbine site 2

4.4.4 Allowable turbulence intensity

"The effective turbulence intensity (TI) must be less than the design Ti in the range from 60 % of rated wind speed (the wind where maximum power production is reached) and the cut-out velocity. The design TI is a function of wind speed and it is scaled by the reference TI of the turbine certificate".

From the WAT help files, the effective turbulence is defined as the turbulence intensity that causes the same material damage as the turbulence from all directions. This requirement can hence be seen as a limit for the turbulence-inflicted equivalent load that the material can withstand at a given wind speed range, in order to remain undamaged (Risø DTU).

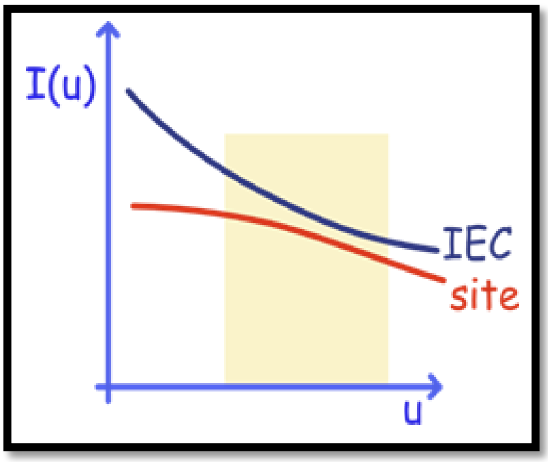

Figure 74 - Allowable turbulence intensity (Risø DTU National Laboratory for Sustainable Energy, 2011)

4.4.4.1 Turbine site 1

For a wind turbine with a hub height of 40.5 meters, the simulation results show that the requirement regarding the allowable turbulence intensity is unfulfilled for a class IIA turbine. It is thus necessary to choose a special class turbine also at this site, with a maximum TI_{ref} at 0.20 to fulfill the requirements.

At a hub height of 70 meters the simulation shows a similar result, with the allowable turbulence intensity criteria being exceeded for an IIA turbine. A special class turbine with a maximum TI_{ref} at 0.18 fulfills the requirements.

4.4.4.2 Turbine site 2

At Turbine site 2 with a wind turbine hub height of 40.5 meters, the simulation shows that the requirement regarding the allowable turbulence intensity is fulfilled for a class IC turbine.
At a hub height of 70 meters the allowable turbulence intensity criteria is well within the requirements for a special class turbine.

4.4.5 Allowable wind-speed distribution

"IEC 61400-1 has an additional rule that the actual wind-speed probability must be less than assumed for the fatigue calculations behind the turbine certificate in the range 20-40 % of the reference velocity".

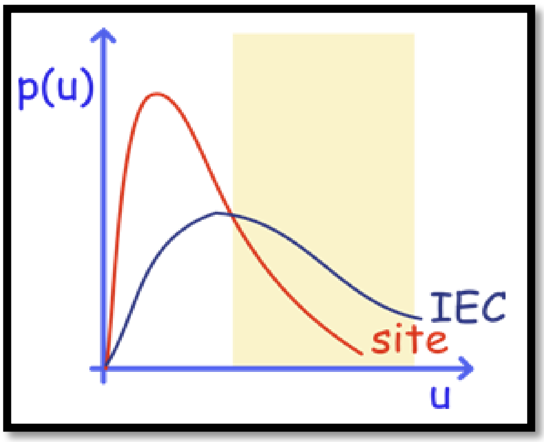

Figure 75 - Allowable wind-speed distribution (Risø DTU National Laboratory for Sustainable Energy, 2011)

4.4.5.1 Turbine site 1

The allowable wind-speed distribution requirement is fulfilled at both hub heights, with a special class turbine.

4.4.5.2 Turbine site 2

For Turbine site 2, the allowable wind-speed distribution requirement is also fulfilled for both the class IC turbine at 40.5 meters hub height and the special class turbine at 70 meters hub height.

4.4.6 Complex terrain

IEC 61400-1 states that "*the standard deviation of the longitudal component of turbulence shall be increased in order to account for the distortion of the turbulent flow*", and defines a turbulence structure correction parameter C_{ct}:

$$C_{ct} = \frac{1}{1.375}\sqrt{1 + \left(\frac{\sigma_2}{\sigma_1}\right)^2 + \left(\frac{\sigma_3}{\sigma_1}\right)^2} \quad \textbf{(22)}$$

Where the sigma values are standard deviation of the three velocity components for longitudal, lateral and vertical velocity perturbations, respectively. If the site is deemed complex, the background turbulence intensity must be multiplied by the C_{ct} factor.

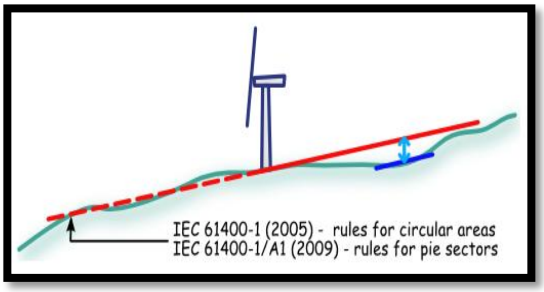

Figure 77 - Complex terrain (Risø DTU National Laboratory for Sustainable Energy, 2011)

The WAT cannot estimate a C_{ct} factor when an S-class turbine is applied. The C_{ct} factor is thus calculated when applying IIA at Turbine site 1, and IC at Turbine site 2.

4.4.6.1 Turbine site 1

For the simulation with hub heights of 40.5 and 70 meters, WAT reports that the terrain conditions are normal, with a C_{ct} factor of 1.0. The results for the 70 meters hub height is shown in Figure (76).

Turbine site 1	<5zhub		<10zhub		<20zhub				
Sector	slope	exArea	slope	exArea	slope	exArea	Status	Energy	Cct
0	-	-	1.6	0.00	0.8	0.00	ok	10.6%	
30	-	-	1.6	0.00	0.8	0.00	ok	8.7%	
60	-	-	1.5	0.00	0.8	0.00	ok	11.1%	
90	-	-	1.6	0.00	0.8	0.00	ok	23.9%	
120	-	-	1.6	0.00	0.8	0.00	ok	4.9%	
150	-	-	1.6	0.00	0.8	0.00	ok	6.2%	
180	-	-	1.6	0.00	0.8	0.00	ok	6.1%	
210	-	-	1.5	0.00	0.7	0.00	ok	1.7%	
240	-	-	1.1	0.00	0.6	0.00	ok	1.0%	
270	-	-	1.3	0.00	0.1	0.00	ok	1.4%	
300	-	-	1.5	0.00	0.5	0.00	ok	6.9%	
330	-	-	1.5	0.00	0.8	0.00	ok	17.3%	
All	0.2	0.00	-	-	-	-	ok	100%	
Conclusion							normal	0.0%	1.000

Figure 76 - WAT terrain complexity evaluation for Turbine site 1 at 70 meters hub height

4.4.6.2 Turbine site 2

At 40.5 and 70 meters hub height WAT evaluates the terrain conditions as complex, with correction factors, C_{ct}, of 1.099 and 1.079 for the respective heights. Figure (78) shows the result table from WAT for Turbine site 2 at 70 meters hub height. Simulation in WAT results in a complex terrain classification for Turbine site 2, while Turbine site 1 is located in normal terrain. This seems like an acceptable estimate, as Turbine site 2 is placed on a hilltop, while Turbine site 1 is placed on flat land, close to the shore. Turbulence levels are still estimated to be highest for Turbine site 1, which is corresponding to the authors' view of the impact the mountainous region in the

Turbine site 2	<5zhub		<10zhub		<20zhub				
Sector	slope	exArea	slope	exArea	slope	exArea	Status	Energy	Cct
0	-	-	8.2	11.44	3.8	25.63	fail	6.2%	
30	-	-	10.7	12.39	8.6	53.51	fail	7.6%	
60	-	-	9.4	12.47	7.3	50.55	fail	12.4%	
90	-	-	7.1	12.38	0.9	22.64	fail	35.2%	
120	-	-	6.2	12.26	0.9	24.68	fail	5.6%	
150	-	-	5.4	10.92	4.2	23.66	fail	3.5%	
180	-	-	7.2	12.97	2.6	12.97	fail	2.8%	
210	-	-	8.6	13.35	0.8	13.35	fail	1.4%	
240	-	-	14.3	13.40	6.5	40.11	fail	1.3%	
270	-	-	16.4	13.03	9.4	54.15	fail	2.6%	
300	-	-	15.1	11.57	9.3	52.69	fail	8.4%	
330	-	-	12.8	11.39	8.4	48.60	fail	13.2%	
All	3.4	25.99	-	-	-	-	fail	100%	
Conclusion							complex	100.0%	1.079

Figure 78 - WAT terrain complexity evaluation for Turbine site 2 at 70 meters hub height

east has on the turbine location. Since the C_{ct} factor cannot be extracted when applying a special class turbine, these simulation results are disregarded.

4.4.7 Air density

"The standard specifies that the average air density must not exceed 1.225 kg/m³ (or a limit specified by the turbine manufacturer) for wind speeds larger than the rated speed. In principle this assessment requires a joint statistic of wind speed and temperature, and thus it is not a WAT feature."

As an estimate, the WAsP air density calculator is utilized with an altitude of 0 meters and 0°C. The air density for such a condition is estimated to 1.2692 kg/m^3 – thus above the criterion. As this is a problem for almost all wind farms, it is assumed to not be a problem.

4.4.8 Extreme wind speed based on 3-sec periods

"The extreme wind is normally based on a fifty-year recurrence period and 10-min averaging period. This extreme wind is compared to the reference wind speed V_{ref} of the wind turbine class. As an alternative, a special fifty-year extreme wind with 3-sec averaging period V_{e50} may be compared to 1.4 V_{ref}. The present version of WAT does not attempt to estimate the 3-sec extreme wind."

4.4.8.1 Turbine site 1

The 1.4 x V_{ref} extreme wind speed for the turbine with 40.5 meter hub height is **54.2 m/s.** While the corresponding result for 70 meter hub height is **57.5 m/s**.

4.4.8.2 Turbine site 2

The calculations show that the 1.4 x V_{ref} extreme wind at 40.5 meters hub height is equal to **69.6 m/s** at Turbine site 2. For a hub height of 70 meters the result is **71.3 m/s**.

4.4.9 Classification of turbines

The previous assessments have, according to the IEC classification system, resulted in the following classes for the turbines, at 40.5 m.a.g.l and 70 m.a.g.l hub heights. For Turbine site 1, which is located close to the dumping station in Nanortalik, an IEC IIA turbine is required, at hub heights of both 40.5 and 70 m.a.g.l. This is due to the exceedance of the allowable turbulence intensity criterion, described in Chapter (4.4.4).

Turbine site 1 - IEC classification	
40.5 / 70 m a.g.l	IEC S

Table 36 - Turbine site 1 - IEC classification

For Turbine site 2 an IEC 1 C turbine is needed for a hub height of 40.5 m.a.g.l, while a special class IEC I turbine is needed for a 70 m.a.g.l. turbine.

Turbine site 2 - IEC classification	
40.5 m a.g.l	IEC 1 C
70 m a.g.l	IEC S

Table 37 - Turbine site 2 - IEC classification

Due to the requirement of a special class turbine at both sites, an additional cost is added on top of the turbine price obtained by the wind turbine manufacturer, WinWind. This is further undergone in Chapter (10.2.1), where the investment costs regarding the wind turbine is set.

5 WIND FARM CALCULATION

In the previous chapters, the wind climate of the Nanortalik region and two potential sites for a wind turbine have been described. Based on this work, the predicted output for a wind turbine can be calculated. As the locations have been determined, only the size of the turbine remains to be decided. This is a rather complex matter, as it affects both economic and technical issues. In this analysis it is chosen to model the wind penetrated energy system (for more information see Chapter (8)) with an output power level of 1 MW. This corresponds to approximately 70 % coverage of the total consumption in the city. Considering the relatively low consumption in Nanortalik (see Chapter (2)), the penetration of wind power must be controlled in order to maintain a certain agreement with the governing grid codes.

5.1 Isolated Wind-Diesel System

By implementing wind into a rather small isolated system (like the one in Nanortalik), there are certain limits for how much wind power that can be implemented in order to maintain a stable AC grid. The optimum amount of wind power is defined by limits given by the level of technology used in the system, the complexity of the system and the required power quality. Thus, the amount of wind power must be based on a thorough analysis of the system, and it is not desired to implement as much wind power as possible. Be advised that the share

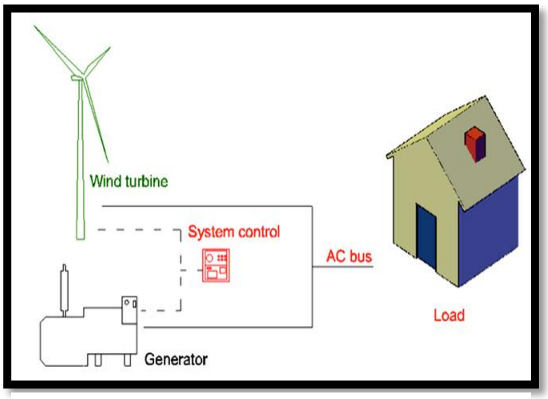

Figure 79 - Principal sketch of a wind-diesel system (Energy Phoenix)

of wind power implementation is not unbounded. In (Ackermann, 2005) the amount of tolerable wind power penetration in a wind-diesel system is described. As the amount of energy obtained from the wind power is considerable, it has a large influence on the performance and economics of the system. Therefore, the book introduces two parameters to define the system parameters:

- Instantaneous power penetration
- Average power penetration

The instantaneous power penetration is defined as the ratio of instantaneous wind power output (kW) to instantaneous primary electric load (kW), given in the following equation:

$$Instantaneous\ penetration = \frac{P_{wind}}{P_{load}} \quad \textbf{(23)}$$

The instantaneous penetration is mainly a technical measure, as it determines the component and control principles of the system.

The average power penetration is defined as the ratio of average wind energy output (kWh) to average primary electric load (kWh), measured over for example days, months or years.

$$Average\ penetration = \frac{E_{wind}}{E_{load}} \quad \textbf{(24)}$$

The average penetration is mainly an economic measure, as it reveals the share of wind power produced energy in the total production (Lundsager & Baring-Gould, Wind Power in Power Systems, 2005).

In (Lundsager, Bindner, Clausen, Frandsen, Hansen, & Hansen, 2001) the following recommendation is presented:

"Isolated wind power plant system configurations, where standard wind turbines are connected directly to an existing large, independent diesel powered grid possibly with several power plants, with a power penetration of max. 25 - 50 %. They will always be installed on existing grids, and the wind turbines (or wind turbine clusters) will have their own control functions ensuring that the stability and other control functions of the grid are not disturbed."

Considering that this report is 11 years old and that it is intended to implement electric boilers as dump load, it is assumed that this number can be increased substantially. Thus, a wind penetration of 70 % is assumed possible. It can be argued that 70 % wind power penetration in an isolated system might induce complications regarding the grid code compliance. This is not considered in this study, as the electric power system aspects are neither scope nor main goal of the investigations in this analysis.

5.2 Wind Turbines

The turbine that represents the 1 MW output level is chosen based on the power curve, which is especially important in low wind areas. The turbine is a WinWind WWD-1 D60, manufactured by the Finnish company with the same name. The power curve of this turbine has a steep curve for the low wind speeds, thus the output at even small velocities are acceptable. The company has been contacted, and the necessary documentation and questions regarding power curves, transport and other issues have been answered. As this analysis does not include grid quality calculations, this turbine represents the optimum solution where most of the energy demand in Nanortalik is satisfied.

For the output level of 600 kW, which only represents an alternative to the main turbine, one of the preinstalled turbines in WAsP is chosen – Vestas V44.

5.2.1 WinWind WWD-1 D60

The WindWind WWD-1 D60 has a rated power of 1 000 kW and a rotor diameter of 60 m. It has a cut-in wind speed of 4 m/s and a cut-out wind speed of 20 m/s, whereas the rated wind speed is 13 m/s. The turbine is shown in Figure (80):

Figure 80 - WinWind WWD-1 D60 (WinWind, 2009)

The power curve of the WinWind WWD-1 is presented in Figure (81). As can be seen from the power curve, a wind speed of 7.31 m/s (which is the mean wind speed at Turbine site 2) has an average production of approximately 300 kW. This corresponds to 68 % of the yearly mean electric load in Nanortalik, where the percentage is found by utilizing the average electricity production as P_{load} in Equation (23).

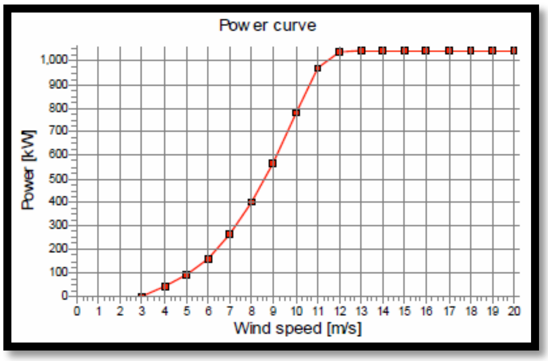

Figure 81 - Power curve of WinWind WWD-1 D60 (WinWind, 2003)

The power curve data is based on preliminary power curve measurements of 60 m 1 MW rotor and aerodynamic calculations. The WinWind turbine is chosen due to its good performance in the low wind speed range, which is important as the Nanortalik area, can be classified as a low to medium wind speed region. The power curve is valid for the following conditions (WinWind, 2009):

1. The turbulence intensity is 8 to 15 %
2. The air density is 1.225 kg/m^3
3. Clean Blade and horizontal inflow are considered, including the nacelle tilt angle and rotor coning
4. The power is measured on the low voltage side
5. Cut in and Cut out hysteresis have not been considered

The Winwind power curve shown in Figure (81) has been implemented manually in the WAsP software since no power curves for WinWind turbines are implemented in the software initially. This results in more accurate AEP calculations for the project, as the alternative is to use a power curve for a similar turbine, which could have different operational characteristics despite an equal rated power.

5.2.2 Vestas V44

The Vestas V44 has a rated power of 600 kW and a rotor diameter of 44 m. It has a cut-in wind speed of 5 m/s and a cut-out wind speed of 20 m/s, whereas the rated wind speed is 17 m/s. The turbine is shown in Figure (82):

Figure 82 - Vestas V44 (The Windpower, 2012)

The power curve of the Vestas V44 is presented in Figure (83). The average production of the turbine with a wind speed of 7.31 m/s is approximately 150 kW – thus half of the WinWind turbine. This corresponds to 34 % of the average yearly electric load in Nanortalik.

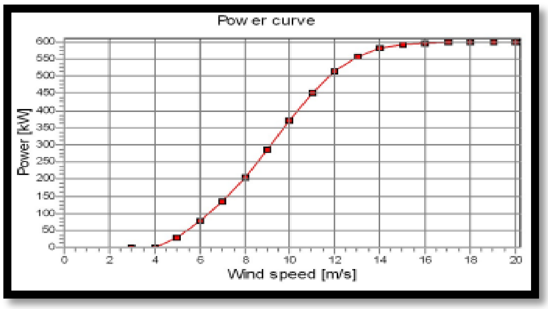

Figure 83 - Power curve of Vestas V44 (Kulak Energia, 2012)

5.3 Annual Energy Production

The annual energy production (AEP) is simulated based on the calculated Weibull distribution of the wind (Chapter (3)) and the power curves (Chapter (5.2)). The equation for the AEP is:

$$E_i = T f_i \int_0^{\infty} p_i(U) P(U) \mathrm{d}U \qquad \textbf{(25)}$$

Where:
T = The number of hours in one year
fi = The frequency of the sector in question
pi(U) = The Weibull pdf of wind in sector i
P(U) = The power curve of the turbine

The wind regime measured by the meteorological mast is transferred to the two respective wind turbine sites by the assumption that the geostrophic wind is the same at the three locations. This is reasonable considering that the distance is less than 4 km.

By calculating the friction velocities for twelve sectors, the geostrophic velocity of the sector can be calculated. Assuming that this is the same at the two turbine sites, the velocities in the respective sectors can be found by analyzing the roughness length conditions and transferring the measurements to the site using the same equations. The friction velocity is given in the following equation:

$$U(z) = \frac{u_\star}{\kappa} \log\left(\frac{z}{z_0}\right) \qquad \textbf{(26)}$$

Where:
U(z) = The mean wind speed for the given sector
k = Experimental constant
U_* = The friction velocity
Z_0 = Roughness length of the sector
Z = Height of met mast / turbine

The geostrophic velocity is calculated by:

$$G = \frac{u_\star}{\kappa} \sqrt{\left(\log\left(\frac{z_i}{z_0}\right) - A\right)^2 + B^2} \qquad \textbf{(27)}$$

Where:
z_i = Friction velocity with rotation of the earth taken into account
A = Weibull scale factor
B = Weibull shape factor

Knowing the geostrophic velocities, and by applying the assumption that the area of matter has the same geostrophic velocities in the respective sectors, the wind regime at the turbine sites can be estimated.
The annual energy production (AEP) is simulated in the WAsP software, based on the wind climate, the resource grid and the location of the wind turbines – all elaborated in the previous sections. The result of the simulations is summarized in Table (38):

Simulation results AEP		
Turbine site	**WinWind WWD-1**	**Vestas V44**
1	2 359 MWh	1 074 MWh
2	2 984 MWh	1 598 MWh

Table 38 - Annual energy production of Turbine site 1 and Turbine site 2

The production from Turbine site 2 is 26.5 and 48.7 % larger than for Turbine site 1 for the two turbine types. In addition, the problems regarding turbulence and noise level at Turbine site 2 is much smaller than for Turbine site 1.

5.4 Losses

The wind farm results obtained from the WAsP simulation only include the internal wake losses in the wind farm. As this is a single wind turbine farm, there are no such losses present. However, there are some other losses that need to be included in the final wind farm calculation, such as internal efficiency, availability, turbine performance and environmental restrictions.

5.4.1 Internal efficiency

The electrical losses is present from the generator until the power is delivered to the grid, thus eventual converter losses, transformer losses and transfer losses are all included. The losses from generator to the internal transformer is included in the power curve of the WinWind turbine, thus it is also included in the WAsP simulation. The internal efficiency therefore includes losses in the internal transformer and converter, and is assumed to be **99 %**.

5.4.2 Availability

The turbine manufactures all gives availability guarantees for how many hours of the year they guarantee that their turbines will be ready for producing power. Suzlon, which is a well known turbine manufacturer, guarantees 97 % availability for their turbines. The same availability is assumed in this analysis for the WinWind turbine.

5.4.3 Other losses

In addition to the already mentioned losses, transport losses in addition to some support functions to the wind turbine, as lights, yaw-gear, fans, cooling systems, data and communication systems etc. which all represents a loss in the turbine needs to be included.

There are also losses related to scheduled stops due to service, in addition to reduced production due to icing and other nature related losses. In addition a turbulence reducing measure could be to reduce the production when the wind direction implies a high possibility of turbulence. All of these are not considered in this analysis, and it is

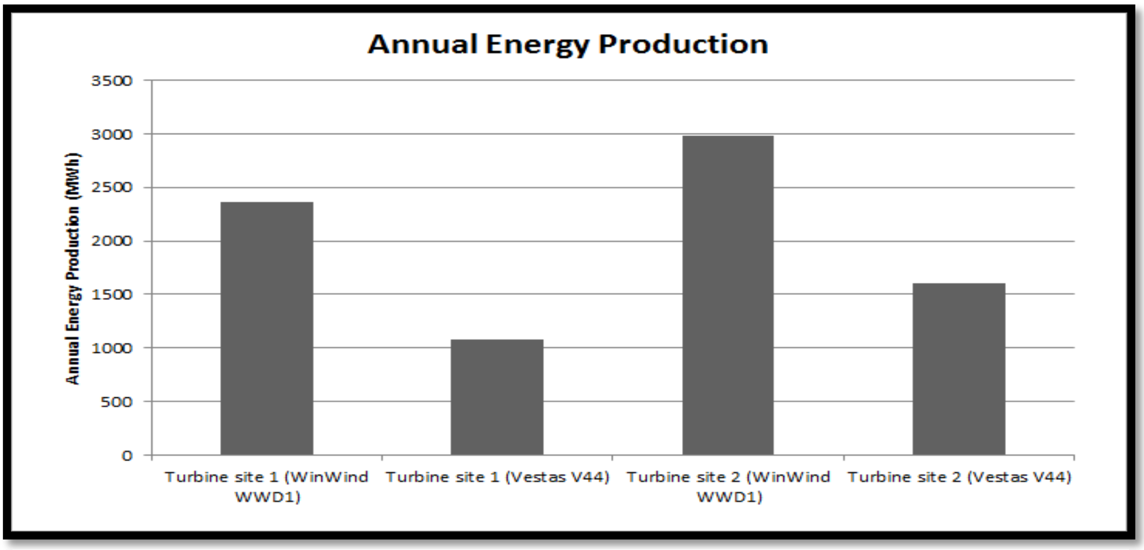

Figure 84 - Annual energy production

assumed that the total efficiency for all of these is 95 %.

5.4.4 Total efficiency

The total efficiency is calculated on the basis of the mentioned loss categories. As there are several losses that are not undergone, the uncertainty is rather large. The total efficiency for the two sites is given in Table (39):

Total efficiency	
Turbine site 1 / 2	91.2 %

Table 39 - Total efficiency

Turbine site 2 should have a lower efficiency due to the longer cable, but this is not considered in this analysis as the difference is small. Hence Turbine site 2 is also given a total efficiency of 91.2 %.

5.5 Technical Description of The Wind farm

The proposed wind farm solutions for the Nanortalik energy system is a 1 MW WinWind WWD-1 wind turbine located either at the mountainous area northwest of the city at Turbine site 2 or at Turbine site 1, which is closer to the town. The wind turbine has a hub height of 70 m, a rotor diameter 60 m – thus a total height of 95 m. It is assumed that the manufacturer, WinWind, can deliver the WWD-1 turbine as a class “S” turbine for both Turbine site 1 and Turbine site 2. An additional price is applied for the special class turbine in the economic calculations.

The final choice of the WinWind WWD-1 turbine is based on the well fit between the power curve of the wind turbine and the analysed wind climate of Nanortalik. This choice is based on the assumption that the electrical grid can handle this level of wind power penetration, with a dump load in the system. In terms of hub height is the height of 70 meters chosen due to an improved wind resource, without significantly increasing the costs.

Key figures of the wind farms are given in Table (40), whereas additional technical descriptions can be found in Appendix C.

Nanortalik wind farm WinWind WWD-1 at Turbine site 1/2	
Operating data	
Rated power	1 000 kW
Cut-in wind speed	4 m/s
Rated wind speed	13 m/s
Cut-off wind speed	20 m/s
Rotor	
Rotor diameter	60 m
Rotational speed	8 - 26 rpm
Swept area	2 827 m^2
Tower	
Type	Tubular tower
Hub height	70 m
Other	
Distance from residential	300 m / 3 900 m

Table 40 - Technical description of the wind farm

5.6 Uncertainties

In feasibility studies of wind farms, there are many factors that needs to be taken into account, and each of these factors are associated with risks and uncertainties. In this chapter some important uncertainties to the wind farm projects in general are presented, together with some more site-specific discussions. However, icing and tower shadowing are omitted. Additionally, some important limitations are illuminated.

In order to evaluate the wind resource at a site in a proper manner, at least 12 months of consistent measurements is required. However, by applying one year of measurements the seasonal variations might be covered, but definitely not the long-term variations. In order to estimate the wind resource over the wind turbines' technical lifetime of 20 years, several years of measurements needs to be applied.

For this study, three significantly consistent and validated measurement years have been used. Although the data have been validated by means of two screening processes, the data has not been cross-predicted, as this would not be appropriate. The reason for this is due to the poor quality of measurements available. At the heliport, the measurement altitude is 10 meters, and due to the surrounding buildings it is highly likely that some flow distortion is present. The heliport measurement instruments also lack a proper maintenance schedule. To date, the instruments are not being revised unless there is a case of visual damage on the devices (Jakobsen K. R., 11427 Arctic Technology , 2012). However, as the primary reference anemometer is Risø P2546, both the calibration and quality of measurements throughout the three-year period is trustworthy. This instrument is known to be rougher than the NRG anemometers and also having a smaller distance constant giving more accurate results, especially in the turbulent conditions the mast is located in.

5.6.1 Uncertainties in the calculations

WAsP analyses the input data provided by the measurement file, whereas the output is presented by Weibull distributions associated to the 30 degrees sectors and a wind rose, referring to the frequency of wind directions. At 1601 there is no odd wind regime; hence the mean Weibull fits pretty well to the wind data histogram. This verification is of high importance, as this is the basis for net AEP (Annual Energy Production) computation, which is the main factor in a wind power feasibility study. Note that Weibull distribution is not referring to the exact wind climate, but such approach has proven to be a good practice. The deviation is due to normalization and is to be disregarded (Berg, 45701 Introduction to Micro Meteorology for Wind Energy, 2011).

Worst case long-term production estimates based on 14 year actual data	1 year of data	2 year of data	3 year of data
Actual production figures	+/- 30 %	+/- 20 %	+/- 10 %
Wind index corrected production figures	+/- 15 %	+/- 10 %	+/- 5 %

Table 41 - Worst-case deviation between actual and estimated production based on 1, 2 or 3 years of measurement. The deviations are based on a 14 year period of actual data (EMD International A/S)

The uncertainties associated to the computed annual energy production by means of the number of valid measurement years are clearly presented by Table (41). In the case of three years of measurements with adequately recovery rate, the worst-case can result in an actual AEP production corresponding to 85 % of the WAsP's net AEP prediction. The need for long-term correction or validation is therefore tremendously important and vital for the project feasibility and risk assessment. Long-term wind regime prediction is carried out in Chapter (3.11). Some additional uncertainties associated with the figures in Table (41) can be expected due to the turbines being situated in complex terrain.

The final determination of location will also be affecting the certainty of the observed wind climate, as Turbine site 1 and Turbine site 2 have different terrain. Turbine site 1 is where the measurements are carried out, hence the uncertainties is lower at this site. However, as the terrain's elevation is different for Turbine site 2, the regime estimation at this site is characterized by a higher uncertainty. WAsP is in general known to be more accurate in wind climate estimation of sites similar to the measurements station. Turbine site 2 will be more affected by speed-up effect, which is in general underestimated by WAsP. This uncertainty will certainly also be of importance in terms of 50 year extreme wind estimation, hence it is, in this context, preferable to utilize a safety margin relative to the IEC standard.

5.6.2 Additional losses

"The net AEP calculated by WAsP is the ideal annual energy production that can be produced by the wind farm when wake losses only have been taken into account. This, however, is not the production that will be fed into the electrical grid at the point of common coupling (PCC). Several additional losses will occur between the wind turbine rotor(s) and the PCC" (Mortensen, Planning and Development of Wind Farms: Wind Resource Assessment and Siting, 2011). Even though the wind resource is thoroughly studied, the net AEP bias and standard deviation are statistically respectively 2 % and 5% (Mortensen, Wind resource mapping and wind farm modelling, 2011).

Even though the wind resource is thoroughly studied and by means of great data quality, WAsP still provides a power production, which normally corresponds to an "over-prediction" regarding the power actually being supplied to PCC (Point of Common Coupling). This is due to a normal wind power plant efficiency of approximately 10 % (Mortensen, 2011). Such as icing, dust, electrical losses, downtime, are all among factors not included in the WAsP net annual energy production estimate. For instance, electrical losses are in general larger and thus of more importance for off-shore wind farms. In case of AC (Alternating Current), the reason for this is poorer power factors and more losses being associated to the typically longer distance to PCC. This illustrates that such factors are site-specific and the various deductions have to be performed project-specific.

In this analysis, the electrical efficiency from point of common connection (PCC) to consumer is neglected. The wind power plant will be replacing some of the existing diesel driven production units, hence lowering generator, transformer and transmission loss associated to such electricity generation in Nanortalik.

5.6.3 Atmospheric stability

Until the field trip and mounting of the Sonic Anemometer, there have not been any measurements that could be of great help to express the complexity of atmospheric stability conditions in or around Nanortalik (Jakobsen K. R., 11427 Arctic Technology , 2012).

In general, the condition at night is more stable, while at daytime the soil is heated up by the sun and thus creating unstable conditions. The standard heat flux value for land refers to slightly stable conditions. The result of this is an approximation to neutral condition, which facilitates simplifications in computation and extrapolation of the heat flux and vertical profile in the IBL (Internal Boundary Layer) (Berg, 45701 Introduction to Micro Meteorology for Wind Energy, 2011). *"WAsP contains a stability model that can handle conditions which are not neutral, but not too far from neutral"* (Machefaux, 2012).

The atmospheric stability in Nanortalik is, however, assumed to be significantly different than for Denmark. In Greenland in general, the summer is characterized by long sunny days, whereas the winters in the south is characterized by limited daylight of a couple of hours (Greenland Explored). These climatic differences are likely to be of importance, however they are not taken into account based on the available data and performed research.

At Danish soil, the standard WAsP value of heat flux of – 40 W/m^2 is applied. This approach is verified to be of good practice for NW European conditions (Machefaux, 2012). The uncertainty of the heat flux profile in Nanortalik, and thus computation by means of the standard value leads to that wind speeds at hub height are characterized by uncertainties. In order to minimize the uncertainty associated to the required extrapolation by WAsP, the extrapolation length is reduced.

All in all, the ignorance of the atmospheric stability conditions in Nanortalik, predominantly means uncertainties associated to the winds speeds at hub height for the different sectors and thus the resulting power production. However, based on the weather conditions in south Greenland, it is expected that the condition is more unstable during summers, whereas more stable during winters. Bearing this in mind, it is expected that the prediction error relating to the orographic model in WAsP is larger for the unstable conditions at summer, while being significantly smaller for the stable winter conditions (Bowen & Mortensen, 2004). To what extent the seasonal conditions are characterized by stable and unstable conditions and affection of the associated WAsP prediction errors cannot be commented upon or analysed, in the lack of relating measurements.

	Loss category	Additional losses type	Typical values
1	Availability	• turbine availability • grid availability	97% > 99%
2	Electrical efficiency	• operational electrical efficiency • wind farm consumption	1-2%
3	Turbine performance	• power curve adjustments • high-wind hysteresis	1-2%
4	Environmental	• blade degradation and fouling • icing or temperature shutdown	1-2%
5	Curtailments	• wind sector management • noise, visual and environmental	Design dependent

Table 42 - Additional losses not included in the WAsP net AEP. The figures presented are the main and typical ones for an onshore wind farm located in NW Europe (Mortensen, Planning and Development of Wind Farms: Wind Resource Assessment and Siting, 2011)

6 GRID CONNECTION

Nanortalik's grid system is an isolated system, which means that it has no interconnection to other towns, cities or power stations other than their own diesel generator stations. The electricity network is a three phase system, where the electricity is distributed at 6 kV in the transmission lines, and step down transformers connects the consumers at a voltage level of 400 V.

An isolated power system is most often utilized for local power supply in remote areas, such as in Nanortalik. These systems are mainly powered by diesel power plants. Isolated systems cannot consist solely of renewable technologies that are not dispatchable. Wind power is not dispatchable, at least to some point. Its power output can be down regulated but the maximum is limited by the instantaneous wind resource. A combination of dispatchable and non dispatchable power generating utilities is therefore the most applicable, such as a wind/diesel system.

These types of systems are also called hybrid energy systems, and are characterized by a combination of power generation sources often with dispatchable load banks such as electricity boilers. The load banks can be utilized to cover fluctuations in the power production, by for example using excessively produced energy for heating.

Wind/diesel systems supplies power, using wind power to reduce the fuel consumption of the diesel generators, while at the same time maintaining the required power quality. The systems economic viability can be strongly related to the value of reduced fuel consumption, a matter discussed in Chapter (10), regarding economical calculations (Lundsager & Baring-Gould, Wind Power in Power Systems, 2005).

The typical characteristics of an isolated system can be summed up by the following five points cited from the book Wind Power in Power Systems (Lundsager & Baring-Gould, Wind Power in Power Systems, 2005):

"- *The system has only one or a few diesel generating sets. By using a number of diesel generators of cascading size, an optimal loading of the diesel generators can be obtained, thus increasing the efficiency of the diesel plant.*

- *The existing power system has simple system controllers, often only the governors and voltage regulators of the diesel generators, possibly supplemented by load-sharing or self-synchronising devices.*

- *The local infrastructure may be limited and there may be no readily available resources for operation, maintenance and replacement.*

- *Fuel is generally expensive and is sometimes scarce and prone to delivery and storage problems.*

- The diesel engines provide adequate frequency control by the adjustment of the production to meet the load and voltage control by modifying the field on the generator."

6.1 Grid Specifications in Nanortalik

Information regarding key parameters of the grid system is vital for any analysis where integration of new energy production units is the goal. This section describes the most relevant parameters for Nanortalik, as well as it states the related requirements/grid codes given by Elmyndighet.gl.

6.1.1 Grid frequency

The grid frequency is not a fixed value, but a value varying with smaller deviations from a set point such as 50 or 60 Hz. For Nanortalik's grid system, the operating frequency is 50 Hz, with maximum allowable deviations of ± 10 %. The grid frequency indicates if the grid system is under/overloaded. If for example the generators reach their capacity, without being able to compensate for the load on the grid, the frequency will drop until demand is accomodated. A stable grid frequency indicates that the el-production magnitude is corresponding to the magnitude of the electrical load in the grid.

According to Elmyndighet.gl, the average frequency measured over 300 seconds is required to be within 50 Hz ± 10 % (Grønlands Elmyndighet, 2010).

6.1.2 Voltage level

According to Nukissiorfiit, the electricity is distributed at 6 kV in the transmission grid, whereas it is stepped down to 400 V at the consumers' connection points. Grønlands Elmyndighet states that electricity shall be delivered as three phase 230/400 V 50 Hz alternating current. The regulations for the voltage quality is given in "DEFU rekommandation nr 16" and "DEFU rekommandation nr 21", published by "Dansk Energi Forskning og Utvikling". These regulations cover the requirements for the voltage quality in the 400 V grid as well as in medium voltage grids with voltage levels of 1kV to 36 kV. Further, a few of the relevant requirements are cited. These threshold values are recommended to be complied with at any time in the point of delivery.

The delivered voltage

Low voltage & Medium voltage grid: *The RMS value of the delivered voltage, measured as a 10 minute mean, is required to be within ± 10 % of the nominal voltage,* U_n.

Rapid voltage deviations

Low-voltage grid:
Rapid voltage changes should generally not exceed 5 % of the nominal voltage, U_n. *Changes up to 10 % of* U_n *is considered acceptable a few times per day.*

Medium-voltage grid:
Rapid voltage changes should generally not exceed 4 % of the nominal voltage, U_n.

Drop in voltage level

Low-voltage grid:
Transient changes in the voltage level should normally not cause the voltage to drop to less than 85 % of the nominal voltage, U_n (Dansk Energi - Forskning og Udvikling, 2011).

Medium-voltage grid:
Voltage drops should normally not occur.

6.1.3 Power factor

The power factor is the ratio of active power to the apparent power in the investigated circuit, from 0 to 1, where unity power factor indicates that the power delivered to load is 100 % active power (P). According to Nukissiorfiit they operate their generators at a power factor of minimum 0.90, which is the requirement given in "Stærkstrømsbekendtgørelsen", a regulation including security provisions for:

- *Electricity generating production plants and distribution facilities.*
- *Installations in homes and commercial buildings.*
- *Requirements for the design of electrical equipment* (Grønlands Elmyndighet, 2011).

These requirements for the power factor are present to maintain an efficient flow in the system. The operator in the Nukissiorfiit facilities in Qaqortoq stated that they were operating at a power factor of approximately 0.95-0.97 at any time, while the operator in Nanortalik stated that their generators operated at approximately 0.92-0.93, both inside the requirements. Further study on the power factor of the generators in Nanortalik has been undergone, and the data sample that has been overviewed is not in compliance with the statement from the operator at Nukissiorfiit.

A two week period has been studied, where the power factor, reactive power and active power has been logged hourly. The power factor has been calculated manually to see if it corresponds to the power factor logged by Nukissiorfiit. The power factor is calculated for each hour by equation (28):

$$\cos(\varphi) = \frac{Active\ power}{\sqrt{(Active\ power^2 + Reactive\ power^2)}} \qquad \textbf{(28)}$$

The utilized data is from 01.09.2007 to 14.09.2007. Figure (85) shows the plotted power factor values for each hour during the two weeks in question.

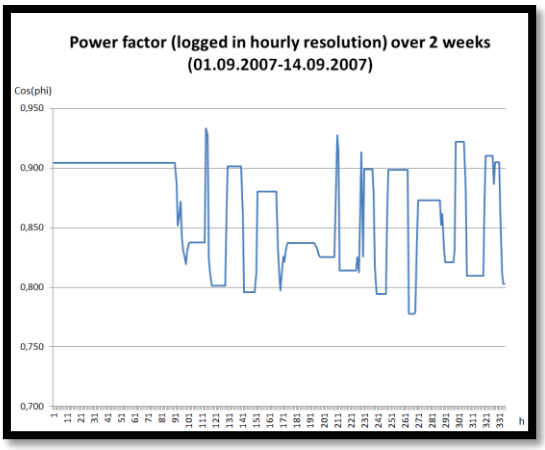

Figure 85 - Logged power factor during 2 weeks of operation

At first, it can be seen that the power factor is fixed at a constant value, 0.904, during the first 90 hours of the period. This is unrealistic, as the power factor normally varies within small limits during the day. Secondly, after the first 90 hours, the power factor does indeed vary, but with very high steps which again seems to not comply with the statements from Nukissiorfiit. It can be seen that the lowest cos (φ) value logged during this period is 0.778, which is 15.7 % lower than the requirements of cos (φ) ≥ 0.9.

Manual power factor calculations have been undergone for the logged data, and the result of the calculations is shown in Figure (86). The calculated results differ from the logged values by having a specific pattern throughout the two week period. The lowest

calculated power factor value is 0.828, still 8.7 % below the requirement.
It seems that the calculated values fit better and represents the regulation of power factor more realistically. The trend line for the calculated logged power factor has a decreasing trend over the period. This indicates that there can be something wrong with the logging of power factor data in Nukissiorfiit's systems, an allegation that was also supported by power plant engineer, Erling Lorentsen, at Nukissiorfiit Nanortalik.

Further, the power factor values have been studied to calculate the frequency of power factor values that are within the requirements, and thus finding the percentage of time that the requirements are satisfied.

Table (43) shows the overview of the two weeks, where the value 1 indicates that the requirement is upheld 100 % that day. Since this is hourly resolution, the results may be a bit off, but it gives an indication of the power factor situation during the studied period.

Frequency of power factor within requirements			
Req PF >=0.9		Req PF >=0.9	
Logged	**Freq**	**Calculated**	**Freq**
Day 1	1	Day 1	0,17
Day 2	1	Day 2	0,21
Day 3	1	Day 3	0,13
Day 4	0,79	Day 4	0,21
Day 5	0,08	Day 5	0,17
Day 6	0,46	Day 6	0,17
Day 7	0	Day 7	0,13
Day 8	0	Day 8	0,25
Day 9	0,08	Day 9	0,04
Day 10	0,04	Day 10	0,13
Day 11	0	Day 11	0,17
Day 12	0	Day 12	0,17
Day 13	0,29	Day 13	0,25
Day 14	0,42	Day 14	0,29
Total	5,17		2,46
% of time	**36,9 %**	**% of time**	**17,6 %**

Table 43 - Frequency of power factor values within requirements (PF >= 0.9)

From Table (43) it can be seen that the power factor requirement of >=0.9 is upheld 36.9 % of the time for the logged val-

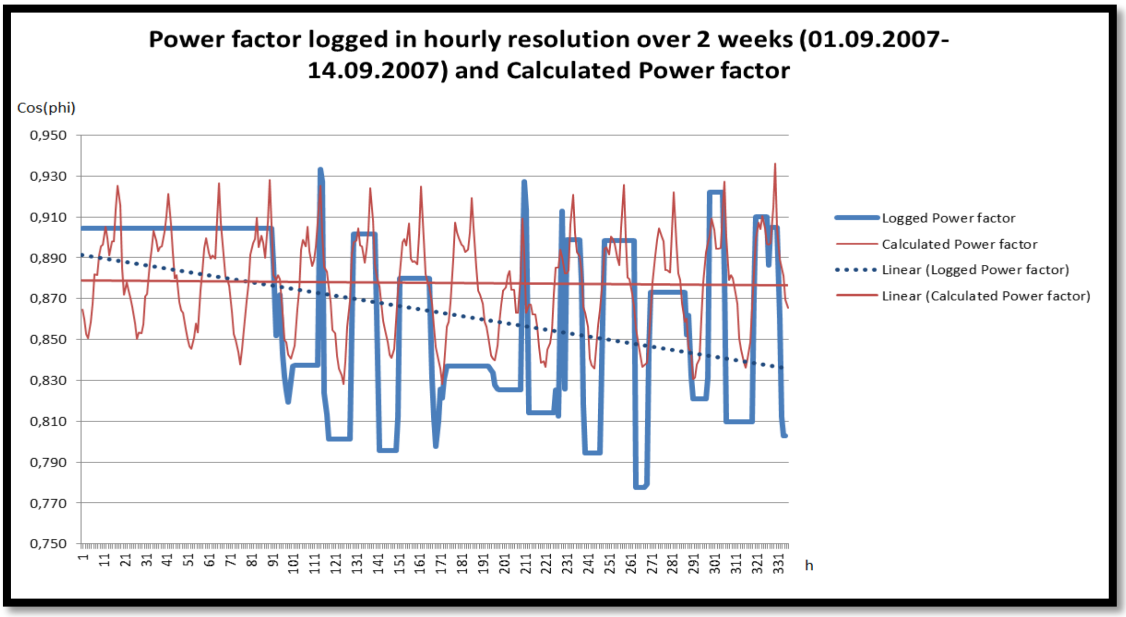

Figure 86 - Logged and calculated Power factor in hourly resolution over time period of 2 weeks, with corresponding trend-lines.

ues, while only 17.6 % of the time for the calculated values. The logged values have a higher satisfy-rate mostly due to the constant cos (φ) values for the first 90 hours. By lowering the requirement to ≥0.89 the following results are obtained:

Frequency of power factor within requirements			
Req PF >=0.89		Req PF >=0.89	
Logged	**Freq**	**Calculated**	**Freq**
Day 1	1	Day 1	0,46
Day 2	1	Day 2	0,46
Day 3	1	Day 3	0,42
Day 4	0,79	Day 4	0,46
Day 5	0,08	Day 5	0,38
Day 6	0,46	Day 6	0,42
Day 7	0	Day 7	0,29
Day 8	0	Day 8	0,42
Day 9	0,08	Day 9	0,08
Day 10	0,33	Day 10	0,29
Day 11	0,63	Day 11	0,42
Day 12	0	Day 12	0,33
Day 13	0,29	Day 13	0,46
Day 14	0,42	Day 14	0,46
Total	6,08		5,33
% of time	**43 %**	**% of time**	**38 %**

Table 44 - Frequency of power factor values within requirements (PF >= 0.89)

It is observed that the logged values satisfy the power factor requirement of ≥ 0.89 at 43 % of the time, whereas the calculated values satisfy-rate is 38 %. This mainly indicates that a large magnitude of the calculated power factor values was only off to the regulating requirement of 0.9 by a factor of one hundredth. Further, plots of the minimum, average and maximum daily power factor is presented. They all show that the calculated power factor is higher over the sample period of 2 weeks. By looking at the average power factor per day, seen in Figure (87), it is also seen that the power factor values does not comply with the expectations and statement from Nukissiorfiit. Future work on the power factor results from Nukissiorfiit Nanortalik is advised. From this study it can be concluded that there is a high possibility of faults/errors in the logging process, especially as there are longer periods of time where the power factor values are constant.

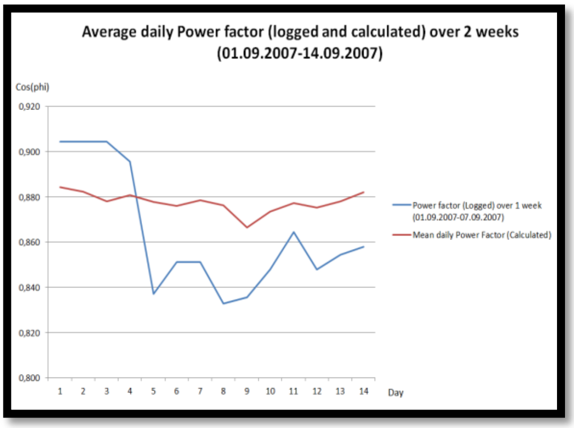

Figure 87 - Average daily power factor over 2 weeks

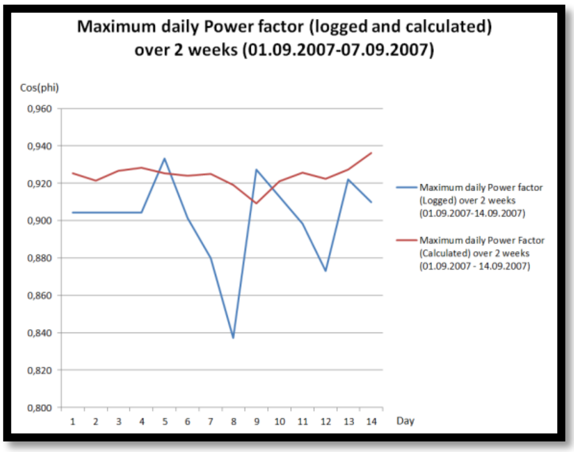

Figure 88 - Maximum daily power factor over 2 weeks

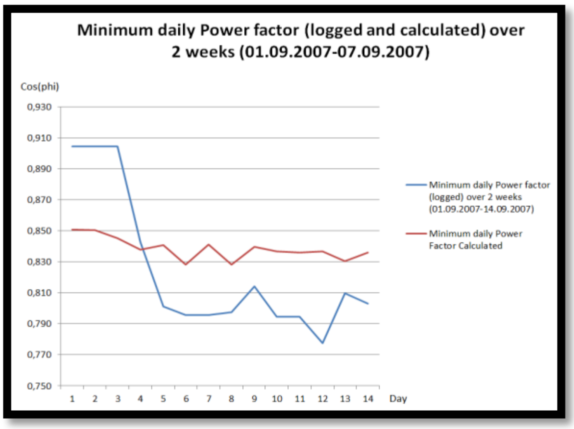

Figure 89 - Minimum daily power factor over 2 weeks

Figure 90 - Connection point and met mast site (Google Earth)

6.2 The Connection Point

The possibilities of connecting the wind turbine to the local grid has been investigated for both alternative wind farm sites. The following section presents the two connection points, as well as introducing some new equipment that must be set up for safely integrating the wind turbine to the grid.

6.2.1 Connection point for alternative 1

A connection point for the wind turbine at site alternative 1 has been found. There is already a substation (N5) present, approximately 250 meters in linear distance away from the position of the met mast, shown in Figure (90). This substation acts as a connection point for the industrial buildings close to the dump site north of the substation. The transformer in the substation steps the voltage level down from 6 kV to the consumer level of 400 V. The wind turbine can connect to the high voltage side of the transformer and its power output may thus be distributed through the high voltage cables in the town. For safely connecting a wind turbine to this connection point, a smaller building needs to be constructed where the switchgear should be installed. It is also possible that a transformer house must be built, to step down the outgoing voltage of the wind turbine to 6 kV. This transformer housing can be placed nearby the turbine, and act as an intermediary between turbine and distribution transformer/connection point.

6.2.2 Switchgear

A switchgear is a circuit-breaking device which is used to control, protect and isolate electrical equipment. A device like this is needed between the connection point and the wind turbine to ensure that no electrical equipment may be damaged during faults. Standardized equipment for such tasks are the Gas Insulated Switchgear systems (GIS), which provide reliable protection applicable for medium-voltage to high-voltage distribution systems. The GIS system consists of conductors and contacts insulated by sulfur hexafluoride gas, SF_6, under high pressure. The concept of the system is to disconnect the two conductors inside a medium with dielectric properties. SF_6 is found to be an optimal gas with great dielectric properties able to extinguish arcs of high temperature within microseconds. Such systems where the SF_6 gas acts as the interrupting medium between the contacts are often utilized for voltage levels from 52 kV and up.

6.2.2.1 Applicable switchgear for Nanortalik

Since the HV voltage level is 6 kV, and possibly 12 kV at highest, a medium-voltage GIS is advised, such as the 8DA10 gas-insulated, vacuum circuit breaker from Siemens. This switchgear system can operate at voltages from 4.16 kV up to 38 kV. The difference from this system and the previously described is that the SF_6 gas is mainly used for insulation, whereas the properties of vacuum are used when interrupting the contacts. Siemens states the following about the equipment:

" MV GIS is approximately 1/5th the size of conventional air-insulated switchgear depending upon the voltage rating and is suitable for systems where small size, arc resistance, environmental immunity and/or reduced maintenance needs are important. (Siemens)"

Figure 91 - 8DA10 GIS vacuum circuit breaker (Siemens)

The dimensions are shown in the following illustration, and prove that the switchgear can be well suited in a smaller building besides the present substations.

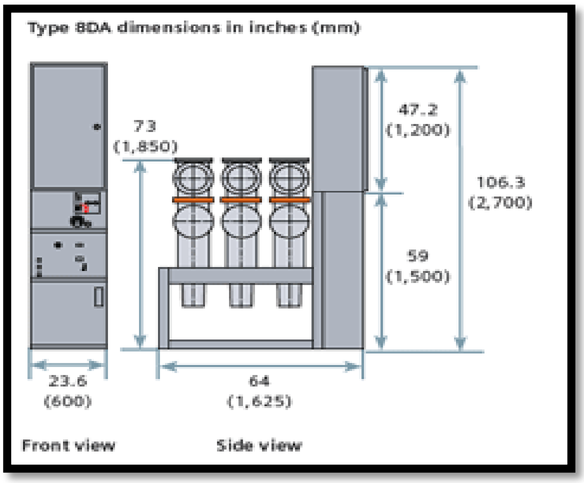

Figure 92 - Dimensions of Siemens 8DA switchgear (Siemens)

6.3 Connection Point for Alternative 2

For Turbine site 2, the closest connection point is the N6-substation located in the north-western part of Nanortalik, just past the graveyard. Figure (94) shows the exact position, while Figure (93) shows both the prospected wind turbine site and the connection point. The substation is positioned approximately 2900 meters in linear distance from the prospected wind turbine site. As for the N5-substation, this substation would also require an additional building where switchgear can be installed.

The N6 substation acts as the same way as the N5 substation, down-stepping the 6 kV voltage to 400 V for the consumers to connect. It could also here be needed to install a transformer close to the turbine (or close to the N6 substation), to step-down the outgoing wind turbine voltage to 6 kV, so that the transmission can be covered by cables they already have access to in Nanortalik.

It could also be mentioned that there might be problems with cable trench-digging in some parts of the cable route, especially in the rocky terrain leading up to the turbine site. A possibility could be to lay the cables on the surface and covering them with half-steel pipes as protection. This is although not regarded in this analysis, as a per meter price is obtained from Nukissiorfiit, covering the cable, trench digging and labour cost.

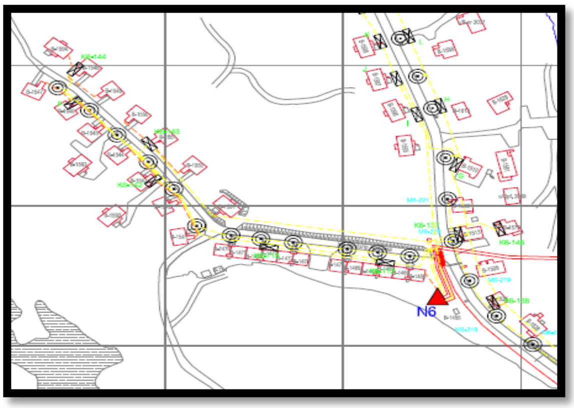

Figure 94 - N6 connection point (Nukissiorfiit)

Figure 93 - Prospected wind turbine site and connection point (Google Earth)

6.4 Assessment of Grid Strength in Nanortalik

The power flow in the Nanortalik power system can be characterized by some key parameters such as active power, reactive power and their relation; the power factor. This section first describes the basic theory of reactive/active power flow, as well as discuss the measured values for Nanortalik, and lastly conclude whether the grid is capable of receiving new power of 1 MW magnitude or not.

The strength of the grid is important both with respect to quality of the delivered energy and physical damages on equipment. A weak grid is generally consisting of smaller conductors, which reach their thermal limit and overheat, thus inducing heat losses in the transmission phase. The voltage is also subject to a deviating phenomenon. This deviation can be due to injection of active and reactive power, and is inversely proportional to the grid strength. Thus, a stronger grid results in lower flicker and harmonic effects, as well as smaller voltage deviations which can be represented by the power factor, cos(φ), shown in Figure (95).

6.4.1 Active/Reactive power and Power factor

Reactive power is the power that is induced due to the presence of inductance or capacitance in the load. Figure (96) shows the relation between active power (P), the reactive power (Q), and the apparent power, denoted S. Any AC system consisting of inductors and capacitors consume both active and reactive power. The active power is the power that is utilized for useful work, whereas the reactive power supports the voltage regulation and reliability.

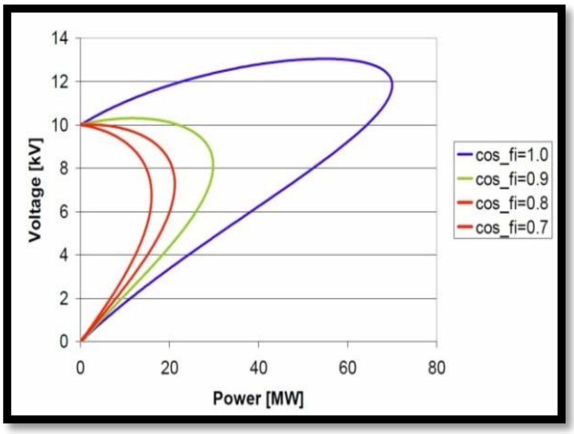

Figure 95 - Power factor impact on voltage (Cronin, 2012)

Energy that is stored in capacitive or inductive devices of the grid give rise to reactive power flow. This flow is strongly influential to the voltage levels across the system. It is therefore strongly needed to maintain control of voltage and reactive power flow to operate a system within the grid requirements. The power factor is equal to the ratio between the active power and apparent power. For Nanortalik, it is required that the power factor is at minimum 0.90.

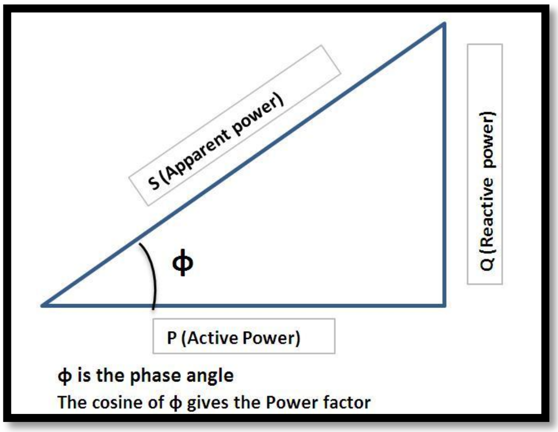

Figure 96 - The power triangle (Electrotechnic)

It is desirable to have as high power factor as possible, although reactive power is needed in AC systems, to support the transmission process of active power. A higher power factor decreases the amounts of losses in the system, e.g. although doing no active work, the reactive power heats conductors in the system which give rise to additional losses (Parmar, 2011). As the study of the power factor showed that cos (φ) was less than the requirements for most of the time during the test sample period, it is assumed that the logging equipment is faulty.

6.4.2 Grid strength

According to Nukissiorfiit in Qaqortoq, the cables utilized in Nanortalik and Qaqortoq are the same. The high voltage cable capacity in Nanortalik is 12 kV, but the system is operated at 6 kV for the high voltage transmissions. The distribution cables running at 400 V are also over-dimensioned.. By over-dimensioning the cables, the relative load on the cables are lower, hence giving lower thermal losses, which means that the voltage control becomes easier. According to Nukissiorfiit, they had a relative peak load of approximately 50-60 %, which gives lower voltage variations within the radials of the grid. The cables are over-dimensioned to easily control the voltage at the load outlets, and for savings in terms of high labor costs for maintenance etc.

It is also worth noting that the local fish factory in Nanortalik, which stopped producing some years ago due to poor fishing conditions (Greenlandic Broadcasting Corporation, 2012), has restarted its operation. This industry will thus be a larger load in the system. According to Nukissiorfiit in Qaqortoq, the grid strength is at the present time very good in Nanortalik, indicating that the added load will not induce any problems. It can also be noted that industry related to gold extraction in the vicinity of Nanortalik can flourish again, after new resources have been revealed in Jokums Shear, close to Nanortalik (Greenlandic Broadcasting Corporation, 2012). This is a positive development for the municipality, which might lead to population increase and thus increase in electricity demand.

6.5 Dump Load Possibility

This section describes the importance of dump load possibilities in a wind / diesel system, as well as discussing the choice of boiler capacity for the Nanortalik energy system.

6.5.1 Importance of dump load in wind/diesel systems

In terms of balancing the power in the system, a dump load solution with an electrical boiler is advised. The dump load is needed to divert the excess power production from the wind turbine in a controllable load. The electricity boiler comes to use when the wind energy production is high at same time as the consumption level is low. The diesel generators generally have a minimum load defined by the manufacturer. Hence, if the minimum production, plus the wind power production, surplus the consumption demand, there will be spare power. This power can be utilized in an electrical boiler to provide heat for the district heating system. This way all generated power from the wind turbine can be utilized and at the same time the boiler and/or other dump load solutions helps maintaining the required frequency level of 50 Hz (Lundsager & Baring-Gould, Wind Power in Power Systems, 2005).

6.5.2 Capacity and type of electric boiler

The electric boiler capacity is determined through the simulation of the power system in Nanortalik. The results of the simulations show that a 1 200 kW boiler can cover all excessive power in the system. One electric boiler of the same type as utilized in Qaqortoq is needed. The boiler runs at a voltage level of 400 V, and hence must an additional transformer for the boiler also be installed.

6.6 Cables From Wind Turbine to Connection Point

The cables utilized in the present system have the following specification:

Specification	*HV-cable*	*LV-cable*
Voltage capacity	12 kV	400 V
Cross-section	95 mm^2	150 mm^2

Table 45 - Cable specification (Nukissiorfiit, 2012)

According to Nukissiorfiit the HV-cables are capable of operating at 12 kV although running only at 6 kV. Cables are over-dimensioned to ease voltage control and facilitate a voltage upgrade.

6.6.1 Turbine site 1

The cable from the wind turbine to the N5 substation can be buried in trenches near the existing gravel road which reaches into the prospected wind farm area. If a second transformer stepping down the output voltage of the wind turbine is built, cables should be laid in trenches from wind turbine to the additional transformer station, and then further to N5.

The cables used are of the same type that as the ones present in the existing grid; a high voltage cable with 12 kV maximum capacity, but operated at 6 kV with a cross-section of 95 mm^2. For the smaller section between the wind turbine and the additional transformer station cables with capacity of transferring at 22 kV is needed.

6.6.2 Layout of cable for Turbine site 1

The cable route from the N5 substation to the wind turbine is shown in Figure (97).

The blue line represents the cable route, lying in trenches along the prospected road. Switchgear and possibly a transformer station can be placed where the blue circle is, and the cable must go through these stations before connecting to the wind turbine.

The approximated length of the external

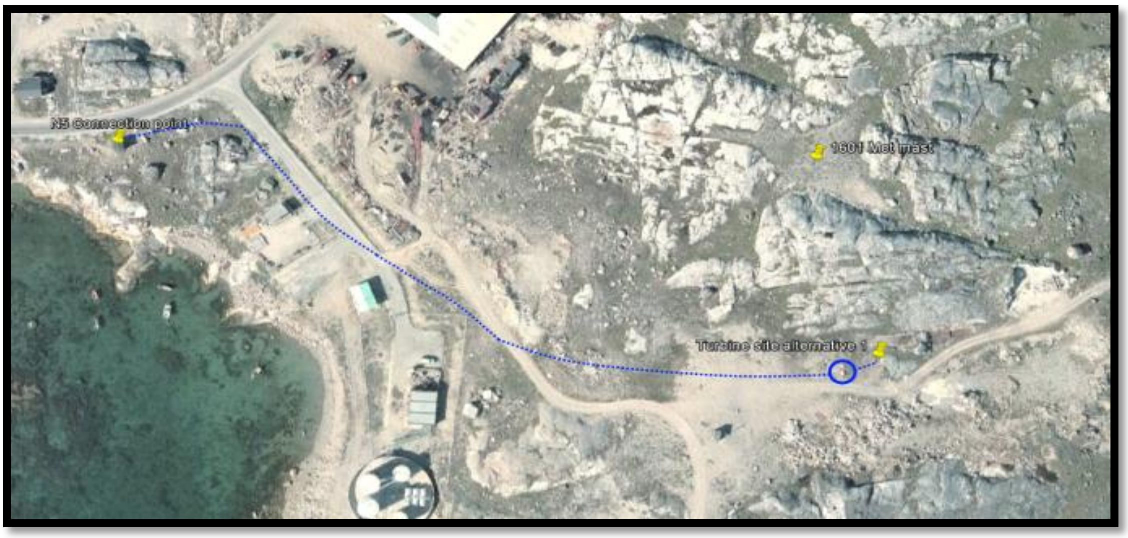

Figure 97 - Cable layout from wind turbine to connection point N5 (Google Earth)

cable is 270 meters from the wind turbine to substation N5.

6.6.3 Turbine site 2

The cable from the wind turbine to the N6 substation can be buried in trenches near the constructed gravel road, purposely built to access and transport equipment to the wind farm site. As with alternative 1, if an additional transformer station is needed, the cable is laid in a trench from the wind turbine through this transformer station, and then connected to the N6 substation. The same cables as alternative 1 is utilized, due to low distance to connection point and the fact that the same wind power capacity is installed at both alternatives. It is also a question of economy; Nanortalik has access to the 12 kV cables, which might reduce the need for costly import from Europe. It is however not expected that they have 3 200 meter of 12 kV in their stock. A possibility could be to ship cables from the larger cities, such as Nuuk and Sisimiut, and hence reduce need for cross-boarder transportation.

6.6.4 Layout of cable for Turbine site 2

The cable route from the N6 substation to the wind turbine is shown in Figure (98). The switchgear and possibly transformer station is shown as a blue circle, whereas the blue line represents the cable layout. The approximated length of the cable from N6 to the wind turbine is 3200 m. The cable is laid in trenches close to the new road up to the part where it must climb the mountain. From there it is proposed to be laid straight up towards the wind turbine on the ground with half-pipes as protection.

6.7 Operation and Control of Wind/Diesel system

This section describes some aspects of the present control system, as well as describing how the wind turbine should be integrated to the energy system, to maintain the given grid requirements.

Figure 98 - Cable layout from wind turbine to connection point N6 (Google Earth)

6.7.1 The present control system

The present system consists of frequency control through governors for each of the diesel generators and sensors in the grid system measuring the frequency at the load points. The governors automatically adjusts the rotational speed of the generators in order to stay within the given frequency requirement of 50 Hz ± 10 %. An automatic voltage regulator system is also active, where output voltage is regulated by changing the turn's ratio of the transformers, so that the secondary side voltage is within acceptable limits. This type of control also includes a dead band, where the controller will not do any changes. This is to prevent the controller from constantly adjusting the voltage as it varies by smaller but acceptable steps. There is also a delay-time included, so that rapid voltage changes that go beneath the dead band and back into the dead band, within given time are accepted. Their system also had fixed spinning reserves for each hour of the day. They could adjust the amount of fixed power in the software shown in Figure (99).

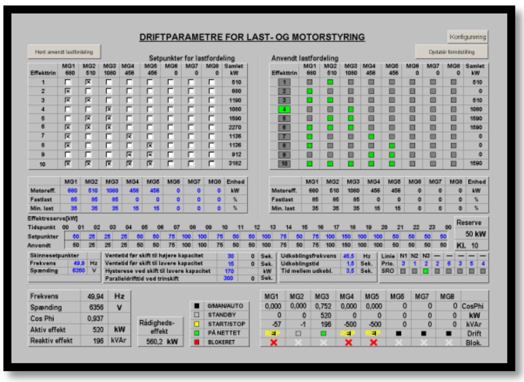

Figure 99 - Monitoring and control system software. Screen-dump from Nukissiorfiit Nanortalik

The generators also operated with so called hysteresis-adjustment. This is an operating mode that prevents the generators from switching on and off frequently, when operating in the borderline between two capacity levels, for example at a load point where the second or third generator needs to switch on. The ΔkW-factor was set to 170 kW in Nanortalik. This concept is illustrated in Figure (100).

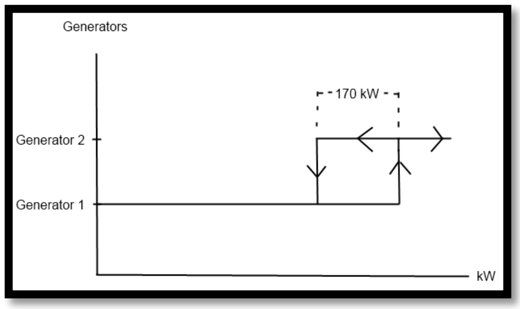

Figure 100 - Hysteresis adjustment concept

From the illustration it can be seen that the down-adjustment point is 170 kW lower than the up-adjustment point. The ΔkW-factor is adjustable through the control system software.

6.7.2 Additional system equipment for integration of wind power

The WWD-1 turbine features a turbine controller with a remote monitoring and logging system. This system is connected to the grid network, so that Nukissiorfiit can remotely control and monitor the turbine performance from their power station. According to WinWind, the logger can record actual and cumulative production data, as well as alarms and stops in the system. It can all be controlled over internet. The turbine also has an alarm and self-diagnostics system implemented. If the turbine has a malfunction, the system will alarm the operator with a failure reason, and the fault can be remotely corrected by the operator.

Figure 101 - Nukissiorfiit Nanortalik - Prospected base of operation, control and monitoring of wind turbine

The self-diagnosis system adjusts the turbines settings according to the wind and weather condition, by for example analyzing the need for generator and lubrication oil heating under freezing conditions.

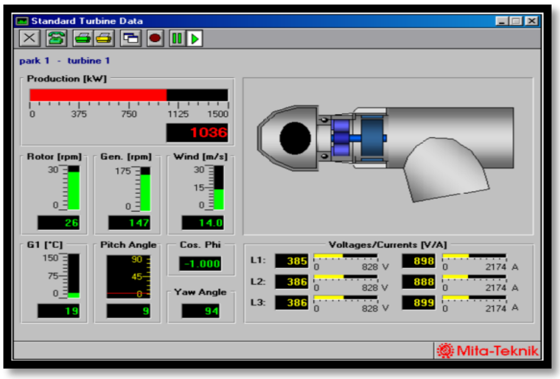

Figure 102 - Wind turbine monitor GUI (WinWind, 2003)

The external conditions are monitored by the use of an anemometer and wind vane. This equipment is equipped with an ice-prevention system, which suits the rough climate during winter months in South-Greenland. To ensure grid compliance, a liquid cooled IGBT (Insulated-gate bipolar transistor) frequency converter is utilized a long with a transformer stationed in the tower (WinWind). Figure (102) shows a typical graphical user interface (GUI) that comes with the wind turbine. This can be utilized to monitor temperatures, production, currents/voltages etc. in a clear and illustrative manner. The energy production logger is also user-friendly, and 10 minute average data can be retrieved at the control room in Nukissiorfiit at fixed intervals. This data can be saved as Excel files, MS Access files or ASCII text files (WinWind, 2003). An example of a production plot is shown in Figure (103).

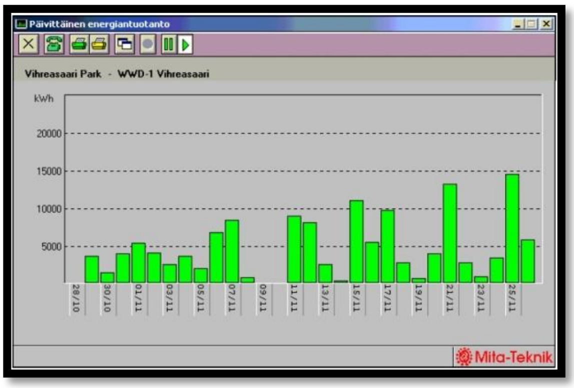

Figure 103 - Example of daily energy production report

6.8 Grid Analysis

A more throughout study on the grid in Nanortalik is recommended to obtain the most realistic results when assessing wind energy integration in the power system of Nanortalik. According to Erling Lorentsen at Nukissiorfiit in Nanortalik, an overall grid analysis in all Greenlandic cities is budgeted. The analysis will be undergone in near future, but no specific time was given (Nukissiorfiit, 2012).

6.9 Summary of Grid Equipment costs

A variety of electrical components is needed in order to connect the wind turbine to the grid in Nanortalik. The costs of these components are presented in the following section. Firstly, the joint expenditures for both site alternatives are presented in Table (46). The wind turbine itself and the required additional components to connect the wind turbine to the grid have a total cost of **8.02 million DKK**.

Cost of electrical equipment			
Component	Unit price [DKK/Unit]	Quantity [Units]	Total price [DKK]
Wind turbine	7460 000	1	7460 000
Transformer	100 000	1	100 000
Switch-gear	285 000	1	285 000
Electrical boiler	125 000	1	125 000
Boiler transformer	50 000	1	50 000
Total			8 020 000

Table 46 - Cost of electrical equipment

Cable costs come in addition, and have a specific price related to each site alternative. The cable costs for site alternative 1 are shown in Table (47).

Cost of cables for site alternative 1			
Component	Unit price [DKK/m]	Length [m]	Total price [DKK]
HV/LV Cables	40	270	10 800
Cable trenches with labour	900	270	243 000
Total			253 800

Table 47 - Cost of cables for site alternative 1

A total cost of **253 800 DKK** is estimated for the cables and trench-digging from the N5 substation to the wind turbine site. The corresponding cost estimates for site alternative 2 is shown in Table (48). The cable expenses is equal to **3.008 million DKK** for site alternative 2. The cost of cables is assumed to be the same per meter for both sites, as this was the estimated figure that was obtained by interviewing Nukissiorfit. A higher price for the short cable route is although reasonable, as the start-up cost are more or less the same regardless of length. This has not been further assesed, and is therefore not regarded in this analysis.

Cost of cables for site alternative 2			
Component	Unit price [DKK/m]	Length [m]	Total price [DKK]
HV/LV Cables	40	3 200	128 000
Cable trenches with labour	900	3 200	2 880 000
Total			3 008 000

Table 48 - Cost of cables for site alternative 2

This results in a total grid cost of **8.273 million DKK** for site alternative 1, and a total of **11.028 million DKK** for alternative 2.

7 CONSTRUCTION, OPERATION AND MAINTENANCE

In this chapter the different aspects of construction, operation and maintenance will be assessed, together with an economical overview of the cost related to the different aspects.

7.1 Construction

The construction method of wind turbines is almost identical regardless if it is one turbine or one hundred. This results in good standards for the construction phase. A time schedule is easy to create and maintain, but factors like weather conditions, fault on significant equipment etc. can delay the project. On this basis it can be seen that few wind power projects are delivered late or over budget (Wind Energy - The Facts Part 1).

Throughout the construction phase it is important to maintain a high safety standard. This will be assessed in Chapter (9.1.1).

The construction of a wind power project has many different aspects, not just the erection of the wind turbine. First the different construction areas need to be defined and assessed. Then the transportation of the turbine needs to be planned and prepared for. This entails transportation of the turbine by boat, quay access and capacity, road access and construction, construction of the foundation etc. All these aspects will be more thoroughly assessed in this chapter.

There will be different construction areas for the different sites, and some common ones. The main construction areas for the two sites will be at the actual sites, but road construction/improvements must also be undergone, especially for Turbine site 2. The common construction areas for the two sites will be the first part of the road construction from the quay area in through the town of Nanortalik.

At Turbine site 1 the main construction area will be at the site and it will cover approximately 2 000 m^2, including the temporary storage area. At Turbine site 2 the main construction area will be smaller with an approximated 1700 m^2. At site two the temporary storage area is located in a different place, which will be assessed later in this chapter. Figure (104) and (105) shows a visualization of the approximated main construction area of Turbine site 1 and Turbine site 2, respectively.

Figure 104 - Construction area Turbine site 1

Figure 105 - Main construction area Turbine site 2

7.2 Transportation

The transportation of the wind turbine from the manufacturer to the site is divided into two parts in this analysis. Part one is the transportation by boat from manufacturer to the quay of Nanortalik, and the second part is transportation by truck from the quay to the site. In addition to this the quay access has been assessed.

7.2.1 Turbine delivery

In terms of turbine delivery the transportation of the turbine from manufacturer to site is assessed. In this analysis a WinWind 1 MW turbine is studied. The turbine manufacturer is located in Espoo, just outside of Helsinki, Finland, and hence the total transportation route for the turbine is from Espoo, Finland, to Nanortalik, Greenland.

Transportation of wind turbines is a very challenging operation, and is usually done either by the manufacturer or by a specialized, highly qualified company. The blades on the WinWind turbine are approximately 29 meters long, and the nacelle weighs nearly 40 tones. With such heavy weights and large dimensions, the requirements for both the transporting vessels and the roads are strict. The turbine first needs to be transported to the quay in Helsinki by special trucks on the local roads in Finland. From the quay in Helsinki the transportation continues by boat to the quay in Nanortalik. This is the main part of the wind turbine transportation.

The boat used for transportation of the turbine needs to fulfill some requirements. The most critical requirement is cargo space. Since wind turbines are very space consuming the boat needs to be of certain dimensions.

In addition to the actual turbine, some other space consuming technical equipment is also shipped, e.g. the truck used for transporting the wind turbine from the quay in Nanortalik to the site. The boat also needs to transport all other needed equipment regarding both transportation and erecting of the turbine, such as the crane, together with the civil workers. The weight of the different parts of the turbine is assumed to not be an issue for the requirements of the boat.

The last section of the turbine transportation is from the quay in Nanortalik to the specific site of the turbine. This is done by the truck shipped together with the turbine. The transportation of the turbine from the quay to the site results in some requirements for both roads and quay. This will be assessed later in the analysis.

The total cost for the transportation of the turbine is usually included in the price for the wind turbine. This price includes transportation from manufacturer to the site, as being assessed here. The price given from the manufacturer is however very site specific for each project, and hence in this analysis an average price of 1.2M€ is used.

This price also includes installation and commissioning of the turbine. From the WinWind contact person it was stated that "*The transportation included in this price is an "average" transportation, and hence certainly be higher if the transportation was to a "hard-to-reach" site"* (Gilmore, 2012).On this basis the sites in this analysis are assumed to be "hard-to-reach" sites and an additional 200 000 € is added for the turbine delivery.

7.3 Quay Access

The quay in Nanortalik is located on the eastern part of the city center and is well shielded from both harsh weather conditions and drifting icebergs in the area. The quay access in Nanortalik is an important part of the transportation of the wind turbine. The dimensions of the quay together with the water depth can constrain the size of both the ship and the specific turbine, and hence provide a large impact on the project.

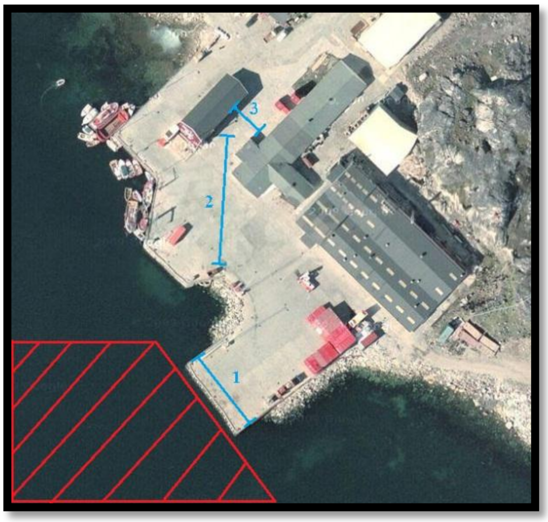

Figure 106 - Quay of Nanortalik

The first subject being assessed in this analysis is the quay access. In Figure (106) the main quay in Nanortalik is located in the lower part of the figure. As can be seen, a red hatched area is visualized just outside the main quay. This area indicates approximately where the water depth is greater than 10.5 meters. This is assumed to be enough for the transportation ship used by the manufacturer. Based on this, the only possible location where the boat can be docked is by the main quay. From here, all offloading from the ship will take place, by use of the ship crane.

Furthermore there are some lines and numbers assigned to the visualization in Figure (106). These indicate the critical distances, which have been measured on site, and are listed beneath.

Distances	
1	30 meters
2	50 meters
3	9.6 meters

Table 49- Quay dimensions

It is assumed that all containers and other temporary stored items are removed from the quay during the transportation of the wind turbines. This is essential due to limited space when maneuvering the wind turbines from the quay area.

Based on this assumption and the measured dimensions, it is concluded that the quay is large enough for receiving the wind turbine; hence further transportation of the wind turbine and other technical equipment from the quay to the two sites is possible.

7.4 Road Access

This chapter assesses the access road route to the two wind turbine sites. Theory of wind turbine transportation and corresponding criteria given by turbine manufacturer is presented. These criteria are the basis for critical points of both existing and new road routes. The road routes and critical points are the results of field inspection. In the following section the associated solutions are presented.

Provision of new road routes is carried out by assessment of terrain and soil conditions in the given area. This is undergone with focus on cost-minimizing and economic feasibility. The terrain complexity is visually assessed, while the upper layer's soil condition is examined by means of soil sampling. This way the carrying capability of the present soil is referred to.

In order to describe the challenges and to give the best overview of the access road route and area, it has been appropriate to resort to an active use of illustrations.

7.4.1 Road network in Nanortalik

The existing road network in the city of Nanortalik consists of a bonded upper layer, i.e. asphalt. This is based on legislations and best practice due to, e.g. air pollution, safety issues related to grip capability and stop distance based on material's friction coefficient according to (Jørgensen A. S., 2012) and (Statens Vegvesen, 2010).

Information regarding the quality of the roads in Greenland is hard to state. The Greenlandic roads are more or less constructed by means of Danish standards. However, the landscape and climate is way different from Denmark to south-western Greenland. A combination of this, old roads and unknown quality of work and layer materials, the carrying capability of the road is unknown (Jørgensen A. S., 2012). Nonetheless, the roads are assumed to withstand axel pressure of maximum 8 000 kg and 14 500 kg of maximum "boggie" pressure (Grønlands Hjemmestyre and Grønlands Tekniske Organisation, 1987).

In Greenlandic cities, the roads are divided in terms of their function. Table (50) refers to this relation.

The roads in Nanortalik is measured to be 5.5 meter wide, hence they are designed for a high activity, where the vehicles are not so heavily loaded.

Classification	*Traffic*	*Road width [m]*	*Speed factor*	*Links*
Town roads	High and heavy	6.0 - 8.0	40 km/h	Some neighborhoods
District roads	High, but not so heavy	4.0 - 5.0	40 km/h	Some districts within a neighborhood
Local roads	Moderate	4.0	30 km/h	Some residential groups
Residential roads	Low	3.0	15 km/h	Individual residential

Table 50 - Maximum road gradients (Arktisk teknologi, 2002)

Figure 107 - Road width measurement

7.4.2 New road

The new road to Turbine site 2 will be a gravel road, as it will be situated outside of the city. Additionally, the new section of the access road routing will not be available to the public, as it will be a property of Nukissiorfiit and not the local authorities. This simplifies the requirements for the road routing, e.g. do not need road lights etc., and at the same time lowering the maintenance costs. Outside of the construction period, the road will be characterized as a low traffic road, where traveling maintenance workers and revision of the affiliated secondary station will be the main traffic activity.

The new road is based on the proposed gravel road between Sisimiut and Kangerlussuaq, however with a driving width of 4 m, instead of 3.5 m (Løgstrup, et al., 2003). On the other hand, an axel pressure of 15 000 kg is not necessary, as heavier transport will not be allowed on the city roads (Villumsen, et al., 2007). Hence the layers will be constructed somewhat thinner, in order to sustain the presumed maximum carrying capability stated for the city roads. In terms of critical inclinations, the general gravel road slope requirements are given by Table (51). Specifically for heavy transportation, this surface material is primarily an issue with respect to friction.

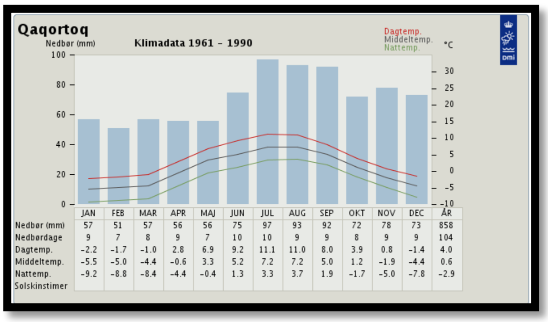

Figure 108 - Climate data in Qaqortoq (Danmarks Meteorologiske Institut, 2012)

There is no danger of permafrost incidents in Nanortalik. "Subsurface frost occurs, per definition, when the temperature falls below 0°C. Permafrost, however, requires that the temperature remains below 0°C for two successive years. A rule of thumb is that the average surface temperature has to be below -3°C for permafrost to develop" (Villumsen, et al., 2007).

"At Sisimiut and Kangerlussuaq the average annual temperature is -3.9 and -5.7 °C respectively", while the long-term average temperature in Qaqortoq is 0.6 degrees (Villumsen, et al., 2007). Since Nanortalik

Classification	Gradient [‰]	Gradient [°]	Distance [km]
Absolute maximum	120	6.8	< 0.5
Normal maximum	100	5.7	< 2.0
Sought maximum	80	4.6	

Table 51 - Maximum road gradients (Jørgensen, Buhelt, Meincke, & Mortensen, Vej mellem Sisimiut og Kangerlussuaq, 2002)

is located not far from Qaqortoq, in southern direction and also along the coast, the climate is assumed to be more or less the same.

To determine the layers and their associated thickness of the road, a thorough geological and geophysical survey has to be carried out. Table (52a) and Table (52b) refer to a proposal for South-Greenlandic gravel road layers, depending on selection of sub base material and the soil condition. This is a matter of achieving the required axel pressure.

The municipality's contracting department has the responsibility for undergoing road construction in the Greenlandic cities. However, the market outside the cities is private. GSM (Greenlandic Mining Service) and Qaqortoq Entreprenørforretning are designated as possible local contractors, which holds the necessary experience, machines and knowledge regarding technical drawings (Qaqortoq Kommune, 2012).

7.4.3 Basic Principles of Wind Turbine Access Road Construction and Transportation

The minimum requirements in relation to road dimensioning and transportation are more or less equally standardized for most wind turbine manufacturers. Dimensions vary a lot between models and manufacturers, e.g. weight of nacelle. However, in order to maintain road axel pressure re-

Solution on soft soil	*Thickness [mm]*	*Solution on rough soil*	*Thickness [mm]*
Material		**Material**	
Gravel wear layer	50	Gravel wear layer	50
Stable gravel	180	Stable gravel	180
Sub base layer (sand/rock)	1670	Sub base layer (sand/rock)	330
Base of sludge		Base of stone/gravel/rock	
Total thickness	**1900**	**Total thickness**	**560**

Solution on soft soil	*Thickness [mm]*	*Solution on rough soil*	*Thickness [mm]*
Material		**Material**	
Gravel wear layer	50	Gravel wear layer	50
Stable gravel	150	Stable gravel	150
Screed	100	Screed	100
Sub base layer (chipping/stone)	1450 (1600)	Sub base layer (chipping/stone)	160
Filter layer/filter cloth	150 (0)	Base of stone/gravel/rock	
Base of sludge			
Total thickness	**1900**	**Total thickness**	**530**

Table 52 – a) Gravel road layers and associated thickness. "Sub base layer" material as chipping/stone. By use of filter cloth, the values in bracket apply b) Gravel road layers and associated thickness. "Sub base layer" material as sand/rock (Bennedsen, 2007)

quirements, a transport vehicle with sufficient axels needs to be utilized. Different transport methods and vehicles are used to suit the limitation of the route ((Maxine Helliwell, 2012). Normally different vehicles are used in transportation of the various spare parts. Figure (110) illustrates one type of wind turbine blade transport vehicle.

The transport specifications referred to in this chapter are provided by Enercon's "Access Roads and Crane Platforms" manual for their E53, 800 kW machine (Krey, 2007). Requirements are verified to be reasonable by cross-checking other wind turbine transport datasheets, including Win-WinD's WWD-1 EU60 turbine.

As Table (53) refers to, the maximum permitted slope for gravel are lower than for paved roads. The requirement is also more conservative than the general gravel road slope gradient. However, neither types of surface are sufficient for the critical inclinations occurring at the proposed access road route. These matters are addressed in Chapter (7.4.4).

Parameter	*Requirement*
Useful width of carriageway	4 m
Clearance width	5 m
Clearance height	4.6 m
Radius of curve (external)	28 m
Incline gradient (loose/gravel surface)	70 ‰ / 4 °
Incline gradient (fixed/paved surface)	120 ‰ / 6.8 °
Ground clearance of transport vehicles	0.15 m

Table 53 - Minimum requirements of access roads

In the Enercon manual it is stated to be a basic principle that any roadways, bridges or access roads have to withstand the transportation with a maximum axel and vehicle pressure, respectively of 10 tons and 120 tons. The Greenlandic roads are assumed that they cannot handle such a highly concentrated force. Equation (29) refers to the minimum required number of axels on the transport vehicle for the above stated scenario.

$$Naxles = \frac{\text{Maximum vehicle pressure}}{\text{Maximum axel pressure}} = \frac{120 \text{ tons}}{8 \text{ tons/axel}} = 15\ axles \quad \textbf{(29)}$$

The road and transport structure clearances referred to by Table (53) are illustrated by Figure (109). Note that the clearance height of 4.6 m is not an issue to take into account for neither of the routings, as there are no bridges or other types of vertical obstructions.

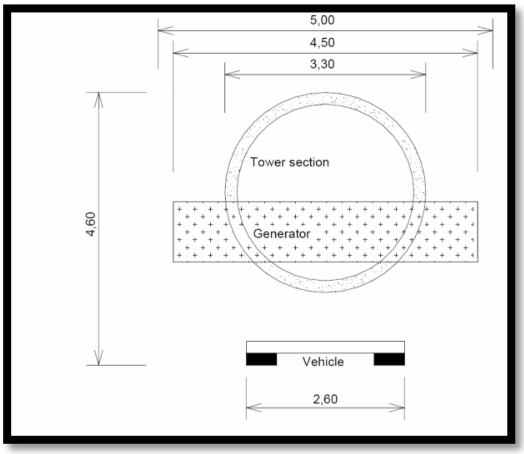

Figure 109 - Minimum required transport structure clearances

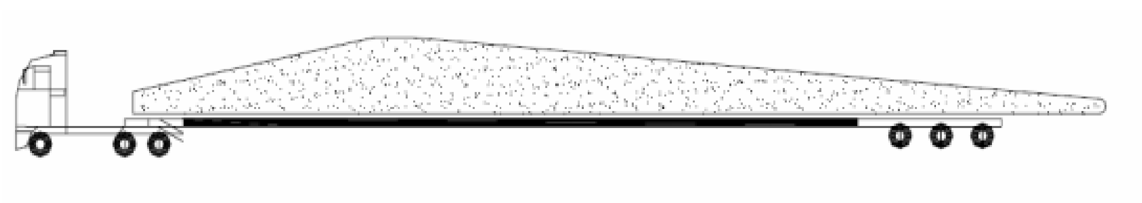

Figure 110 - Semi trailer, rotor blade transportation

However, in case of turns the clearance and road width requirements might differ, dependent upon the degree of the turn. On the existing road network in Nanortalik there are found some critical turns, which are adressed to in Chapter (7.4.4). The necessary measures have to be according to the minimum requirements of intersections and curves. These requirements are illustrated by Figure (111) and (112). The hatched areas in Figure (111) and (112) need to be cleared of obstacles, as the load might in some cases protrude from the transport vehicle and into these zones.

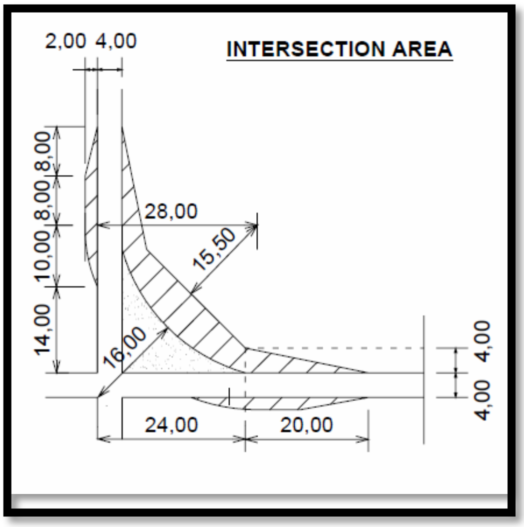

Figure 112 - Minimum requirements of road intersections

The hatched areas in Figure (111) and (112) need to be cleared of obstacles, as the load might in some cases protrude from the transport vehicle and into these zones. This is most often an issue related to transportation of the rotor blades. All the above stated requirements, regarding road construction and transportation, have to be followed to the letter. However, the turbine manufacturer must always be consulted with prior to any construction work.

7.4.4 Access Road Route

The access route for both turbine sites being assessed is illustrated by Figure (113). Google Earth is used to measure the road lengths. The approximated road lengths between sectors for the two access road routes are given by the Table (54) and (55).

Turbine site 1		
From	**To**	**Distance [km]**
Section 1	Section 2	0.33
Section 2	Section 3	0.53
Section 3	Section 4	0.20
Total		**1.06**

Table 54 – Turbine site 1 sections and associated distance

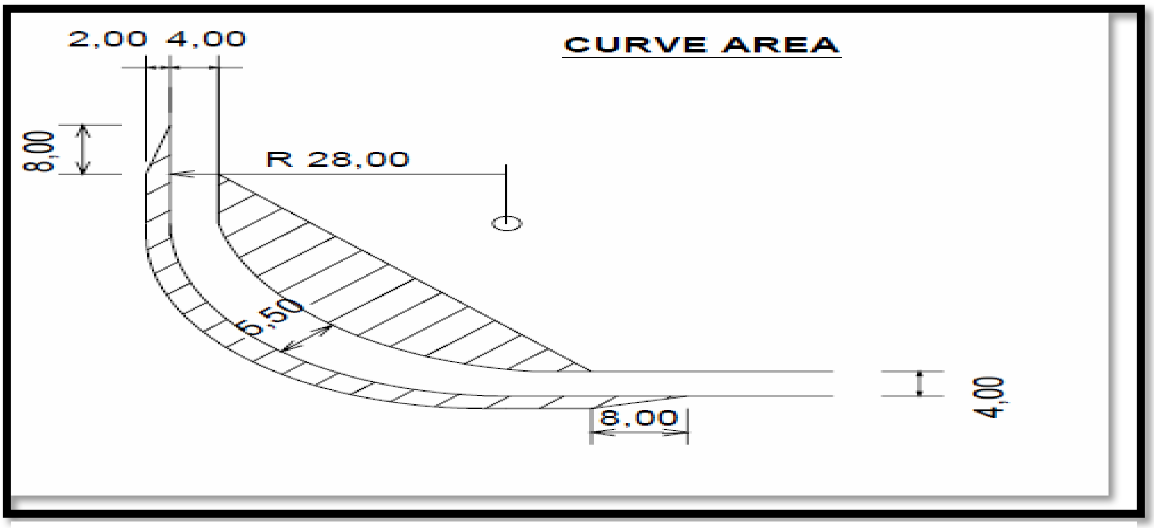

Figure 111 - Minimum requirements of road curves

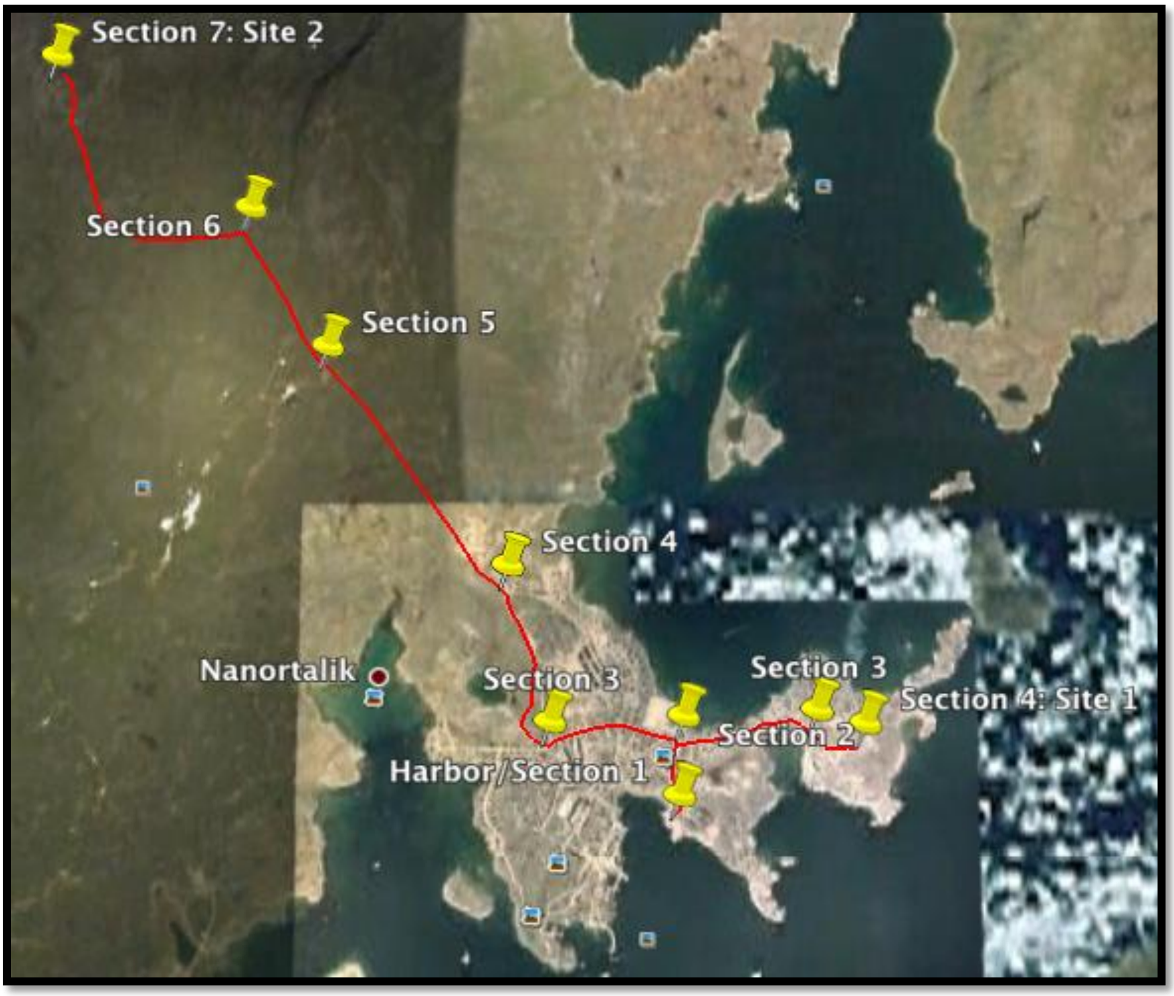

Figure 113 - Road route and section division

In realization of Turbine site 1, the total length of the road route required to be constructed is only 0.20 km.

Turbine site 2		
From	**To**	**Distance [km]**
Section 1	Section 2	0.33
Section 2	Section 3	0.55
Section 3	Section 4	0.71
Section 4	Section 5	1.10
Section 5	Section 6	0.61
Section 6	Section 7	1.17
Total		**4.47**

Table 55 - Turbine site 2 sections and associated distance

The length of the required road that needs to be constructed for Turbine site 2 is more accurately measured to 3.72 km. Measurements are carried out by means of a GPS tracker where the proposed road route has been walked through.

7.4.4.1 Sections

In assessment of the access road, both existing and new, the routing have been divided into sections. Each section is illustrated, commented and potential critical points or obstacles are presented. The division into sections of the new road route is carried out by means of visual investigation and assessment of the terrain and soil condition. Figure (113) shows the access road routing and corresponding sections. The existing road dimensions are verified by walking the route while using a measuring band of 50 meters. By this execution the inadequate turns were located. In all such illustrations presented, the red line shows to a length of 50 meters.

Section 1: Common Access Route

The first section is defined from the harbor to the cross road where the transportation route parts for the two sites.

Critical points

The first critical point in section 1 is the turn at (0486893 W, 6667198 N), which is too sharp. The road in this part needs to be wider, and some street light stanchions needs to be removed in order to make the turn. The next turn to the right at Matessenip Aqqutaa (0486811 W, 6667209 N) will also be of issue. The water trench at the left side needs to be in pipes beneath the expansion of the road to make the turns. Street light stanchions also create an issue for the right turn, as the vehicle is forced to expand the road on the left side due to buildings on the right side.
Instead of following the existing road routing, another possible solution is applied. There is a large gravel area behind the Royal Arctic Line storage facility, which can be used for the first turn, and by further correcting the vehicle the next turn can be made without any issue. In this way the street lights does not need to be leveled down and put up at a new location; as well the width of the road does not need to be expanded.

In order to accomplish the possible solution, some measures are needed. Steel pipes are needed in the water trench where the road is crossing, and then a sufficient road layer above the steel pipes must be applied to handle the axel pressure of the vehicle. The intersecting road is given a clearance of 2 meters, instead of 1 meter. Further the gravel area needs to be prepared to obtain the required axel pressure.

Visual aspect

Figure 114 - Critical left-turn

Figure 115 - Critical right-turn

Figure 116 - Solution: Area of new route and turnaround

The scatter rectangle in Figure (116) illustrates the new route and available area to turnaround the vehicle. The length of the area is measured to 60 m, while a width of

30 m is assumed to be adequately for the vehicle to manage the first turn and adjusting for the next turn.

7.4.4.2 Turbine site 1

The following sections are for the access road exclusively to Turbine site 1, located to the east of the city. Here an assessment of the critical points, possible solutions and measures is performed.

Section 2

The first critical point in section two is the turn with GPS coordinates: 0486841 W, 6667372 N. House number 264, owned by a local electrician company (Aut. El-installatør, Hans J. Rasmussen), is blocking the right-turn. Figure (117) illustrates this.

Figure 117 - Critical turn and location of warehouse

The scatter area shows the warehouse that needs to be cleared away in order to make the turn. Unfortunately, the owner was out of reach in the period of the stay in Nanortalik, due to illness. Although the warehouse is old and dilapidated, it is assumed that the company wants to keep their storage facility. Hence a compromise is made for this study, by building a new storage approximately 20 m in the eastern direction. This solution needs to be approved by the electrician company.

Figure 118 - Water trench behind warehouse

An additional critical point related to the turn is a water trench located behind the warehouse. The same measure as in section 1 is applied. This is shown in Figure (118).

The next critical point in section 2 is another turn with GPS coordinates: 0487275 W, 66674567 N. This turn is the right-turn before the dump site.

Figure 119 - Critical turn

The scattered area shows the area where the road needs to be expanded in order for the vehicle to manage the turn.

Section 3

The third section for Turbine site 1 is the start of the new road that needs to be developed. In this section there is an already existing gravel road that needs to be extended and improved.

Figure (120) illustrates the starting point of the new road to Turbine site 1. This gravel road needs to be expanded and prepared to achieve sufficient road requirements. It can be noted that the surrounding terrain is rocky.

Length of the new road is approximately 0.20 km and located between Section 3 and Section 4: Turbine site 1 in Figure (123).

Figure 120 - Existing gravel road

Section 4

Section 4 for Turbine site 1 consists of the actual turbine site. At the site some road and area enhancement is required. The area diameter is larger than the utilized measurement band; hence the turbine site is larger than 50 meter in diameter. Figure (121) and (122) illustrates the site area and dimensions.

Figure 121 - Turbine site 1: Measuring site diameter in north/south direction

Figure 122 - Turbine site 1: Measuring site diameter in east/west direction

The ground is flat and consisting of both hard and solid soil, whereas the upper layer

Figure 123 - Google Earth visualization of the new required road route

is covered by sand. The total utilized site area is estimated to be approximately 2 000 m^2, corresponding to a radius of 25 meters. Note that this is only an approximation in relation to cost estimation, as the site's final design will not be circular, but facilitated for transport vehicle turnaround at site.

7.4.4.3 Turbine site 2

The remaining sections covered in this chapter are related to the access road for Turbine site 2. Also here the road is divided into sections where critical points, terrain and soil conditions are assessed.

Section 2

The first critical point assessed in section 2 is a critical turn with GPS coordinates: 0486841 W, 6667372 N. At the end of the road cross of section 1, the left-turn is too sharp. Hence the inner turn area of the road needs to be expanded.

Figure 124 - Critical turn

The scattered area in Figure (124) shows the area where the road needs to be expanded in order for the vehicle to manage the turn. The next critical point is also a turn with GPS coordinates: 0486330 W, 6667351 N. At the turn of diversion of the existing asphalt road, towards the drinking water of Nanortalik, the road at inner turn area needs to be somewhat expanded in order to manage the turn.

Figure 125 - Critical turn

The scattered area shows the area where the road needs to be expanded in order for the vehicle to manage the turn.

A natural routing would be to follow the gravel road turning to the right; however this routing is not possible due to a residential area resulting in limited space.

Figure 126 - Natural routing not an option

Section 3

Section 3 includes the start of the new road, and hence the end of the already existing road. Further some visual aspects are shown.

Figure 127 - Terrain section 3

The first part of section 3 is dominated by swampy areas, as the route is passing the right side of the city's drinking water. Hence routing is selected to be as far as possible to the easterly direction, away from the drinking water. The terrain consists of soft grass, including a few water spots and rocks. In order to dry the soil and to not risk unnecessary damage to the road related to moisture, the water has to be drained away from the proposed routing. The next part of section 3 contains a critical turn with GPS coordinates: 0486202 W, 6667957 N. This turn is visualized in Figure (128).

Figure 128 - Critical turn requires leaving the gravel road

The access road cannot continue on the existing gravel road routing, due to the lack of space between the buildings. The new routing continues to the left of the residential area. The last part of section 3 also contains a critical point with GPS coordinates 0486155 W, 6667986 N, shown in Figure (129).

Figure 129 - Critical ground issue: Gaps in terrain

There are gaps in the terrain, hence these needs to be filled up to obtain sufficient road requirements. The local sediments can be used in this process.

Section 4

Section 4 starts by the end of the city and hence only critical points in terms of terrain challenges are present. In Figure (130) a visual aspect of the section is presented. As can be seen in the figure, the terrain is partly rocky, with some spots with soft soil. The access road routing will follow the easterly side of the valley.

The first critical point in section 4 is an inclination, which is too steep for transportation. The hill is divided into two parts in the assessment, each given a constant slope angle. This is presented in Table (56a) and (56b). The critical inclination in Section 4 is vizualised in Figure (133). On the figure it can be seen that the slopes are corresponding to 11.8° and 19.4°.

Figure 130 - Terrain section 4

In order for the transportation vehicle to manage this slope, it needs to be within the requirements given by the turbine manufacturer. This can be obtained by blowing and chiseling away some of the ground at the top of the hill, while the lower part needs sediments to achieve the suitable angle. As the slope is greater than 4 degrees and the vehicle is heavily loaded, the upper layer of the road at the inclination could be asphalted. This would provide better friction than gravel; hence a larger gradient (6.8 degrees) would work. However, such a solution is not recommended due to maintenance (Jørgensen A. S., 2012). Figure (131) shows the visual aspect of the critical inclination.

Section 5

The 5th section related to Turbine site 2 has no critical points, but contains more challenging terrain. In Figure (132) a visualization of the section is shown.

Figure 131 - Critical hill

Figure 132 - Terrain section 5

Location	*GPS coordinates*	*Altitude (+/- 4) [m]*
Bottom	0484438 W, 6669986 N	126
Mid	0484568 W, 6669921 N	168
Top	0485104 W, 6669483 N	197

From	*To*	*Horizontal length (m)*	*Average gradient [‰]*	*Average gradient [°]*
Bottom	Mid	33.4	209,5	11,8
Mid	Top	42.7	351,1	19,4

Table 56 - a) Critical hill's GPS coordinates. b) Critical hill's gradients

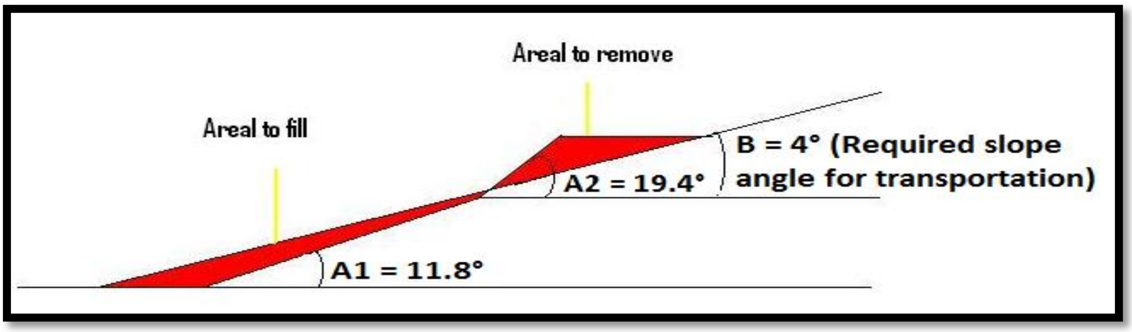

Figure 133 - Critical hill's dimensions

The terrain characterized as rocky, is covered by both small and medium sized rocks, where the rocks need to be cleared away. Figure (132) describes the remaining terrain to turbine site.

Section 6

Section 6 contains the crossing of the valley and the inclination to Turbine site 2. Here the critical point will be the inclination to the site. The first part of this section, whereas the road route is crossing the valley, consists of rocks and grass. The ground layer of the slope to turbine site is rocky. As mentioned the critical part in section 6 is the inclination to the turbine site. The slope is divided into two parts, each given a constant slope angle, just as the previous inclination.

Figure 134 - Terrain section 6

Due to the steepness of the slopes and the distance, the road cannot be designed to be straight up to the turbine site. The assessed solution is to make a number of turns up the hill instead, giving less steepness of the road. Hence this part of the routing will be somewhat extended relative to the primarily measured distance. The long distance and degree of the slope prevents a solution such as submitted for the hill in section 4. Not only would it be very expensive, but as the turbine site at top of the mountain is limited to space, it would reduce the turbine site significantly. By applying such a solution, the turbine site would thus be at much lower altitude. Figure (134) shows the inclination in context.

Section 7

Section 7 is the actual Turbine site 2. Here the terrain is explained and space issues are assessed. Figure (135) shows the terrain at the site.

Figure 135 – Terrain at Turbine site 2

Location	*GPS coordinates*	*Altitude (+/- 6) [m]*
Bottom	0485539 W, 6668778 N	29
Mid	0485506 W, 6668805 N	36
Top	0485491 V, 6668845 N	51

From	*To*	*Horizontal length (m)*	*Average gradient [‰]*	*Average gradient [°]*
Bottom	Mid	198	212,1	12,0
Mid	Top	153	189,5	10,7

Table 57 - a) Critical hill's GPS coordinates. b) Critical hill's gradients

The terrain is rocky and a bit uneven. The maximum altitude difference between the corners of the site is measured to be approximately 2 meter. Facilitation of turbine spot is assumed to require some smaller amount of dynamite and chiseling. Figure (136) shows a visualization of the turbine site. The critical issue related to the turbine site is the available area at the top of the mountain. An expansion of the space at the site would require more drastic measures, which is not cost efficient.

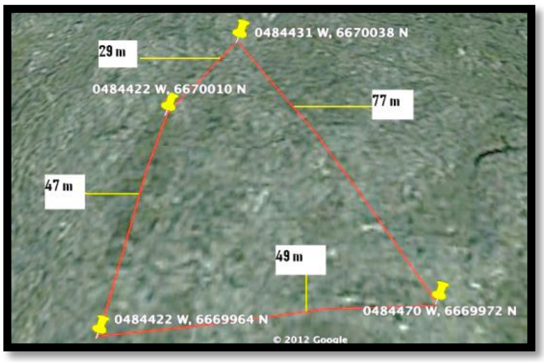

Figure 136 - Google Earth visualization of designated area at Turbine site 2

Hence the turnaround of vehicle and short term storage area is planned to be located at the bottom of the mountain. Such a solution is assumed to be significantly cheaper, as the terrain already has a natural prepared area. The vehicle needs to reverse down to this location to pick-up spare parts and for turnaround. If this would be situated at the turbine site, then an excessive amount of dynamite and heavy operations would be needed in order to facilitate the area. An approximation of the turbine site area is 1700 m2. The designated area for vehicle turnaround and short term storage is dimensioned as a 70 x 30 m rectangle. The dimensions and terrain of this area is illustrated by Figure (137) and (138).

Figure 137 - Google Earth visualization of designated area for short term storage and turnaround

The rectangle in the figure is a visualization of the short term storage location.

Figure 138 - Designated area for short term storage and turnaround

There has also been investigated an alternative solution for the access road to Turbine site 2. By erecting a wind turbine at Turbine site 2, a total of 3.7 km of road needs to be constructed. For a single wind turbine project and the situation in Greenland, this is a substantial share of the total project cost. As the site is situated by the island's coastline in the northern direction, an option of transporting the crane, turbine etc. by a mobile vessel to this coastline has been assessed.

Figure 139 - Coastline investigation by Turbine site 2

A map of sea depths at the coastline of Nanortalik has not been obtained. As neither the municipality nor the Royal Arctic Line has such a track, the coastline in this area has been inspected and visually assessed regarding the feasibility. The nearby coastline appeared to be shallow, where the depths were more or less below half a meter. Such a solution is therefore disregarded in this study.

In the case of wind Turbine site 2, most of the access road is not provided. Hence a large share of the access road needs to be constructed in order to transport the wind turbine and installation equipment with a vehicle to the turbine's position. In order to give an indication related to the costs and assessment of the feasibility of constructing the road at the given route, soil samples have been taken. This only gives partly an indication of the soil conditions, as the sampling is only undergone on the upper layer and carried out manually by use of a shovel. Further geological and geophysical investigation of soil conditions and rock properties in the area is considered necessary to determine the final road route and cost of road preparation.

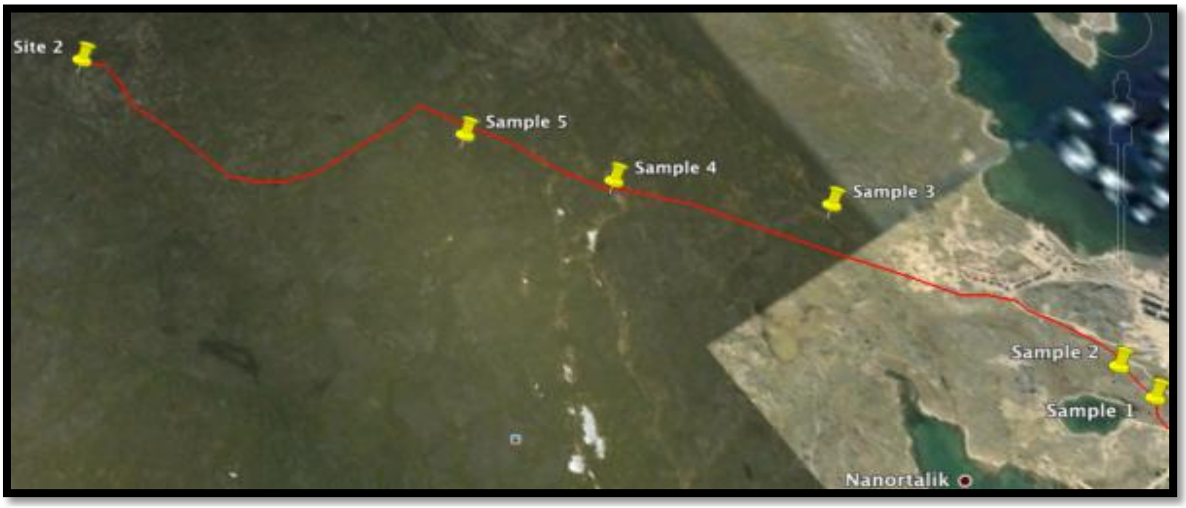

Figure 140 - Google Earth visualization of selected sample locations

Sample no.	GPS coordinates	Sample depth (cm)	Soil property of upper layer and comments
1	0486252 W, 6667491 N	35	Swampy and soft soil, due to the drinking water. Almost no rocks. Need to remove this layer to obtain the required axel pressure of the road. Soil needs to be dried before road construction and also drained away from the road route.
2	0486243 W, 6667611 N	10	Hard soil and small rocks.
3	0485948 W, 6668435 N	60	Normal grassed soil. Soft, without rocks and low relative humidity. Need to remove this layer to obtain the required axel pressure of the road. This layer is estimated to be approximately twice as thick as for area of sample 1.
4	0485491 W, 6668845 N	5	Hard soil and small rocks.
5	0485228 W, 6669202 N	5	Hard soil and small rocks.

Table 58 - Soil samples

The evaluation of where to undertake the samples is done according to visual inspection of the ground, where the soil seemed to change property. Some samples are carried out in order to ensure that the soil property remained unchanged. Figure (140) shows the location of where the different samples are taken, whereas Table (58) is presenting an overview of the different samples. Further on the different samples and their type are explained.

Soft layers

For the first and third sample the upper layer is soft. The first sample is in a swampy area, while the third one is executed in an area of “normal grass”. Both areas are classified as being soft soiled.

Figure 141 - Sample 1

The following quote regarding cohesive soils is stated in the report “Access Roads and Crane Platforms”:

“In the cases of cohesive soils, the use of a geotextile or geogrid is recommended, as this makes for better distribution of the load across the access road’s subgrade. It will also increase the access road’s service life and durability. During construction, plate load bearing tests should be carried out to ensure that the necessary bearing capacity is achieved” (Krey, 2007).

This practice should also be applied to other types of surface conditions, not only soft, cohesive soils.

Rough layers

Sample number 2, 4 and 5 have common soil properties at the upper layer. The ground is compact, including dried soil and small rocks. Figure (143) illustrates the ground condition for these samples.

Figure 142 - Sample 3

Figure 143 - Sample 4 - Similar to sample nr. 2 and 5

7.4.4.4 Economics

In this sub-chapter the economics of the different aspects of the access road are assessed. The two access roads for the two sites have been assessed individually.

Road and other pavements

The cost of road is based on the investigation of the proposed road between Kangerlussuaq and Sisimiut. Regardless of realization of Turbine site 1 or Turbine site 2, this road construction project is of a substantially smaller scale. This will certainly result in establishment cost, concerning the roads, being a larger share of the total cost. On the other hand, there is no need to account for permafrost in Nanortalik. Other factors, such as difference in necessary road width and axel pressure, also entail some uncertainties. However, the mean cost per km is assumed to be an acceptable approximation (Jørgensen A. S., 2012). Based on this project, the same average cost estimate of 3.1 million DKK per km is utilized for preparation of turbine site and turnaround areas (Landsstyreområdet for Boliger, Infrastruktur og Miljø, 2004). All road construction in the city area has to be asphalted. This applies to all needs of road expansion regarding critical turns, however not to the proposed shortcut area by the harbor, as this area will only be used as routing by the wind turbine transportation company. After the construction phase, this routing will be closed for access. The cost per turn expansion will be marginal and is hence given a symbolic value of 25 000 DKK.

Cost of steel pipes in the water trenches is assumed to be somewhat the same as for power cable protection. The required lengths are the same as the width of intersecting road. The cost is estimated to be 450 DKK per meter (Nukissiorfiit d. Q., 2012).

Turbine site 1

The following costs are related to the access road to Turbine site 1. The total road length required to be constructed is 0.20 km. The different expenditures for the access road to Turbine site 1 are listed beneath.

Costs:

- Road: 0.20 km.
- Road expansion at two turns.
- Turbine site (turnaround/short-term storage)
- Shortcut area
- Four locations where steel pipes are needed
- Demolition and construction of a new warehouse

Turbine site 1	
Road/Surface preparation	**Cost (Mill. Dkk)**
Normal road (0.2 km)	0.62
Road expansion (2x)	0.05
Turbine site	1.55
Shortcut area	1.395
Steel pipes (4x)	0.01
Warehouse	0.2
TOTAL	**3.83**

Table 59 - Costs for Turbine site 1

The costs for demolition and construction of a new warehouse have not been obtained, hence given the symbolic value of 200 000 DKK. Further on it can be seen that the shortcut area stands for a substantial part of the total cost of the access road to Turbine site 1. The total cost for the access road is calculated to be **3.83 mDKK**.

Turbine site 2
The same procedure has been applied for Turbine site 2. The total road length required to be constructed is 3.72 km. However, a compromise is made for the section ranging from the bottom to the top of the mountain, where the turbine site is located. This is based on a necessary road extension due to steep inclination, extra need for ground preparation and corresponding uncertainties. The cost is given a symbolic sum as three times the road cost per km. The initially measured length from the bottom to the top of the mountain is approximately 0.36 km. The different expenditures for the access road at Turbine site 2 are listed beneath.

Costs:

- Road: normal pricing for 3.36 km, while triple pricing for 0.36 km
- Road expansion at two turns
- Turbine site
- Turnaround and short-term storage
- Shortcut area
- Two locations where steel pipes are needed

Turbine site 2	
Road/Surface preparation	**Cost (Mill. DKK)**
Normal road (0.2 km)	10.42
Expensive road (0.36 km)	3.35
Road expansion (2x)	0.05
Turbine site	1.32
Turnaround and storage area	1.63
Shortcut area	1.395
Steel pipes (2x)	0.0054
TOTAL	**18.16**

Table 60 - Costs for Turbine site 2

As can be seen in Table (60) the dominating factor for the cost of the access road to Turbine site 2 is the normal road construction. This is due to the fact that this site is located further away from the city. The total cost for the access road to Turbine site 2 is calculated to be **18.16 mDKK**.

7.5 Foundation

The wind turbines foundation is generally chosen on the basis of the assessed sites soil conditions, economy and the strength to endure the loads induced by the calculated extreme winds for the site. This analysis will present an overall assessment of the foundation alternatives, which means that no load calculations will be undergone.

7.5.1 Gravity foundation

A gravity foundation with a spread footing relies on the soil overburden and added concrete mass to provide sufficient weight and strength to keep the foundation stable at extreme wind speeds (Morgan & Ntambakwa, 2008). The most common type of foundation for wind turbines is the hexagonal shaped large concrete pad, dug down in the ground and reinforced with sufficient amounts of filler. This type of foundation commonly uses 300-400 m^3 of concrete and large amounts of rebar when constructed.

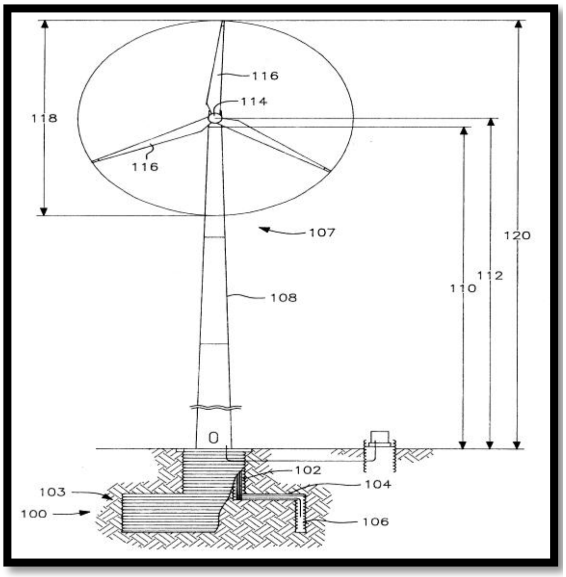

Figure 144 - Gravity foundation sketch (Free Patents Online)

7.5.2 Rock-anchor foundation

A rock-anchor foundation is better suited at sites with strong bedrock. This type of foundation utilizes the strength of the bedrock by grouting massive steel bars in deep boreholes, and post-tensioning the steel afterwards.

This type of foundation reduces the amounts of material needed, which is especially interesting for the two sites in Nanortalik. Due to the low access of materials and rocky conditions, the rock-anchor foundation is found the most appropriate. Different alternatives of the rock-anchor foundation can be chosen, from a single monopile driven deep into the ground, to multiple piles driven a bit shorter into the ground, where a circular steel arrangement is mounted on the piles providing a steady and strong foundation for the wind turbine.

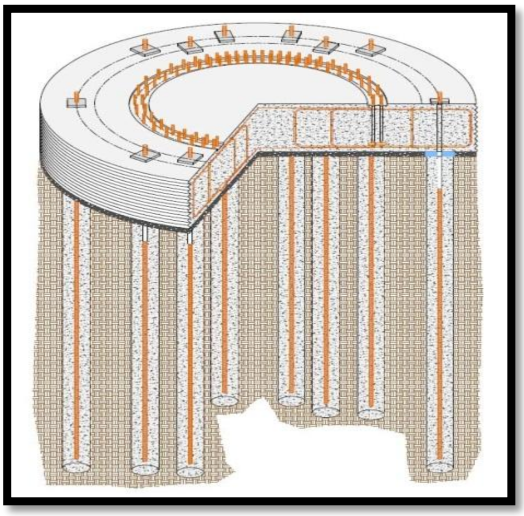

Figure 145 - Rock-anchor multi pile foundation (Earth Systems Global, inc, 2011)

7.5.3 Foundation at Turbine site 1

The soil conditions at turbine site can be described as follows:

Upper layer is densely packed gravel/soil mixture with smaller grain sizes. The estimated depth to rock is 10-20 cm. A sampling of ground has been tried, to visually inspect and estimate the depth to mountain/rock but without success due to hardness of upper layer. Geological surveys should be undergone to assess the strength and porosity of the rock layer. It is assumed that the upper layer will be removed, and that rock is the layer-medium that must be considered when constructing the foundation.

Figure 146 - View towards wind Turbine site 1 (North-East direction)

On the basis of the soil conditions and with the economy in mind, a rock-anchor foundation with multiple piles has been found to be most appropriate for Turbine site 1. This will reduce the need to transport large quantities of concrete and rebar, which is an expensive matter in Greenland. It is also believed that it is an easier operation to drill multiple more shallow boreholes, instead of one very deep.

7.5.4 Foundation at Turbine site 2

The soil conditions at Turbine site 2 can be described as follows:

As it is in mountainous terrain the layer-medium is purely rock, of unknown quality. Geotechnical surveys must be undergone to determine the rock quality, before a final conclusion of foundation can be taken. It is assumed that the rock quality is good enough to utilize a rock-anchor foundation with multiple piles such as for site alternative 1.

7.5.5 Construction phase of foundation

It is further assumed that the foundation can be shipped with the wind turbine from Denmark, and that the local contractor "Qaqortoq Entreprenør" can assemble the foundation with the help of the work drawings and guidelines that follow with the foundation. It is also assumed that the tools and mechanical equipment needed to construct the foundation is at Qaqortoq Entrepenør's disposal. The needed concrete must be bought and transported from Iceland. This is due to the varying quality of the concrete produced in Greenland (Municipality N. , 2012) .

Figure 147 - View towards wind Turbine site 2 (East)

7.5.6 Technical solution

A concrete plate area which is sloped to drain away water from the tower is mounted on top of piles that are drilled into the mountain. The piles are driven approximately into the mountain/ground in order to create a stable condition for the tower under wind turbine operation.

Figure 148 - Piles driven into mountain (Earth Systems)

The concrete plate area is mounted on top of the piles, and acts as the connection point between the bottom part of turbine tower and the piles, as shown in Figure (149).

Figure 149 - Bottom of turbine tower is mounted on concrete plate area (Earth Systems)

According to Troms Kraft Produksjon AS, a Norwegian energy group in the county of Troms, it requires approximately 100 m^3 of concrete for a multi pile solution in mountainous conditions. For marshes and swamps it requires approximately 400 m^3. The cost of the foundation is hence estimated by finding the price for 100 m^3 of concrete, and adding some additional costs related to the labor and the mounting/drilling of piles/pile holes (Troms Kraft Produksjon AS, 2008). By use of the V & S Greenland database, the foundation is estimated to cost **302 800 DKK.**

Further geological studies are strongly recommended if a wind turbine is to be placed at either Turbine site 1 or Turbine site 2.

7.5.7 Decommissioning of wind turbine

After the technical lifetime of the wind turbine, the operation of the wind turbine eventually can become infeasible. This means that it must either be replaced by another turbine (repowering) or decommissioned. During the field trip, the Municipality in Nanortalik was questioned regarding this matter, and the answer was that they wanted the wind turbine to be shipped out, for example to Denmark. This is a normal way of handling industrial waste in Greenland (Government of Greenland, 2010).

There will be no need to remove concrete bases, as they can be hid under filler, stones and other materials. Service roads can be removed if wanted, although they can be of use for the society. It is assumed that the road for both alternatives is kept for further use. The switchgear station and substation for the transformer must also be removed unless the municipality in Nanortalik can utilize the equipment, by reconditioning and reusing it. If not it must be shipped back to Denmark along with the wind turbine. The equipment can then be scrapped or recycled with revenue according to the market price of scrap metal at that time.

Scrap metal revenue from the tower and the generator can cover some of the expenses of getting the site back to its original state since the influenced area is not that large, thus the largest costs regarding the decommissioning will be the transport back to

Denmark. In the economic analysis the decommissioning cost will be corresponding to the transport cost from Finland. The turbine manufacturer, WinWind, has estimated approximately **200 000 €** for this procedure, which is equal to **1 492 000 DKK** (Rod Gilmore, 2012).

7.5.8 Crane Capacity and delivery

In order to install the different parts and erect the turbine at the site, a crane is needed. The crane needs to be able to lift the heaviest parts of the turbine up to hub height, which in this case is approximately 40 tones (the nacelle) up to 70 meters. This requires a big crane with a large capacity. A crane of this size and capacity is assumed to be impossible to find in Greenland; hence the crane will be shipped in parts together with the wind turbine. Further on it is assumed that the crane on the boat has the capacity of lifting the parts from the boat to the truck.

7.5.8.1 Crane requirements

The following section describes the crane requirements, which are taken from an Enercon turbine of approximately the same size as WinWind WWD-1.

The key to ensure safety with respect to crane operation in the construction phase is the crane platform. The crane platform should be placed on a level surface located above ground level in order to ensure that water is dispersed properly.

The maximum support pressure of the uti-

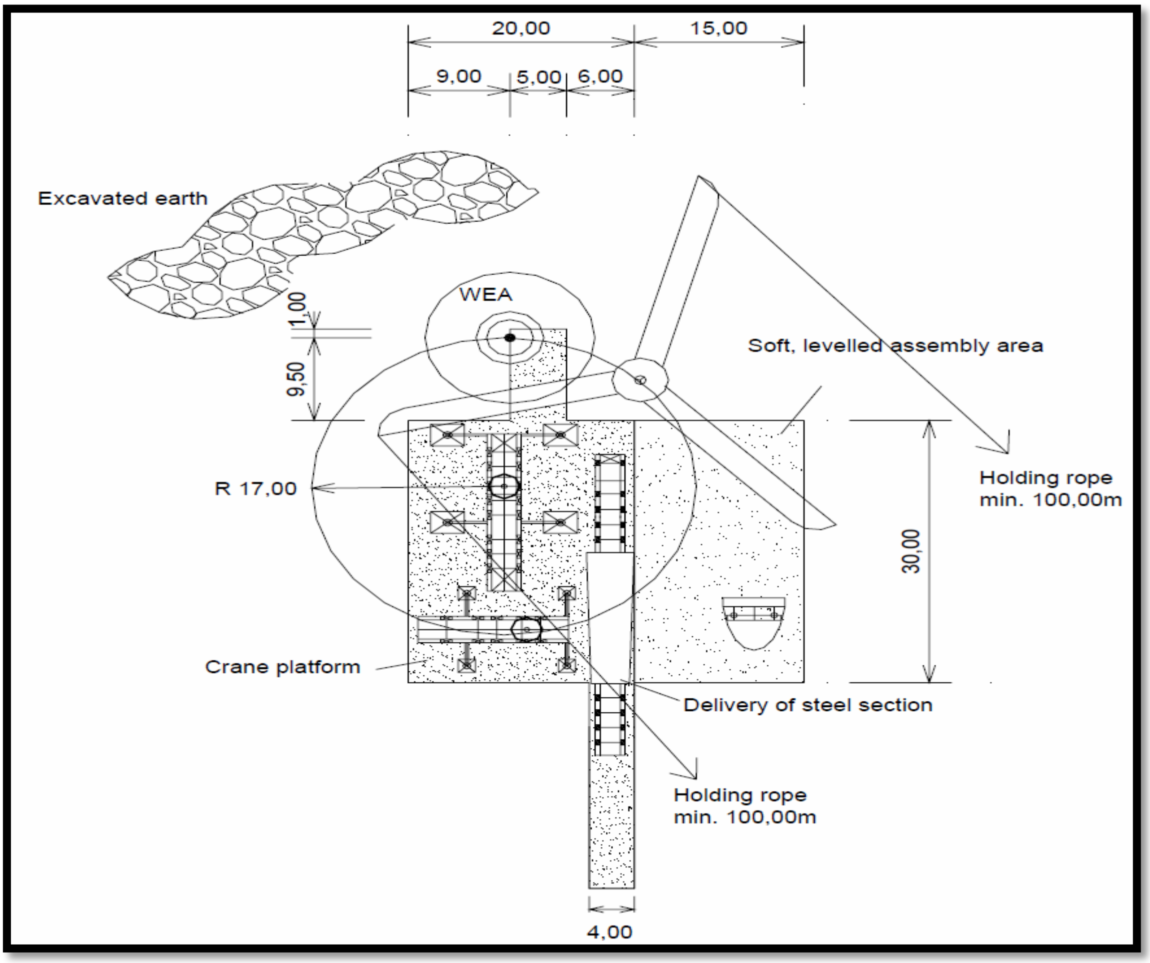

Figure 150 - Crane platform dimensions standard

lized crane is 200 tones and is supported on the crane platform by load distribution plates. The maximum surface pressure can reach 185 kN/m^2. In order to make sure that the surface of the ground can handle this, it is assumed that the surface can handle twice the pressure of the roads, which is mentioned earlier in this chapter. For simplicity the cost of this is assumed to be twice the price of the road per square meter.

When calculating the dimensions of the crane platform the standard visualized in Figure (150) is used. This is important to calculate in order to optimize all the work when installing the turbine (Enercon, 2007). The total area of the crane platform is calculated to be 600 m^2 according to the standard.

Further on it is assumed that this is the only crane needed, except a small local crane to lift of the main crane parts from the trucks.

Table (61) shows an overview of the extra cost of the surface beneath the crane platform.

Cost of crane platform	
Subject	**Cost (DKK)**
Road cost (km)	3 100 000
Road cost (m^2)	536.7
Cost of crane platform	338 220

Table 61 - Cost of crane platform

7.5.9 Temporary storage location

The temporary storage location is the location where the parts of the wind turbine is stored temporary while installing the turbine. In this project it is only one wind turbine and hence the requirement of the size of the temporary storage location is less than what it would have been for a larger project.

For Turbine site 1, the temporary storage location will be at the site, located on the 2 000 m^2 construction area mentioned earlier in this chapter.

For Turbine site 2, the temporary storage location is located just before the final ascent to the site. This location is visualized in Figure (137).

7.6 Operation and Maintenance

Operation and maintenance costs consist of a sizeable share of the total annual costs of a wind turbine. The costs can easily be in the range of 15-25 % of the total cost per kWh produced over the lifetime of the turbine. These costs involve insurance, regular maintenance, repairs, spare parts and administration costs. As a result of this, the operation and maintenance attracts more and more attention in the wind power industry (Wind Energy - The Facts Part 3). A study on operation and maintenance made in Denmark discovered that the annual cost of operation and maintenance on old wind turbines were on average 3 % of the turbine cost. But as a result of the gained attention on this aspect of wind power, the newer turbines have an annual cost of operation and maintenance of 1.5 – 2 % (Wind Measurement International, 2012). In this analysis the annual operation and maintenance cost are assumed to be 2 % of the original cost of the turbine based on the fact that it is only one turbine.

7.6.1 Local participation

A method to do cost-minimizing of the operation and maintenance costs is to have one or more local technicians performing most of the maintenance. The turbine supplier will do an annual maintenance as a standard routine and then it is up to the local technicians to do weekly, monthly and semiannually maintenance on the turbine.

The uncertainty in this project is, however, what level of experience the local technicians have. Since Greenland does not have a full scale wind turbine, it is safe to say that no, or very few, local technicians have experience from wind energy.

In order to do cost reduction on the operation and maintenance, the local technicians then have to attend to a training program for maintenance on the specific turbine.

7.6.2 Annual service from WinWind

The turbine needs an annual and thoroughly maintenance. This entails a thoroughly inspection of every part of the turbine. The wind turbine will during this maintenance be stopped, and decoupled from the grid. This is done in order to ensure a safely working environment for the technicians.

This annual service with technicians from WinWind makes it possible to make a conclusion of the current status of the turbine with respect to wear on specific parts and fatigue on the turbine.

The turbine will also be equipped with a monitoring system which will be implemented in the SCADA system. This monitoring system will measure vibrations, oil temperatures etc. This will be monitored by WinWind from a remote location. This system can measure if there are some irregularities in specific parts, and therefore predict if a part is about to fail. On this basis spare parts can be ordered in advance and hence make the availability of the turbine as high as possible.

8 NANORTALIK ENERGY SYSTEM INCL. WIND POWER

The proposed new energy system in Nanortalik consists of diesel generators, oil burners, an electrical boiler and wind power. By implementing wind power into the system, a significant reduction in power demand from the diesel generators are experienced – both with respect to electricity and heat. As the wind power is fluctuating, there are periods where the wind power is larger than the electricity demand in the town. Thus, it is reasonable to install a dump load to utilize the wind power to its maximum. This dump load consists of an electricity boiler used to supply energy to the district heating system. For the periods where the wind power is lower than the demand, the existing diesel generators and oil boilers need to be utilized.

In this chapter, a model is described which analyses the Nanortalik energy system including wind power. The model is based on a 1 year representative of energy consumption in the town and 3 year of wind measurements. Based on the three years of data, an average power production is found and used in the representative year of the system. Based on the representative year, the annual revenue from the new system versus the old system is found together with the reduction in CO_2 emissions.

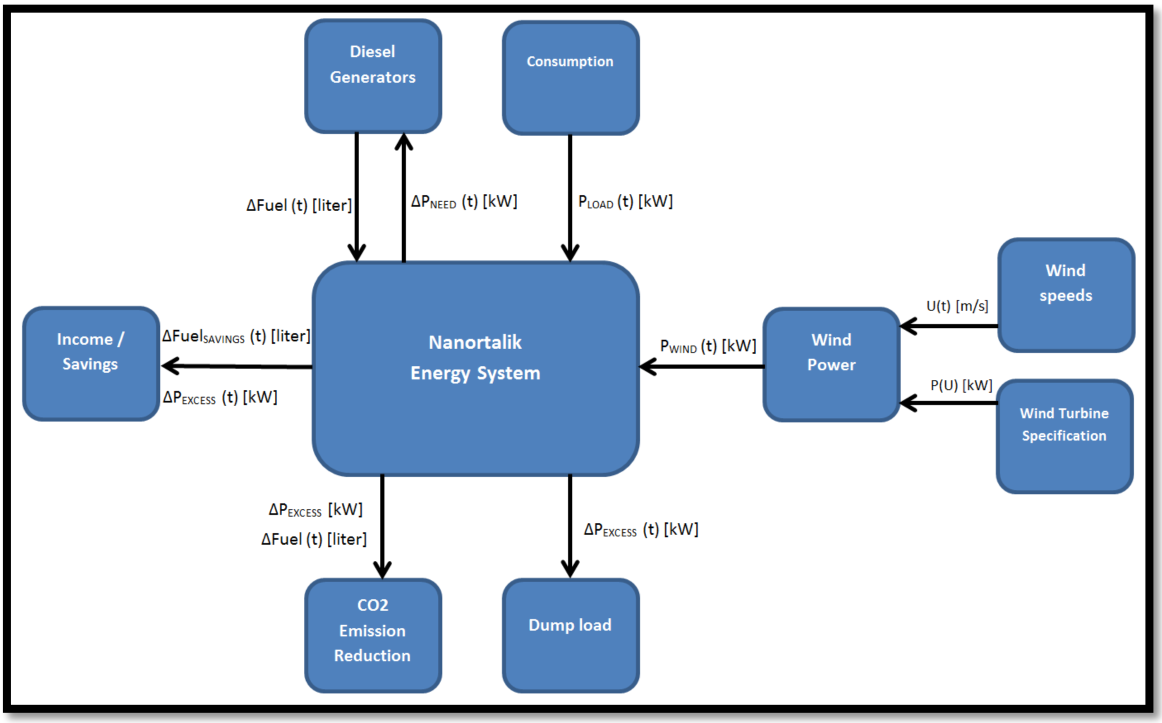

Figure 151 - Schematic overview of Nanortalik energy system incl. wind power

The model is designed to calculate the power production from the wind turbine for each of the time series (years) which are implemented into the model, after which an average of each 10 min average power output is calculated. The average of the power outcome is used instead of the mean wind speed of the measurements due to the power in the wind, given by Equation (30):

$$P = \frac{1}{2} A \rho V^3 \qquad \textbf{(30)}$$

Where:
P = Power (W)
A = Swept area (m^2)
V = Wind Speed (m/s)

A schematic overview of the proposed energy system is given in Figure (151). As can be seen from the figure, the system has input from the diesel generators, the consumption data, the wind power data, whereas the output of the model is the amount of power delivered to the dump load, the energy demand from the diesel generators and the annual income/savings for the new system compared to the old system.

In the following sections, the different parts of the model is undergone, including how they work, which assumptions that are made and what the outcome if each part is.

8.1 Consumption

The consumption in the Nanortalik energy system consists of power used for electricity and heat to the district heating system. In this analysis only the first mentioned is regarded, as data for the heat consumption in the town is not obtained. It is therefore assumed that the entire surplus from the wind turbine is fed to the electricity boiler and used in the district heating system.

The consumption data for the year described in Chapter (2) is used in the energy model – April 2011 to April 2012. The consumption data is thoroughly described in Chapter (2). As stated in the mentioned chapter, it is assumed that the consumption in the town equals the generator production; hence the losses are not included.

8.2 Diesel Generators

In the power system model, the diesel generator block in Figure (151) represents the three main diesel generators existing in the Nanortalik power system. Back-up generators have not been taken into account, as this is a feasibility study of implementation of additional power, not a dynamic fault study with associated power system controllers.

The actual fuel consumption with respect to generator loadings have not been obtainable from neither Nukissiorfiit nor Man Diesel SE (formerly Man B&W Diesel AG), hence approximated diesel fuel consumption with regard to generator loading have been utilized (SE, 2012). Such chart for various power ratings gives fuel consumption at 25, 50, 75 % and full loading (Diesel Service & Supply). However, although several sources seem to give the same values and that the fuel consumption may be assumed to be linear in the range of ¼ to full loading of the diesel generators, this is far from the actual case in the range of no load to ¼ load. As the consumption characterization for this range is of unknown origin for the generators, and to put a fuel value for such operation, the relation is for this study assumed to be linearized. The operational and associated fuel consumption characteristics for each generator are illustrated by Figure

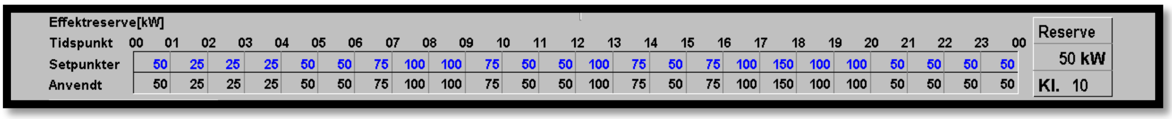

Figure 152 - Spinning reserves with regard to time of day

(153). Set points refer to the provided fuel consumption with respect to generator loadings.

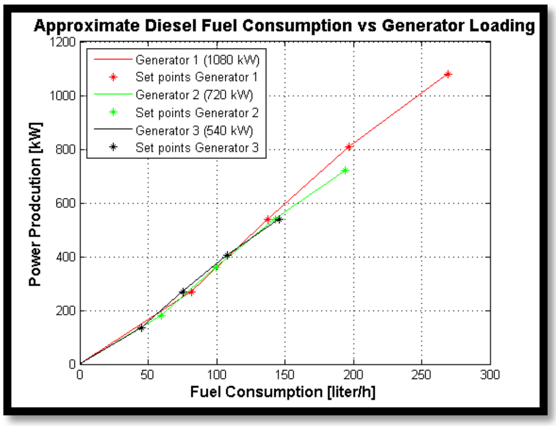

Figure 153 - Diesel fuel consumption with regard to generator loadings

Generator loading below 25 % is desired to avoid to the greatest extent. As long as the required diesel generator production does not exceed the generator rating of the smallest generator (540 kW), this is used as the primary conventional production unit. This way the share of operation in the range of 0-25 % generator loading is reduced.

In order to obtain safe operation, the requirement regarding spinning reserves for such small isolated system is conservative. Figure (152) illustrates the spinning reserve requirements on hourly basis throughout a day in Nanortalik.

Between 17 and 18 at the afternoons, the peak spinning reserve occurs. As this is a feasibility study, the operation is not optimized, hence the peak spinning reserve of 150 kW is utilized at all time. This means

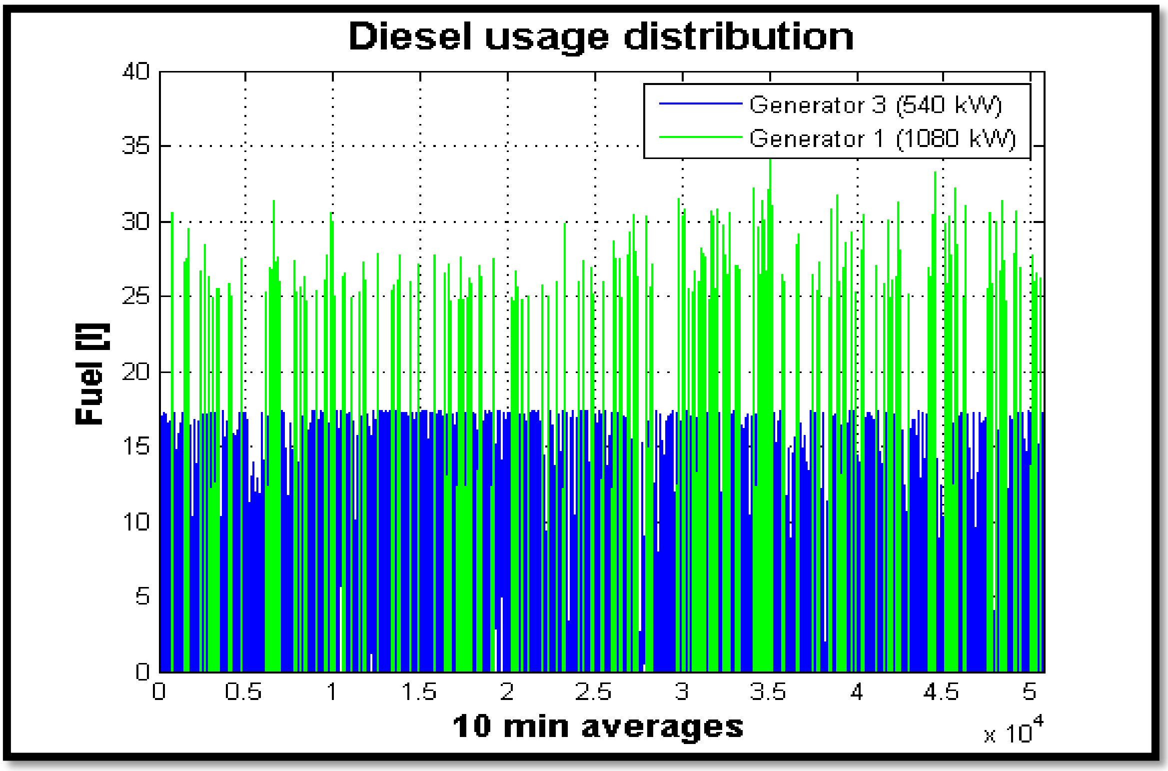

Figure 154 - Fuel consumption distribution and magnitude

that for demand larger than rated power of the smallest diesel generator subtracted the spinning reserve, corresponding to 390 kW, the largest diesel generator of 1080 kW is for simplicity designated to immediately take over as conventional production unit. Figure (154) illustrates the distribution and consumption magnitude of diesel usage associated to the designated production control. Note that the hysteresis control of the generator is not taken into account, due to this being a steady state simulation of the system. This means that all calculations are undergone on vector-basis, hence not varying with time such as in a dynamic study. By modelling the energy system dynamically, other control aspects of the generators and wind turbines could be included, but since the goal of the conducted model is to calculate the fuel savings in terms of implementing a wind turbine, this is not considered.

8.3 Wind Power

The data utilized in the model is the three year of validated data from the 1601 met mast in Nanortalik. It is assumed that the wind speed distribution at 50 meter height is the same for Turbine site 1, which is located in the vicinity of the met mast. In order to upscale the wind speeds in terms of hub height a factor of 1.027 has been utilized, which is based on the extrapolated mean wind speed at hub height in WAsP, and the measured mean wind speed at 50 meters at the mast.

For Turbine site 2 the wind speeds are adjusted by a factor of 1.225, which is based on the mean wind speeds of the data at Turbine site 1, transferred to hub height, and the extrapolated mean wind speed result at Turbine site 2. In this case, the Weibull distribution of the wind speeds at Turbine site 2 will not be accurate, and cannot be utilized as a representation of the wind distribution. It is assumed that the data still can be utilized in the model; since the generated model of the energy system is based on obtaining an overall feasibility of the project, and that the sum of the power output at Turbine site 2 will match the sum obtained in WAsP.

In the model, the wind speed vectors for both sites are set up so that the data runs from April to April, in correspondence to the available data for the consumption. Hence, the seasonal variability is also taken into account.

8.3.1 Wind Power distribution

The wind speed datasets for Turbine site 1 and Turbine site 2 have been used to create a wind power distribution for both sites. By applying the power curve for the WinWind WWD-1 turbine to the model and assigning the cut-in / cut-out limits, the power output value for each 10 minute average wind speed have been found. This is done by interpolating between the vectors giving the relationship between power and wind speed and the actual wind speed per time step. Figure (155) shows the power curve for the WinWind WWD-1 turbine.

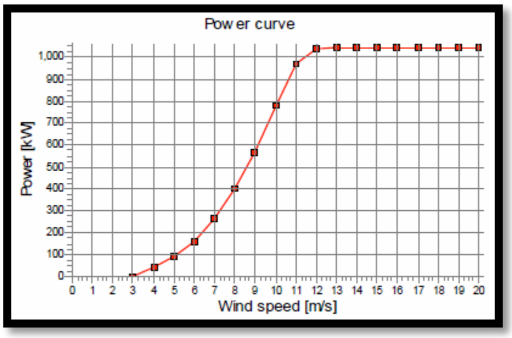

Figure 155 - Power curve for WinWind WWD1

In order to create an annual power distribution of the system, based on the three years, the power output values have been averaged for each time step for the three years. This is done based on power output instead of the wind speed in order to retain the fluctuations in the wind, giving a more realistic simulation. If the average had been done based on wind speed, the power distribution would have been more affected due to Equation (30), where the wind speed is cubed. This would have resulted in a more average power production, giving an artificial power distribution from the wind turbine. For the generator data that has been obtained in this analysis, the relationship between generator loading and generator fuel consumption is approximately linear. This means that the cost and fuel reduction results will be approximately the same as if each year with data was utilized in the model separately and meaned in the end. Figure (156) shows the annual wind power distribution that has been utilized for Turbine site 1 in the model, based on three years of measurements.

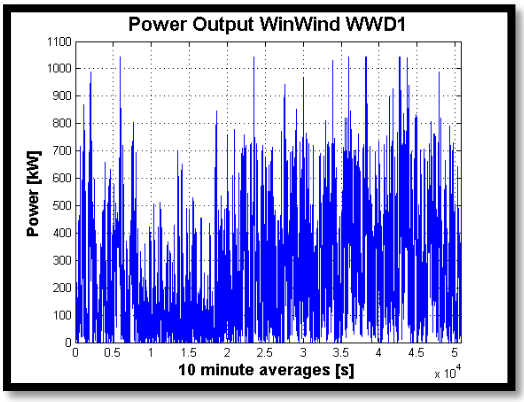

Figure 156 - Power Output WinWind WWD1 for Turbine site 1

The annual wind power distribution at Turbine site 2 has the same form, but is upscaled to higher values.

8.4 Dump Load

A dump load is also part of the new proposed energy system in Nanortalik. The chosen dump load in the system is an electrical boiler, which is connected to the already existing district heating system. The purpose of the dump load is to use the surplus power from the wind turbine, instead of shutting it down. This opens the opportunity to install a wind turbine with higher rated power, since the surplus can be sold and used in the district heating system.

The chosen electric boiler is a 1 200 kW Dyrhoff boiler, which is made in Norway. This is the exact same electric boiler as installed in Qaqortoq, and hence proven to fit good in such heating systems. Figure (157) shows a picture of the electric boiler installed in Qaqortoq.

Figure 157 - Electric boiler

This is a boiler with a large nominal output power. Hence the boiler is capable of handle the surplus power from the wind turbine, regardless of surplus power magnitude, since the rated power of the boiler is larger than the rated power of the wind turbine.

The efficiency of the boiler is assumed to be 99 % (Thermsaver). In order to transport the surplus wind power from the wind turbine to the electric boiler, a transformer is needed, which is assumed to have an efficiency of 95 %, making the overall efficiency of the power transformation to the district heating system approximately 94% (Jensen, 2012). With a known wind power production and power consumption based over one or several years, the surplus wind power can be calculated. Figure (158) is a plot illustrating the surplus power in this energy system over one year.

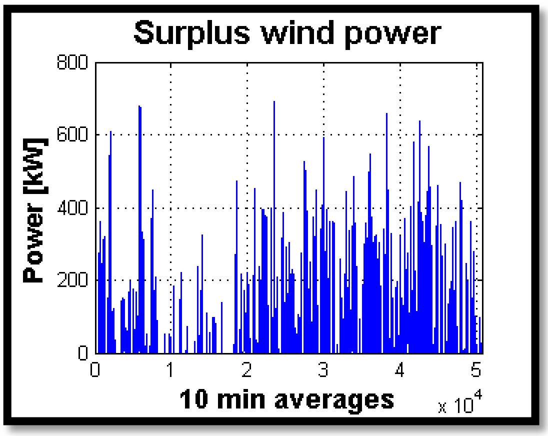

Figure 158 - Surplus wind power

The maximum amount of surplus wind power over a 10 minutes average is 692 kW, which is well within the rated power of the electric boiler. It is further assumed that all of this surplus power is produced and hence the limit of the district heating system is not reached. The selling price to the district heating system is based on a fixed tariff, which is fixed for one year at the time for all of Greenland. In this analysis the price for 2012 is used, 782 DKK/MWh (Nukissiorfiit, 2012).

The district heating system is normally heated by use of oil boilers and hence the use of wind power will create a reduction in CO_2 emissions. This makes the project a good measure against air pollution in the arctic areas.

8.5 Output from Energy Model

The output from the energy model is the saved oil (and thus saved fuel costs) and CO_2 emissions for the wind penetrated system compared with the existing system. In Figure (159), the diesel usage distribution for the Nanortalik energy system is presented with and without wind power in the system. In the figure, the pink and green plot represent the fuel usage of Generator 1 (1 080 kW) and Generator 3 (540 kW) for the existing system without wind power, respectively. The black and blue plots represent the fuel consumption for the same generators for the system with wind power.

Several properties for the two systems are observed from Figure (159). For a system consisting of diesel generators, the mean consumption exceeds the operating limit for Generator 3 (390 kW), hence Generator 1 is operated approximately 60 % of the time. Considering that the mean power consumption in Nanortalik is 438 kW, such usage is not preferable due to efficiency. Also it is observed that Generator 3 is not operated at a consumption level less than 11.5 l. As a consequence of the large usage of Generator 1, the fuel consumption is high. The annual fuel consumption without wind power in the system is approximately 1 million liters, and the annual CO_2 emission is 888 tones.

By including wind power in the system, the usage of Generator 1 is reduced significantly (98 %), whereas the usage of Generator 3 is increased (38 %). This is beneficial since in such an operating setting the generator can operate at a higher efficiency – hence with dramatically lower fuel consumption. In 36 % of the year, the wind power has a larger production than consumption; hence

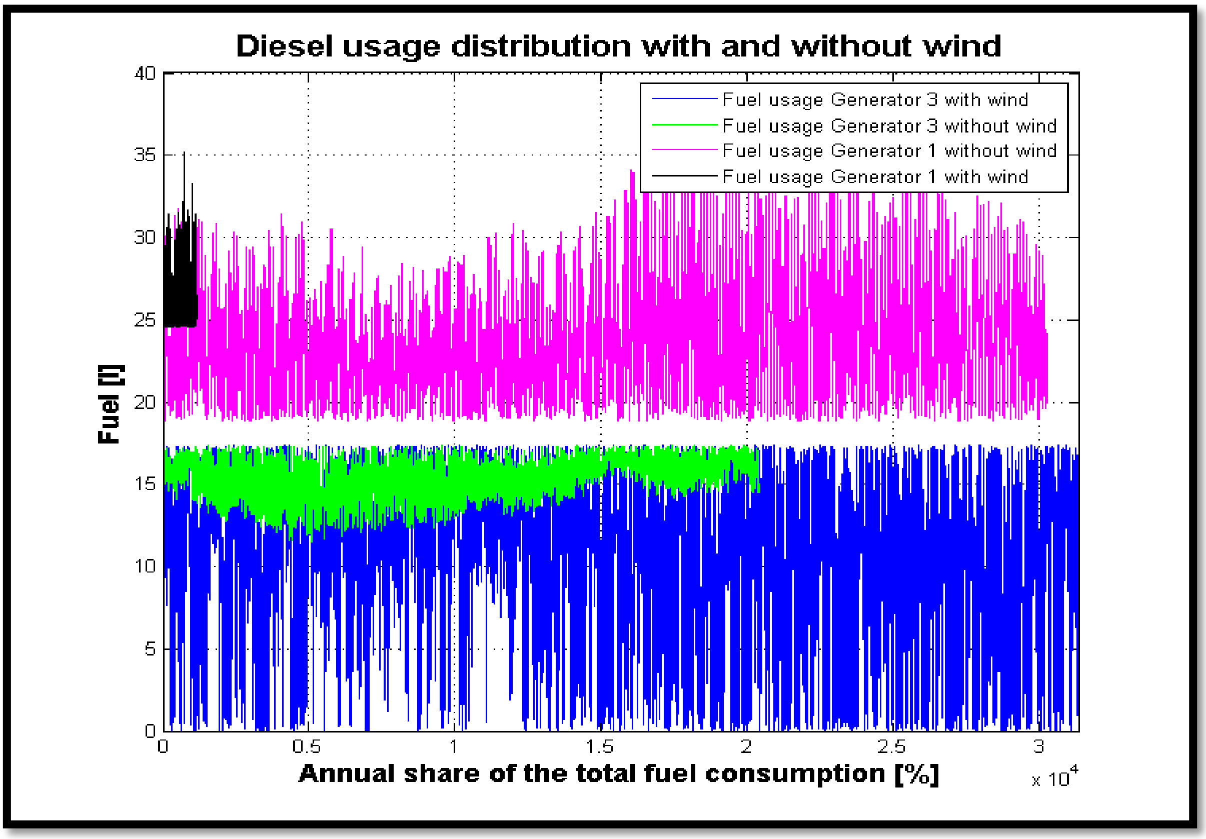

Figure 159 - Diesel consumption distribution with and without wind power implemented in the system

a surplus of power is experienced. In these periods the power is used to produce heat for the district heating system, which leads to an increased revenue.

A last property observed from Figure (159) is the operation setting of approximately 390 kW (max power for Generator 3 and min power for Generator 1). At this setting, the fuel consumption for Generator 3 is 17 liters for a 10 min period, whereas the consumption for Generator 1 is 19 liters per period. Consequently, the efficiency of Generator 3 is approximately 10 % higher for such a setting.

8.5.1 Heat- and diesel prices

In order to calculate the saved fuel and CO_2 emission for the wind penetrated system compared to the existing system, the following prices for heat and diesel is used:

Energy System Prices	
Heat price	0.782 DKK / kWh
Diesel price	5.85 DKK / liter

Table 62 - Energy system prices

The heat price used in this analysis can be found in the report ”Varmepriser pr. 1. januar 2012” from (Nukissiorfiit, 2012). In the report the price for district heating is 0.782 DKK / kWh.

The price for the generator fuel is obtained by Polaroil, the largest oil supply company in Greenland. On the 31st of July 2012, Polaroil released a statement where it was determined that the litre price for gas oil, petrol, paraffin and Jet A-1 would be reduced from after the 1st of August 2012.

Here, the gas oil price was reduced from 6.15 DKK/liter to 5.85 DKK/liter. The gas oil price operated within this analysis is hence 5.85 DKK/litre (KNI A/S, 2012).

8.5.2 Results for Turbine site 1

The results from the energy model are presented in Table (63):

Results from the energy system model – Turbine site 1	
Fuel savings (l)	519 620
Fuel savings (DKK)	3 039 800
Total heat income (DKK)	222 710
Total annual economic benefit (DKK)	3 262 500
Total lifetime economic benefit (DKK)	65 250 000
CO_2 savings (tones)	542

Table 63 - Results from the energy system model

By implementing the wind turbine into the system, a reduction in fuel consumption of 519 620 liters is the result. This corresponds to an annual saving of 3.04 million DKK. In addition, due to the surplus of wind power in several periods, annual revenue of 222 710 DKK is obtained.

The total lifetime economic benefit obtained from the wind power implementation is approximately **65 million DKK**, and in addition 542 tones CO_2 is reduced due to reduction in diesel and crude oil (from the oil burners).

8.5.3 Results for Turbine site 2

The results from the energy model for Turbine site 2 are presented in Table (64):

Results from the energy system model – Turbine site 2	
Fuel savings (l)	628 970
Fuel savings (DKK)	3 679 400
Total heat income (DKK)	389 160
Total annual economic benefit (DKK)	4 068 600
Total lifetime economic benefit (DKK)	81 372 000
CO_2 savings (tones)	693

Table 64 - Results from the energy system model

By implementing the wind turbine into the system at Turbine site 2, a reduction in fuel consumption of 628 970 liters is the result. This corresponds to an annual saving of 3.68 million DKK. In addition, due to the surplus of wind power in several periods, annual revenue of 389 160 DKK is obtained.

The total lifetime economic benefit obtained from the wind power implementation is approximately **81 million DKK**, and in addition 693 tones CO_2 is reduced due to reduction in diesel and crude oil.

8.5.4 Comments to the results

It is seen that due to the high diesel price, the benefit of having renewable energy sources in the system is relatively high. It is impossible to predict how the oil prices will develop in the future, as large fundings are allocated to enhance the oil recovery.

Whether the total economic benefit from the fuel savings exceeds the investment- and operational costs is investigated in Chapter (10).

9 ENVIRONMENTAL IMPACT ASSESSMENT

In relation to development of a wind power plant, some specific environmental issues have to be assessed. In this report only a superficial analysis has been carried out, based on the key issues related to wind turbines.

Greenland as a country is very sensitive to measures that impact their nature, especially because of the arctic conditions. Because of this sensitivity, an environmental impact assessment is very important. The goal of the assessment is to clarify measures so that implementation of wind power affects the surroundings and wildlife as little as possible.

Greenland has currently very little experience with wind power. On this basis there is an absence of a unique legislation for wind energy in Greenland. In this report the legislation and guidelines from the Danish government is followed.

With help from NunaGIS the surrounding nature and wild life has been inspected. It is hereby found that implementation of a wind turbine has very little or no impact to wildlife at a critical level. A figure of the critical areas in the Nanortalik area can be found in Appendix (F). NunaGIS provides a digital atlas with geographical information themes such as bird colonies, sensitive areas, historic buildings etc. (NunaGIS).

9.1 Critical EIA Issues and Mitigation of Impacts

Here the most critical EIA issues are presented together with possible mitigation of the impacts. Since there was no impact on wildlife at a critical level, only safety issues and impacts on the inhabitants of Nanortalik are presented.

9.1.1 Construction Period

During the construction period the site will be closed for the public to maintain a high level of safety. The roads leading from the harbor to the site may also need some reinforcements in order to transport the turbine without damaging the road or cause dangerous situations. This is thoroughly described in Chapter (7).

There will also be a time schedule planned for both electric infrastructure, construction of roads and site, and installation of the turbine. This time schedule will be followed as far as possible without lowering the safety standards. This is to ensure that infrastructure is ready when erecting the turbines.

9.1.2 Visual impact

When erecting the turbine it will have a visual impact on the landscape. Because of the total height of the turbine together with the flat terrain in the city of Nanortalik, the turbine at Turbine site 2 will be visual from

Figure 160 - Visualization of the turbine at Turbine site 2

all parts of the city. At the main site, the turbine will be visible from most parts of the town, but since it is over 3 km away, the visual impact is assessed as small.

Figure (160) visualizes the turbine in the landscape, but this picture is also taken far from the city of Nanortalik, meaning that the visual impact from the city will be much smaller.

People react differently to wind turbines in the landscape, but there has been done surveys that found some key factors that most people means are good mitigation measures (Clausen, Visual impact and shadow flickering, 2012). The measures are listed in the following:

- Logical pattern
- Geometrical
- Not seen like random
- Same type and size of turbines
- Prefer slow rotation, although a larger construction

Although some of the points here are not relevant for this project due to the use of only one turbine they are listed because of their importance in general for wind farms. The last point is of biggest interest in this project, where it is stated that people prefer slow rotating but larger wind turbines. A slow rotating wind turbine will be used in this project to minimize the visual impact on the inhabitants in Nanortalik. This is also not a problem since most modern wind turbines today are in general slowly rotating.

9.1.3 Safety Issues

In general there are two situations where a wind turbine could cause damage to the public (DTI Sustainable Energy Programmes, 2001):

- Turbines shedding a part of a blade or a whole blade
- Ice being shed when starting up the turbine

In terms of safety issues the turbine is IEC standard certified. The turbine is also regularly maintained, and under surveillance to prevent dangerous malfunctioning errors. This will in almost all cases prevent parts of the blades being shed off. In terms of icing, signs will be installed, so that a defined "danger zone" for icing is known. This will give the public a warning about possible ice being shed from the turbine.

9.1.4 Decommissioning

In general a decommissioning plan is created where it is specified which components that will be removed, the costs related to the removal and possible scrap values. The purpose of this plan is to identify the methodology that will be used to mitigate potential impacts resulting from decommissioning the site at the end of the projects lifetime (American Consulting Professionals of New York, 2008).

During decommissioning, safety is an important issue. In this project all the safety requirements that holds in the construction period, also applies for the decommissioning. The turbine will be decommissioned and sold for repowering. The reinforced road will be returned to its original state if this is desired; otherwise it will be kept as it is where maintenance responsibility is left to the municipality or other clients of interest. The site itself will also be returned to its original state and the fundament will either be decommissioned or recycled in regulation to Greenlandic legislation. It is often proven that the foundation should be left as it is, because in many cases that will lead to less environmental impact, compared to the impact when digging it up (DTI Sustainable Energy Programmes, 2001). The cables and electrical infrastructure will also be decommissioned and recycled if this is desired. There will be made a plan and a time schedule on how and when this should be done, and to what extent. This plan will be made before the construction of the site is started to ensure that all parts agrees on the procedure.

9.1.5 Neighbors

The whole city of Nanortalik can be considered as a neighbor of the wind turbine at Turbine site 1, as the turbine will only be approximately 450 meters from the centre of the town. The closest building is located 300 meters from the turbine in the western direction. At Turbine site 2 the closest neighbors are over 3 km away.

In terms of visual impact for the people of Nanortalik, there will only be one wind turbine so the issue of patterns and layouts will not be evaluated. This will make it easier to determine a site and the visual impact will be smaller. The turbine will also be painted with neutral colors in order to blend in with the skyline which will also reduce the visual impact.

Figure 161- Theoretical 15 km visibility zone

In Figure (161) a theoretical visibility zone of 15 km is shown. In this context the approximated 3 km distance to the city from the wind turbine seems little. However the effects of cover from mountains etc. are not taken into account in the theoretical visibility zone.

In Denmark, the UK, Germany and the Netherlands there have been numerous studies that have revealed that people who live near wind turbines are in general more in favor of wind turbines (Clausen, Visual impact and shadow flickering, 2012). These studies rely on surveys conducted before and after construction of wind farms. It is hence difficult to assess whether the people of Nanortalik will consider the wind turbine to be visually disturbing or not at Turbine site 2. Turbine site 1 is closer, and is hence a potentially larger source of visual disturbance, as the wind turbine will stand out as a predominant construction on the peninsula, North-East of the town.

9.1.5.1 Acoustical impact

Noise from modern wind turbines is aerodynamically sourced. The modern wind turbines are carefully designed and produced to minimize the noise. The mechanical noise from the generator and gearbox is negligible in modern turbines due to sound isolation materials in the nacelle.

In 2011 the Danish legislation for noise limits on wind turbines were updated. This update includes specific rules for the low-frequency part of noise. The total wind turbine noise were however not modified in this update and is set to maximally 44 dB(A) for outdoor levels and 39 dB(A) in noise sensitive areas, such as residential areas. These limits apply at a wind speed of 8 m/s and at a height of 10 meters. At a wind speed of 6 m/s the limits are 42 and 37 dB(A) respectively (Aalborg Universitet, 2012).

In this project the new Danish legislation will be maintained. At Turbine site 1 the acoustical impact may be a problem as the nearest livable house only is located only 300 meters away. However, the maximum theoretical noise level from high quality wind turbines will be below the 44 dB(A), from this distance, according to the Danish legislation (Clausen, Environmental impact of wind energy - Birds, bats, noise and EMI, 2012).

9.1.5.2 Shadow flickering

Wind turbines will cast a shadow on the surrounding area at a sunny day. The rotation of the rotor makes a flickering shadow which can be annoying if you live close to the turbine. There is no legislation on this matter in Denmark, but there is a recommendation that the flickering should occur less than 10 hours/year (Clausen, Visual impact and shadow flickering, 2012). In this case the Danish recommendation will be used.

In order to actually experience shadow flickering multiple conditions must occur at once. First of all it needs to be a sunny day, further the sun needs to be in the right position, as well as low enough in the sky. In addition to this, the rotor has to be pointing in the right direction and the turbine has to be operating. Shadow flickering is hence not a frequent and persistent disturbance.

In Nanortalik, houses/public buildings are located only to the west of Turbine site 1, meaning that in order to get shadow flickering, the sun has to be in the east. The sun also has to be low on the sky so the time of possible shadow flickering will be in the mornings at summer and winter time. In Nanortalik there is also a mountain in the east which will reduce the distance of the shadow because the sun needs to be higher in the sky. The rotor also has to be pointed directly to the east or west. After inspecting the wind rose the wind is estimated to come from East or West 10.2 % of the time.

If all these factors are added together, the conclusion will be that shadow flickering will not be an issue for the project. If it however turns out to be an issue, the best mitigation measure is to shut down production during these hours, or compensate the affected households.

9.1.6 Aviation Traffic

Aviation traffic is crucial to investigate when planning a wind farm. It is of high importance that the site and height of the wind turbine does not conflict with the aviation traffic.

The site close to the city is of most importance in this context. The frequent traffic of helicopters to the nearby heliport may be an issue, and aviation routes have to be investigated.

The aviation routes of Nanortalik are visualized in Figure (162) beneath.

As can be seen on the figure, the aviation routes from the heliport are from the south-east and north-northeast. The site is located east of the heliport and there is expected little to no conflicts with the aviation

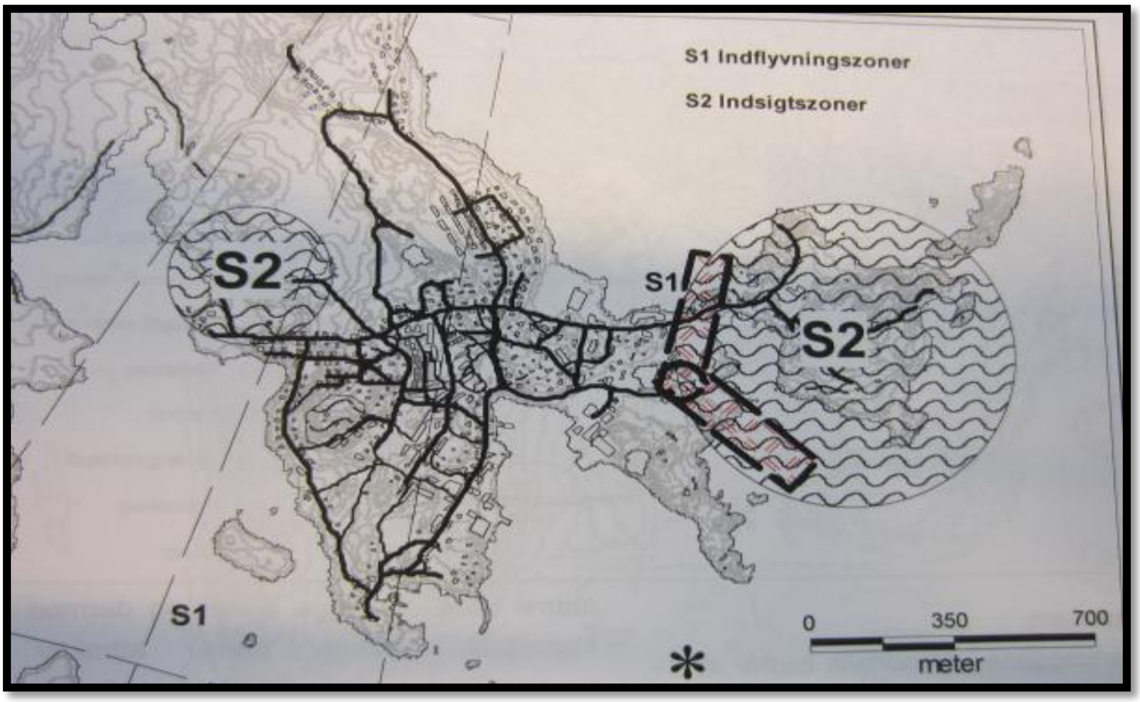

Figure 162 - Aviation routes in Nanortalik

routes. The turbine will however be equipped with signaling lamps in order to be visual from a larger distance.

9.2 Local Acceptance Assessment (LAA)

The local acceptance of a wind farm project is of high importance. In order to characterize the level of social acceptance for wind energy in Nanortalik, a local acceptance assessment has been done. First some basic theory will be explained.

With increasing levels of social concerns regarding climate change, wind energy as a renewable green energy source has a stable and strong level of social support in a global context. The latest evidence on social acceptance of wind energy is within the EU countries, where 71 % of the European citizens are in favour of this energy source (Wind Energy - The Facts Part 5). This is visualized in Figure (164) together with other energy sources. It has also been proven that the local acceptance is of crucial importance for the development of wind power projects. In addition to this it has been discovered that the majority of the citizens living nearby a wind farm across the European countries favour their local wind farm (Wind Energy - The Facts Part 5).

9.2.1 The Triangle Model

The local acceptance of wind power entails both the attitude towards wind energy projects and the increasing number of siting decisions made at a local level. Local acceptance is because the technical characteristics of wind energy interact with the everyday life of the local inhabitants. In this context a formulation of the concept "social acceptance" is created called the triangle model, which is shown in Figure (163).

Figure 163 - The triangle model (Wind Energy - The Facts Part 5)

The model differs between three key dimensions of social acceptance:

- Socio-political acceptance
- Community acceptance
- Market acceptance

Socio-political acceptance is related to acceptance of technologies and policies at a general level. This relates acceptance of key

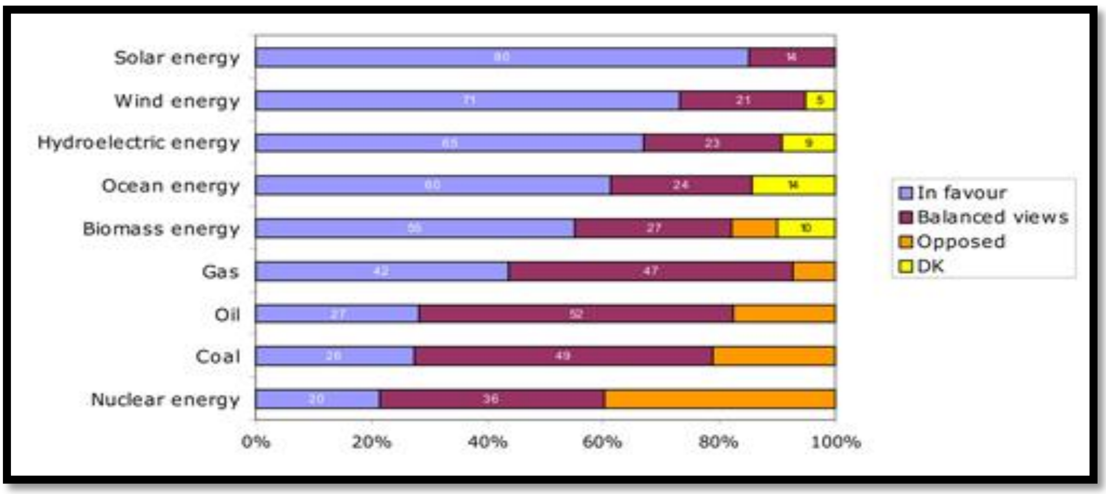

Figure 164 - General attitudes towards energy sources in the EU

stakeholders and policymakers. Stakeholders and policymakers involved in renewable policies are crucial in the planning issues.

Community acceptance relates to the acceptance of specific projects at a local level, involving potentially affected inhabitants, key local authorities and key local stakeholders. This is also the form of acceptance that will be assessed for Nanortalik in this report.

Market acceptance refers to the process of which market parties adopt and support the wind energy (Wind Energy - The Facts Part 5).

The idea of the model is to separate the social acceptance of wind energy in different dimensions. This provides a better understanding of the whole process of acceptance.

9.2.2 Acceptance by the community

In some cases the community acceptance from the community is hard to retrieve and quantify. This is often related to possible affected inhabitants. Some of the possible affected inhabitants may be against the wind farm project because it is close to their homes. This resistance is often based on prejudice and lack of information about the impact of the wind turbines. On this basis a well-known concept called NIMBY or Not In My Back Yard is created. This concept states that the people are not against wind power in general but does not want the wind turbines in their surroundings.
If the majority of the impacted inhabitants have this opinion, the project can be delayed and in worst cases rejected. A solution to this problem is to arrange information meetings regarding the wind farm project and encourage participation from the locals. This will lead to a better understanding of wind power and possibly increase the level of acceptance of wind power due to the offer of participation in the project. In order to characterize the local acceptance in Nanortalik, a survey is conducted and undergone. Based on this survey the level of acceptance in Nanortalik is identified.

9.2.3 Acceptance by the local municipality

Acceptance from the local municipality is also a key issue for the project. This is related to the Socio-political acceptance in the triangle model. In this case it is the key policymakers that are of interest, the municipality of Nanortalik. It is expected that the municipality in Nanortalik will be supportive to a project involving implementation of renewable energy in their system. This can be expected due to the development of energy prices worldwide. Since the goal of this project is to reduce the total energy cost, by implementing wind power and substituting it with fossile fuel usage, it can be looked upon as a positive contribution to the local community as a whole.

The construction, installation and operation of a wind turbine will also create engineering, construction and maintenance jobs of high value in the local community. This should be of high priority for the municipality of Nanortalik.

The local municipality’s future plans state that they have a strong request from the local community to enhance the use of sustainable energy resources, especially wind power and solar power, in the future. This is a good indication from both the municipality and the local community that they will accept a wind power plant in the area. The fact that they have this statement under local requests (Kommune Kujalleq, 2012) is a promising start when assessing a possible wind power project.

9.2.4 Survey

In order to characterize the local opinion on wind energy and a possible wind energy project in Nanortalik, a survey has been made and was undergone during the field trip to Nanortalik, Greenland. One of the goals of the survey was to get a good spread of the population to participate. All age groups and both sexes have been represented in the survey. In order to identify the locals' opinion about wind power the results from the survey was assessed.

9.2.4.1 Presentation of the survey

The survey was based on basic questions regarding wind energy in general and a possible wind power project in Nanortalik. Topics regarding visual impact and location of the wind turbine were also included. The whole survey with all questions can be seen in Appendix (G).

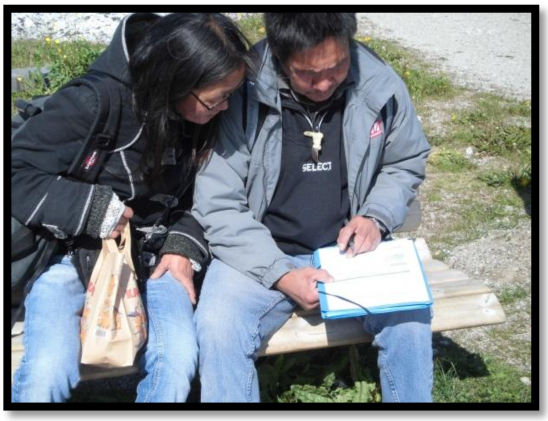

Figure 165 – Local inhabitants answering the survey

The local municipality office in Nanortalik was helpful and handed out some surveys to people in their waiting room, while the rest were carried out in the streets of Nanortalik.

9.2.4.2 Results from the survey

In total 39 of the people asked were willing to take the survey. This is approximately 2.7% of the population in Nanortalik, which is a roughly good share of the population. If then a confidence interval is chosen, a margin of error can be calculated. In this analysis a confidence interval of 95 % is chosen, and the calculated margin of error is then +/- 15.5 %. This means that there is a 95 % chance that the answers would lie within ± 15.5 % of the answers given in the current survey, if the whole population of Nanortalik participated in the survey (Aksnes media, 2011).

The first question in the survey regarded the locals' general impression of wind energy. The aim of this question was to see if there was any prejudice against wind energy. Figure (166) shows the result.

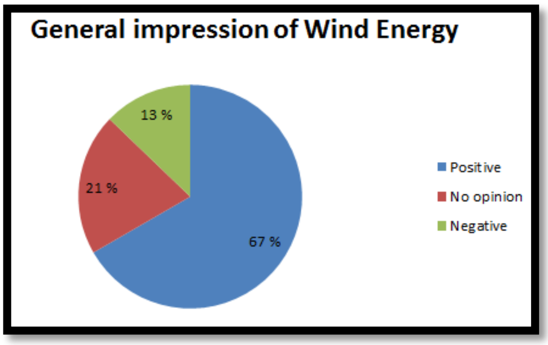

Figure 166 - Result of the general impression of Wind Energy

As the plot shows, only 13% of the people asked were negative to wind energy in general and 67% of them were positive. This is a good indication that there is little prejudice against wind energy. The next question was more specifically related to implementing a wind turbine in Nanortalik, and the general opinion of that, regardless of the location. Figure (167) shows the results.

This is a very promising result for the potential wind power project in Nanortalik.

79% of the people were positive to such a project and not a single person was negative. This indicates that the population is positive to the project in general.

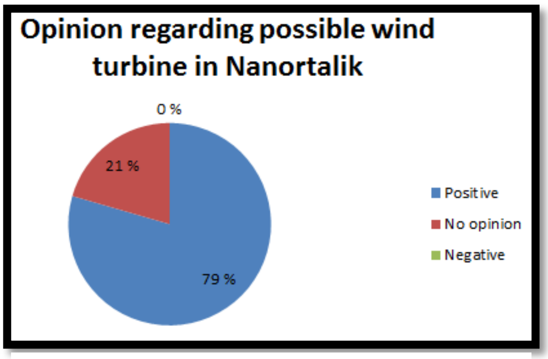

Figure 167 - Opinion regarding possible wind turbine in Nanortalik

The last subject presented here, is the locals' interest in renewable energy. The city of Nanortalik obtains all of its electricity from diesel generators, so a renewable energy source should be of interest. Figure (168) shows the result on this topic from the survey. As can be seen from Figure (168) almost 70% of the people participating in the survey are interested in renewable energy.

If the results are summed up, the general population in Nanortalik is very positive to wind energy and a possible wind energy project in Nanortalik. Since the response from the local municipality also was very positive, the local acceptance level is evaluated to be very good. This will not be considered as a problem for the project in this analysis.

9.3 Zero alternative

Wind energy is a renewable energy source with a large potential. The local municipality in Nanortalik and the local inhabitants have a goal of implementing more renewable energy sources in the system (Municipality of Nanortalik, 2008). Developing this project is thus a good measure towards reaching the goal, not just for Nanortalik, but for Greenland in general. Turbine site 2, which is located furthest away from the city, induces little or no visual pollution in terms of erecting it at a distance of over 3 km from the city. This project can also possibly stabilize the electricity price in the future; due to a lower consumption of oil and therefore the electricity price will not be that sensitive to the oil price. If the project is discouraged the electricity price will follow the oil price in the future. Also the future goals of the municipality and the wishes of the local inhabitants will not be reached.

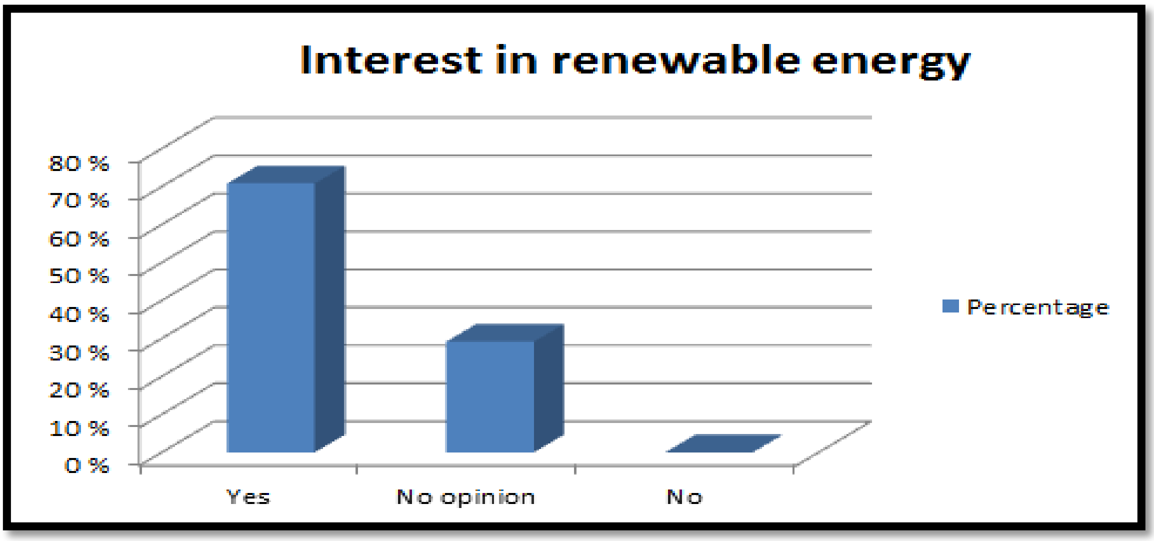

Figure 168 - Results of the opinion of a possible wind turbine in Nanortalik

10 ECONOMIC ANALYSIS

This section covers a socio-economic analysis of the implementation of wind turbines in Nanortalik. As described in Chapter (2); the current electricity production is based on fuel-driven generators where the waste heat is utilized in a district heating system.

In general for the whole of Greenland, the consumers cost of electricity, water and heat were totalized in a "one-cost system" until 2004. After a renovation of the pricing system, the energy costs were divided. This differentiation of the prices has resulted in variable prices from town to town, dependent on the local power supplier. Figure (169) shows the development of the energy prices for households either in liters for fuel, or kWh for heating and electricity. The prices for petrol (indicated by the light blue graph) and gas/diesel oil (grey) show an increasing trend after 2004. The cost of electricity (dark blue) and heat (black) has been stable since 1985 (Grønlands Statistik, 2011). In 2010 the mean electricity price in Greenland was 2.10 DKK / kWh, whereas gas/diesel-oil and petrol was priced at 4.27 DKK / liter.

The trend of the energy costs in Greenland reaffirms the arguments that additional renewable energy production can be beneficial, also for small scale systems such as in Nanortalik. Such an investment contributes to the reduction of fossil fuel consumption, thus lowering emissions and pollution. Greenland's authorities aim to meet the requirements in the Kyoto agreement, where the goal is to reduce the emission of CO_2 by 8 %. At the same time they are in need of industrial development which generally counteracts green energy goals. It is thus of high importance that research for economically feasible renewable energy projects are undergone, in order to secure

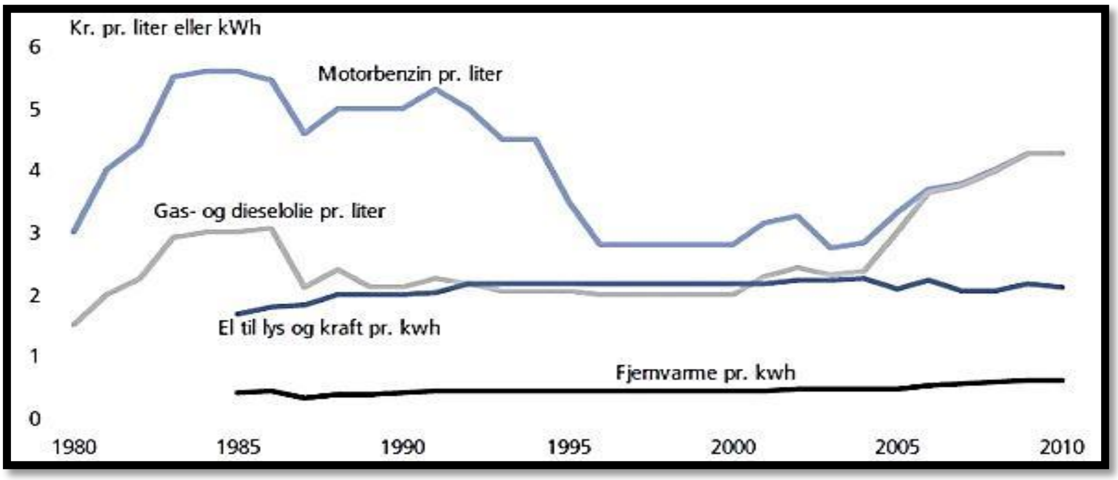

Figure 169 - Greenlandic energy prices for households (Grønlands Selvstyre, 2011)

and support the development of the Greenlandic people or other arctic environments, in the best way possible.

In this socio-economic analysis the modeled energy system is at first utilized to do calculations on fuel-savings, and thus cost-savings, as well as pollution. Further a discussion regarding job opportunities for the locals in Nanortalik follows, and an investment budget for installing a wind farm in Nanortalik is presented, as well as an operation and maintenance cost budget. To determine the wind farms feasibility, all obtained figures are processed in a datasheet that calculates the key economic parameters for the wind farm implementation and operation.

10.1 Benefits for the Nanortalik Society

Introducing wind energy in Nanortalik will result in many benefits for the local community, and possibly it can set an example so that other communities will follow with renewable development. This section presents some benefits for Nanortalik in connection with setting up a wind turbine on the north-eastern peninsula of the town.

10.1.1 Reduced oil consumption

By including renewable energy in Nanortalik's energy system, the diesel generators can be offloaded part of the time. This results in savings in the form of fuel and pollution. Together with the increasing costs of gas and diesel-oil this can be increasingly beneficial for Nanortalik as a society, and for the consumers in terms of economy. A motivation for the Nanortalik community is that they will set an example in terms of renewable development in Greenland. If a project like this is feasible and successful in their community, it can be developed in other communities as well.

The amount of reduced oil consumption where presented in Chapter (8) regarding the Energy System Model.

10.1.2 Less pollution

Greenland's CO_2 emission from energy consumption is presented in Figure (170). An increase of 14.7 % is observed from year 2009. This resulted in a total emission magnitude of 675920 tons of CO_2 in 2010.

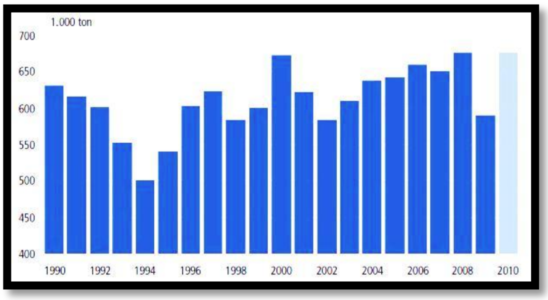

Figure 170 - CO2 emission from energy consumption in Greenland ((Grønlands Statistik, 2011))

The drastically increase is due to an increase in gasoil consumption, in conjunction with geological studies and oil exploration. According to Grønlands Statistik, this industry was responsible for 16 % of Greenland's total energy consumption in 2010 (Grønlands Statistik, 2011).

The amount of reduced CO_2-emissions where presented in Chapter (8).

10.1.3 Dependence on foreign governments and prices

On the road to full political independency the Greenland communities struggle economically and rely on substantial subsidies from Denmark. The country receives approximately 3 billion DKK each year, minus their revenues in the trading market (The International Political Review, 2011).

Installing wind turbines in Nanortalik can act as a small step towards independence, mainly due to two reasons; firstly wind turbines should be looked upon as an investment that returns revenue in the long run, and secondly it can replace some of the power generation based on fossil fuels. Both an increase in industrial revenue and reduction in fuel demand will help a community like Nanortalik in the right direction.

10.1.4 Increased work possibilities

Although an installation of a single wind turbine will not induce substantial work opportunities, there will be labor requirements both in the building-, operation- and decommissioning process.
There will be tasks such as road and trench preparation, remediation, restoration of soil conditions after turbine removal etc. which can be done by local workers. Wind turbine maintenance courses can also be introduced to involve workers interested in maintenance work regarding the wind turbine. It would also be possible to establish a local guild which involves future development of wind energy and other renewable sources in Greenland. Some of these measures will require further knowledge and competence regarding wind energy, and thus can opportunities like these encourage locals to take a degree in sustainable technology.

10.2 The Investment Budget

The utilized investment costs are based on figures from European projects, since it is complicated to obtain cost estimations for similar projects in the Arctic region. It is expected that some of the budget posts have a higher price than the average European cost, since such a project would require expensive transportation and has a limited access to needed equipment. Thus, some posts are adjusted to a higher price due to the reduced accessibility in Greenland.

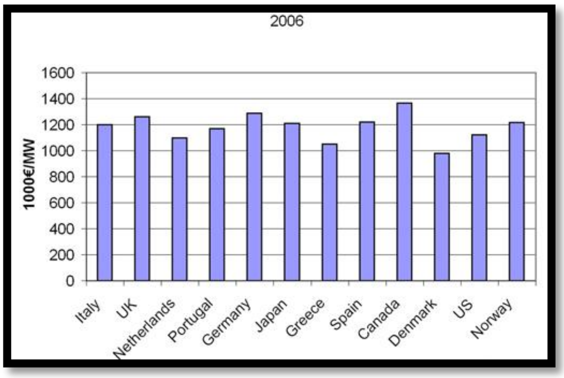

Figure 171 - Total investment cost in 1000 €/MW (Wind Energy - The facts)

Figure (171) shows an example of the variety of total investment costs in different countries. The projects costs are given in €/MW and all data is collected from onshore wind projects. According to the web page "Wind Energy - The facts" the average total investment cost for an onshore project in Europe was €1.23 million/MW in 2006 (Wind Energy - The facts).

10.2.1 Wind Turbine

According to the wind farm economic report "Vindmøllers Økonomi", published by EMD.dk, the estimated cost for the turbine itself was 8.3 million DKK per MW in 2010 (EMD.dk, 2010). This estimate includes the erecting and installation of the wind turbine. WinWind has estimated a package price of 1.2 million euro, which is equal to 8.952 million DKK, for a 1 MW wind turbine. This package price is according to WinWind based on an average turbine installation, with the transport, commissioning and installation costs included. The manufacturer has also stated that the price would be somewhat higher for a “hard to reach”-site (Gilmore, Cost estimation for wind turbine, 2012). It is assumed that Greenland is a hard to reach site since WinWind has no experience with installing wind turbines in this country, and hence the package price is given an additional fee of 200 000 € related to transport costs. This is further undergone in Chapter (10.2.2).

A class "S" turbine is needed at Turbine site 2, which induces some further costs for the turbine, which can be 20-30 % more expensive. It is assumed that the turbine is 20 % more costly, and hence that it costs 10.742 million DKK for the turbine at both turbine sites.

*Based on the figures obtained by WinWind the wind turbine costs are estimated to be **10.742 million DKK** for both sites.*

10.2.2 Transportation

The transportation costs include both the transport of the wind turbine, as well as transportation of the equipment that is required to move and install the turbine. There is also transportation costs related to the material needed for the foundation. On the basis of the estimates given by WinWind, a transportation cost of 200 000 € is assumed. This price also applies to the decommissioning of the wind turbine, as it is assumed that the wind turbine is shipped out of Greenland when it surpasses its lifetime.

*Based on the figures obtained by WinWind the transportation of the wind turbine costs **1.492 million DKK**. This includes transportation of additional equipment needed to erect the wind turbine.*

10.2.3 Foundation

The foundation costs are highly related to the soil conditions as well as the hub height and total weight of the wind turbine. EMD estimates that the typical price for foundation is in the range of 0.4 to 0.66 million DKK/MW. By utilizing “V & S”-prisdata an estimated cost of 302 800 DKK is assumed for the foundation. The cost is lower than the estimate given in the EMD.dk report. This might be due to the multipile foundation that is chosen for Nanortalik, which considerably reduces the amount of concrete needed, compared to gravity foundations.

*The foundation costs have been found to be **0.302 million DKK** per MW.*

10.2.4 Road costs

The cost of roads can be a substantial part of the investment budget, depending on the geography and location of the wind farm. Since this is a single wind turbine project, the road costs have a large impact on the project’s economy. The following table shows the total road construction costs for both site alternatives:

	Total road construction cost
Turbine site 1	**3 826 800 DKK**
Turbine site 2	**18 159 400 DKK**

Table 65 - Road costs for both alternatives

An additional cost of **338 200 DKK** is also added for each site, in order to prepare the ground for the crane that erects the turbine. See Chapter (7) for more details regarding the road costs.

10.2.5 Erecting process

As this feasibility study focuses on a single turbine wind farm, it is assumed that the erecting process is taken care of by Win-Wind and hence included in the wind turbine investment cost. It is known that the erecting process can vary a lot depending on the weather conditions, as well as topographical conditions, thus a specific figure for the erecting process in Nanortalik is difficult to obtain.

10.2.6 Electrical equipment

There are multiple components that are needed when connecting a wind turbine to the public grid. This includes transformers, high and low voltage cables, switch gear etc. In this analysis, the estimated electrical equipment costs vary from Turbine site 1 to Turbine site 2 due to the difference in cable length. The following table presents the total cable costs, including labour and cable trenches for Turbine site 1.

Cost of cables for site alternative 1			
Component	**Unit price [DKK/m]**	**Length [m]**	**Total price [DKK]**
HV/LV Cables	40	270	10 800
Cable trenches with labour	900	270	243 000
Total			**253 800**

Table 66 - Cable costs for Turbine site 1

For Turbine site 2, the following cable costs are estimated:

Cost of cables for site alternative 2			
Component	**Unit price [DKK/m]**	**Length [m]**	**Total price [DKK]**
HV/LV Cables	40	3 200	128 000
Cable trenches with labour	900	3 200	2 880 000
Total			**3 008 000**

Table 67 - Cable costs for Turbine site 2

In addition to the cable costs, there is joint equipment needed for both alternatives. The cost of these components are shown in Table (68):

Cost of electrical equipment			
Component	**Unit price [DKK/Unit]**	**Quantity [Units]**	**Total price [DKK]**
Transformer	100 000	1	100 000
Switch-gear	285 000	1	285 000
Electrical boiler	125 000	1	125 000
Boiler trans-former	50 000	1	50 000
Total			**560 000**

Table 68 - Cost of additional electrical equipment

The electrical equipment costs are summarized in Table (69). It can be seen that the cable expenses have a high share of the total cost of additional electrical components; hence is the electrical equipment for Turbine site 2 far more expensive.

Total cost – electrical equipment	
Site alternative	**Total grid cost [DKK]**
1	**813 800**
2	**3 568 000**

Table 69 - Total cost of electrical equipment

10.2.7 Design and management

There is a variety of costs related to the design and management of a wind farm. These costs can include construction management, pre-reports and analyses, consultancy, accounting and general project development. According to EMD.dk the base cost for this is approximately 500 000 DKK per MW. Due to the small scale of the project, it is assumed that the costs regarding designed and management are reduced by 67 %.

The design and management is estimated to have a total cost of 165 000 DKK in Nanortalik, due to the projects small scale.

10.2.8 Environmental Impact Assessment (EIA)

The cost of the environmental impact assessment is well connected to the size of the prospected wind farm area and regional knowledge regarding environmental issues. This is therefore a highly uncertain budget cost, as there is little literature available on the environmental issues in and around Nanortalik. This post includes all work done to assess the prospected area, as well as equipment needed for test sampling etc. EMD.dk estimates that the EIA has an estimated cost of 74 000 €/MW. This seems a little high, especially for a single wind turbine project, thus:

The Environmental Impact Assessment in Nanortalik is estimated to have a total cost of 100 000 DKK.

10.2.9 Various

Various costs are estimated to be 52 200 € / MW. This budget post is 100 % site specific and can be seen as the economical buffer, which handles unexpected costs associated with broken equipment, delay in deliveries etc.

An accurate estimate is hard to obtain, but with the isolated towns reduced accessibility of equipment, as well as long sea-routes in case of emergency service, the total various cost is estimated to 123 000 DKK.

10.2.10 Total Wind Farm Investment

The total investment cost for the wind turbine setup on site alternative 1 and 2 in Nanortalik is **17.56** and **34.65 million DKK,** respectively. It can be seen that the road construction costs is equal to a large share of the difference in investment costs.

10.3 Operation and Maintenance Costs

Over the lifetime of the wind turbine, there are running operation and maintenance costs that must be budgeted. The report "Vindmøllers Økonomi" has recorded data regarding the O&M costs for Danish wind turbines for several years. Their database utilized in the report consists of 1 213 operational wind turbine years, where 48 % of these wind turbines are run by energy companies, and the remaining 52 % are privately operated wind turbines. It must be stated that the operation and maintenance estimates are based on Danish wind climate and weather conditions, which can be very different from the climate experienced in Southern-Greenland. It will however give an indication of what price level the operation and maintenance costs lies on.

Figure (172) presents EMD.dk's collected data where the x-axis shows the operating year of the wind turbine, while the y-axis shows Danish cents per produced kWh. The straight line starting in the sixth year represents the average O&M cost that gives the best representation/estimate over the wind turbine lifetime. This is due to the fact that the contractual guarantees usually expire after 5 to 6 years. From Figure (172) it can be seen that the average O&M costs were approximately 10 Danish cents per kWh.

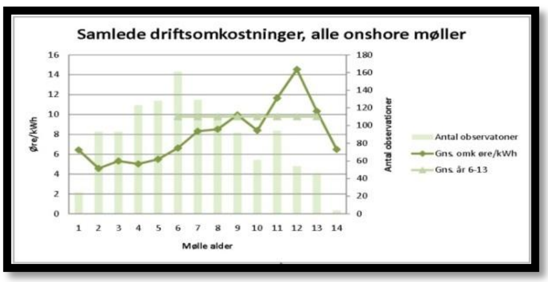

Figure 172 - Operation and Maintenance costs per kWh (EMD.dk, 2010)

EMD.dk has also published a graph which shows the O&M cost in relation to installed capacity. Figure (173) shows the O&M costs for all private owned wind turbines. The x-axis is the operating year of the wind turbine, while the y-axis represents DKK / kW. The O&M costs are divided into 6 parts which can be translated (from bottom): reparation, service, insurance, administration, land compensation and various.

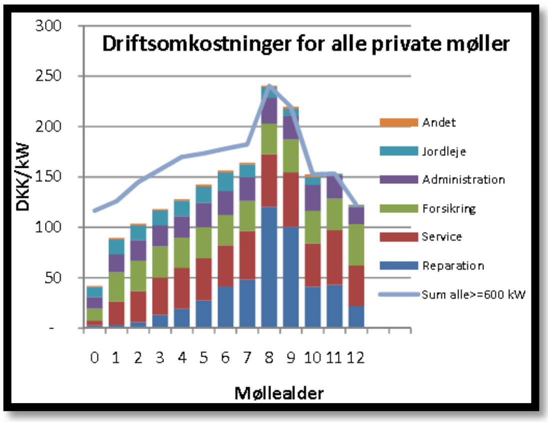

Figure 173 - Operation and maintenance costs per installed capacity (EMD.dk, 2010)

It is stated in the report that 150 DKK/kW is a good estimate for the wind turbine over the whole lifetime. This yields an O&M cost of 150 000 DKK per year for a 1 MW wind turbine in Nanortalik. Due to Greenlands low accessibility to service and reparation this is adjusted to 179 000 DKK per year, which is a realistic estimate, according to (Wind Measurement International, 2012).

The O&M cost utilized in the analysis is thus 179 000 DKK / year.

The operation and maintenance post consist of five main parts, which will be further undergone. Figure (174) shows how the total O&M cost is distributed from the 5th year of operation to the 7th. From the figure it can be seen that expenditures related to service are highest, followed by reparation and insurance, administration, land compensation and then the various post.

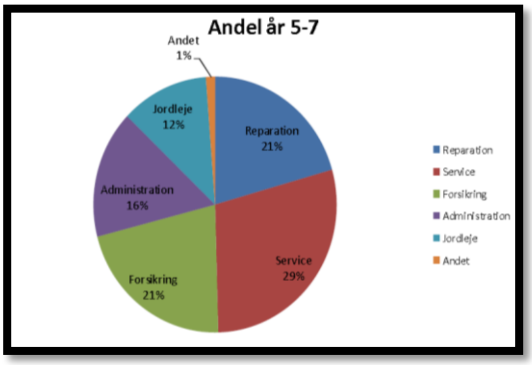

Figure 174 - The six components of the O&M costs (EMD.dk, 2010)

10.3.1 Reparation costs

This component can represent both reparation and replacement of equipment. For this project, there is a risk that this component will be higher, due to high turbulence intensity at the prospected wind farm site. This can induce stress and fatigue damage on the turbine, which can lead to more frequent and severe reparations.

10.3.2 Service

The service component takes account of the service agreements, scheduled maintenance, monitoring. Because of the sites long distance to service-partners, as well as the accessibility and complications when lodging required service equipment, there is a risk that this component will have a higher magnitude.

10.3.3 Land Compensation

Land compensation is naturally a site specific expenditure that can vary a lot. Since this is a project where only a single wind turbine is planned, it is assumed that this component of the O&M cost will have a lower magnitude.

10.3.4 Administration and Insurance

Administration covers the cost of economical work, such as creating budgets and doing cost calculations, as well as salary, office requisites etc. Insurance covers the insurance for the wind turbine. The administration component is of more importance for larger projects as there are more resources in circulation.

10.3.5 Various

This post is 100 % site specific, and can vary to a large degree from project to project. Like the corresponding post in the presentation of the investment budget, it represents an economical buffer, which handles unexpected or site specific requirements, for example: costs related to consultancy for road construction etc.

10.3.6 Subsidies

It is expected that no subsidies and feed-in tariffs is added to the income of the wind turbine, since there are no such arrangements in Greenland (Municipality & Kujalleq, 2012).

10.4 Key Financial Figures

This section presents the calculated results for the key financial figures for the wind implementation in Nanortalik. Each parameter is given a small introduction.

The financial calculations are based on the fuel cost savings of implementing a wind turbine to the Nanortalik power system. The energy model's financial results are extracted and further utilized in calculations where a discount rate is included. The described investment costs are summed up, and a 20 year life lifetime calculation is undergone. The following sections present the key financial figures that are obtained when implementing a wind turbine in Nanortalik.

10.4.1 Discount Rate

The discount rate reflects the return that the capital owners expect to achieve from the capital that they have contributed to the project. This rate consists of the three components; inflation, risk and time-preference. Time-preference is a component that varies between 2-4 %. This component is influenced by stock market, where higher prices of stocks can lead to a higher interest rate. The risk component can range from 1-4 %, and is related to the risk/uncertainties of the project. Inflation represents the rise of prices for goods and services over a time period.

According to (Wind Energy - The Facts Part 3) the discount rate usually ranges from 5 to 10 % per annum. Due to the uncertainties regarding this project a discount rate in the higher end of this range is chosen, 8 %.

The discount rate is a parameter that is difficult to determine, especially for a wind power project in Arctic regions. It is hence performed sensitivity analysis of the discount rate in Chapter (10.5), along with other critical parameters.

For this analysis the discount rate is set to 8 %.

10.5 Net Present Value (NPV)

The Net Present Value (NPV) is defined as the sum of all relevant present values, and is widely used as a measure of economic value when comparing different investments, or doing feasibility studies for given projects. It is calculated by subtracting the discounted value of cash expenditures from the discounted value of cash inflow (Manwell, McGowan, & Rogers, 2002).

The NPV of a cost C to be paid each year for N years can be written as:

$$NPV = \sum_{t=1}^{N} \frac{C_t}{(1+r)^t} \qquad \textbf{(31)}$$

Where:

- Ct = yearly cash flow
- r = the discount rate
- t = the year

A positive NPV result indicates that the project is profitable / feasible.

By implementation of a wind turbine in Nanortalik, the following net present value results are obtained:

NPV results (mDKK)	
Turbine site 1	0.1127
Turbine site 2	-12.35

Table 70 - NPV results

The calculations show that implementation of wind energy in Nanortalik is feasible for Turbine site 1, but only marginally. The financial losses are greater for Turbine site 2, due to large expenses related to road construction. This leads to an unfeasible project for the alternative site, with a total loss of 12.35 million DKK over the lifetime of the turbine.

10.5.1 Internal Rate of Return (IRR)

The internal rate of return (IRR) is another measure of the profitability of a project. It is defined as the discount rate that gives an NPV of 0 over the lifetime of the project. Hence, an IRR larger than the discount rate, r, results in a profitable project.

Internal Rate of Return	
Turbine site 1	8.115 %
Turbine site 2	1.245 %

Table 71 - Internal Rate of Return results

As seen in Table (71), the IRR for Turbine site 1 is marginally higher than the discount rate, indicating profitability in the project. For Turbine site 2 the IRR is far below the discount rate, and hence is the project unfeasible.

10.6 Sensitivity Analysis

It is important to determine which parameters that is critical to the economy of the project. This can be done by applying sensitivity analysis on different parameters and review the key financial figures results. This section determines the most critical parameters, as well as applying sensitivity analysis on them. The following critical parameters are investigated for ± 10 % sensitivity:

- AEP
- Diesel price
- Investment cost

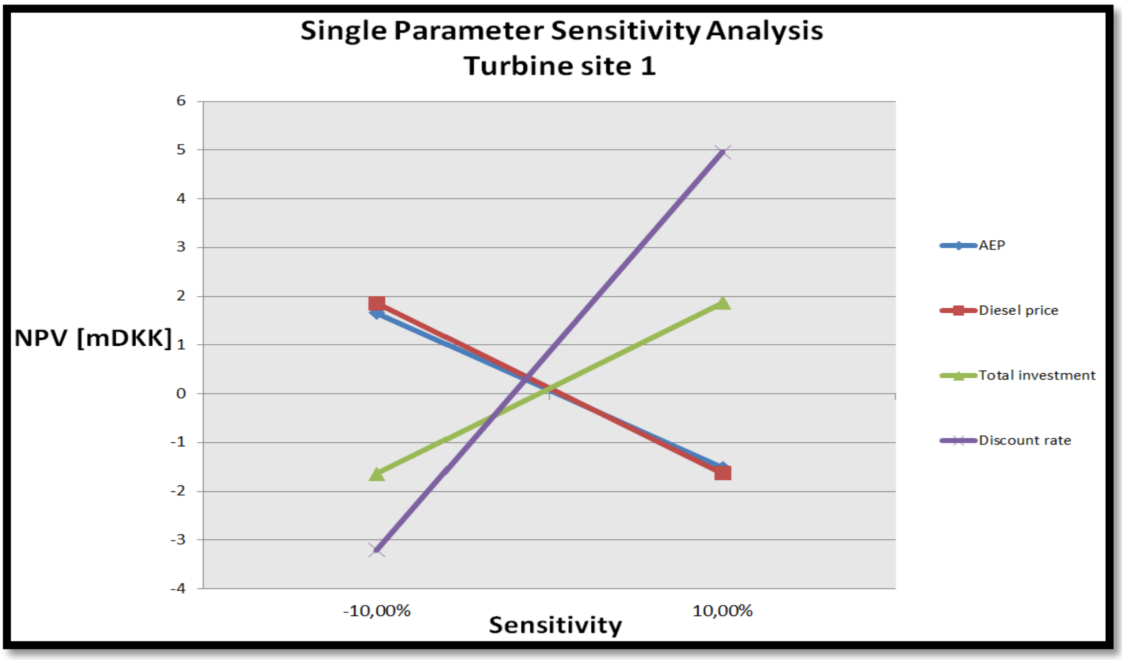

Figure 175 - Single parameter sensitivity analysis on Turbine site 1

It is also of interest to see the effect of changing the discount rate. In this sensitivity analysis it is given ± 2 % so that the tested discount rates are 6 % and 10 %.

10.6.1.1 Turbine site 1

From Figure (175) it can be seen that four of the tested scenarios induces a feasible project. This is when the discount rate is 6 %, when the diesel price is 10 % higher, total wind turbine production 10 % higher and the total investment costs are reduced by 10 %. From the star diagram it can also be observed that the diesel price and AEP almost have the exact same sensitivity to the projects feasibility. By applying ± 10% sensitivity on both parameters, the end results are nearly equal. Further it can be seen that the total investment cost is the second most critical parameter. This is within expectations, since single wind turbine projects usually are very dependent on the total investment costs.

10.6.1.2 Turbine site 2

Neither of the scenarios applied to Turbine site 2 returns an economic feasible project. This is due to the large investment costs related to the road construction. As a single turbine project, the road cost itself has a far too large share compared to the power output of the turbine. By adding more wind and hence increasing the AEP the results could have looked different. This additional power input would of course be limited by the power systems capability, and is hence not a realistic scenario. From Figure (176) it is seen that the best result is obtained with a discount rate of 6 %, which is expected. The discount rate has a severe impact on the projects feasibility, meaning that a small variation in the rate results in a large impact for the revenue. It can also be seen that the investment cost is far more critical for Turbine site 2, as expected. The parameters can be ranked by the variation from -10 % sensitivity to +10 % sensitivity. By this it is seen that the discount rate is the most critical parameter, followed by the investment

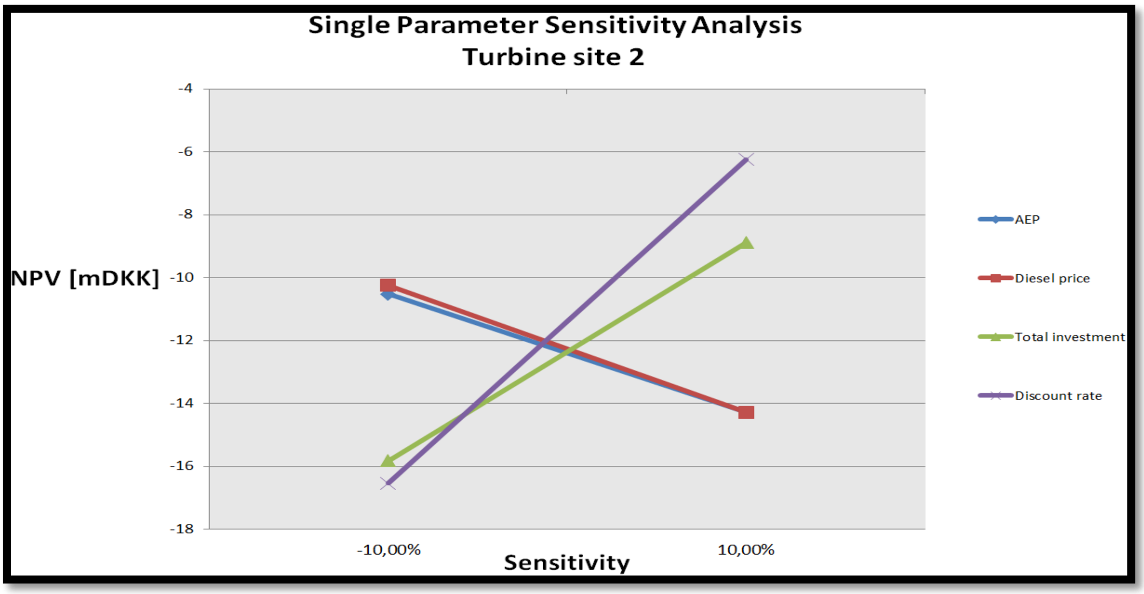

Figure 176 - Single parameter sensitivity analysis on Turbine site 2

costs, and then the diesel price and AEP. The latter two parameters are found to be fairly equal in terms of their impact on the projects economy.

From the sensitivity analysis it can be concluded that a single turbine project of this magnitude at Turbine site 2 should be disregarded, whereas Turbine site 1 can prove profitable.

10.7 Economical Overview

By reviewing the sensitivity analysis it is clear that implementation of a single 1 MW wind turbine in Nanortalik is a risky investment. The calculated results should still be looked upon with a fair amount of uncertainty, due to simplifications in the energy system model and uncertain figures for the investment costs. The results still give an indication of the problems regarding single wind turbine installation in a hard to reach site, such as Turbine site 2. The road expenses are simply too high for a single turbine project to become feasible at such a location. Turbine site 1 returned slightly positive figures, mostly related to the reduced investment cost in comparison to Turbine site 2. However, with the uncertainties regarding the project in mind, and the rather low estimated economic outcome of the project, great care should be taken when assessing these positive results. It should still be noted that wind turbine implementation generate other benefits which are difficult to put a price on, as discussed in Chapter (10.1). In order to decide whether wind turbines can be implemented in a feasible way in Nanortalik, further and more thorough economical analysis should be undergone. The figures utilized in this analysis consist of a mixture of both real obtained prices and approximated estimates. This induces an uncertainty regarding the economical results. From the resources the author's have acquired, it can be concluded that implementation of a 1 MW can be feasible for Turbine site 1, whereas high investment costs for Turbine site 2 results in an unprofitable investment.

11 RELEVANT LEGISLATION AND PROCEDURE FOR PERMITTING

Greenland has no relevant legislation for wind energy at all, so this project will follow the Danish legislation system. Since Denmark has a well-established legislation system for wind energy, and close relation to Greenlandic development, this is assumed to be the best solution. In this analysis, only the most important legislation issues are discussed.

The health and safety legislation requires the use of components that are certified for fire and electrical safety regulations (EnergyBible, 2010). The overall intention by this regulation is that the equipment does not lead to an increased damage in case of fire, and that the employer has to take reasonable care to avoid risks through the construction and operation phase.

In order to satisfy this legislation, a team could be created with responsibility of making a plan for maintaining personnel safety in all aspects – and make sure that the plan is followed. A Health and Safety policy, which includes all parts and members of the project, could also be established (Renewable UK, 2010).

Electrical legislation is due to regulations regarding the wind turbine’s connection to the grid. The Grid Codes states requirements for the wind farm output power in terms of frequency, reactive power, voltage flickering etc. The main purpose of the legislation is to protect the grid system. The grid specifications relevant for Nanortalik are discussed in Chapter (6.1).

Noise restrictions are present in several countries. In Denmark the legislation states that the noise level of the turbines should not exceed 44dB(A) for outdoor levels and 39dB(A) in noise sensitive areas. This has been discussed in Chapter (9.1.5.1). This will however not be an important issue in this project as both sites have a sufficient distance to the nearest residential house, although one of them with a larger margin than the other.

Some countries also have legislations in terms of shadow flickering. This occurs when the sun is low in the sky, and could affect nearby inhabitants – due to the rotational movement of the turbines, which could cause shadow flickering which the human eye reacts negatively to. The shadow flickering is dependent on many factors at the same time, and therefore it is not legislated in all countries. In Denmark the shadow flickering is not explicitly regulated by the planning authorities, whereas in Germany there has been a court resolution that tolerated 30 hours of actual shadow flickering through a year. In Denmark there is a recommendation that the actual flickering should be less than 10 hours per year. This problem can be resolved by careful planning and good use of the right software e.g. WindSim (Clausen, Visual impact and shadow flickering, 2012). The shadow flickering is not considered to be a large concern due to the location of the sites and the surrounding factors, as discussed earlier.

In addition to the mentioned licenses above, an environmental impact assessment (EIA) has to be carried out. This has to some extent been reviewed in Chapter (9).

Also erecting of all new constructions needs to be approved by the Greenlandic building legislation (Jakobsen K. R., 11427 Arctic Technology , 2012).

11.1 Procedure for Permitting

Since Greenland does not have any legislation regarding wind turbines, the Danish legislation is followed. In Denmark the political framework conditions for erecting wind turbines onshore have been agreed in the Energy Policy Agreement of 21st February 2008 and entered into force on 1st of January 2009. Here it is stated that the municipalities are responsible for securing the necessary planning basis for wind turbines, in order to receive a license for development (Danish energy agency, 2009). This must include basic information regarding the size and number of turbines, the main scope of the investigations, and limitations to the actual location.

The application of the project further goes through a citizen hearing with a following assessment of comments and consultation responses, if received. This is followed by a drafting of supplementation to the municipality plans and local plans, which includes adjustments of the project based on the general environmental assessment.

Then the public phase starts, where the announcement of the proposed plans takes place. If required another citizen meeting is held, with following processing of objections and comments received in the meeting. Then a final adoption of the plans and issuing of EIA approval are done. After this there is a complaint period (Danish energy agency, 2009).

This is the general guidelines in Denmark where the Danish Energy Agency has to assess the EIA, all other factors are assessed by the local municipality. In this project the Greenlandic government has to assess the EIA and the local municipality has to assess the other steps. The final license for development will be given by the government.

12 FIELD WORK

This section will give an overview of what was experienced and undergone during the field trip to the Kujalleq region in South Greenland. The trip started on the 31.07.2012 and ended 16.08.2012. During the stay seven different towns/locations were visited. The following table shows the time plan during our stay in Greenland.

The flight from Kastrup Copenhagen to the airport in Narsarsuaq lasted approximately 4.5 hours. After a short visit to Narsaq we proceeded to Qaqortoq, where we stayed for 7 days. On the 06.08.2012 we travelled to our other main destination, Nanortalik, where we stayed for the rest of the period. The following chapters will describe further what was experienced and undergone in the main locations we visited.

Date	Location	Activity	Accomodation
31-07-2012	CPH-Narsasuaq-Narsaq-Qaqortoq	Travel from CPH to Narsasuaq, boat transfer to Qaqortoq with stop in Narsaq. Narsaq: visit local power plant. Arrive to Qaqortoq in the evening	Dormitory
01-08-2012	Qaqortoq	Meeting with the head of the technical department, visiting the power plant and the control office of Nukissiorfiit	
02-08-2012	Qaqortoq	Hiking trip to the grid connection ca. 30km 1 day trip	
03-08-2012	Qaqortoq	Visiting the location of the new airport	
04-08-2012	Qaqortoq	Hiking to the western part of the island	
05-08-2012	Qaqortoq	Visiting other possible location for WT, packing, preparation to departure	
06-08-2012	Qaqortoq - Saarloq - Alluitsup -Nanortalik	Boat transfer to Nanortalik with stops in two settlements to visit their power plant	Tourist hut
07-08-2012	Nanortalik	get to know the town, preparation to field work at TREF	
08-08-2012	TREF	Hiking to TREF station, 900 m above sea level, put down the mast	TREF
09-08-2012	TREF	Install the mast, put up new equipment	
10-08-2012	TREF	Hiking back to Nanortalik	Tourist hut
11-08-2012	Nanortalik	Lowering the mast	
12-08-2012	Nanortalik	Install new equipment	
13-08-2012	Nanortalik	Erect the mast	
14-08-2012	Nanortalik	Hiking in Nanortalik	
15-08-2012	Nanortalik	Hiking in Nanortalik	
16-08-2012	Nanortalik-Narsarsuaq-CPH	Travel from Nanortalik to CPH with a stop in Narsarquaq	

Table 72 - Time schedule in South Greenland

12.1 Narsaq

We arrived in Narsaq by boat after landing in Narsarsuaq. During our stay in Narsaq we visited the local power plant, and we also had a look at the met mast that was installed there.

Figure 177 - The group in front of an iceberg in Narsaq

During our guided tour of the local power plant, driven by Nukissiorfiit, we looked at the generators, switch-room and the control room. The following picture shows the diesel generators placed in the generator room.

Figure 178 - The generators in Narsaq

We were quite surprised how clean and professional the generator room looked, and we also got an insight on their control system in Narsaq. Figure (180) shows the monitoring/system control application that was utilized.

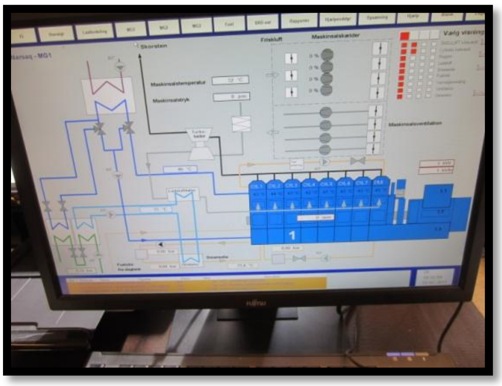

Figure 180 - Monitoring/Control system in Nukissiorfiit Narsaq

After being guided through the local power station we inspected a met mast that was placed in the outmost part of the town. There the other group who utilized data from this mast took GPS coordinates to make sure their maps and inputs were correct. After this a boat picked us up and brought us to Qaqortoq, our first main destination.

Figure 179 - Met mast in Narsaq with cup anemometer and wind vane

12.2 Qaqortoq

In Qaqortoq we did a variety of activities, both related to the projects and some just for experiencing Greenland. During our first day we looked at the met mast both at the local Heliport and at a mountain just west of the city center. This mast was not of interest for this project, but the other project inspected the met mast sites with respect to roughness and obstacles. The next day we took a trip to one of the Qaqortoq-group's potential wind farm site, nearby the local waste handling industry.

During day 4 of the trip we held a presentation for the municipality in Qaqortoq where we outlined our projects and discussed some issues with the local politicians and development department. They also presented their future city plans for the Kujalleq region.

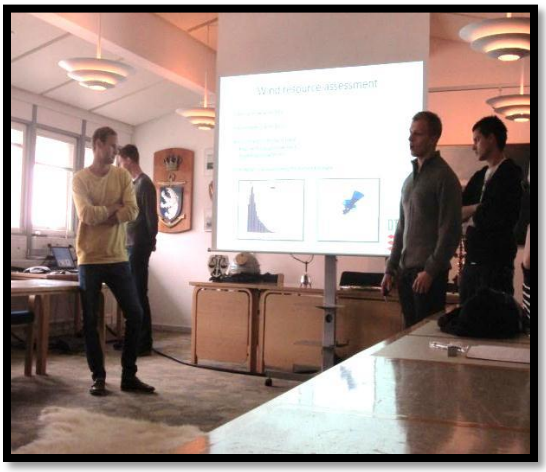

Figure 181 - Presenting our project for the municipality in Qaqortoq

After meeting the municipality we went down to Nukissiorfiit where they showed us how the energy system was operated, as well as showing us the generators, transformers and switch-gear. We also utilized this time to get some information regarding the grid systems and cost estimations related to electrical equipment in South-Greenland.

Figure 183 - HV transformer outside of the switch-gear facility, Nukissiorfiit Qaqortoq.

After the visit to Nukissiorfiit we went to the Royal Arctic office, where we tried to get our hands on some information regarding vessel and quay capacity.

The next two days went on a 30 km hiking trip towards a coupling station which we did not reach, as well as working with our report and the information that was gathered.

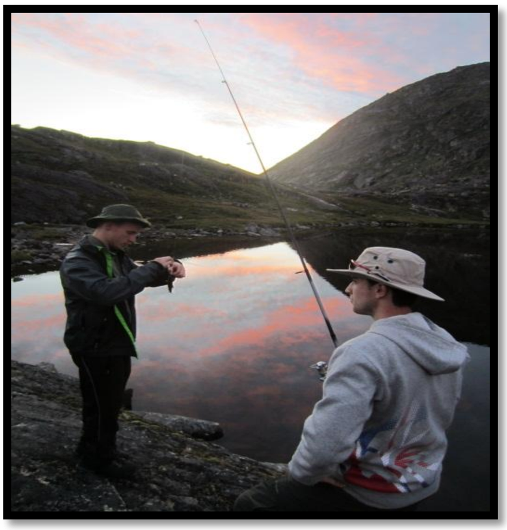

Figure 182 - Spare time activities included fishing in Qaqortoq

12.3 Nanortalik

Monday the 7th of August we travelled to Nanortalik by boat, visiting two smaller settlements on the way. It was an interesting experience to see how people lived outside of the urban districts, especially in Sarlooq. Here there were approximately 15 houses powered by a local diesel fuel generator, as well as a smaller grocery store which got its supplies from Qaqortoq by boat.

When arriving in Nanortalik there were a number of assignments that we had to fulfill to gather information regarding this feasibility study. The main tasks relevant for this study can be divided into 3 parts: site investigation and wind turbine transport planning, meetings with local firms and municipality and surveys. We also did some practical work, which included changing equipment on the 1601 met mast, as well as extending the met mast at TREF telecommunication station. The following sections will describe both the theoretical and practical work that was undergone during our field trip.

12.3.1 Site investigation

A total of three potential wind turbine sites were inspected in terms of visual inspection of topography, transport accessibility, grid access and visual impact to settlement together with the general impression we have from the acquired wind data. With the Nanortalik harbor as a starting point we walked the planned road route, to all three alternatives, logging GPS coordinates at the critical points along the road and then discussing a solution for each critical point, as presented in the road section under the construction Chapter (7.4). By walking with a 50 meter measure tape in between us, representing the wind turbine transport vehicle, we could easily observe which route to the turbine site that was least complicated and demanded minimum reconstruction.

For the wind turbine alternative site located in the unpopulated area north-west on the island, we walked the prospected road route and observed transportation obstacles along the way, as well as tracking the route with GPS coordinates. Both alternatives were

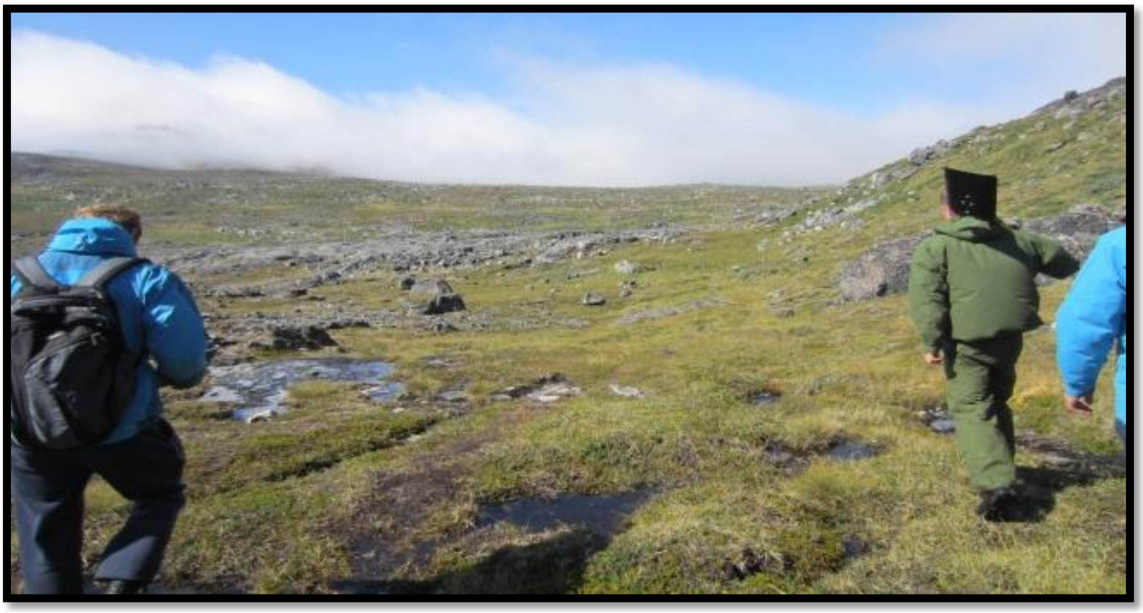

Figure 184 - Road route inspection. A shovel was brought to do some soil samples along the way

inspected with both the topography (roughness) and obstacles in mind.

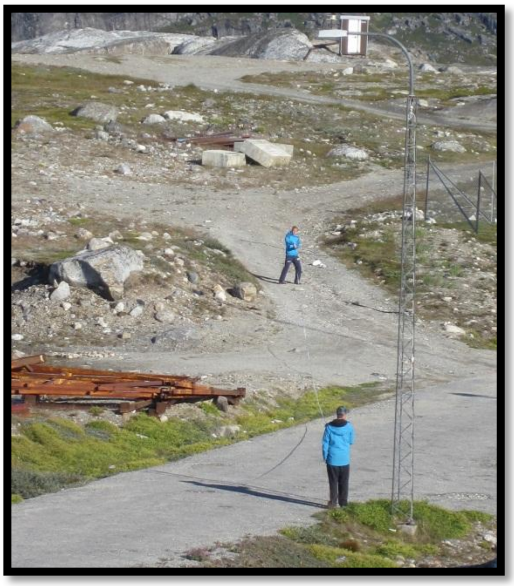

Figure 185 - Road observation routine. Close to 1601 met mast site.

12.3.2 Meetings with local firms and municipality

During our stay in Nanortalik we visited a number of firms as well as the local municipality office. The municipality had some information regarding our questions concerning road capability and construction routines, as well as some input on the general population decrease in Nanortalik. They also accepted to hand out some of our surveys to the locals that visited the municipality during the week.

We also visited the local power plant, where we discussed grid capability, connection points and the operation of the system. Erling Lorentsen showed us the monitoring/operation software that were utilized, and we had a look at the generators that we have obtained data from.

The Royal Arctic office was also visited, where we got some answers regarding quay capacity as well as seabed depths in and around the harbor. We were also in contact with INI, which operates the central heating system in Nanortalik. Due to language issues we did not acquire too much information there, but we appreciated that they gave us the opportunity to look at their facilities.

12.3.3 Carrying out surveys

In between the practical work, described

Figure 186 - The group investigating the local harbor, in terms of transportation

later in this chapter, and our investigations related to the feasibility analysis, we handed out surveys to locals in the streets of Nanortalik. This was a nice way to come in contact with the local population and hear about their opinions on renewable energy projects. As the survey results shows, most of the survey participants had a positive opinion regarding wind energy and renewable energy in general.

Figure 187 - The church in the old part of Nanortalik

12.3.4 Practical work: Equipment change on 1601 met mast.

Thursday 9th of August the whole of the travelling group spent the day at the 1601 met mast site, where we descended the 50 meter tall mast and stripped it down for instruments, wires and booms.

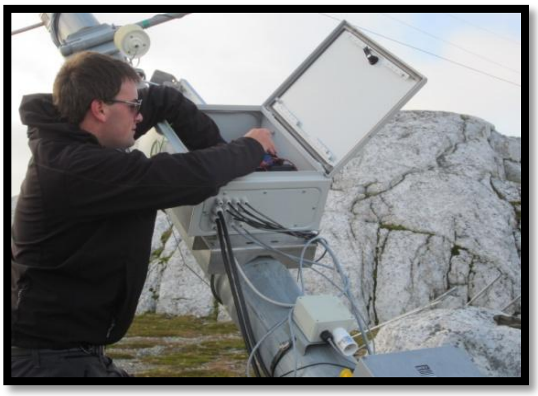

Figure 188 - Electrical installations on 1601 mast

Later on the same day the new booms were mounted. On Friday a part of the travelling group went to install the new equipment while we worked on road routes to one of the site alternatives.

The next day we were supposed to erect the mast, but this operation was postponed to Sunday due to high wind speed that morning. The wind speed was lower on Sunday, and we erected the 50 meter tall mast in approximately 4 hours

Figure 189 - Erecting the met mast

A lot of adjustments of the supporting wires were made in order to stabilize the mast and make it vertically level. When this operation was successfully done, we packed our bags and took the boat to the mountain where the TREF communication station was located.

12.4 TREF Communication Station

We hiked 900 height meters and brought all our needed equipment the same day that we erected the met mast in Nanortalik. When arriving at the TREF station we immediately lowered the 4 meter mast and stripped it from equipment. After a good night of sleep we extended the mast with another 8 meters, installed new equipment on the mast, and did all the wiring. Unfortunately we did

Figure 190 - Balancing the met mast at TREF

a mistake while erecting the 12 meter mast, which resulted in loss of some equipment, and 2 meters of the mast section was broken. We were then forced to remove the 2 meter section from the tubular mast and redo the wiring and adjustment of instruments.

After discussing the method of erecting the mast, we found a new solution which worked well and we could safely raise the met mast without any flaws. At this point we had to postpone the boat-pickup to the next morning, due to our unexpected fault earlier that day. The next morning we were picked up by boat and transported back to Nanortalik to enjoy the last days of a successful, educating and interesting trip to South Greenland.

Figure 191 - The upgraded met mast at TREF

13 CONCLUSION

The study of implementation of wind power in Nanortalik has, based on the studied conditions, proven to be viable. However, erection of a WinWind WWD-1 D60 1 MW on the two different turbine sites returns two different economic results. It is found that Turbine site 1 marginally returns a positive net present value over the 20 years, whereas implementation of the 1 MW turbine at Turbine site 2 is unprofitable, by a large margin. These statements are written in terms of the price estimations regarding the project and in terms of a discount rate at 8 %. The various cost estimations have proved to be quite a challenge to obtain; hence the site specific figures include uncertainties.

In determination of the key financial figures, Turbine site 1 returns a positive NPV of 112 700 DKK, whereas Turbine site 2 results in a negative NPV of 12.35 million DKK. These computations are based on an 8 % discount rate, which is known to be of fair assumption for such project in the wind industry. The computation would be desired to be performed based on Nukissiorfiit's discount rate for such a project; however this has not been obtainable. As the risk of development of excessive infrastructure in Nanortalik, this rate seems to be optimistic valued.

Turbine site 1, located by the measurement mast, is clearly the most promising from an economic standpoint. In addition, this site is easier viable in terms of construction. Lowering the discount rate seems to be the greatest affection on the site's economic feasibility. By for example lowering the discount rate to 6 percent, such as performed in the sensitivity analysis, the NPV of the project is equal to 4.96 million DKK.

On the other hand; Turbine site 2 seems to be out of reach from an economic standpoint. The wind resource at this site is proven to be good; however, as this is a one wind turbine project the cost of infrastructure becomes excessive. None of the single parameter sensitivity analysis seems to affect the economics of this site to a significant extent. Primarily, the difference from the sites is the intervention in nature and measures needed to be carried out. The negative NPV of approximately 12.3 million DKK for Turbine site 2 is solely represented by the cost of road construction.

13.1 Discussion and Further Work

Ignoring the fact that the project seems to be economical inattractive, at least for Turbine site 2, the project might still be of interest, either by significant investment reduction or the desire of a green development in Nanortalik. In this regard, there are several factors that come into mind and aspects that this study does not adequately cover.

Realization of the wind farm proves to save approximately half the fuel consumption of the diesel generators. Additionally, a wind turbine at 1 MW has proven to save quite some fuel consumption by the oil boilers at times of exceeding electricity production. Savings in regard to fossil fuels is a national goal of Greenland. The project would make the Greenlandic electricity price substantially less affected by the oil market. Even more important, it would result in a less dependency on resource supply from foreign countries, as Greenland imports 100 % of their oil consumption. The latter statement arguing for more independency is a growing concern of several European countries, which in long-term perspective means security of supply. However, in short-term this means unreliable production and power quality as a result of an intermittent resource.

The project is a positive measure in terms of making Greenland greener; however, it seems more prudent to initiate such projects in the area around Nuuk or Sisimiut, if either of these cities are in need of additional power. This statement is based on the need of a greater capacity implementation to push down the per MW cost and in conjunction to the future prognosis of electricity consumption and development of Nanortalik. Further work would primarily be to obtain final financial figures for the various records related to Turbine site 1. As this is in order, the discount rate required from Nukissiorfiit needs to be taken into account, in determination of economic feasibility of erecting a wind turbine at this location. The cost estimations assumed to be of greatest uncertainty in the conjunction to Turbine site 1, is the cost of reinforcement of the WinWind turbine from IEC class IIIC to S and transportation and installation of wind turbine. Regarding the IEC class there are some additional uncertainties, as there atmospheric condition is of unknown origin. However, in fact a Sonic Anemometer was mounted on the 1601 met mast at the field trip August 2012; hence such analysis and more thorough determination of actual turbulence intensity can and is recommended in any further study. The unknown atmospheric condition also affects the credibility of the WAsP wind regime analysis and production estimation. In addition the cost and solution of maintenance is subject to some uncertainty, as none of the wind turbine manufacturers have maintenance office in Greenland. However, a figurative price estimate is given.

The power system model in this study is superficial in means of analysis of fuel savings and associated emission reduction of carbon dioxide. This is assumed to be adequate for a pre-study of the economic feasibility, as there are so many uncertainties associated to the economics. However, the larger question of challenge is in terms of system reliability, stability and control. An important part, especially in determination of implementation of wind power in such small isolated grid system, is analysis of the wind power in terms of power quality and safe operation. In this matter, the interaction between the wind power control and the conventional units has to be analyzed, as well as the inertia and damping of the system. These matters are strongly encouraged to be investigated in terms of wind power implementation and determination of system's feasible wind power capacity limit.

Additionally, it must be noted that the system model has not taken into account the dynamical limit of dump load, as this has not been obtainable from the district heating company, INI. This is definitely of interest in determination of wind power capacity, as well as assessment of other form of dump loads in conjunction to system stability.

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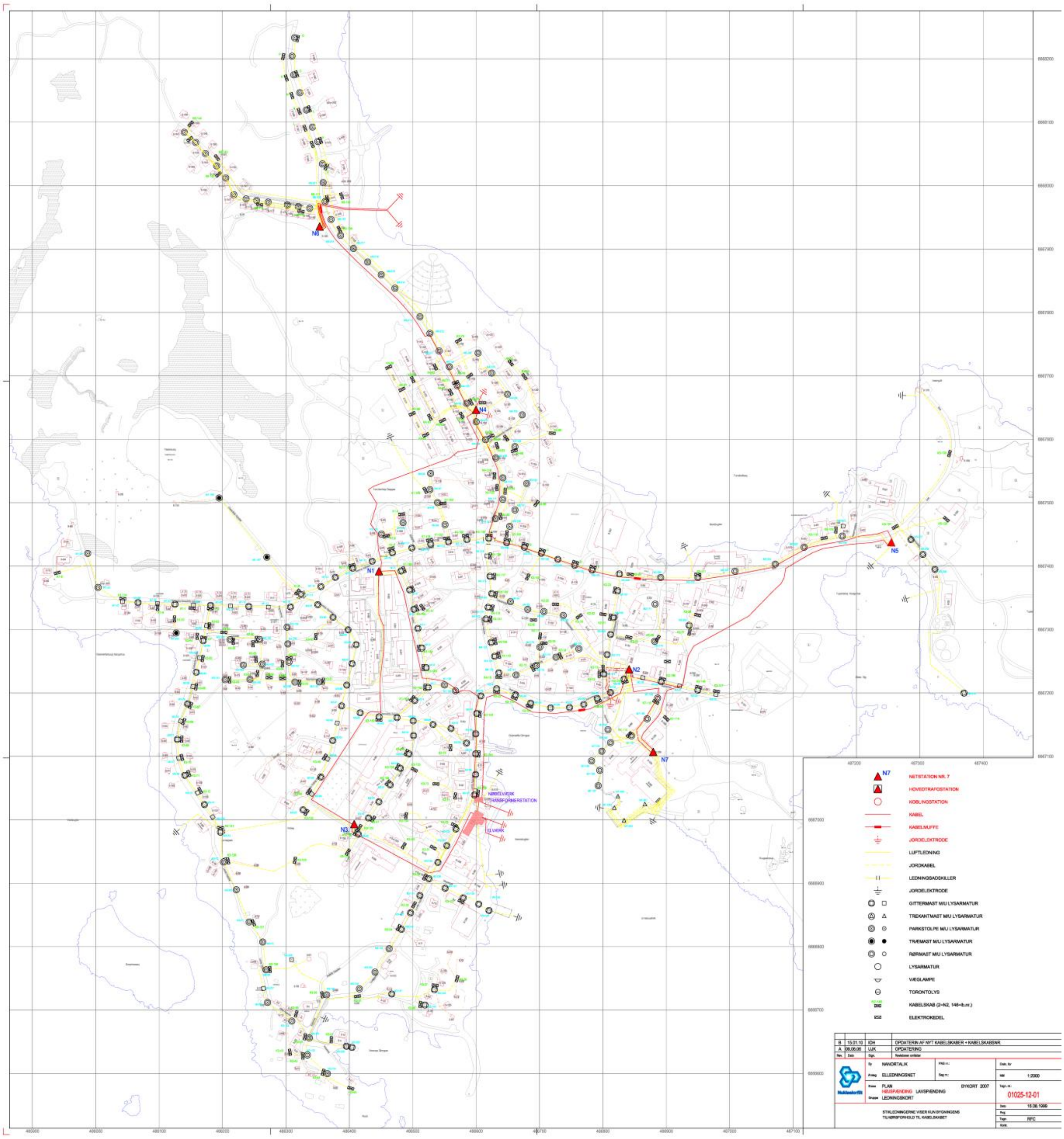
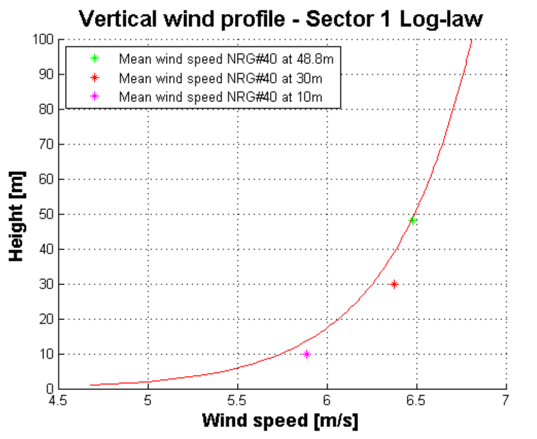
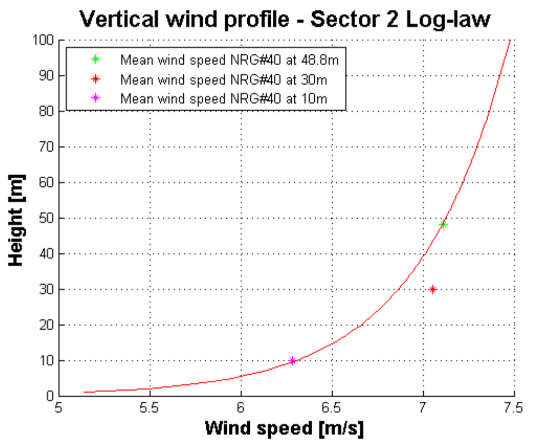
A GRID MAP NANORTALIK

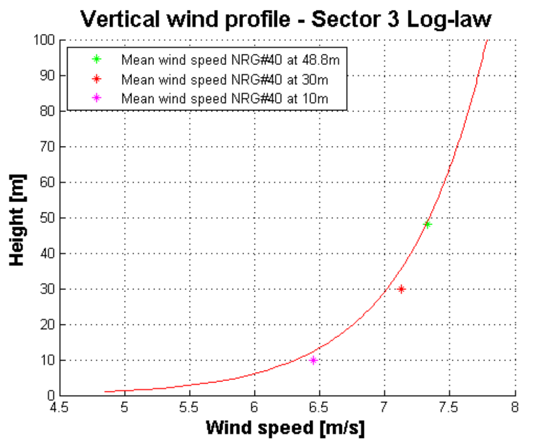


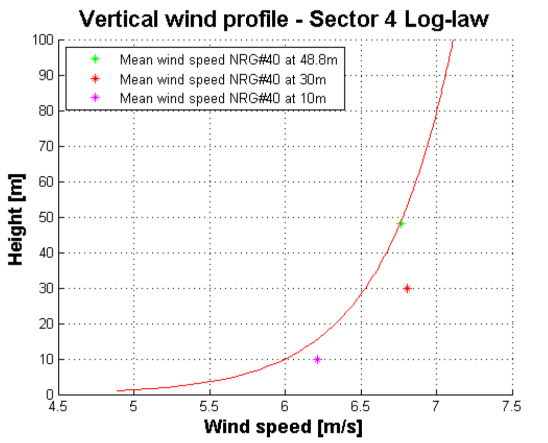
B VERTICAL WIND PROFILE OF ALL SECTORS AT 1601 MET MAST

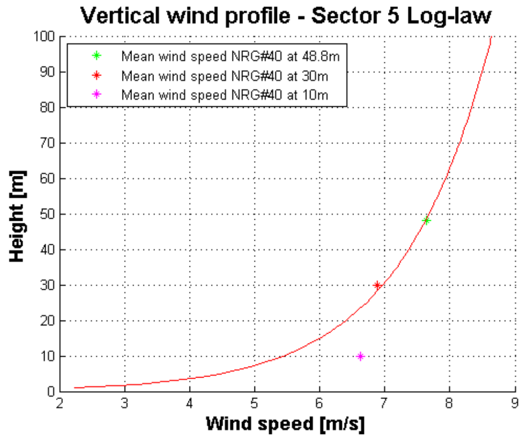
Vertical wind profile of all sectors at 1601 mast.

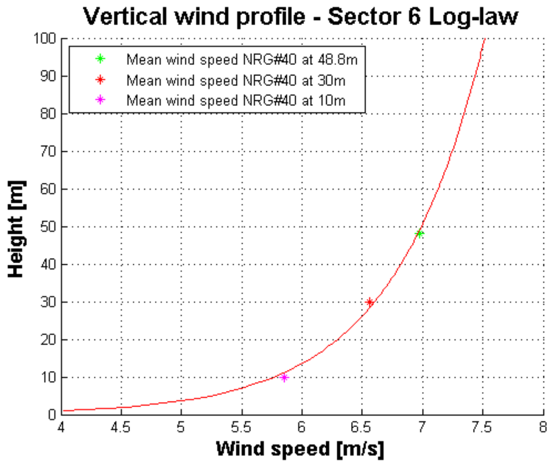


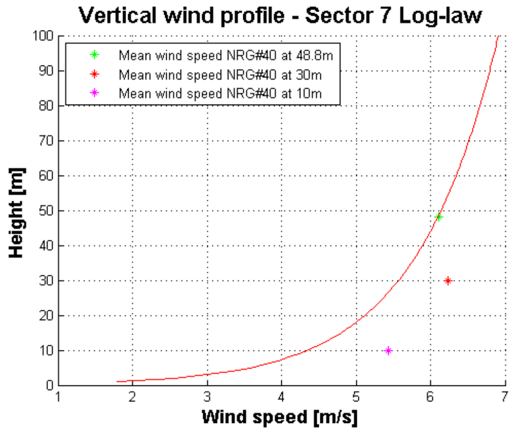


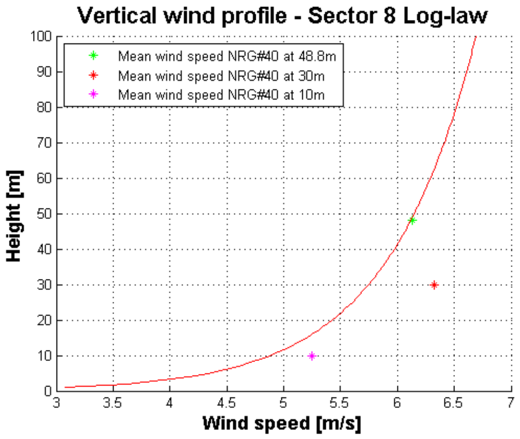


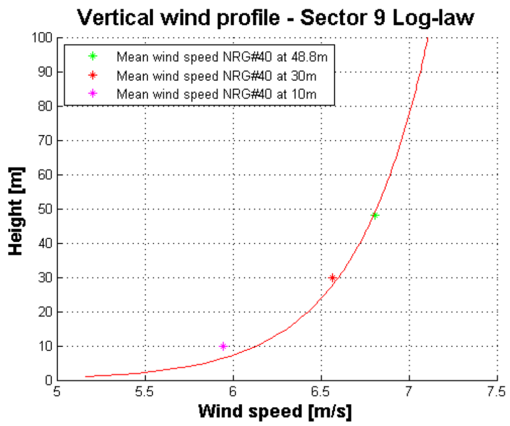


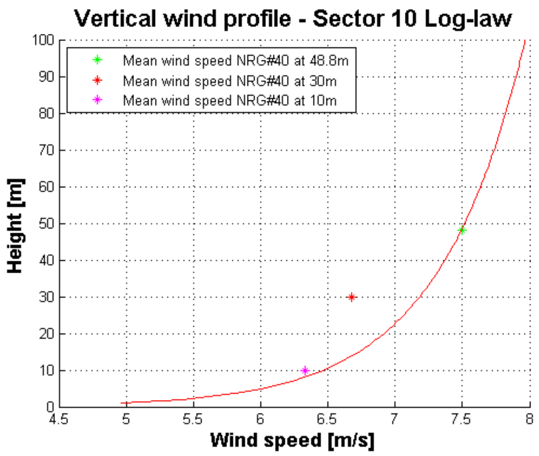

Vertical wind profile - Sector 5 Log-law
Mean wind speed NRG#40 at 48.8m
Mean wind speed NRG#40 at 30m
Mean wind speed NRG#40 at 10m
Height [m]
Wind speed [m/s]

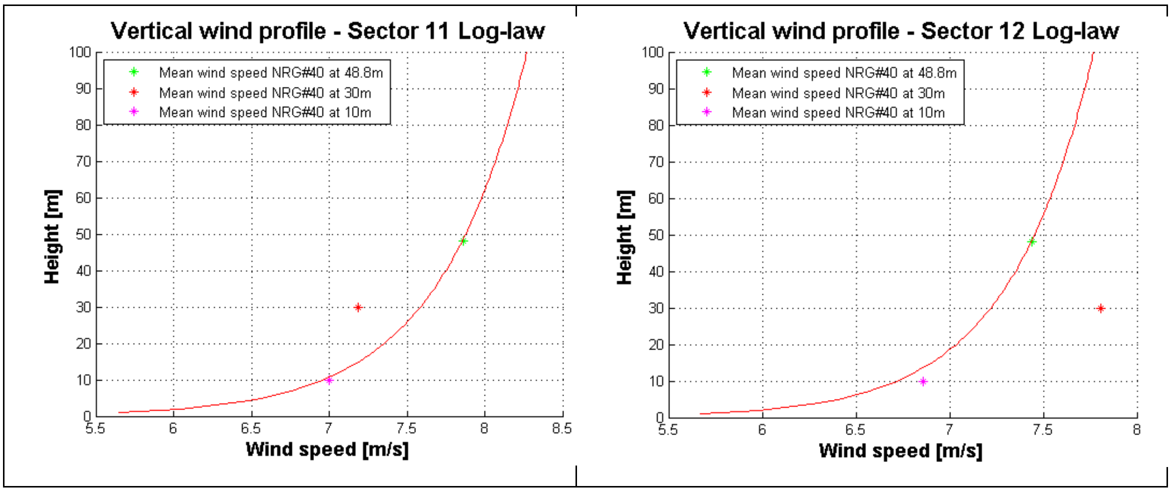

Vertical wind profile - Sector 6 Log-law
Mean wind speed NRG#40 at 48.8m
Mean wind speed NRG#40 at 30m
Mean wind speed NRG#40 at 10m
Height [m]
Wind speed [m/s]


Vertical wind profile - Sector 7 Log-law
Mean wind speed NRG#40 at 48.8m
Mean wind speed NRG#40 at 30m
Mean wind speed NRG#40 at 10m
Height [m]
Wind speed [m/s]


Vertical wind profile - Sector 8 Log-law
Mean wind speed NRG#40 at 48.8m
Mean wind speed NRG#40 at 30m
Mean wind speed NRG#40 at 10m
Height [m]
Wind speed [m/s]


Vertical wind profile - Sector 9 Log-law
Mean wind speed NRG#40 at 48.8m
Mean wind speed NRG#40 at 30m
Mean wind speed NRG#40 at 10m
Height [m]
Wind speed [m/s]


Vertical wind profile - Sector 10 Log-law
Mean wind speed NRG#40 at 48.8m
Mean wind speed NRG#40 at 30m
Mean wind speed NRG#40 at 10m
Height [m]
Wind speed [m/s]



The sectors represent wind speeds from the following wind directions:

Sector	*Wind direction [degrees]*
Sector 1	15-45
Sector 2	45-75
Sector 3	75-105
Sector 4	105-135
Sector 5	135-165
Sector 6	165-195
Sector 7	195-225
Sector 8	225-255
Sector 9	255-285
Sector 10	285-315
Sector 11	315-345
Sector 12	345-15

C WINWIND WWD-1 TURBINE (1 MW)

WINWIND WWD-1-D60 IEC3 1000 60.0 !O!

File C:\Documents and Settings\utktur\My Documents\WindPRO Data\WTG Data\EMD\WINWIND WWD-1-D60 IEC3 1000 60.0 !O!.wtg

Company	WINWIND
Type/Version	WWD-1-D60 IEC3
Rated power	1,000.0 kW
Secondary generator	0.0 kW
Rotor diameter	60.0 m
Tower	Tubular
Grid connection	50 Hz
Origin country	FI
Blade type	EU-60
Generator type	Variable
Rpm, rated power	25.6 rpm
Rpm, initial	7.7 rpm
Hub height(s)	70.0; 0.0 m
Maximum blade width	2.55 m
Blade width for 90% radius	0.78 m
Valid	Yes
Creator	EMD
Created	06.07.2011 14:35
Edited	06.07.2011 14:35

Power curve: Level 0 - calculated - 0 - 07-2009
Source Manufacturer

Source date	Creator	Created	Edited	Default	Stop windSpeed [m/s]	Air density [kg/m3]	Tip angle [°]	Power control	CT curve type
13.07.2009 00:00	EMD	14.04.2008 13:43	27.07.2009 15:48	Yes	20.0	1.225	0.0	Pitch	User defined

Power curve

Wind speed	[m/s]	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
Power	[kW]	0.00	43.00	91.00	161.00	262.00	400.00	568.00	780.00	972.00	1,041.00	1,045.00	1,045.00	1,045.00	1,045.00	1,045.00
Ce		0.000	0.388	0.420	0.430	0.441	0.451	0.450	0.450	0.422	0.348	0.275	0.220	0.179	0.147	0.123

Wind speed	[m/s]	18.00	19.00	20.00
Power	[kW]	1,045.00	1,045.00	1,045.00
Ce		0.103	0.088	0.075

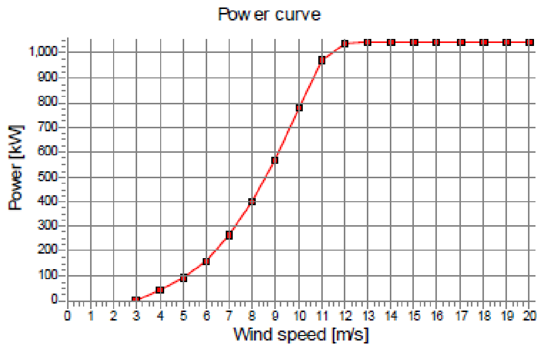
Ct curve

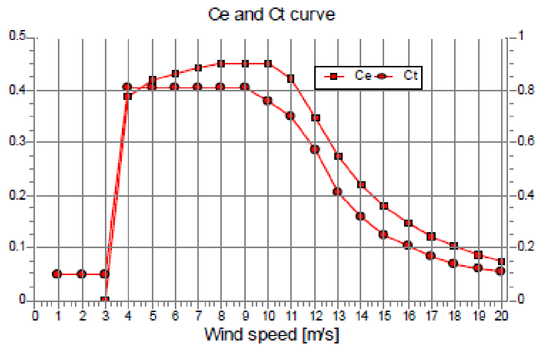
Wind speed	[m/s]	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
Ct		0.10	0.10	0.10	0.81	0.81	0.81	0.81	0.81	0.81	0.76	0.70	0.57	0.41	0.32	0.25	0.21	0.17	0.14	0.12	0.11

HP curve comparison

Vmean	[m/s]	5	6	7	8	9	10
HP value	[MWh]	1,302	2,096	2,908	3,694	4,351	4,936
Level 0 - calculated - 0 - 07-2009	[MWh]	1,474	2,326	3,182	3,943	4,553	4,988
Check value	[%]	-12	-10	-9	-6	-4	-1

The table shows comparison between annual energy production calculated on basis of simplified "HP-curves" which assume that all WTGs performs quite similar - only specific power loading (kW/m^2) and single/dual speed or stall/pitch decides the calculated values. Productions are without wake losses.
For further details, ask at the Danish Energy Agency for project report J.nr. 51171/00-0016 or see WindPRO manual chapter 3.5.2.
The method is refined in EMD report "20 Detailed Case Studies comparing Project Design Calculations and actual Energy Productions for Wind Energy Projects worldwide", jan 2003.
Use the table to evaluate if the given power curve is reasonable - if the check value are lower than -5%, the power curve probably is too optimistic due to uncertainty in power curve measurement.





WinWinD

1(1)

KSe, 04.02.2009

Power Curve WWD1

The power curve data is based on preliminary power curve measurements of 60m 1 MW rotor and aerodynamic calculations.

The power curve is valid for the following conditions

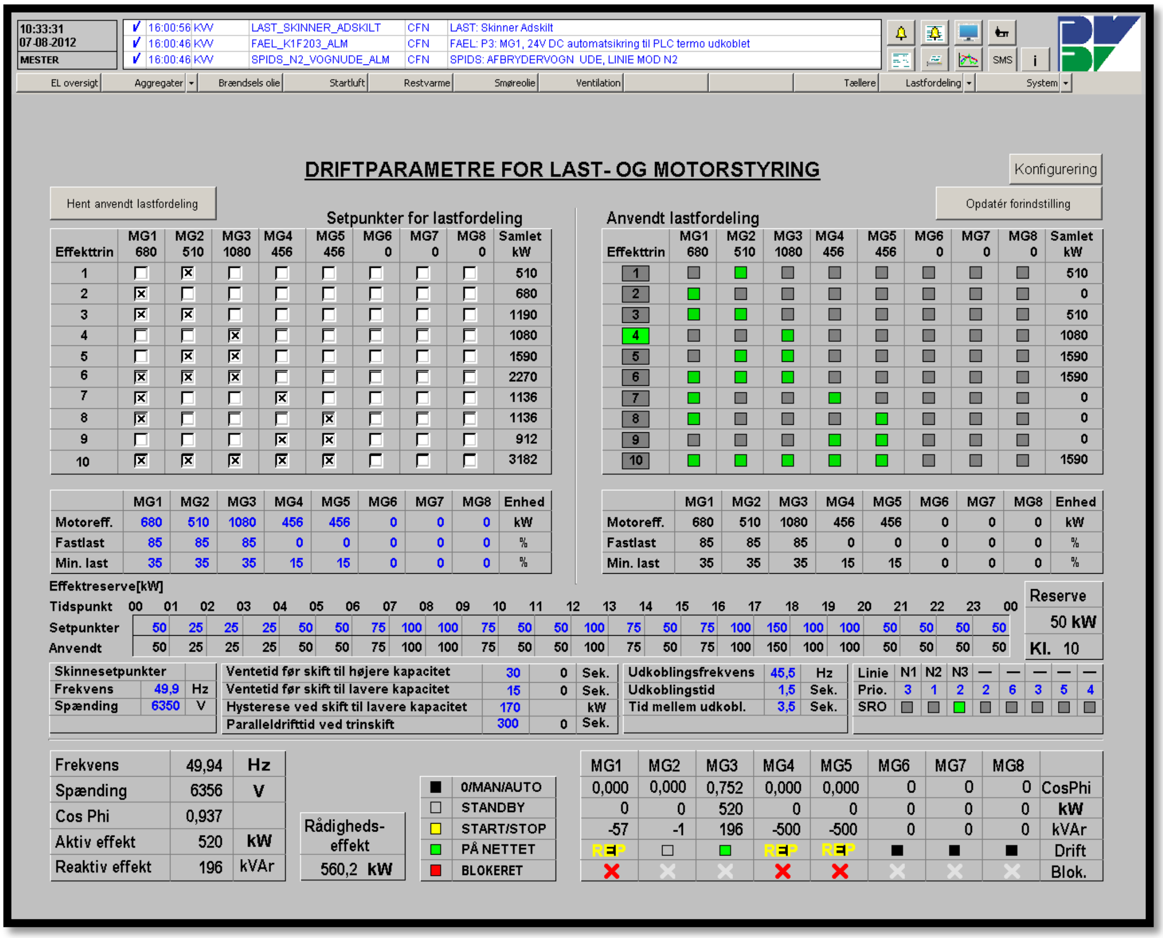
1. The turbulence intensity is 8 to 15 %
2. The air density is 1.225 kg/m^3
3. Clean Blade and horizontal inflow are considered, including the nacelle tilt angle and rotor coning
4. The power is measured on the low voltage side.
5. Cut in and Cut out Hysteresis have not been considered

Wind Speed	Power	Cp_Electric
4	43	0.38
5	91	0.42
6	161	0.43
7	262	0.44
8	400	0.45
9	568	0.45
10	780	0.45
11	972	0.42
12	1041	0.35
13	1045	0.28
14	1045	0.22
15	1045	0.18
16	1045	0.15
17	1045	0.12
18	1045	0.10
19	1045	0.09
20	1045	0.08

Reactive power / Power factor

The power factor can be set as a fixed value between ±0.95. Anyhow the set range is only valid when U=Un. When the turbine is stopped the power factor is << 1 due to time there is capacitive load of transformer but no active load.

D PARAMETERS OF LOAD AND ENGINE MANAGEMENT



E PEER RATING OF TEAM MEMBERS

Peer Rating of Team Members

Name ANDREAS GRØSVIK LAUKHAMMER Group #________

Please write the names of all of your team members, INCLUDING YOURSELF, and rate the degree to which each member fulfilled his/her responsibilities in completing the homework assignments. The possible ratings are as follows:

Excellent	Consistently went above and beyond—tutored teammates, carried more than his/her fair share of the load
Very good	Consistently did what he/she was supposed to do, very well prepared and cooperative
Satisfactory	Usually did what he/she was supposed to do, acceptably prepared and cooperative
Ordinary	Often did what he/she was supposed to do, minimally prepared and cooperative
Marginal	Sometimes failed to show up or complete assignments, rarely prepared
Deficient	Often failed to show up or complete assignments, rarely prepared
Unsatisfactory	Consistently failed to show up or complete assignments, unprepared
Superficial	Practically no participation
No show	No participation at all

These ratings should reflect each individual's level of participation and effort and sense of responsibility, not his or her academic ability.

Name of team member	Rating
TORKEL D. LØLAND	VERY GOOD
KRISTIAN SÆBØ	VERY GOOD
STIAN R. MANGER	VERY GOOD
ANDREAS G. LAUKHAMMER	VERY GOOD

Your signature:

R.M. Felder, 1997. Each student fills out this form, instructor collects and uses to adjust team project grades for individual team members using procedure on following page.

E-16

Peer Rating of Team Members

Name Torkel Dyrkorn Løland **Group #**______________

Please write the names of all of your team members, INCLUDING YOURSELF, and rate the degree to which each member fulfilled his/her responsibilities in completing the homework assignments. The possible ratings are as follows:

Excellent	Consistently went above and beyond—tutored teammates, carried more than his/her fair share of the load
Very good	Consistently did what he/she was supposed to do, very well prepared and cooperative
Satisfactory	Usually did what he/she was supposed to do, acceptably prepared and cooperative
Ordinary	Often did what he/she was supposed to do, minimally prepared and cooperative
Marginal	Sometimes failed to show up or complete assignments, rarely prepared
Deficient	Often failed to show up or complete assignments, rarely prepared
Unsatisfactory	Consistently failed to show up or complete assignments, unprepared
Superficial	Practically no participation
No show	No participation at all

These ratings should reflect each individual's level of participation and effort and sense of responsibility, not his or her academic ability.

Name of team member	Rating
Torkel D Løland	Very good
Andreas G. Lauthaug	Very good
Stian R. Manger	Very good
Kristian Sæbø	Very good

Your signature: Torkel D. Løland

R.M. Felder, 1997. Each student fills out this form, instructor collects and uses to adjust team project grades for individual team members using procedure on following page.

E-16

Peer Rating of Team Members

Name KRISTIAN SÆBØ Group #__________

Please write the names of all of your team members, INCLUDING YOURSELF, and rate the degree to which each member fulfilled his/her responsibilities in completing the homework assignments. The possible ratings are as follows:

Excellent	Consistently went above and beyond—tutored teammates, carried more than his/her fair share of the load
Very good	Consistently did what he/she was supposed to do, very well prepared and cooperative
Satisfactory	Usually did what he/she was supposed to do, acceptably prepared and cooperative
Ordinary	Often did what he/she was supposed to do, minimally prepared and cooperative
Marginal	Sometimes failed to show up or complete assignments, rarely prepared
Deficient	Often failed to show up or complete assignments, rarely prepared
Unsatisfactory	Consistently failed to show up or complete assignments, unprepared
Superficial	Practically no participation
No show	No participation at all

These ratings should reflect each individual's level of participation and effort and sense of responsibility, not his or her academic ability.

Name of team member	Rating
KRISTIAN SÆBØ	VERY GOOD
ANDREAS G. LAUKGAARD	VERY GOOD
STIAN R. MENGER	VERY GOOD
TORKEL D. LØLAND	VERY GOOD

Your signature: Kristian Sæbø

R.M. Felder, 1997. Each student fills out this form, instructor collects and uses to adjust team project grades for individual team members using procedure on following page.

E-16

Peer Rating of Team Members

Name Stian Ramm Mangers   **Group #**____________

Please write the names of all of your team members, INCLUDING YOURSELF, and rate the degree to which each member fulfilled his/her responsibilities in completing the homework assignments. The possible ratings are as follows:

Excellent	Consistently went above and beyond—tutored teammates, carried more than his/her fair share of the load
Very good	Consistently did what he/she was supposed to do, very well prepared and cooperative
Satisfactory	Usually did what he/she was supposed to do, acceptably prepared and cooperative
Ordinary	Often did what he/she was supposed to do, minimally prepared and cooperative
Marginal	Sometimes failed to show up or complete assignments, rarely prepared
Deficient	Often failed to show up or complete assignments, rarely prepared
Unsatisfactory	Consistently failed to show up or complete assignments, unprepared
Superficial	Practically no participation
No show	No participation at all

These ratings should reflect each individual's level of participation and effort and sense of responsibility, not his or her academic ability.

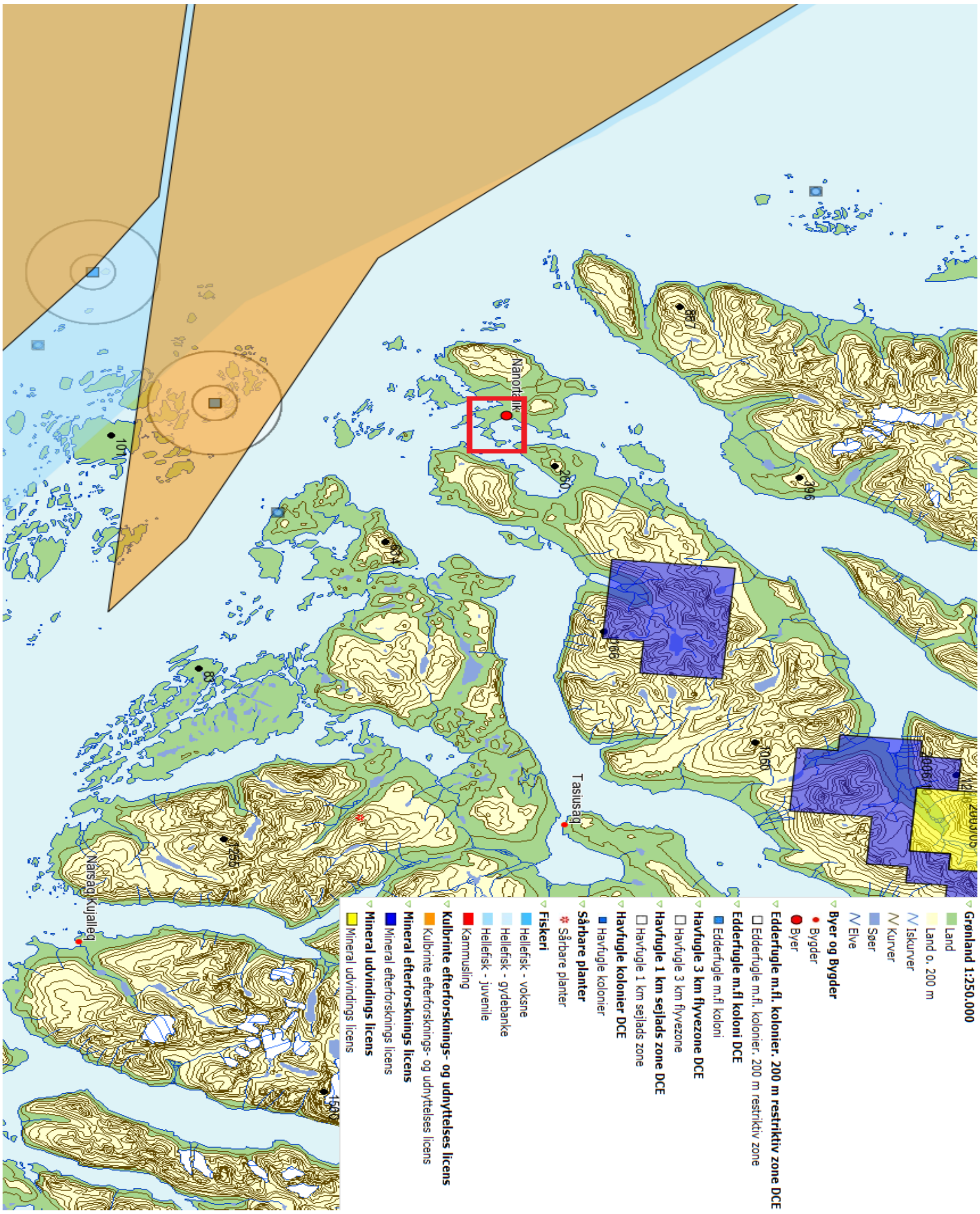
Name of team member	Rating
Torkel D. Løland	Very good
Andreas G. Lockhanas	Very good
Kristian Sæbø	Very good
Stian Mange	Very good

Your signature: [signature]

R.M. Felder, 1997. Each student fills out this form, instructor collects and uses to adjust team project grades for individual team members using procedure on following page.

E-16

F NUNAGIS ENVIRONMENTAL IMPACT ASSESSMENT ILLUSTRATION

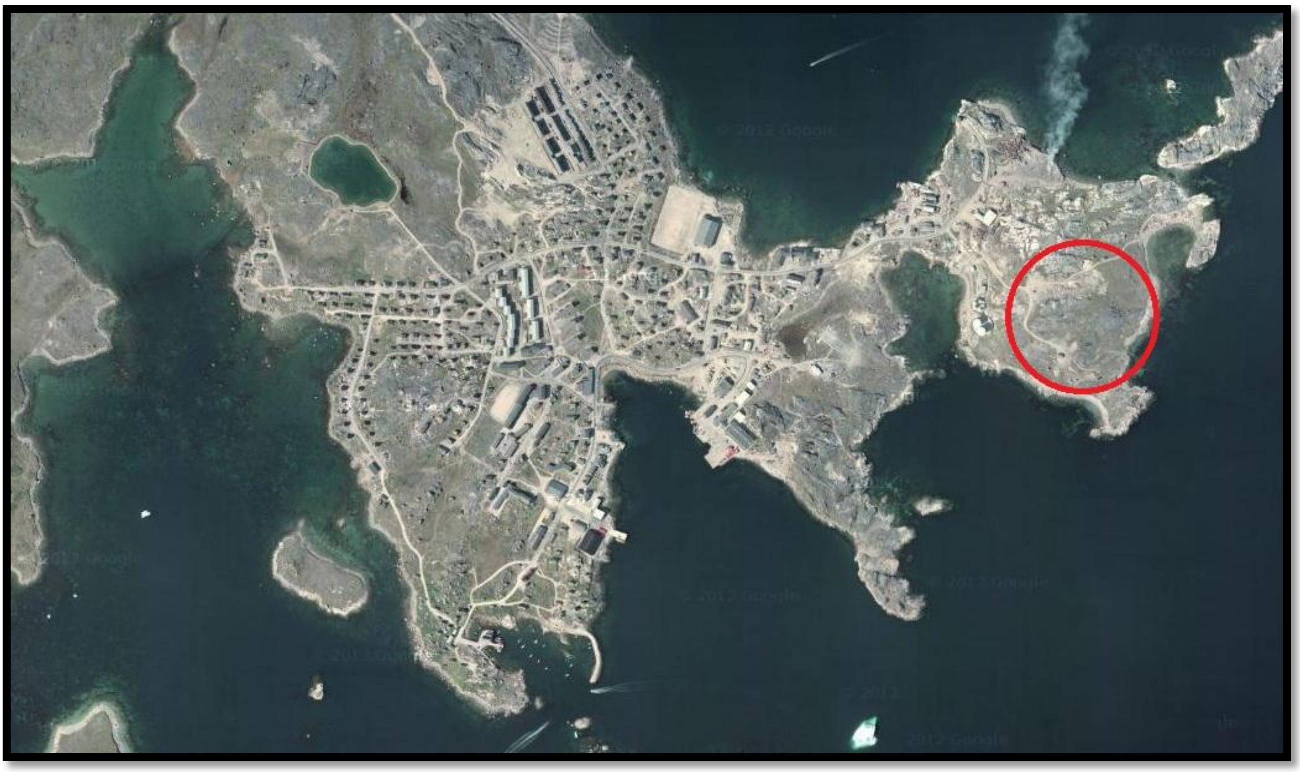


G THE CONDUCTED SURVEY

We are four Norwegian students that are part of the MSc. Program “Wind Energy” at the Technical University of Denmark. In that regard we are taking a course named “Arctic Technology”, which focuses around different issues in Greenland.
In our project we are going to do a feasibility study of implementation of wind power into the Nanortalik energy system. In this study we will find out if it is possible, both technically and economically, to replace some of the fossil fuel consumption by introducing wind power into the system.
In order to reveal the local inhabitants point of view, we have made this questionnaire which will give us a general impression of what the interest of the locals are.
Please put a circle around your answer, and hopefully you will also take the time to elaborate your meanings in the designated space.

Questionnaire					
Age:	<20	20-30	20-45	45-60	60+
Sex:	Male				Female
What is your general impression of wind energy?	Positive		No opinion		Negative
What is your opinion regarding a possible wind turbine(s) in Nanortalik?	Positive		No opinion		Negative
If one or more wind turbines were set up in the area marked with a red circle on the next page, would this be a disturbance in your daily life?	Yes		No opinion		No
If yes, why?					
Would a visible wind turbine be an issue for you personally?	Yes		No opinion		No

If yes, why?			
Are you interested in a renewable energy production?	Yes	No opinion	No
Are you satisfied with the electricity prices today?	Yes	No opinion	No
Would it be acceptable to possibly pay more for an environmentally "healthy" energy production?	Yes	Maybe	No
If no, why?			
Would you be interested to participate in operation/maintenance of a wind turbine in Nanortalik?	Yes	Maybe	No



Thank you very much for your participation!

H ECONOMIC CALCULATION EXCEL SHEETS

Nanortalik Wind Farm		Unit
Installed capacity - WinWind	1	MW
Site Alternatives Production [GWh]		Unit
Alternative 1	2,359	GWh
Alternative 2	2,984	GWh

Benefit of Wind Turbine Implementation	
Model results - Fuel savings	
Alternative 1	
20 year benefit (Fuel savings in DKK)	65250000
Yearly benefit (Fuel savings in DKK)	3262500
Benefit per kWh (Fuel savings in DKK / kWh)	1,025026401
Alternative 2	
20 year benefit (Fuel savings in DKK)	81372000
Yearly benefit (Fuel savings in DKK)	4068600
Benefit per kWh (Fuel savings in DKK / kWh)	0,792608091

Energy production			Wind Farm Efficiency
Full load hours Alt 1	2151,408	h	0,912
AEP Alt. 1 (incl loss)	**2151408**	kWh	
Full load hours Alt 2	2721,408	h	
AEP Alt. 2 (incl loss)	**2721408**	kWh	

Investment Expected 2012	Estimated cost	Estimated cost
	Alternative 1	**Alternative 2**
	mDKK	mDKK
Wind Turbine	10,7424	10,7424
Transportation	1,492	1,492
Foundation	0,302	0,302
Electrical Equipment (- Wind Turbine)	0,8138	3,568
Road	3,8268	18,1594
Design, management	0,165	0,165
Environmental Impact Assessment	0,1	0,1
Various	0,123	0,123
Total	**17,565**	**34,6518**
Total O&M cost	3,58	
Total Investment Costs		
Total Investment Cost - Alternative 1 [mDKK]	**17,5650**	
Total Investment Cost - Alternative 2 [mDKK]	**34,6518**	

Operation and Maintenance cost	
Yearly O&M [mDKK]	0,179
O&M Alt 1 [mDKK/kWh]	8,32013E-08
O&M Alt 2 [mDKK/kWh]	6,57748E-08
Project discount rate	
Discount rate	8%

Nanortalik Wind Farm Turbine site 1

Economic parameters		
Life time	20	years
O&M	0,000000083	mDKK/kWh
Net power production	2151408	kWh/year
Benefits in fuel savings	1,025026401	DKK/kWh
Discount rate	0,08	

Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
Investment [m€]	-17,57																					-17,57
O&M [mDKK]		-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	
Benefit [mDKK]		3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	3,26	65,25
Cash flow [mDKK]	-17,57	2,86	2,64	2,45	2,27	2,10	1,94	1,80	1,67	1,54	1,43	1,32	1,22	1,13	1,05	0,97	0,90	0,83	0,77	0,71	0,66	12,7092575

Average Annual Savings [mDKK]	1,513712877
20 year wind farm production [GWh]	43,02816
Key financial figures	
Net Present Value of savings [mDKK]	**0,1127**
Internal Rate of Return (IRR)	**8,115%**
Simple Payback time [years]	**11,60391794**

Nanortalik Wind Farm Turbine 2

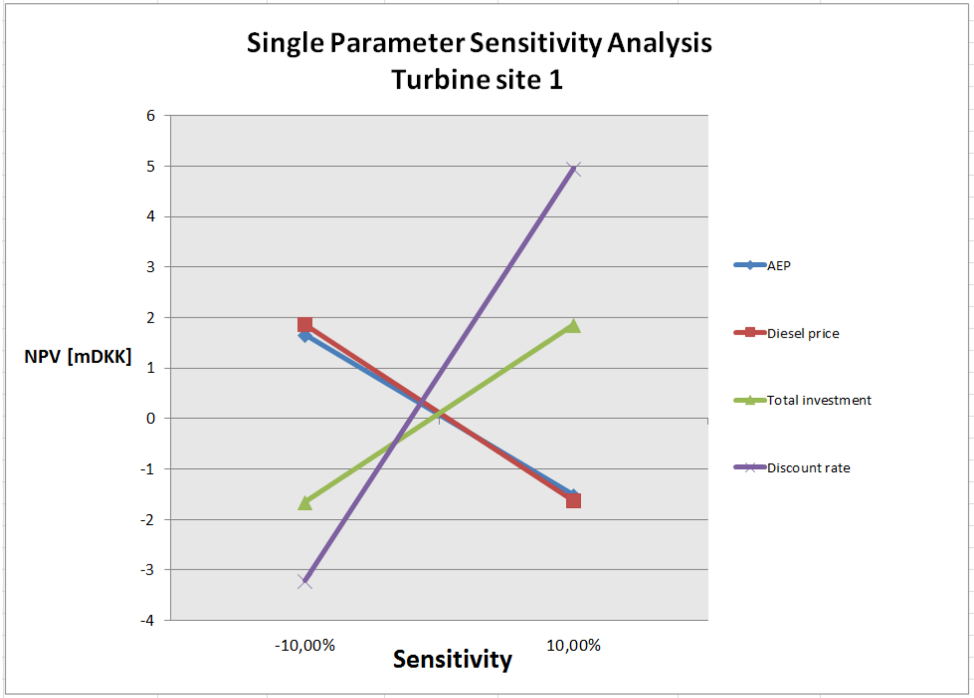
Economic parameters		
Life time	20	years
O&M		mDKK/kWh
Net power production	2721408	kWh/year
Benefits in fuel savings	1,025026401	DKK/kWh
Discount rate	0,08	

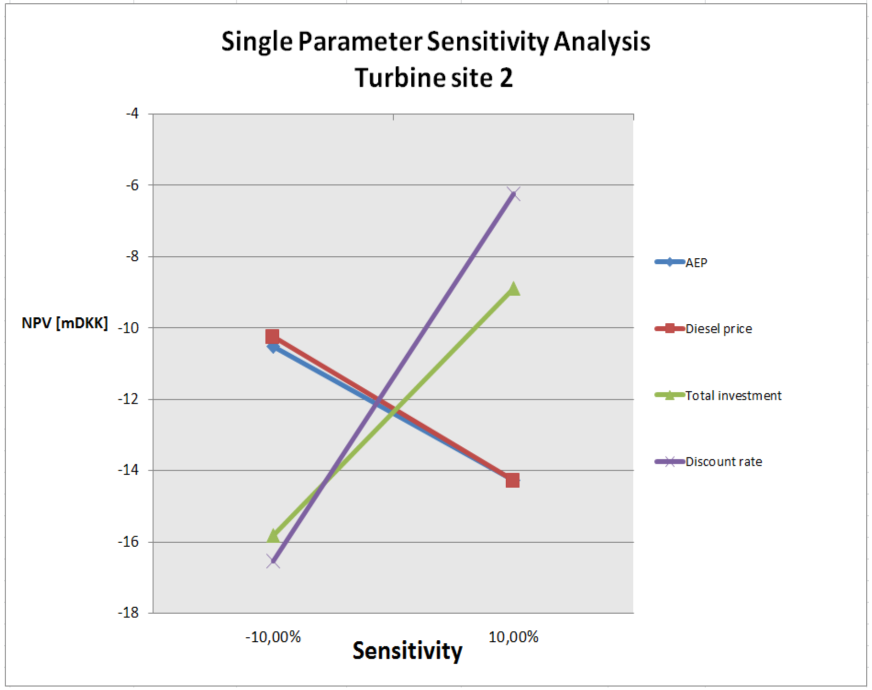
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	Total
Investment [m€]	-34,65																					-34,65
O&M [mDKK]		-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	-0,18	
Benefit [mDKK]		4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	4,07	81,37
Cash flow [mDKK]	-34,65	3,60	3,33	3,09	2,86	2,65	2,45	2,27	2,10	1,95	1,80	1,67	1,54	1,43	1,32	1,23	1,14	1,05	0,97	0,90	0,83	3,53686616

Average Annual Savings [mDKK]	1,909433308
20 year wind farm production [GWh]	54,42816
Key financial figures	
Net Present Value of savings [mDKK]	**-12,3528**
Internal Rate of Return (IRR)	**1,245%**
Simple Payback time [years]	**18,14768804**

Single parameter analysis for alternative 1 - Nanortalik						
Component	Scenario 1	Scenario 2	NPV (Sc1)	NPV diff % (Sc1)	NPV (Sc2)	NPV diff % (Sc2)
AEP	1,1	0,9	1662000	-109,478954	-1518100	392,78
Diesel price	1,1	0,9	1855500	-113,84134	-1629900	313,2
Total investment	1,1	0,9	-1643800	-87,94136529	1869200	-323,2
Discount rate	0,1	0,06	-3206100	-64,6782328	4957000	-79,58

Single parameter analysis for alternative 2 - Nanortalik						
Component	Scenario 1	Scenario 2	NPV (Sc1)	NPV diff % (Sc1)	NPV (Sc2)	NPV diff % (Sc2)
AEP	1,1	0,9	-10528200	-392,78	-14273300	392,78
Diesel price	1,1	0,9	-10243300	-313,2	-14273300	313,2
Total investment	1,1	0,9	-15818000	323,2	-8887600	-8887600
Discount rate	0,1	0,06	-16539100	79,58	-6242100	-79,58





I MATLAB SCRIPTS

Vertical wind profile at 1601 mast

```
%-----------------------------------------------------------------------
-----
% Vertical wind profile at 1601 mast, Nanortalik
%-----------------------------------------------------------------------
-----

% Loading filtered datafile
clc;clear all;close all

load('Data_Riso_filtered_1.txt')
WD_ch8=Data_Riso_filtered_1(1:52560,27);
load('NRG_48m_filtered.mat')
WS_48=data1(1:52560,3);
load ('NRG_30m_filtered.mat')
WS_30=data1(1:52560,7);
load ('NRG_10m_filtered.mat')
WS_10=data1(1:52560,11);

% Assuming same WD for all cups. Thus only extract filtered WS data
from 10
% 30 and 48.

%-----------------------------------------------------------------------
-----
% Filtering data, to obtain stable conditions.
%-----------------------------------------------------------------------
-----
for filtering=1
for i=1:length(WS_48)
    if WS_48(i)<= 4.3
       WS_48(i)=4.35;
    end
    WS_48_test=WS_48;

%     WS_48(i)=WS_48_test(i)<998;
end

for i=1:length(WS_48)
    if WS_30(i)<= 4
       WS_30(i)=4.1;
    end
    WS_30_test=WS_30;

%     WS_48(i)=WS_48_test(i)<998;
end
```

```
for i=1:length(WS_48)
    if WS_10(i)<= 4
       WS_10(i)=4.1;
    end
    WS_10_test=WS_10;

%      WS_48(i)=WS_48_test(i)<998;
end
end
%----------------------------------------------------------------------
-----
% Calculating mean values in each height level. Period of 2 years.
%----------------------------------------------------------------------
-----

% Mean wind speeds in height level: 10m 30m 48.8m
u48=mean(WS_48)
u30=mean(WS_30)
u10=mean(WS_10)
z=1:100; % meters

%----------------------------------------------------------------------
-----
% Sector-wise mean wind speed
%----------------------------------------------------------------------
-----

for i=1
disp('Sector 1 (15-45 degrees)')
j=1;
for i=1:length(WS_48)
if 15 <= WD_ch8(i) && WD_ch8(i) < 45
WS_48_1(j)=WS_48(i);
WS_10_1(j)=WS_10(i);
WS_30_1(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 2 (45-75 degrees)')
j=1;
for i=1:length(WS_48)
if 45 <= WD_ch8(i) && WD_ch8(i) < 75
WS_48_2(j)=WS_48(i);
WS_10_2(j)=WS_10(i);
WS_30_2(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 3 (75-105 degrees)')
j=1;
for i=1:length(WS_48)
if 75 <= WD_ch8(i) && WD_ch8(i) < 105
WS_48_3(j)=WS_48(i);
WS_10_3(j)=WS_10(i);
WS_30_3(j)=WS_30(i);
j=j+1;
end
```

```
end

disp('Sector 4 (105-135 degrees)')
j=1;
for i=1:length(WS_48)
if 105 <= WD_ch8(i) && WD_ch8(i) < 135
WS_48_4(j)=WS_48(i);
WS_10_4(j)=WS_10(i);
WS_30_4(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 5 (135-165 degrees)')
j=1;
for i=1:length(WS_48)
if 135 <= WD_ch8(i) && WD_ch8(i) < 165
WS_48_5(j)=WS_48(i);
WS_10_5(j)=WS_10(i);
WS_30_5(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 6 (165-195 degrees)')
j=1;
for i=1:length(WS_48)
if 165 <= WD_ch8(i) && WD_ch8(i) < 195
WS_48_6(j)=WS_48(i);
WS_10_6(j)=WS_10(i);
WS_30_6(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 7 (195-225 degrees)')
j=1;
for i=1:length(WS_48)
if 195 <= WD_ch8(i) && WD_ch8(i) < 225
WS_48_7(j)=WS_48(i);
WS_10_7(j)=WS_10(i);
WS_30_7(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 8 (225-255 degrees)')
j=1;
for i=1:length(WS_48)
if 225 <= WD_ch8(i) && WD_ch8(i) < 255
WS_48_8(j)=WS_48(i);
WS_10_8(j)=WS_10(i);
WS_30_8(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 9 (255-285 degrees)')
j=1;
```

```
for i=1:length(WS_48)
if 255 <= WD_ch8(i) && WD_ch8(i) < 285
WS_48_9(j)=WS_48(i);
WS_10_9(j)=WS_10(i);
WS_30_9(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 10 (285-315 degrees)')
j=1;
for i=1:length(WS_48)
if 285 <= WD_ch8(i) && WD_ch8(i) < 315
WS_48_10(j)=WS_48(i);
WS_10_10(j)=WS_10(i);
WS_30_10(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 11 (315-345 degrees)')
j=1;
for i=1:length(WS_48)
if 315 <= WD_ch8(i) && WD_ch8(i) < 345
WS_48_11(j)=WS_48(i);
WS_10_11(j)=WS_10(i);
WS_30_11(j)=WS_30(i);
j=j+1;
end
end

disp('Sector 12 (345-15 degrees)')
j=1;
for i=1:length(WS_48)
if 345 <= WD_ch8(i) && WD_ch8(i) <= 360 || 0 <= WD_ch8(i) && WD_ch8(i)
< 15
WS_48_12(j)=WS_48(i);
WS_10_12(j)=WS_10(i);
WS_30_12(j)=WS_30(i);
j=j+1;
end
end
end
for i=1
% Sector-wise mean values for 48.8m equipment
Mean_WS_48_sector1=mean(WS_48_1)
Mean_WS_48_sector2=mean(WS_48_2)
Mean_WS_48_sector3=mean(WS_48_3)
Mean_WS_48_sector4=mean(WS_48_4)
Mean_WS_48_sector5=mean(WS_48_5)
Mean_WS_48_sector6=mean(WS_48_6)
Mean_WS_48_sector7=mean(WS_48_7)
Mean_WS_48_sector8=mean(WS_48_8)
Mean_WS_48_sector9=mean(WS_48_9)
Mean_WS_48_sector10=mean(WS_48_10)
Mean_WS_48_sector11=mean(WS_48_11)
Mean_WS_48_sector12=mean(WS_48_12)
Mean_WS_48_All_Sectors =mean(WS_48)
```

```
% Sector-wise mean values for 10m equipment
Mean_WS_10_sector1=mean(WS_10_1)
Mean_WS_10_sector2=mean(WS_10_2)
Mean_WS_10_sector3=mean(WS_10_3)
Mean_WS_10_sector4=mean(WS_10_4)
Mean_WS_10_sector5=mean(WS_10_5)
Mean_WS_10_sector6=mean(WS_10_6)
Mean_WS_10_sector7=mean(WS_10_7)
Mean_WS_10_sector8=mean(WS_10_8)
Mean_WS_10_sector9=mean(WS_10_9)
Mean_WS_10_sector10=mean(WS_10_10)
Mean_WS_10_sector11=mean(WS_10_11)
Mean_WS_10_sector12=mean(WS_10_12)
Mean_WS_10_All_Sectors =mean(WS_10)

% Sector-wise mean values for 30m equipment
Mean_WS_30_sector1=mean(WS_30_1)
Mean_WS_30_sector2=mean(WS_30_2)
Mean_WS_30_sector3=mean(WS_30_3)
Mean_WS_30_sector4=mean(WS_30_4)
Mean_WS_30_sector5=mean(WS_30_5)
Mean_WS_30_sector6=mean(WS_30_6)
Mean_WS_30_sector7=mean(WS_30_7)
Mean_WS_30_sector8=mean(WS_30_8)
Mean_WS_30_sector9=mean(WS_30_9)
Mean_WS_30_sector10=mean(WS_30_10)
Mean_WS_30_sector11=mean(WS_30_11)
Mean_WS_30_sector12=mean(WS_30_12)
Mean_WS_30_All_Sectors =mean(WS_30)
end

%----------------------------------------------------------------------
-----
% Sector-wise vertical wind profile
%----------------------------------------------------------------------
-----

% Assigning roughness to sectors
z01_sec1=0.00004;
z01_sec2=0.00004;
z01_sec3=0.0005;
z01_sec4=0.00004;
z01_sec5=0.2;  % 0.2
z01_sec6=0.005;
z01_sec7=0.2;
z01_sec8=0.02;
z01_sec9=0.000005;
z01_sec10=0.0005;
z01_sec11=0.00005;
z01_sec12=0.000004;

%----------------------------------------------------------------------
-----
% Log-law applied to all sectors
%----------------------------------------------------------------------
-----

% General input:
kappa=0.4; % Von-Karman constant.
```

```
z_mast=48.8;
z=1:100;
for loglawing=1
% Sector 1
for i=1
uf_1(i)=(Mean_WS_48_sector1*kappa)/log(z_mast/z01_sec1)
U_sec1_log(z,i)=(uf_1/kappa)*log(z/z01_sec1)
end

% Sector 1
for i=1
uf_1(i)=(Mean_WS_48_sector1*kappa)/log(z_mast/z01_sec1)
U_sec1_log(z,i)=(uf_1/kappa)*log(z/z01_sec1)
end

% Sector 2
for i=1
uf_2(i)=(Mean_WS_48_sector2*kappa)/log(z_mast/z01_sec2)
U_sec2_log(z,i)=(uf_2/kappa)*log(z/z01_sec2)
end

% Sector 3
for i=1
uf_3(i)=(Mean_WS_48_sector3*kappa)/log(z_mast/z01_sec3)
U_sec3_log(z,i)=(uf_3/kappa)*log(z/z01_sec3)
end

% Sector 4
for i=1
uf_4(i)=(Mean_WS_48_sector4*kappa)/log(z_mast/z01_sec4)
U_sec4_log(z,i)=(uf_4/kappa)*log(z/z01_sec4)
end

% Sector 5
for i=1
uf_5(i)=(Mean_WS_48_sector5*kappa)/log(z_mast/z01_sec5)
U_sec5_log(z,i)=(uf_5/kappa)*log(z/z01_sec5)
end

% Sector 6
for i=1
uf_6(i)=(Mean_WS_48_sector6*kappa)/log(z_mast/z01_sec6)
U_sec6_log(z,i)=(uf_6/kappa)*log(z/z01_sec6)
end

% Sector 7
for i=1
uf_7(i)=(Mean_WS_48_sector7*kappa)/log(z_mast/z01_sec7)
U_sec7_log(z,i)=(uf_7/kappa)*log(z/z01_sec7)
end

% Sector 8
for i=1
uf_8(i)=(Mean_WS_48_sector8*kappa)/log(z_mast/z01_sec8)
U_sec8_log(z,i)=(uf_8/kappa)*log(z/z01_sec8)
end

% Sector 9
```

```
for i=1
uf_9(i)=(Mean_WS_48_sector9*kappa)/log(z_mast/z01_sec9)
U_sec9_log(z,i)=(uf_9/kappa)*log(z/z01_sec9)
end

% Sector 10
for i=1
uf_10(i)=(Mean_WS_48_sector10*kappa)/log(z_mast/z01_sec10)
U_sec10_log(z,i)=(uf_10/kappa)*log(z/z01_sec10)
end

% Sector 11
for i=1
uf_11(i)=(Mean_WS_48_sector11*kappa)/log(z_mast/z01_sec11)
U_sec11_log(z,i)=(uf_11/kappa)*log(z/z01_sec11)
end

% Sector 12
for i=1
uf_12(i)=(Mean_WS_48_sector12*kappa)/log(z_mast/z01_sec12)
U_sec12_log(z,i)=(uf_12/kappa)*log(z/z01_sec12)
end
end

for IEC_method_total=1

    alpha_tot=log(u30/u10)/log(30/10);
for i=1
    U_sec_tot(z,i)=u48(i,1)*(z/48.8).^alpha_tot;
end

figure(13)
hold on
plot(u10(i),z(10),'*g',u30(i),z(30),'*r',u48(i),z(49),'*m',...
    U_sec_tot(:,i),z,'r')
title('Vertical wind profile all sectors IEC - 1601 mast',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 10m','Mean wind speed NRG#40 at
30m',...
    'Mean wind speed NRG#40 at 48.8m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

end
% ---------------------------------------------------------------------
-----
% Plotting the vertical wind profiles
% ---------------------------------------------------------------------
-----
close all
for plotting=1

% Sector 1
figure(1)
hold on
plot(Mean_WS_48_sector1(i),z(48),'*g',Mean_WS_30_sector1(i),z(30),...
```

```
    '*r',Mean_WS_10_sector1(i),z(10),'*m',U_sec1_log(:,i),z,'r')
title('Vertical wind profile - Sector 1 Log-law',...
    'FontSize',16,'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 2
figure(2)
hold on
plot(Mean_WS_48_sector2(i),z(48),'*g',Mean_WS_30_sector2(i),z(30),...
    '*r',Mean_WS_10_sector2(i),z(10),'*m',U_sec2_log(:,i),z,'r')
title('Vertical wind profile - Sector 2 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 3
figure(3)
hold on
plot(Mean_WS_48_sector3(i),z(48),'*g',Mean_WS_30_sector3(i),z(30),...
    '*r',Mean_WS_10_sector3(i),z(10),'*m',U_sec3_log(:,i),z,'r')
title('Vertical wind profile - Sector 3 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 4
figure(4)
hold on
plot(Mean_WS_48_sector4(i),z(48),'*g',Mean_WS_30_sector4(i),z(30),...
    '*r',Mean_WS_10_sector4(i),z(10),'*m',U_sec4_log(:,i),z,'r')
title('Vertical wind profile - Sector 4 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 5
figure(5)
hold on
plot(Mean_WS_48_sector5(i),z(48),'*g',Mean_WS_30_sector5(i),z(30),...
```

```
    '*r',Mean_WS_10_sector5(i),z(10),'*m',U_sec5_log(:,i),z,'r')
title('Vertical wind profile - Sector 5 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 6
figure(6)
hold on
plot(Mean_WS_48_sector6(i),z(48),'*g',Mean_WS_30_sector6(i),z(30),...
    '*r',Mean_WS_10_sector6(i),z(10),'*m',U_sec6_log(:,i),z,'r')
title('Vertical wind profile - Sector 6 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 7
figure(7)
hold on
plot(Mean_WS_48_sector7(i),z(48),'*g',Mean_WS_30_sector7(i),z(30),...
    '*r',Mean_WS_10_sector7(i),z(10),'*m',U_sec7_log(:,i),z,'r')
title('Vertical wind profile - Sector 7 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 8
figure(8)
hold on
plot(Mean_WS_48_sector8(i),z(48),'*g',Mean_WS_30_sector8(i),z(30),...
    '*r',Mean_WS_10_sector8(i),z(10),'*m',U_sec8_log(:,i),z,'r')
title('Vertical wind profile - Sector 8 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 9
figure(9)
hold on
```

```
plot(Mean_WS_48_sector9(i),z(48),'*g',Mean_WS_30_sector9(i),z(30),...
    '*r',Mean_WS_10_sector9(i),z(10),'*m',U_sec9_log(:,i),z,'r')
title('Vertical wind profile - Sector 9 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at 
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 10
figure(10)
hold on
plot(Mean_WS_48_sector10(i),z(48),'*g',Mean_WS_30_sector10(i),z(30),..
.
    '*r',Mean_WS_10_sector10(i),z(10),'*m',U_sec10_log(:,i),z,'r')
title('Vertical wind profile - Sector 10 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at 
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 11
figure(11)
hold on
plot(Mean_WS_48_sector11(i),z(48),'*g',Mean_WS_30_sector11(i),z(30),..
.
    '*r',Mean_WS_10_sector11(i),z(10),'*m',U_sec11_log(:,i),z,'r')
title('Vertical wind profile - Sector 11 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at 
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid

% Sector 12
figure(12)
hold on
plot(Mean_WS_48_sector12(i),z(48),'*g',Mean_WS_30_sector12(i),z(30),..
.
    '*r',Mean_WS_10_sector12(i),z(10),'*m',U_sec12_log(:,i),z,'r')
title('Vertical wind profile - Sector 12 Log-law',...
    'FontSize',16,...
    'FontWeight','bold')
legend('Mean wind speed NRG#40 at 48.8m','Mean wind speed NRG#40 at 
30m',...
    'Mean wind speed NRG#40 at 10m','Location','NorthWest')
xlabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
ylabel('Height [m]','FontSize',14,'FontWeight','bold')
grid
```

```
end
```

Investigation of measurement instruments quality in assessment of correlations and primary references

```
clear all;close all;clc

data1 = load('1601_data_Without_Headlines.txt');

%data1= data1(1:156912,:);

%k=6*1*24*365; % no. measurements/year

%% CORRELATION BETWEEN WD INSTRUMENTS

% CORRELATION BETWEEN WD INSTRUMENTS IN TERMS OF WD AVG DATA

WD_ch8 = data1(:,27);
WD_ch7 = data1(:,23);

WD_std_ch8 = data1(:,28);
WD_std_ch7 = data1(:,24);

WD_std_ch8_exceed3 = find(WD_std_ch8<=3); % USE 1.5 instead of 3 gives
0.0258 instead of  0.1116
WD_std_ch8_exceed2 = find(WD_std_ch8<=2);
WD_std_ch8_exceed1_5 = find(WD_std_ch8<=1.5);
WD_std_ch8_exceed1 = find(WD_std_ch8<=1);
WD_std_ch8_exceed0_5 = find(WD_std_ch8<=0.5);

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WD_ch8_month(n) = sum(WD_ch8(1:(n*i)-1))/i;
    WD_ch7_month(n) = sum(WD_ch7(1:(n*i)-1))/i;
    for n=2:44
        WD_ch8_month(n) = sum(WD_ch8((n-1)*i:(n*i)-1))/i;
        WD_ch7_month(n) = sum(WD_ch7((n-1)*i:(n*i)-1))/i;
    end
end

figure(1) % Correlation of avg wind direction of ice-free and 200#P
instruments (NEED TO DO THIS WITH STD.DEV ! ! !)
plot(WD_ch8_month,'-r')
hold on
plot(WD_ch7_month,'-b')
hold on
legend('200 #P','IceFree')
plot(WD_ch8_month,'.r')
hold on
plot(WD_ch7_month,'.b')
hold on
hold off
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Average Wind Direction [°]','FontSize',14,'FontWeight','bold')
title('Correlation of Wind Direction between Wind
Vanes','FontSize',16,...
'FontWeight','bold')
grid
```

```
set(gca,'XTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10','Jan 11','Jun 11'})


% CORRELATION BETWEEN WD INSTRUMENTS IN TERMS OF WD STD.DEV DATA

WD_ch8_std = data1(1:156912,28);
WD_ch7_std = data1(1:156912,24);

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WD_ch8_std_month(n) = sum(WD_ch8_std(1:(n*i)-1))/i;
    WD_ch7_std_month(n) = sum(WD_ch7_std(1:(n*i)-1))/i;
    for n=2:36
        WD_ch8_std_month(n) = sum(WD_ch8_std((n-1)*i:(n*i)-1))/i;
        WD_ch7_std_month(n) = sum(WD_ch7_std((n-1)*i:(n*i)-1))/i;
    end
end


figure(2) % Correlation of avg wind direction of ice-free and 200#P
instruments (NEED TO DO THIS WITH STD.DEV ! ! !)
plot(WD_ch8_std_month,'-r')
hold on
plot(WD_ch7_std_month,'-b')
hold on
legend('200 #P','IceFree')
plot(WD_ch8_std_month,'.r')
hold on
plot(WD_ch7_std_month,'.b')
hold on
hold off
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Standard Deviation Wind Direction
[°]','FontSize',14,'FontWeight','bold')
title('Correlation of Wind Direction between Wind
Vanes','FontSize',16,...
'FontWeight','bold')
grid
set(gca,'XTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})

% CORRELATION BETWEEN WS INSTRUMENTS

data1= data1(1:156912,:);
WS_3 = data1(:,15);

k = 6*1*24*365; % Number of measurements of one year.
WS_riso = data1(:,15);
WS_NRG_50m = data1(:,3);
WS_icefree = data1(:,19);


i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WS_riso_month(n) = sum(WS_riso(1:(n*i)-1))/i;
    WS_NRG_50_month(n) = sum(WS_NRG_50m(1:(n*i)-1))/i;
    WS_icefree_month(n) = sum(WS_icefree(1:(n*i)-1))/i;
```

```
    for n=2:36
        WS_riso_month(n) = sum(WS_riso((n-1)*i:(n*i)-1))/i;
        WS_NRG_50_month(n) = sum(WS_NRG_50m((n-1)*i:(n*i)-1))/i;
        WS_icefree_month(n) = sum(WS_icefree((n-1)*i:(n*i)-1))/i;
    end
end

figure() % Correlation between the top three instruments
plot(WS_riso_month,'-b')
hold on
plot(WS_NRG_50_month,'-r')
hold on
plot(WS_icefree_month,'-g')
hold on
plot(WS_riso_month,'.b')
hold on
plot(WS_NRG_50_month,'.r')
hold on
plot(WS_icefree_month,'.g')
hold on
legend('Risø P2546A','NRG#40','NRG HAE IceFree 3')
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Wind Speed [m/s]','FontSize',14,'FontWeight','bold')
title('Wind speed correlation for the top three instru-
ments','FontSize',16,...
'FontWeight','bold')
grid
set(gca,'XTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10','Jan 11','Jun 11'})


k = 6*1*24*365; % Number of measurements of one year.
WS_NRG_50m = data1(1:k,3);
WS_NRG_30m = data1(1:k,7);
WS_NRG_10m = data1(1:k,11);

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WS_month_NRG_50m(n) = sum(WS_NRG_50m(1:(n*i)-1))/i;
    WS_month_NRG_30m(n) = sum(WS_NRG_30m(1:(n*i)-1))/i;
    WS_month_NRG_10m(n) = sum(WS_NRG_10m(1:(n*i)-1))/i;
    for n=2:12
        WS_month_NRG_50m(n) = sum(WS_NRG_50m((n-1)*i:(n*i)-1))/i;
        WS_month_NRG_30m(n) = sum(WS_NRG_30m((n-1)*i:(n*i)-1))/i;
        WS_month_NRG_10m(n) = sum(WS_NRG_10m((n-1)*i:(n*i)-1))/i;
    end
end


figure() % Vertical wind profile plot, 10, 30, 50 m
plot(WS_month_NRG_50m,'-r')
hold on
plot(WS_month_NRG_30m,'-b')
hold on
plot(WS_month_NRG_10m,'-g')
hold on
legend('NRG#40 50 m','NRG#40 30 m','NRG#40 10 m')
plot(WS_month_NRG_50m,'.r')
hold on
```

```
plot(WS_month_NRG_30m,'.b')
hold on
plot(WS_month_NRG_10m,'.g')
hold on
hold off
axis([1 12 3.5 8.5])
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Wind Speed [m/s]','FontSize',14,'FontWeight','bold')
title('Correlation between NRG#40 instruments','FontSize',16,...
'FontWeight','bold')
grid
set(gca,'XTickLabel',{'Jul 07','Dec 07','Jun 08'})
```

Main script for validation routine and processing of data

```
clear all, close all, clc


data1 = load('1601_data_Without_Headlines.txt');

%% DATA TABLE PRE-PROCESSING
data_1st_pre =data1(1:52171,:); %26.06.2007 - 26.06.2008)
data_2nd_pre =data1(52172:104730,:); %26.06.2008 - 26.06.2009)
data_3rd_pre =data1(104731:156912,:); %26.06.2009 - 26.06.2010)
data_4th_pre =data1(156913:192786,:); %26.06.2010 - 26.06.2011)
data_2007_2010_pre=data1(1:156912,:); %26.06.2007 - 26.06

measurements_year = 6*1*24*365;

% 1st year
mean_WS_1st = mean(data_1st_pre(:,15));
std_dev_WS_1st = mean(data_1st_pre(:,16));
data_rec_1st = length(data_1st_pre)/measurements_year;

% 2nd year
mean_WS_2nd = mean(data_2nd_pre(:,15));
std_dev_WS_2nd = mean(data_2nd_pre(:,16));
data_rec_2nd = length(data_2nd_pre)/measurements_year;

% 3rd year
mean_WS_3rd = mean(data_3rd_pre(:,15));
std_dev_WS_3rd = mean(data_3rd_pre(:,16));
data_rec_3rd = length(data_3rd_pre)/measurements_year;

% 4th year
mean_WS_4th = mean(data_4th_pre(:,15));
std_dev_WS_4th  = mean(data_4th_pre(:,16));
data_rec_4th  = length(data_4th_pre)/measurements_year;

% 2007-2010 (Three first years)
mean_WS_2007_2010 = mean(data_2007_2010_pre(:,15));
std_dev_WS_2007_2010  = mean(data_2007_2010_pre(:,16));
data_rec_2007_2010  =
length(data_2007_2010_pre)/(3*measurements_year);
```

```
%% DEF
WS_4 = data1(:,15);
T4 = data1(:,31);
data1= data1(1:156912,:);


WS_3 = data1(:,15);
WS_mean_untreated = mean(WS_3)
WS_std_untreated = mean(data1(:,16));

data_rec_untreated = length(data1)/(6*1*24*365*3)


%% RANGE TEST

% WIND SPEED: AVG (HORIZONTAL)

figure()
plot(WS_3,'b')
hold on
m_line = refline([0 WS_mean_untreated]);
set(m_line,'color','r')
hold on
sneg_line = refline([0 WS_mean_untreated-WS_std_untreated]);
set(sneg_line,'color','g')
legend('Measured Wind Speeds','Mean Wind Speed','Mean Standard Devia-
tion')
spos_line = refline([0 WS_mean_untreated+WS_std_untreated]);
set(spos_line,'color','g')
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Wind speed [m/s]','FontSize',14,'FontWeight','bold')
title('Measured Wind Speeds (10 min resolu-
tion)','FontSize',16,'FontWeight','bold')
set(gca,'XTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})

offset=0.35;
WS_avg_exceed = find(WS_3<=offset); % Spikes valid

figure()
plot(WS_avg_exceed)
title('Distribution of erroneous data in time series
','FontSize',16,'FontWeight','bold')
xlabel('Number of erroneous data','FontSize',14,'FontWeight','bold')
ylabel('Measurement number','FontSize',14,'FontWeight','bold')


% WIND SPEED: STD. DEV. (HORIZONTAL)

std_dev3 = data1(:,16);
std_dev3_valid = length(find(std_dev3>0 & std_dev3<3));
std_dev3_invalid = length(std_dev3) - length(find(std_dev3>0 &
std_dev3<3)); %1911

find_invalid_std_dev3_0 = find(std_dev3<=0);
find_invalid_std_dev3_3 = find(std_dev3>=3);
```

```
figure()
plot(find_invalid_std_dev3_3,':','LineWidth',3)
hold on
plot(find_invalid_std_dev3_0,':r','LineWidth',3)
hold on
hold off
legend('Exceeds upper limit','Exceeds lower limit')
xlabel('Number of erroneous data','FontSize',14,'FontWeight','bold')
ylabel('Date','FontSize',14,'FontWeight','bold')
title('Distribution of erroneous
data','FontSize',16,'FontWeight','bold')
set(gca,'YTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})
grid


% GUST (HORIZONTAL)
gust = data1(:,17);
%max_gust_invalid = find((gust)>=35); % VALID
min_gust_invalid = find((gust)<=0.35);

% WIND DIRECTION (HORIZONTAL)

% WD test for channel 8: (MINIMUM ERROR)
WD_avg_ch8 =
length(find(0<=data1(1:156912,27)<360))/length(data1(1:156912,27)); %
100%
WD_std_ch8 = data1(:,28);
WD_gust_ch8 =
length(find(0<=data1(1:156912,29)<360))/length(data1(1:156912,29)); %
100%

WD_std_ch8_exceed3 = find(WD_std_ch8<=3); % DO NOT USE ! ! ! DERIVED
BELOW !
WD_std_ch8_exceed75 = find(WD_std_ch8>=75);


k=6*1*24*365; % no. measurements/year

% CORRELATION BETWEEN WD INSTRUMENTS IN TERMS OF WD AVG DATA
WD_ch8 = data1(1:k,27);
WD_ch7 = data1(1:k,23);

WD_std_ch8 = data1(1:k,28);
WD_std_ch7 = data1(1:k,24);

WD_std_ch8_exceed3 = find(WD_std_ch8<=3); % USE 1.5 instead of 3 gives
0.0258 instead of  0.1116
WD_std_ch8_exceed2 = find(WD_std_ch8<=2);
WD_std_ch8_exceed1_5 = find(WD_std_ch8<=1.5);
WD_std_ch8_exceed1 = find(WD_std_ch8<=1);
WD_std_ch8_exceed0_5 = find(WD_std_ch8<=0.5);

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WD_ch8_month(n) = sum(WD_ch8(1:(n*i)-1))/i;
    WD_ch7_month(n) = sum(WD_ch7(1:(n*i)-1))/i;
```

```
    for n=2:12
        WD_ch8_month(n) = sum(WD_ch8((n-1)*i:(n*i)-1))/i;
        WD_ch7_month(n) = sum(WD_ch7((n-1)*i:(n*i)-1))/i;
    end
end


% CORRELATION BETWEEN WD INSTRUMENTS IN TERMS OF WD STD.DEV. DATA

WD_ch8_std = data1(1:156912,28);
WD_ch7_std = data1(1:156912,24);

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WD_ch8_std_month(n) = sum(WD_ch8_std(1:(n*i)-1))/i;
    WD_ch7_std_month(n) = sum(WD_ch7_std(1:(n*i)-1))/i;
    for n=2:(length(WD_ch8)/i)
        WD_ch8_std_month(n) = sum(WD_ch8_std((n-1)*i:(n*i)-1))/i;
        WD_ch7_std_month(n) = sum(WD_ch7_std((n-1)*i:(n*i)-1))/i;
    end
end


% Correlation between ice-free and 200#P wind vane when WD std.dev.
error
% (check channel 7 value when channel 8 has error ! ! !)

WD_ch8_std_error3 = WD_ch8_std(WD_std_ch8_exceed3,1);
WD_ch7_std_error3 = WD_ch7_std(WD_std_ch8_exceed3,1);

WD_ch8_std_error2 = WD_ch8_std(WD_std_ch8_exceed2,1);
WD_ch7_std_error2 = WD_ch7_std(WD_std_ch8_exceed2,1);

WD_ch8_std_error1_5 = WD_ch8_std(WD_std_ch8_exceed1_5,1);
WD_ch7_std_error1_5 = WD_ch7_std(WD_std_ch8_exceed1_5,1);

WD_ch8_std_error1 = WD_ch8_std(WD_std_ch8_exceed1,1);
WD_ch7_std_error1 = WD_ch7_std(WD_std_ch8_exceed1,1);

WD_ch8_std_error0_5 = WD_ch8_std(WD_std_ch8_exceed0_5,1);
WD_ch7_std_error0_5 = WD_ch7_std(WD_std_ch8_exceed0_5,1);

Temp = data1(:,31);

Temp_WD_std_exceed3=Temp(WD_std_ch8_exceed3,1);
Temp_WD_std_exceed2=Temp(WD_std_ch8_exceed2,1);
Temp_WD_std_exceed1_5=Temp(WD_std_ch8_exceed1_5,1);
Temp_WD_std_exceed1=Temp(WD_std_ch8_exceed1,1);
Temp_WD_std_exceed0_5=Temp(WD_std_ch8_exceed0_5,1);


% ERROR AND TEMPERATURE BELOW ZERO:

WD_std_ice_accretion = find(Temp_WD_std_exceed1<0);

for i=1:length(WD_std_ch8_exceed1)
    Temp_ice_accretion = WD_std_ch8_exceed1(WD_std_ice_accretion,1);
```

```
end

WD_std_error_lower_real = Temp_ice_accretion;

% Temperature

Temp = data1(:,31);

Max_Temp = max(Temp); % Valid
Min_Temp = min(Temp); % Valid

% Pressure

load Matrix_Time_Hour_Pressure.mat
press = Matrix_Time_Hour_Pressure(:,3);
Max_press = max(press); % Valid
Min_press = min(press); % Invalid
Invalid_press = length(find(press<940));


%% RELATIONAL TEST

% GUST

for n=1:length(data1)
    WS_gust_rel_test1(n) = data1(n,17)/data1(n,15);
end

WS_gust_rel_test1_mean = mean(WS_gust_rel_test1);

gust_rel_exceed = find(WS_gust_rel_test1>2.5);

figure()
plot(WS_gust_rel_test1,'b')
hold on
m_line = refline([0 WS_gust_rel_test1_mean]);
l_lineAWS = refline([0 2.5]);
l_line = refline([0 3]);
set(m_line,'color','r')
set(l_lineAWS,'color','g')
set(l_line,'color','m')
legend('Measurement ratios','Mean ratio','AWS Truepower lim-
it','Utilized limit')
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Ratio','FontSize',14,'FontWeight','bold')
title('Ratio between Gust and Average Wind Speed','FontSize',16,...
'FontWeight','bold')
grid
set(gca,'XTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})


%% TREND TEST

% WIND SPEED

i=6;
```

```
for n=1:156912
delta_WS_real(n) = max(WS_4(n:(i+(n-1)))) - min(WS_4(n:(i+(n-1))));
end

find(delta_WS_real>5);
delta_WS_real_exceed5 = find(delta_WS_real>=5); % 4872 errors
delta_WS_real_exceed10 = find(delta_WS_real>=10); % 118 errors

% 10 min instead of 1 hour and 10 m/s instead of 5 m/s

for n = 2:length(data1)
delta_WS(n) = max(WS_3(n-1:n)) - min(WS_3(n-1:n));
end

delta_WS_exceed5 = find(delta_WS>=5);
delta_WS_exceed10 = find(delta_WS>=10); % 1 error at 70687

% AVG. TEMP CHANGE 1 HOUR less or equal 5 deg.

i=6;
for n=1:156912
delta_T(n) = max(T4(n:(i+(n-1)))) - min(T4(n:(i+(n-1))));
end

delta_T_exceed5 = find(delta_T>5); % 215 errors
delta_T_exceed9 = find(delta_T>9); % 0 errors

% Temperature correction T(n) = T(n-1)

o_T=(delta_T_exceed5)';
for i=o_T(:,1);
data1(i,31)=data1(i-1,31);
T4(i)=T4(i-1);
end

i=6;
for n=1:156912
delta_T(n) = max(T4(n:(i+(n-1)))) - min(T4(n:(i+(n-1))));
end

delta_T_exceed5 = find(delta_T>5); % 215 errors
delta_T_exceed9 = find(delta_T>9); % 0 errors


% AVG. PRESS CHANGE 3 HOUR less or equal 1 kPa.

i=3;
for n=1:42358
delta_P(n) = max(press(n:(i+(n-1)))) - min(press(n:(i+(n-1))));
end

delta_P_exceed1 = find(delta_P>10); % 0 errors


%% AIR DENSITY
```

```
Pressure_60min = Matrix_Time_Hour_Pressure(5689:31840,3); % hectoPas-
cal 5689:31840 (FROM 26.06.2007 TO 19.06.2010, thus some error in es-
timation of air density and WPD)

for i=1:length(Pressure_60min)
    if Pressure_60min(i) < 750;
        Pressure_60min(i) = mean(Pressure_60min);
    end
end

Pressure_60min_mean=mean(Pressure_60min);

figure()
plot(Pressure_60min)
hold on
m_line = refline([0 Pressure_60min_mean]);
set(m_line,'color','r','LineWidth',2)
legend('Measurements','Mean Pressure')
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Average Pressure [hPa]','FontSize',14,'FontWeight','bold')
title('Air Pressure','FontSize',16,...
'FontWeight','bold')
grid
set(gca,'XTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})


Temp_mean=mean(Temp);
figure()
plot(Temp)
hold on
m_line = refline([0 Temp_mean]);
set(m_line,'color','r','LineWidth',2)
legend('Measurements','Mean Temperature')
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Average Temperature [°C]','FontSize',14,'FontWeight','bold')
title('Air Temperature','FontSize',16,...
'FontWeight','bold')
grid
set(gca,'XTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})


R = 287; % J/kg*K

for i = 1:length(Pressure_60min)
    Pressure(6*i-5:6*i,1) = Pressure_60min(i,:);
end


for n=1:length(Temp)
Air_density(n) = (Pressure(n,1)*100)/(R*(Temp(n,1)+273));
end
Air_density = Air_density';


Air_density_AVG = mean(Air_density)
Air_density_percentage_larger = ((Air_density_AVG/1.225)-1)*100;
```

```
Air_density_invalid = find(Air_density<1.19); % Same amount of error
for below zero as well, clearly errors.

for i=Air_density_invalid(:,1)
    Air_density(i) = Air_density_AVG;
end

Air_density_mean=mean(Air_density);
figure()
plot(Air_density)
hold on
m_line = refline([0 Air_density_mean]);
set(m_line,'color','r','LineWidth',2)
legend('Measurements','Mean Air Density')
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Air Density [kg/m^3]','FontSize',14,'FontWeight','bold')
title('Air Density','FontSize',16,...
'FontWeight','bold')
grid
set(gca,'XTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})

%% ALL ERRORS DELETED IN ONE LOOP

WS_3(WS_avg_exceed) = 995;
o1=(find(WS_3==995))';

std_dev3(find_invalid_std_dev3_0,:) = 999;
std_dev3(find_invalid_std_dev3_3,:) = 999;
o2=(find(std_dev3==999))';

gust(min_gust_invalid,:) = 998;
o3=(find(gust==998))';

WD_std_ch8(WD_std_error_lower_real) = 994; % SELF-MODIFIED !
WD_std_ch8(WD_std_ch8_exceed75) = 994;
o4=(find(WD_std_ch8==994))';

gust(gust_rel_exceed,:) = 997; % <--- THUS CANNOT DUE THESE TEST ON
ALREADY TREATED DATA, BUT WITH THE ORIGINAL ONE AND THEN DELETE THE
ROWS ! ! !
o5=(find(gust==997))';

WS_3(delta_WS_exceed10) = 996;
o6=(find(WS_3==996))';


o = [o1 o2 o3 o4 o5 o6]';
%o=find(data1(:,:)>990)


for i=o(:,1);
data1(i,:)=[];
Air_density(i,:)=[];
end
```

```
WS_3_nonerror = data1(:,15);

% FRACTION OF ERROR IN TERMS OF TOTAL ERROR:
ERROR_DUE_TO_WS_30 = length(o1)/length(o)
ERROR_DUE_TO_WS_STD = length(o2)/length(o)
ERROR_DUE_TO_MIN_GUST = length(o3)/length(o)
ERROR_DUE_TO_WD_STD = length(o4)/length(o)
ERROR_DUE_TO_GUST_REL = length(o5)/length(o)
ERROR_DUE_TO_DELTA_WS = length(o6)/length(o)


figure()
plot(o1,':b','LineWidth',3)
hold on
plot(o2,':g','LineWidth',3)
hold on
plot(o3,':r','LineWidth',3)
hold on
plot(o4,':m','LineWidth',3)
hold on
plot(o5,':k','LineWidth',3)
hold on
plot(o6,':y','LineWidth',3)
hold on
hold off
legend('Wind Speed (Avg.)','Wind Speed (Std. dev.)','Wind Speed
(Gust)','Wind Direction (Std. dev.)','Wind Speed (Gust/Avg. rela-
tion)','Wind Speed (Delta)', 'Location','SouthEast')
xlabel('Number of errors','FontSize',14,'FontWeight','bold')
ylabel('Date','FontSize',14,'FontWeight','bold')
title('Erroneous data distribution','FontSize',16,...
'FontWeight','bold')
grid
set(gca,'YTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})


WS_mean = mean(data1(:,15))
data_rec = length(data1)/(6*1*24*365*3)


%% WPD

for n=1:length(Air_density)
    WPD(n) = Air_density(n,1)*(WS_3_nonerror(n,1)).^3;
end
length(WPD)
WPD_final = (1/(2*length(Air_density)))*sum(WPD)




%% Montly Avg. Wind Speeds

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WS_month(n) = sum(WS_3(1:(n*i)-1))/i;
```

```
    for n=2:(length(WS_3)/i)
        WS_month(n) = sum(WS_3((n-1)*i:(n*i)-1))/i;
    end
end


%% DATA TABLE POST-PROCESSING
data_1st_post =data1(1:49991,:); %26.06.2007 - 26.06.2008)
data_2nd_post =data1(49992:101072,:); %26.06.2008 - 26.06.2009)
data_3rd_post =data1(101073:152193,:); %26.06.2009 - 26.06.2010)
data_2007_2010_post=data1(1:152193,:); %26.06.2007 - 26.06

measurements_year = 6*1*24*365;

% 1st year
mean_WS_1st = mean(data_1st_post(:,15));
std_dev_WS_1st = mean(data_1st_post(:,16));
data_rec_1st = length(data_1st_post)/measurements_year;

% 2nd year
mean_WS_2nd = mean(data_2nd_post(:,15));
std_dev_WS_2nd = mean(data_2nd_post(:,16));
data_rec_2nd = length(data_2nd_post)/measurements_year;

% 3rd year
mean_WS_3rd = mean(data_3rd_post(:,15));
std_dev_WS_3rd = mean(data_3rd_post(:,16));
data_rec_3rd = length(data_3rd_post)/measurements_year;

% 2007-2010 (Three first years)
mean_WS_2007_2010 = mean(data_2007_2010_post(:,15));
std_dev_WS_2007_2010  = mean(data_2007_2010_post(:,16));
data_rec_2007_2010  =
length(data_2007_2010_post)/(3*measurements_year);





clear data1
%----------------------------------------------------------------------
-----
% Temperature and Pressure at Heliport.
% Temperature at 1601 ( NRG 110S )
%
% Datafiles used: Heliport_2007_2008_2009_Temp_Pressure_No_HL_csv
%                 Wind_data1_kristian_two_years.txt
%----------------------------------------------------------------------
-----

% TEMPERATURE HELIPORT
for i=1
%----------------------------------------------------------------------
-----
% Temperature for Heliport
%----------------------------------------------------------------------
-----
```

```
% Loading temperature data (60 minute averages)
% Data from 26.06.2007 to 26.06.2010 (22636 points) [1:22636] ALL data
% Data from 26.06.2007 to 25.06.2009 (14978 points) [1:14978] 2 years

Heliport_two_years =
dlmread('Heliport_2007_2008_2009_Temp_Pressure_No_HL.csv');
Heliport_Temp=Heliport_two_years(:,6)*0.1;
Heliport_Temp=Heliport_Temp(1:14978);



%----------------------------------------------------------------------
-----
% Dividing 60 minute data into 10 minute averages
%----------------------------------------------------------------------
-----


rep=ones(size(Heliport_Temp))*6;
HT=[];
for i=1:numel(Heliport_Temp)
    HT=[HT repmat(Heliport_Temp(i),1,rep(i))];
end
Heliport_Temp_10minute_avg=HT;
disp('Mean temperatur at Heliport 10meter')
Mean_Heliport_Temp_Before=mean(Heliport_Temp_10minute_avg);

%----------------------------------------------------------------------
-----
% Temperature test if delta T is > 5 and > 9
%----------------------------------------------------------------------
-----
T4=Heliport_Temp_10minute_avg;
i=6;
for n=1:89858
delta_T(n) = max(T4(n:(i+(n-1)))) - min(T4(n:(i+(n-1))));
end

delta_T_exceed5 = find(delta_T>5); % 215 errors
delta_T_exceed9 = find(delta_T>9); % 0 errors

% Temperature correction T(n) = T(n-1)

o_T=(delta_T_exceed5)';
for i=o_T(:,1);
T4(i)=T4(i-1);
end

i=6;
for n=1:89858
delta_T(n) = max(T4(n:(i+(n-1)))) - min(T4(n:(i+(n-1))));
end

delta_T_exceed5 = find(delta_T>5); % 215 errors
% delta_T_exceed9 = find(delta_T>9); % 0 errors

T4(delta_T_exceed5) = 995;
o1=(find(T4==995))';
```

```
% T4(delta_T_exceed9) = 996;
% o6=(find(T4==996))';


o = [o1]';
%o=find(data1(:,:)>990)

for i=o(:,1);
T4(i)=[];
end

T4_nonerror = T4(:,1);

Mean_Heli_Temperature_after_filter=mean(T4)
Heliport_Temp_10minute_avg=T4;

%----------------------------------------------------------------------
-----
% Plotting temperature at Heliport
%----------------------------------------------------------------------
-----

figure(9)
plot(Heliport_Temp_10minute_avg,'b')
m_line = refline([0 Mean_Heli_Temperature_after_filter]);
set(m_line,'Color','r')
title('Heliport temperature')
xlabel('Measurements (n)','FontSize',14,'FontWeight','bold')
ylabel('Temperature (deg C)','FontSize',14,'FontWeight','bold')
legend('Temperature at Heliport 10 meter mast 2007-2009',...
    'Mean temperature' ,'Location','NorthWest')
grid
end
```

Closer investigation of lower limit of standard deviation of wind direction and risk of icing

```
clear all;close all;clc

data1 = load('1601_data_Without_Headlines.txt');

data1= data1(1:156912,:);

k=6*1*24*365; % no. measurements/year

% CORRELATION BETWEEN WD INSTRUMENTS IN TERMS OF WD AVG DATA
WD_ch8 = data1(1:k,27);
WD_ch7 = data1(1:k,23);

WD_std_ch8 = data1(1:k,28);
WD_std_ch7 = data1(1:k,24);

WD_std_ch8_exceed3 = find(WD_std_ch8<=3); % USE 1.5 instead of 3 gives
0.0258 instead of  0.1116
WD_std_ch8_exceed2 = find(WD_std_ch8<=2);
```

```
WD_std_ch8_exceed1_5 = find(WD_std_ch8<=1.5);
WD_std_ch8_exceed1 = find(WD_std_ch8<=1);
WD_std_ch8_exceed0_5 = find(WD_std_ch8<=0.5);

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WD_ch8_month(n) = sum(WD_ch8(1:(n*i)-1))/i;
    WD_ch7_month(n) = sum(WD_ch7(1:(n*i)-1))/i;
    for n=2:12
        WD_ch8_month(n) = sum(WD_ch8((n-1)*i:(n*i)-1))/i;
        WD_ch7_month(n) = sum(WD_ch7((n-1)*i:(n*i)-1))/i;
    end
end

figure(1) % Correlation of avg wind direction of ice-free and 200#P
instruments (NEED TO DO THIS WITH STD.DEV ! ! !)
plot(WD_ch8_month,'r')
hold on
plot(WD_ch7_month,'b')
hold on
hold off
xlabel('Month','FontSize',14,'FontWeight','bold')
ylabel('Average Standard Deviation
[°]','FontSize',14,'FontWeight','bold')
title('Correlation of Std.Dev. between Wind Vanes','FontSize',16,...
'FontWeight','bold')
legend('200 #P','ice-free')
grid
axis([0.5 12 3 12])
set(gca,'XTickLabel',{'Jan','Feb','Mar','Apr','May','Jun',...
'Jul','Aug','Sep','Oct','Nov','Dec'})


% CORRELATION BETWEEN WD INSTRUMENTS IN TERMS OF WD AVG DATA

WD_ch8_std = data1(1:156912,28);
WD_ch7_std = data1(1:156912,24);

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WD_ch8_std_month(n) = sum(WD_ch8_std(1:(n*i)-1))/i;
    WD_ch7_std_month(n) = sum(WD_ch7_std(1:(n*i)-1))/i;
    for n=2:36
        WD_ch8_std_month(n) = sum(WD_ch8_std((n-1)*i:(n*i)-1))/i;
        WD_ch7_std_month(n) = sum(WD_ch7_std((n-1)*i:(n*i)-1))/i;
    end
end

figure(2) % Correlation of std.dev. of wind direction of ice-free and
200#P instruments
plot(WD_ch8_std_month,'r')
hold on
plot(WD_ch7_std_month,'b')
hold on
hold off
xlabel('Month','FontSize',14,'FontWeight','bold')
ylabel('Average Standard Deviation
[°]','FontSize',14,'FontWeight','bold')
title('Correlation of Std.Dev. between Wind Vanes','FontSize',16,...
```

```
'FontWeight','bold')
legend('200 #P','ice-free')
grid
axis([0.5 12 3 12])
set(gca,'XTickLabel',{'Jan','Feb','Mar','Apr','May','Jun',...
'Jul','Aug','Sep','Oct','Nov','Dec'})


% Correlation between ice-free and 200#P wind vane when WD std.dev.
error
% (check channel 7 value when channel 8 has error ! ! !)

WD_ch8_std_error3 = WD_ch8_std(WD_std_ch8_exceed3,1);
WD_ch7_std_error3 = WD_ch7_std(WD_std_ch8_exceed3,1);

% UTILIZED
figure(3)
plot(WD_ch8_std_error3,'r')
hold on
plot(WD_ch7_std_error3,'b')
hold on
hold off
legend('200#P: Measurements Exceeding a Lower Limit of 3°','Ice-free:
Measurements Exceeding a Lower Limit of 3°')
xlabel('Number of Flagged Data','FontSize',14,'FontWeight','bold')
ylabel('Degrees [°]','FontSize',14,'FontWeight','bold')
title('Suspicious Standard Deviation Values of Wind Direc-
tion','FontSize',16,'FontWeight','bold')


WD_ch8_std_error2 = WD_ch8_std(WD_std_ch8_exceed2,1);
WD_ch7_std_error2 = WD_ch7_std(WD_std_ch8_exceed2,1);

figure(4)
plot(WD_ch8_std_error2,'r')
hold on
plot(WD_ch7_std_error2,'b')
hold on
hold off


WD_ch8_std_error1_5 = WD_ch8_std(WD_std_ch8_exceed1_5,1);
WD_ch7_std_error1_5 = WD_ch7_std(WD_std_ch8_exceed1_5,1);

figure(5)
plot(WD_ch8_std_error1_5,'r')
hold on
plot(WD_ch7_std_error1_5,'b')
hold on
hold off


WD_ch8_std_error1 = WD_ch8_std(WD_std_ch8_exceed1,1);
WD_ch7_std_error1 = WD_ch7_std(WD_std_ch8_exceed1,1);

% UTILIZED
figure(6)
```

```
plot(WD_ch8_std_error1,'r')
hold on
plot(WD_ch7_std_error1,'b')
hold on
hold off
legend('200#P: Measurements Exceeding a Lower Limit of 1°','Ice-free:
Measurements Exceeding a Lower Limit of 1°')
xlabel('Number of Flagged Data','FontSize',14,'FontWeight','bold')
ylabel('Degrees [°]','FontSize',14,'FontWeight','bold')
title('Suspicious Standard Deviation Values of Wind Direc-
tion','FontSize',16,'FontWeight','bold')



% UTILIZED
figure(21)
plot(WD_std_ch8_exceed1,':')
hold on
hold off
legend('Measurements Exceeding a Lower Limit of 1°')
xlabel('Number of Suspected Data','FontSize',14,'FontWeight','bold')
ylabel('Date','FontSize',14,'FontWeight','bold')
title('Distribution of Suspected
Data','FontSize',16,'FontWeight','bold')
set(gca,'YTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})
grid

WD_ch8_std_error0_5 = WD_ch8_std(WD_std_ch8_exceed0_5,1);
WD_ch7_std_error0_5 = WD_ch7_std(WD_std_ch8_exceed0_5,1);

figure(7)
plot(WD_ch8_std_error0_5,'r')
hold on
plot(WD_ch7_std_error0_5,'b')
hold on
hold off


% Continuous row errors exceed 1.5 WD std


WD_ch8_std_error_con1 = WD_ch8_std(37583:37855,1);
WD_ch7_std_error_con1 = WD_ch7_std(37583:37855,1);

figure(8)
plot(WD_ch8_std_error_con1,'r')
hold on
plot(WD_ch7_std_error_con1,'b')
hold on
hold off


WD_ch8_std_error_con2 = WD_ch8_std(40499:40579,1);
WD_ch7_std_error_con2 = WD_ch7_std(40499:40579,1);

figure(9)
```

```
plot(WD_ch8_std_error_con2,'r')
hold on
plot(WD_ch7_std_error_con2,'b')
hold on
hold off


WD_ch8_std_error_con3 = WD_ch8_std(43259:43313,1);
WD_ch7_std_error_con3 = WD_ch7_std(43259:43313,1);

figure(10)
plot(WD_ch8_std_error_con3,'r')
hold on
plot(WD_ch7_std_error_con3,'b')
hold on
hold off


WD_ch8_std_error_con4 = WD_ch8_std(48862:48935,1);
WD_ch7_std_error_con4 = WD_ch7_std(48862:48935,1);

figure(11)
plot(WD_ch8_std_error_con4,'r')
hold on
plot(WD_ch7_std_error_con4,'b')
hold on
hold off


WD_ch8_std_error_con5 = WD_ch8_std(51332:51365,1);
WD_ch7_std_error_con5 = WD_ch7_std(51332:51365,1);

figure(12)
plot(WD_ch8_std_error_con5,'r')
hold on
plot(WD_ch7_std_error_con5,'b')
hold on
hold off


Temp = data1(:,31);
Temp_WD_std_exceed3=Temp(WD_std_ch8_exceed3,1);
Temp_WD_std_exceed2=Temp(WD_std_ch8_exceed2,1);
Temp_WD_std_exceed1_5=Temp(WD_std_ch8_exceed1_5,1);
Temp_WD_std_exceed1=Temp(WD_std_ch8_exceed1,1);
Temp_WD_std_exceed0_5=Temp(WD_std_ch8_exceed0_5,1);

figure(13)
plot(Temp_WD_std_exceed3)

figure(14)
plot(Temp_WD_std_exceed2)

figure(15)
plot(Temp_WD_std_exceed1_5)
```

```
%UTILIZED
figure(16)
plot(Temp_WD_std_exceed1,':','LineWidth',3)
hold on
hold off
legend('Temperature of Measurements Exceeding Exceeding a Lower Limit
of 1°')
xlabel('Number of Suspected Data','FontSize',14,'FontWeight','bold')
ylabel('Temperature [° C]','FontSize',16,'FontWeight','bold')
title('Temperature at Data Suspi-
cion','FontSize',16,'FontWeight','bold')
grid
 figure(17)
plot(Temp_WD_std_exceed0_5)

 figure(18)
plot(WD_std_ch8_exceed3)

figure(19)
plot(WD_std_ch8_exceed2)

figure(20)
plot(WD_std_ch8_exceed1_5)


% UTILIZED
figure(21)
plot(WD_std_ch8_exceed1,':','LineWidth',3)
hold on
hold off
legend('Measurements Exceeding a Lower Limit of 1°')
xlabel('Number of Suspected Data','FontSize',14,'FontWeight','bold')
ylabel('Date','FontSize',14,'FontWeight','bold')
title('Distribution of Suspected
Data','FontSize',16,'FontWeight','bold')
set(gca,'YTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09','Jun
09','Jan 10','Jun 10'})
grid

figure(22)
plot(WD_std_ch8_exceed0_5)


% ERROR AND TEMPERATURE BELOW ZERO:

WD_std_ice_accretion = find(Temp_WD_std_exceed1<0);

for i=1:length(WD_std_ch8_exceed1)
    Temp_ice_accretion = WD_std_ch8_exceed1(WD_std_ice_accretion,1);
end
```

Correlation between Heliport 10 meter anemometer and 1601 NRG#40 10 meter anemometer

```
clc
clear all
close all

%-------------------------------------------------------------------------
% Correlation between Heliport 10 meter anemometer and 1601 NRG#40 10 meter
% anemometer
%-------------------------------------------------------------------------

load('Heliport')
load('1601_data_Without_Headlines.txt')

k = 6*1*24*365

% Assigning vectors
WS_NRG_10meter=X1601_data_Without_Headlines(1:k,11);
WS_Heliport=Data_heliport(33448:86007,2);


i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WS_Heliport_month(n) = sum(WS_Heliport(1:(n*i)-1))/i;
    WS_NRG_10meter_month(n) = sum(WS_NRG_10meter(1:(n*i)-1))/i;
    for n=2:12
        WS_Heliport_month(n) =sum(WS_Heliport((n-1)*i:(n*i)-1))/i;
        WS_NRG_10meter_month(n) =sum(WS_NRG_10meter((n-1)*i:(n*i)-1))/i;
    end
end

figure(1) % Correlation between Heliport cup and NRG#40 10meter cup anemometer
plot(WS_Heliport_month,'-b')
hold on
plot(WS_NRG_10meter_month,'-r')
hold on
legend('Heliport 10 meters','NRG#40 10 meters')
xlabel('Date','FontSize',14,'FontWeight','bold')
ylabel('Wind Speed [m/s]','FontSize',14,'FontWeight','bold')
title('Wind speed correlation for Heliport and NRG#40 at 10 meter',...
    'FontSize',16,'FontWeight','bold')
grid
set(gca,'XTickLabel',{'Jun 07','Jan 08','Jun 08','Jan 09',...
    'Jun 09','Jan 10','Jun 10','Jan 11','Jun 11'})
```

Nanortalik Heliport climate station validation

```
clear all, close all, clc

load('Data_heliport_Torkel.mat')

% Data2 = load('Data_heliport.mat');
WS_4 = Data_heliport(:,2);
WD_4 = Data_heliport(:,3);
% T4 = data1(:,31);
Data= Data_heliport(1:156060,:);

%data1 = data1(1:156912,15:17);
WS_4 = WS_4(1:156060);
WS_mean_untreated = mean(WS_4)
% WS_std_untreated = mean(data1(:,16));

% data_rec_untreated = length(Data)/(6*1*24*365*4)
```

```
%% RANGE TEST

% WIND SPEED: AVG (HORIZONTAL)

offset=0.35;
WS_avg_exceed = find(WS_4<=offset); % Spikes valid

% WIND DIRECTION (HORIZONTAL)

% WD test for channel 8: (MINIMUM ERROR)
WD_avg_4 = length(find(0<=Data(1:156060,2)<360))/length(Data(1:156060,2)); %
100%

k=6*1*24*365; % no. measurements/year

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WD_4_month(n) = sum(WD_4(1:(n*i)-1))/i;
    for n=2:12
        WD_4_month(n) = sum(WD_4((n-1)*i:(n*i)-1))/i;
        WD_4_month(n) = sum(WD_4((n-1)*i:(n*i)-1))/i;
    end
end

%% TREND TEST

% WIND SPEED

i=6;
for n=1:156060
delta_WS_real(n) = max(WS_4(n:(i+(n-1)))) - min(WS_4(n:(i+(n-1))));
end

find(delta_WS_real>5);
delta_WS_real_exceed5 = find(delta_WS_real>=5); % 4872 errors
delta_WS_real_exceed10 = find(delta_WS_real>=10); % 118 errors

% 10 min instead of 1 hour and 10 m/s instead of 5 m/s

for n = 2:length(Data)
delta_WS(n) = max(WS_4(n-1:n)) - min(WS_4(n-1:n));
end

delta_WS_exceed5 = find(delta_WS>=5);
delta_WS_exceed10 = find(delta_WS>=10); % 1 error at 70687

%% ALL ERRORS DELETED IN ONE LOOP

WS_4(WS_avg_exceed) = 995;
o1=(find(WS_4==995))';

WS_3(delta_WS_exceed10) = 996;
o6=(find(WS_4==996))';
o = [o1 o6]';
%o=find(data1(:,:)>990)

for i=o(:,1);
Data(i,:)=[];
end
```

```
% FRACTION OF ERROR IN TERMS OF TOTAL ERROR:
ERROR_DUE_TO_WS_30 = length(o1)/length(o)
ERROR_DUE_TO_DELTA_WS = length(o6)/length(o)

WS_mean = mean(Data(:,2))
data_rec = length(Data)/(6*1*24*365*1)

%% Montly Avg. Wind Speeds

i = (6*1*24*30); % Measurement per month, 30 day mothly avg.
for n=1:1
    WS_month(n) = sum(WS_4(1:(n*i)-1))/i;
    for n=2:(length(WS_4)/i)
        WS_month(n) = sum(WS_4((n-1)*i:(n*i)-1))/i;
    end
end

%% Replacing value 360 with 0. For WAsP use
Data;
WD_W_4=Data(:,3);
for i=1:length(Data)
    if WD_W_4(i)>359
       Data(i,3)=0;
    end
   Data;
end

find(Data(:,3)==360)
```

Production calculations

```
clc
clear all
close all
load consumption.mat
load production.mat

for production_data=1
for i=1:length(production)
    if production(i) < 0
        production(i) =
((mean(production(1:69,2:25))+mean(production...
            (71:132,2:25))+mean(production(134:295,2:25))+mean(...
            production(297:362,2:25)))/4);
            end
end

for i=1:length(production)
    production_daily(i) = sum(production(i,2:25))/24;
end

for i=1:length(production_daily)
    if production_daily(i) < 0
        production_daily(i) =
(mean(production_daily(1,2:295))+mean(production_daily(1,297:362)))/2;
    end

    if production_daily(i) > 1000
```

```
        production_daily(i) =
(mean(production_daily(1,2:295))+mean(production_daily(1,297:362))/2);
    end
    production_daily;

end

production_daily;
Mean_production_daily=mean(production_daily);


figure(1)
plot(production_daily)
m_line = refline([0 Mean_production_daily]);
set(m_line,'Color','r')
title('Total production','FontSize',16,...
    'FontWeight','bold')
xlabel('April 2011 - April 2012','FontSize',14,'FontWeight','bold')
ylabel('Production (kW)','FontSize',14,'FontWeight','bold')
legend('Production','Mean production','Location','NorthWest')
grid
axis([0 365 300 550])
end

for General_consumption_data=1

Consumption_generators=data;
Date=data(:,1);
Consumption_gen1=data(:,2);
Consumption_gen2=data(:,3);
Consumption_gen3=data(:,4);

Mean_gen1=mean(Consumption_gen1);
Mean_gen2=mean(Consumption_gen2);
Mean_gen3=mean(Consumption_gen3);
for Total_fuel_consumption=1
for i=1:length(Consumption_gen1)
    if Consumption_gen1(i) == -9999
        Consumption_gen1(i) = Mean_gen1;
    end
    if Consumption_gen1(i) == 0
        Consumption_gen1(i) = Mean_gen1;
    end
    if Consumption_gen1(i) > 4000
        Consumption_gen1(i) = Mean_gen1;
    end

    Consumption_gen1;
end

for i=1:length(Consumption_gen2)
    if Consumption_gen2(i) == -9999
        Consumption_gen2(i) = Mean_gen2;
    end
    if Consumption_gen2(i) == 0
        Consumption_gen2(i) = Mean_gen2;
    end
    if Consumption_gen2(i) > 1500
```

```
        Consumption_gen2(i) = Mean_gen2;
    end
    Consumption_gen2;
end

for i=1:length(Consumption_gen3)
    if Consumption_gen3(i) == -9999
        Consumption_gen3(i) = Mean_gen3;
    end
    if Consumption_gen3(i) == 0
        Consumption_gen3(i) = Mean_gen3;
    end
    Consumption_gen3;
end


Consumption_total=Consumption_gen1+Consumption_gen2+Consumption_gen3;
Mean_total=mean(Consumption_total);
for i=1:length(Consumption_total)
    if Consumption_total(i) > 4000
        Consumption_total(i) = Mean_total;
    end
    if Consumption_total(i) < 2000
        Consumption_total(i) = Mean_total;
    end
    Consumption_total;
end

for i=1:50
    if Consumption_total(i) > 3400
       Consumption_total(i) = Mean_total;
    end
    Consumption_total;
end

for i=350:362
    if Consumption_total(i) < 2600
       Consumption_total(i) = Mean_total;
    end
    Consumption_total;
end

figure(2)
plot(Consumption_total)
grid
m_line = refline([0 Mean_total]);
set(m_line,'Color','r')
title('Total fuel consumption for all generators
(l/day)','FontSize'...
    ,16,'FontWeight','bold')
xlabel('April 2011 - April 2012','FontSize',14,'FontWeight','bold')
ylabel('Fuel consumption (l)','FontSize',14,'FontWeight','bold')
legend('Consumption','Mean consumption','Location','NorthWest')
axis([0 365 2000 3900])
end
end
```

```
for correlation=1
Transformed_consumption_series=Consumption_total/...
    (mean(Consumption_total)/mean(production_daily));

Test= (Consumption_total * mean(production_daily))/...
    mean(Consumption_total);

figure(3)
plot(Transformed_consumption_series,'r')
hold on
plot(production_daily)
title('Correlation consumption and production','FontSize',...
    16,'FontWeight','bold')
xlabel('April 2011 - April 2012','FontSize',14,'FontWeight','bold')
ylabel('Production/Consumption
(kW)','FontSize',14,'FontWeight','bold')

legend('Consumption','Production','Location','NorthWest')
axis([0 365 300 600])
grid

Production_january  =
mean(production_daily(1:length(production_daily)/12));
Production_february =
mean(production_daily((length(production_daily)/12)*1:(length(producti
on_daily)/12)*2));
Production_march    =
mean(production_daily((length(production_daily)/12)*2:(length(producti
on_daily)/12)*3));
Production_april    =
mean(production_daily((length(production_daily)/12)*3:(length(producti
on_daily)/12)*4));
Production_may      =
mean(production_daily((length(production_daily)/12)*4:(length(producti
on_daily)/12)*5));
Production_june     =
mean(production_daily((length(production_daily)/12)*5:(length(producti
on_daily)/12)*6));
Production_july     =
mean(production_daily((length(production_daily)/12)*6:(length(producti
on_daily)/12)*7));
Production_august   =
mean(production_daily((length(production_daily)/12)*7:(length(producti
on_daily)/12)*8));
Production_september=
mean(production_daily((length(production_daily)/12)*8:(length(producti
on_daily)/12)*9));
Production_october  =
mean(production_daily((length(production_daily)/12)*9:(length(producti
on_daily)/12)*10));
Production_november =
mean(production_daily((length(production_daily)/12)*10:(length(product
ion_daily)/12)*11));
Production_december =
mean(production_daily((length(production_daily)/12)*11:(length(product
ion_daily)/12)*12));
```

```
Transformed_consumption_series_january  =
mean(Transformed_consumption_series(1:length(Transformed_consumption_s
eries)/12));
Transformed_consumption_series_february =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*1:(length(Transformed_consumption_series)/12)*2));
Transformed_consumption_series_march    =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*2:(length(Transformed_consumption_series)/12)*3));
Transformed_consumption_series_april    =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*3:(length(Transformed_consumption_series)/12)*4));
Transformed_consumption_series_may      =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*4:(length(Transformed_consumption_series)/12)*5));
Transformed_consumption_series_june     =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*5:(length(Transformed_consumption_series)/12)*6));
Transformed_consumption_series_july     =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*6:(length(Transformed_consumption_series)/12)*7));
Transformed_consumption_series_august   =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*7:(length(Transformed_consumption_series)/12)*8));
Transformed_consumption_series_september=
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*8:(length(Transformed_consumption_series)/12)*9));
Transformed_consumption_series_october  =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*9:(length(Transformed_consumption_series)/12)*10));
Transformed_consumption_series_november =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*10:(length(Transformed_consumption_series)/12)*11));
Transformed_consumption_series_december =
mean(Transformed_consumption_series((length(Transformed_consumption_se
ries)/12)*11:(length(Transformed_consumption_series)/12)*12));

figure(4);
scatter(production_daily,Transformed_consumption_series,'b')
hold on
x=1:1000;
for i=1:1000
    y(i)=i;
end
figure(4)
plot(x,y,'k','LineWidth',2)
hold on
axis([320 560 320 560])
grid
title('Correlation between consumption and production','FontSize',...
    16,'FontWeight','bold')
xlabel('Daily energy production
(kW)','FontSize',14,'FontWeight','bold')
ylabel('Adjusted daily oil consumption
(kW)','FontSize',14,'FontWeight','bold')
legend('Actual correlation measurements','Linear correla-
tion','Location','NorthWest')
figure(4)
```

```
scat-
ter(Production_january,Transformed_consumption_series_january,'filled'
,'r')
hold on
scat-
ter(Production_february,Transformed_consumption_series_february,'fille
d','r')
hold on
scat-
ter(Production_march,Transformed_consumption_series_march,'filled','r'
)
hold on
scat-
ter(Production_april,Transformed_consumption_series_april,'filled','r'
)
hold on
scat-
ter(Production_may,Transformed_consumption_series_may,'filled','r')
hold on
scat-
ter(Production_june,Transformed_consumption_series_june,'filled','r')
hold on
scat-
ter(Production_july,Transformed_consumption_series_july,'filled','r')
hold on
scat-
ter(Production_august,Transformed_consumption_series_august,'filled','
r')
hold on
scat-
ter(Production_september,Transformed_consumption_series_september,'fil
led','r')
hold on
scat-
ter(Production_october,Transformed_consumption_series_october,'filled'
,'r')
hold on
scat-
ter(Production_november,Transformed_consumption_series_november,'fille
d','r')
hold on
scat-
ter(Production_december,Transformed_consumption_series_december,'fille
d','r')
hold on

Yearly_production=sum(production_daily);
Yearly_consumption=sum(Consumption_total);
end

for wednesdays_sundays=1
production(3,2:25);

for i=1:362
    a=production(5,2:25);
end

for i=a
a=production(6,2:25);
```

```
b=production(13,2:25);
c=production(20,2:25);
d=production(27,2:25);
e=production(34,2:25);
f=production(41,2:25);
g=production(48,2:25);
h=production(55,2:25);
i=production(62,2:25);
j=production(69,2:25);
k=production(76,2:25);
l=production(83,2:25);
aa=production(90,2:25);
bb=production(97,2:25);
cc=production(104,2:25);
dd=production(111,2:25);
ee=production(118,2:25);
ff=production(125,2:25);
gg=production(132,2:25);
hh=production(137,2:25);
ii=production(144,2:25);
jj=production(151,2:25);
kk=production(158,2:25);
ll=production(165,2:25);
aaa=production(172,2:25);
bbb=production(179,2:25);
ccc=production(186,2:25);
ddd=production(193,2:25);
eee=production(200,2:25);
fff=production(207,2:25);
ggg=production(214,2:25);
hhh=production(221,2:25);
iii=production(228,2:25);
jjj=production(235,2:25);
kkk=production(242,2:25);
lll=production(249,2:25);
aaaa=production(256,2:25);
bbbb=production(263,2:25);
cccc=production(269,2:25);
dddd=production(276,2:25);
eeee=production(283,2:25);
ffff=production(290,2:25);
gggg=production(297,2:25);
hhhh=production(304,2:25);
iiii=production(310,2:25);
jjjj=production(317,2:25);
kkkk=production(324,2:25);
llll=production(331,2:25);
aaaaa=production(338,2:25);
bbbbb=production(345,2:25);
ccccc=production(352,2:25);
ddddd=production(359,2:25);

Wednesdays=[a;b;c;d;e;f;g;h;i;j;k;l;aa;bb;cc;dd;ee;ff;...
    gg;hh;ii;jj;kk;ll;aaa;bbb;ccc;ddd;eee;fff;ggg;hhh;iii;...
    jjj;kkk;lll;aaaa;bbbb;cccc;dddd;eeee;ffff;gggg;hhhh;iiii;...
    jjjj;kkkk;llll;aaaaa;bbbbb;ccccc;ddddd];
end

for i=a
a=production(3,2:25);
```

```
b=production(10,2:25);
c=production(17,2:25);
d=production(24,2:25);
e=production(31,2:25);
f=production(38,2:25);
g=production(45,2:25);
h=production(52,2:25);
i=production(59,2:25);
j=production(66,2:25);
k=production(73,2:25);
l=production(80,2:25);
aa=production(87,2:25);
bb=production(94,2:25);
cc=production(101,2:25);
dd=production(108,2:25);
ee=production(115,2:25);
ff=production(122,2:25);
gg=production(129,2:25);
hh=production(141,2:25);
ii=production(148,2:25);
jj=production(155,2:25);
kk=production(162,2:25);
ll=production(169,2:25);
aaa=production(176,2:25);
bbb=production(183,2:25);
ccc=production(190,2:25);
ddd=production(197,2:25);
eee=production(204,2:25);
fff=production(211,2:25);
ggg=production(218,2:25);
hhh=production(225,2:25);
iii=production(232,2:25);
jjj=production(239,2:25);
kkk=production(246,2:25);
lll=production(253,2:25);
aaaa=production(260,2:25);
bbbb=production(267,2:25);
cccc=production(273,2:25);
dddd=production(280,2:25);
eeee=production(287,2:25);
ffff=production(294,2:25);
gggg=production(301,2:25);
hhhh=production(308,2:25);
iiii=production(314,2:25);
jjjj=production(321,2:25);
kkkk=production(328,2:25);
llll=production(335,2:25);
aaaaa=production(342,2:25);
bbbbb=production(349,2:25);
ccccc=production(356,2:25);

Sundays=[a;b;c;d;e;f;g;h;i;j;k;l;aa;bb;cc;dd;ee;ff;gg;hh;ii;jj;kk;...
    ll;aaa;bbb;ccc;ddd;eee;fff;ggg;hhh;iii;jjj;kkk;lll;aaaa;bbbb;...

cccc;dddd;eeee;ffff;gggg;hhhh;iiii;jjjj;kkkk;llll;aaaaa;bbbbb;ccccc];
end


load Wednesdays_production.mat;
```

```
load Sundays_production.mat;

Prod_wed=Wednesdays;
Prod_sun=Sundays;

for i=1:24
    Mean_prod_wed(i)=mean(Prod_wed(:,i));
    Mean_prod_wed;
end

for i=1:24
    Mean_prod_sun(i)=mean(Prod_sun(:,i));
end

Mean_mean_prod_wed=mean(Mean_prod_wed);
Mean_mean_prod_sun=mean(Mean_prod_sun);

figure(5)
plot(Mean_prod_sun,'LineWidth', 2)
hold on
figure(5)
plot(Mean_prod_wed,'g','LineWidth', 2)
hold on
m_line = refline([0 Mean_production_daily]);
set(m_line,'Color','r')
title('Mean hourly production Sundays and Wednes-
day','FontSize',16,'FontWeight','bold')
xlabel('Time (h)','FontSize',14,'FontWeight','bold')
ylabel('Production (kW)','FontSize',14,'FontWeight','bold')
grid
axis([1 24 300 700])
legend('Sundays','Wednesdays','Mean produc-
tion','Location','NorthWest')
end
%
% for CDF=1
% %----------------------------------------------------------------------
-------
% %The probability density function of the production:
% %----------------------------------------------------------------------
-------
% load PDF_Matrix
% B = reshape(production.',1,[]);
% for i=1:length(B)
%     if B(i) < 0
%         B(i) = (mean(B(1,2:295))+mean(B(1,297:362)))/2;
%     end
%     if B(i) > 1000
%         B(i) = (mean(B(1,2:295))+mean(B(1,297:362))/2);
%     end
%     B;
%
% end
% figure(6)
% xx = linspace(100,800,100);
% yy = normcdf(xx,mean(B),std(B));
% plot(xx,yy,'r-','LineWidth',2);
% grid
% xlabel('Power production (kW)','FontSize',14,'FontWeight','bold')
```

```
% ylabel('Probability','FontSize',14,'FontWeight','bold')
% title('Cumulative Distribution Function - Power Produc-
tion','FontSize',...
%     16,'FontWeight','bold')
% legend('Theoretical CDF','Location','NorthWest')
% end

for Efficiency_Energy_system=1

    Heat_prod_april = 101000;
    Heat_prod_may   = 49000;
    Heat_prod_june  = 34000;
    Heat_prod_july  = 52300;
    Heat_prod_aug   = 49700;
    Heat_prod_sept  = 71100;
    Heat_prod_oct   = 118100;
    Heat_prod_nov   = 93400;
    Heat_prod_dec   = 139100;
    Heat_prod_jan   = 113000;
    Heat_prod_feb   = 96600;
    Heat_prod_mar   = 104000;

        Heat_prod_tot =
Heat_prod_april+Heat_prod_may+Heat_prod_june+...
        Heat_prod_july+Heat_prod_aug+Heat_prod_sept+Heat_prod_oct+...
        Heat_prod_nov+Heat_prod_dec+Heat_prod_jan+Heat_prod_feb+...
        Heat_prod_mar;


for i=1:length(production_daily)
    eff(i)=((production_daily(i)*24)/(Consumption_total(i)*0.001...
           *42000*840))*3600;
end

Mean_eff  = mean(eff);
Total_eff = ((sum(production_daily)*24+Heat_prod_tot)/...
    (sum(Consumption_total*0.001*42000*840)))*3600;

Mean_eff_apr = mean(eff(1:30));
Mean_eff_may = mean(eff(31:61));
Mean_eff_jun = mean(eff(62:91));
Mean_eff_jul = mean(eff(92:122));
Mean_eff_aug = mean(eff(123:153));
Mean_eff_sep = mean(eff(154:183));
Mean_eff_oct = mean(eff(184:214));
Mean_eff_nov = mean(eff(215:244));
Mean_eff_dec = mean(eff(245:275));
Mean_eff_jan = mean(eff(276:306));
Mean_eff_feb = mean(eff(307:335));
Mean_eff_mar = mean(eff(336:362));

figure(7)
plot(eff)
hold on
m_line = refline([0 Mean_eff]);
set(m_line,'Color','r')
figure(7)
scatter(31,Mean_eff_apr,'filled','r')
```

```
hold on
figure(7)
scatter(61,Mean_eff_may,'filled','r')
hold on
figure(7)
scatter(91,Mean_eff_jun,'filled','r')
hold on
figure(7)
scatter(122,Mean_eff_jul,'filled','r')
hold on
figure(7)
scatter(153,Mean_eff_aug,'filled','r')
hold on
figure(7)
scatter(183,Mean_eff_sep,'filled','r')
hold on
figure(7)
scatter(214,Mean_eff_oct,'filled','r')
hold on
figure(7)
scatter(244,Mean_eff_nov,'filled','r')
hold on
figure(7)
scatter(275,Mean_eff_dec,'filled','r')
hold on
figure(7)
scatter(306,Mean_eff_jan,'filled','r')
hold on
figure(7)
scatter(335,Mean_eff_feb,'filled','r')
hold on
figure(7)
scatter(362,Mean_eff_mar,'filled','r')
grid
title('Electrical efficiency','FontSize'...
    ,16,'FontWeight','bold')
xlabel('April 2011 - April 2012','FontSize',14,'FontWeight','bold')
ylabel('Efficiency','FontSize',14,'FontWeight','bold')
legend('Efficiency','Mean efficiency','Monthly averag-
es','Location',...
    'NorthWest')
axis([0 365 0.25 0.45])
end
```

Long term measurements

```
close all
clear all
clc

load Nanortalik_met_data


for i=1:length(data(:,7));
    if data(i) == -4;
        data(i) = [];
    end
end
```

```
data;

WS = data(:,7)*0.1;

%-----------------------------------------------------------------------
-----
% Filtering out the mean wind speed each year:
%-----------------------------------------------------------------------
-----

WS_1961 = mean(WS(1:881));
WS_1962 = mean(WS(882:1839));
WS_1963 = mean(WS(1840:2798));
WS_1964 = mean(WS(2799:3767));
WS_1965 = mean(WS(3768:4762));
WS_1966 = mean(WS(4763:5762));
WS_1967 = mean(WS(5763:6704));
WS_1968 = mean(WS(6705:8025));
WS_1969 = mean(WS(8026:9410));
WS_1970 = mean(WS(9411:10793));
WS_1971 = mean(WS(10794:12189));
WS_1972 = mean(WS(12190:13582));
WS_1973 = mean(WS(13583:14975));
WS_1974 = mean(WS(14976:16372));
WS_1975 = mean(WS(16373:17769));
WS_1976 = mean(WS(17770:19131));
WS_1977 = mean(WS(19132:20524));
WS_1978 = mean(WS(20525:21657));
WS_1979 = mean(WS(21659:22649));
% % WS_1980 = mean(WS(22650:23330)); Almost no data available
% % WS_1981 = mean(WS(23331:23695)); Almost no data available
% WS_1982 = mean(WS(23696:23999)); Three months missing (Jan-March)
WS_1983 = mean(WS(24001:24362));
WS_1984 = mean(WS(24363:24756));
% WS_1985 = mean(WS(24757:25057)); November and December missing
% WS_1987 = mean(WS(25058:25059)); Only two months available
% WS_2005 = mean(WS(25060:31558)); Three months missing data
WS_2006 = mean(WS(31559:39867));
%WS_2007 = mean(WS(39868:41655)); Only three months available
% WS_2008 = mean(WS(41656:42468)); Only two months available
% WS_2009 = mean(WS(42470:48038)); Several months missing
% WS_2010 = mean(WS(48039:49547)); Only four months available

WS_total =
[WS_1961,WS_1962,WS_1963,WS_1964,WS_1965,WS_1966,WS_1967,...
    WS_1968,WS_1969,WS_1970,WS_1971,WS_1972,WS_1973,WS_1974,WS_1975...
    ,WS_1976,WS_1977,WS_1978,WS_1979,WS_1983,WS_1984,WS_2006];

Mean_WS_total = ([WS_1961+WS_1962+WS_1963+WS_1964+WS_1965+WS_1966+...

WS_1967+WS_1968+WS_1969+WS_1970+WS_1971+WS_1972+WS_1973+WS_1974+...

WS_1975+WS_1976+WS_1977+WS_1978+WS_1979+WS_1983+WS_1984+WS_2006])/22;

figure(1)
scat-
ter([1961,1962,1963,1964,1965,1966,1967,1968,1969,1970,1971,1972,1973,
...
    1974,1975,1976,1977,1978,1979,1983,1984,2006],WS_total)
```

```
m_line = refline([0 Mean_WS_total]);
set(m_line,'Color','r')
xlabel('Years','FontSize',14,'FontWeight','bold')
ylabel('Wind Speed (m/s)','FontSize',14,'FontWeight','bold')
title('Mean Wind Speed distribution 1961-1983',...
    'FontSize',16,'FontWeight','bold')
legend('Mean Wind speeds (m/s)','Mean wind speed (m/s)',...
    'Location','NorthEast')
grid
```

Heliport and 1601 Temperature & pressure calculations

```
clc
close all
clear all

%----------------------------------------------------------------------
-----
% Temperature and Pressure at Heliport.
% Temperature at 1601 ( NRG 110S )
%
% Datafiles used: Heliport_2007_2008_2009_Temp_Pressure_No_HL_csv
%                 Wind_data1_kristian_two_years.txt
%----------------------------------------------------------------------
-----

% TEMPERATURE HELIPORT
for i=1
%----------------------------------------------------------------------
-----
% Temperature for Heliport
%----------------------------------------------------------------------
-----

% Loading temperature data (60 minute averages)
% Data from 26.06.2007 to 26.06.2010 (22636 points) [1:22636] ALL data
% Data from 26.06.2007 to 25.06.2009 (14978 points) [1:14978] 2 years

Heliport_two_years =
dlmread('Heliport_2007_2008_2009_Temp_Pressure_No_HL.csv');
Heliport_Temp=Heliport_two_years(:,6)*0.1;
Heliport_Temp=Heliport_Temp(1:14978);


%----------------------------------------------------------------------
-----
% Dividing 60 minute data into 10 minute averages
%----------------------------------------------------------------------
-----

rep=ones(size(Heliport_Temp))*6;
HT=[];
for i=1:numel(Heliport_Temp)
    HT=[HT repmat(Heliport_Temp(i),1,rep(i))];
end
Heliport_Temp_10minute_avg=HT;
disp('Mean temperatur at Heliport 10meter')
Mean_Heliport_Temp_Before=mean(Heliport_Temp_10minute_avg)
```

```
%-----------------------------------------------------------------------
-----
% Temperature test if delta T is > 5 and > 9
%-----------------------------------------------------------------------
-----
T4=Heliport_Temp_10minute_avg;
i=6;
for n=1:89858
delta_T(n) = max(T4(n:(i+(n-1)))) - min(T4(n:(i+(n-1))));
end

delta_T_exceed5 = find(delta_T>5); % 215 errors
delta_T_exceed9 = find(delta_T>9); % 0 errors

% Temperature correction T(n) = T(n-1)

o_T=(delta_T_exceed5)';
for i=o_T(:,1);
T4(i)=T4(i-1);
end

i=6;
for n=1:89858
delta_T(n) = max(T4(n:(i+(n-1)))) - min(T4(n:(i+(n-1))));
end

delta_T_exceed5 = find(delta_T>5); % 215 errors
delta_T_exceed9 = find(delta_T>9); % 0 errors

T4(delta_T_exceed5) = 995;
o1=(find(T4==995))';

T4(delta_T_exceed9) = 996;
o6=(find(T4==996))';


o = [o1]';
% o=find(data1(:,:)>990)

for i=o(:,1);
T4(i)=[];
end

o = [o1]';
% o=find(data1(:,:)>990)

for i=o(:,1);
T4(i)=[];
end


o3=find(T4==995);

o = [o3]';
for i=o(:,1);
T4(i)=[];
end
```

```
T4_nonerror = T4(:,1);

Mean_Heli_Temperature_after_filter=mean(T4)
Heliport_Temp_10minute_avg=T4;

%----------------------------------------------------------------------
-----
% Plotting temperature at Heliport
%----------------------------------------------------------------------
-----

figure(1)
plot(Heliport_Temp_10minute_avg,'b')
m_line = refline([0 Mean_Heli_Temperature_after_filter]);
set(m_line,'Color','r')
title('Heliport temperature')
xlabel('Measurements (n)','FontSize',14,'FontWeight','bold')
ylabel('Temperature (deg C)','FontSize',14,'FontWeight','bold')
legend('Temperature at Heliport 10 meter mast 2007-2009',...
    'Mean temperature' ,'Location','NorthWest')
grid
end

clear T4
% TEMPERATURE 1601 ( NRG 110S )
for i=1
%----------------------------------------------------------------------
-----
% Temperature for 1601
%----------------------------------------------------------------------
-----

% Loading temperature data
% Data from 26.06.2007 to 25.06.2009 (105264 points) [1:105264] 2
years
load Wind_data1_kristian_two_years.txt;
Timestamp=Wind_data1_kristian_two_years(:,1:3);
Temp_NRG=Wind_data1_kristian_two_years(:,32);
Mean_NRG_Temp=mean(Temp_NRG)

%----------------------------------------------------------------------
-----
% Temperature test if delta T is > 5 and > 9
%----------------------------------------------------------------------
-----

T4=Temp_NRG;
i=6;
for n=1:14978
delta_T(n) = max(T4(n:(i+(n-1)))) - min(T4(n:(i+(n-1))));
end

delta_T_exceed5 = find(delta_T>5); % 215 errors
delta_T_exceed9 = find(delta_T>9); % 0 errors

% Temperature correction T(n) = T(n-1)
```

```
o_T=(delta_T_exceed5)';
for i=o_T(:,1);
T4(i)=T4(i-1);
end

i=6;
for n=1:14978
delta_T(n) = max(T4(n:(i+(n-1)))) - min(T4(n:(i+(n-1))));
end

delta_T_exceed5 = find(delta_T>5); % 215 errors
% delta_T_exceed9 = find(delta_T>9); % 0 errors

T4(delta_T_exceed5) = 995;
o1=(find(T4==995))';

% T4(delta_T_exceed9) = 996;
% o6=(find(T4==996))';


o = [o1]';
%o=find(data1(:,:)>990)

for i=o(:,1);
T4(i)=[];
end

T4_nonerror = T4(:,1);

Mean_NRG_Temperature_after_filter=mean(T4)
Temp_NRG=T4;

%-------------------------------------------------------------------
-----
% Plotting temperature at Heliport
%-------------------------------------------------------------------
-----

figure(1)
plot(Temp_NRG,'b')
m_line = refline([0 Mean_NRG_Temperature_after_filter]);
set(m_line,'Color','r')
title('NRG temperature')
xlabel('Measurements (n)','FontSize',14,'FontWeight','bold')
ylabel('Temperature (deg C)','FontSize',14,'FontWeight','bold')
legend('Temperature at 1601 mast 2007-2009',...
    'Mean temperature' ,'Location','NorthWest')
grid
end

Temp_NRG      = Temp_NRG(1:52560);
Temp_Heliport = Heliport_Temp_10minute_avg(1:52560);

length(Temp_NRG)
length(Temp_Heliport)
```

```
Temp_NRG_january  = mean(Temp_NRG(1:length(Temp_NRG)/12));
Temp_NRG_february =
mean(Temp_NRG((length(Temp_NRG)/12)*1:(length(Temp_NRG)/12)*2));
Temp_NRG_march    =
mean(Temp_NRG((length(Temp_NRG)/12)*2:(length(Temp_NRG)/12)*3));
Temp_NRG_april    =
mean(Temp_NRG((length(Temp_NRG)/12)*3:(length(Temp_NRG)/12)*4));
Temp_NRG_may      =
mean(Temp_NRG((length(Temp_NRG)/12)*4:(length(Temp_NRG)/12)*5));
Temp_NRG_june     =
mean(Temp_NRG((length(Temp_NRG)/12)*5:(length(Temp_NRG)/12)*6));
Temp_NRG_july     =
mean(Temp_NRG((length(Temp_NRG)/12)*6:(length(Temp_NRG)/12)*7));
Temp_NRG_august   =
mean(Temp_NRG((length(Temp_NRG)/12)*7:(length(Temp_NRG)/12)*8));
Temp_NRG_september=
mean(Temp_NRG((length(Temp_NRG)/12)*8:(length(Temp_NRG)/12)*9));
Temp_NRG_october  =
mean(Temp_NRG((length(Temp_NRG)/12)*9:(length(Temp_NRG)/12)*10));
Temp_NRG_november =
mean(Temp_NRG((length(Temp_NRG)/12)*10:(length(Temp_NRG)/12)*11));
Temp_NRG_december =
mean(Temp_NRG((length(Temp_NRG)/12)*11:(length(Temp_NRG)/12)*12));

Temp_Heliport_january  =
mean(Temp_Heliport(1:length(Temp_Heliport)/12));
Temp_Heliport_february =
mean(Temp_Heliport((length(Temp_Heliport)/12)*1:(length(Temp_Heliport)
/12)*2));
Temp_Heliport_march    =
mean(Temp_Heliport((length(Temp_Heliport)/12)*2:(length(Temp_Heliport)
/12)*3));
Temp_Heliport_april    =
mean(Temp_Heliport((length(Temp_Heliport)/12)*3:(length(Temp_Heliport)
/12)*4));
Temp_Heliport_may      =
mean(Temp_Heliport((length(Temp_Heliport)/12)*4:(length(Temp_Heliport)
/12)*5));
Temp_Heliport_june     =
mean(Temp_Heliport((length(Temp_Heliport)/12)*5:(length(Temp_Heliport)
/12)*6));
Temp_Heliport_july     =
mean(Temp_Heliport((length(Temp_Heliport)/12)*6:(length(Temp_Heliport)
/12)*7));
Temp_Heliport_august   =
mean(Temp_Heliport((length(Temp_Heliport)/12)*7:(length(Temp_Heliport)
/12)*8));
Temp_Heliport_september=
mean(Temp_Heliport((length(Temp_Heliport)/12)*8:(length(Temp_Heliport)
/12)*9));
Temp_Heliport_october  =
mean(Temp_Heliport((length(Temp_Heliport)/12)*9:(length(Temp_Heliport)
/12)*10));
Temp_Heliport_november =
mean(Temp_Heliport((length(Temp_Heliport)/12)*10:(length(Temp_Heliport
)/12)*11));
Temp_Heliport_december =
mean(Temp_Heliport((length(Temp_Heliport)/12)*11:(length(Temp_Heliport
)/12)*12));
```

```
x=-20:20;
y=-20:20;



figure(4)
plot(x,y,'k','LineWidth',2)
hold on
grid on
scatter(Temp_NRG_january,Temp_Heliport_january,'filled','r')
hold on
figure(4);
scatter(Temp_NRG,Temp_Heliport,'b')
hold on
figure(4)
plot(x,y,'k','LineWidth',2)
hold on
title('Correlation between measured temperature','FontSize',...
    16,'FontWeight','bold')
xlabel('Temperature measurements 1601 Nanortalik met mast
','FontSize',14,'FontWeight','bold')
ylabel('Temperature measurements Heli-
port','FontSize',14,'FontWeight','bold')
legend('Linear correlation','Montly mean correlation','Correlation
measurements','Location','NorthWest')
scatter(Temp_NRG_february,Temp_Heliport_february,'filled','r')
hold on
scatter(Temp_NRG_march,Temp_Heliport_march,'filled','r')
hold on
scatter(Temp_NRG_april,Temp_Heliport_april,'filled','r')
hold on
scatter(Temp_NRG_may,Temp_Heliport_may,'filled','r')
hold on
scatter(Temp_NRG_june,Temp_Heliport_june,'filled','r')
hold on
scatter(Temp_NRG_july,Temp_Heliport_july,'filled','r')
hold on
scatter(Temp_NRG_august,Temp_Heliport_august,'filled','r')
hold on
scatter(Temp_NRG_september,Temp_Heliport_september,'filled','r')
hold on
scatter(Temp_NRG_october,Temp_Heliport_october,'filled','r')
hold on
scatter(Temp_NRG_november,Temp_Heliport_november,'filled','r')
hold on
scatter(Temp_NRG_december,Temp_Heliport_december,'filled','r')
hold on
scatter(Temp_NRG_january,Temp_Heliport_january,'filled','r')
hold on
```

Wind climate 10 meter

```
clc
close all
clear all

load Wind_data1_kristian.txt
WS_10 = Wind_data1_kristian(1:105264,12);
WD_50 = Wind_data1_kristian(1:105264,28);

for Weibull_distribution = 1
%---------------------------------------------------------------------
-----
%The probability density function of the production:
%---------------------------------------------------------------------
-----
%The mean wind speed, its standard deviation and variance

disp('Mean Wind Speed')
wind_mean=mean(WS_10)

disp('Variance')
var=var(WS_10)

%The probability density function
X=1:1:30;

for j=1:1:30
    a(j)=length(find(WS_10<j));
    b(j)=length(find(WS_10==j));
    bb(j)=length(find(WS_10<j-1));
    bbb(j)=length(find(WS_10==j-1));
    c(j)=a(j)+b(j)/2-bb(j)-bbb(j)/2;
    e(j)=c(j)/length(WS_10);
end

pdf_windspeed=e;

%The A and K parameters of Weibull distribution
k=fsolve(@(k) ((mean(WS_10)/gamma(1+1/k)))^2*(gamma(1+2/k)-
(gamma(1+1/k)^2))...
    -var, 1.3)
A=fsolve(@(A) (A*gamma(1+1/k))-mean(WS_10), 6)

[parmhat] = wblfit(WS_10)

% Calculating weibull pdf
Weibull_pdf=k.*(X.^(k-1)./A^k).*exp(-(X./A).^k); % With calculated A %
k

% Weibull parameters obtained from WAsP:

A_WAsP = 6.4
k_WAsP = 1.39
```

```
weib_function = (k_WAsP/A_WAsP)*((X/A_WAsP).^(k_WAsP-1)).*exp(-
((X/A_WAsP).^k_WAsP));

% Plot probability density function and Weibull distribution

figure(1)
bar(pdf_windspeed)
hold on

figure(1)
plot(pdf_windspeed)

figure(1)
bar(weib_function,'r')
hold on

figure(1)
plot(X,pdf_windspeed,'g--','LineWidth',2)
hold on

figure(1)
plot(Weibull_pdf,'r','LineWidth',2)
hold on

figure(1)
plot(X,weib_function,'k--','LineWidth',2)
hold on

figure(1)
plot(X,pdf('Weibull',X,parmhat(1,1),parmhat(1,2)),'y--','LineWidth',2)
hold on

figure(1)
plot(X,pdf('Weibull',X,A_WAsP,k_WAsP),'m:','LineWidth',2)
hold on

xlabel('Wind Speed (m/s)','FontSize',14,'FontWeight','bold')
ylabel('Probability (%)','FontSize',14,'FontWeight','bold')
title('Measured data and Weibull distribution','FontSize',16,...
    'FontWeight','bold')
legend('Measured data','Weibull distribution calculated', ...
    'Weibull distribution WAsP')
% axis([0 30 0 0.3])
grid



%----------------------------------------------------------------------
-----
%Controlling Scalefactor A
%----------------------------------------------------------------------
-----

disp('Control of scalefactor,A')
disp('Percentage of wind speeds less than scalefactor,A')
size1=size(find(WS_10 < A),1);
size2=size(find(WS_10),1);
```

```
result=(size1/size2)*100

%The cumulative distribution function
figure(2)
cdfplot(WS_10)
grid
xlabel('Wind Speed (m/s)','FontSize',14,'FontWeight','bold')
ylabel('Probability','FontSize',14,'FontWeight','bold')
title('Cumulative Distribution Function - Wind
Speed','FontSize',16,...
    'FontWeight','bold')
Legend('CDF Wind Speed','Location','NorthWest')
axis([0 20 0 1])
grid

for Wind_Rose = 1
F=WS_10;
D=WD_50;

figure(3)
met=wind_rose(D,F,'dtype','meteo');
end
end
```

Wind climate 50 meter

```
clc
close all
clear all

load New_met_data.mat
WS_50 = data1(:,15);
WD_50 = data1(:,27);
T     = data1(:,31);

for Weibull_distribution = 1
%---------------------------------------------------------------------
-----
%The probability density function of the production:
%---------------------------------------------------------------------
-----
%The mean wind speed, its standard deviation and variance

disp('Mean Wind Speed')
wind_mean=mean(WS_50)

disp('Variance')
var=var(WS_50)

figure(1)
plot(WS_50)
m_line = refline([0 wind_mean]);
set(m_line,'Color','r')
xlabel('Measurements','FontSize',14,'FontWeight','bold')
ylabel('Wind Speed (m/s)','FontSize',14,'FontWeight','bold')
title('Wind Speed distribution June 2007-June 2010','FontSize',16,...
    'FontWeight','bold')
```

```
legend('Wind speeds (m/s)','Mean wind speed
(m/s)','Location','NorthWest')
axis([0 105264 0 30])
grid

%The probability density function
X=1:1:30;

for j=1:1:30
    a(j)=length(find(WS_50<j));
    b(j)=length(find(WS_50==j));
    bb(j)=length(find(WS_50<j-1));
    bbb(j)=length(find(WS_50==j-1));
    c(j)=a(j)+b(j)/2-bb(j)-bbb(j)/2;
    e(j)=c(j)/length(WS_50);
end

pdf_windspeed=e;

%The A and K parameters of Weibull distribution
k=fsolve(@(k) ((mean(WS_50)/gamma(1+1/k)))^2*(gamma(1+2/k)-
(gamma(1+1/k)^2))...
    -var, 1.3);
A=fsolve(@(A) (A*gamma(1+1/k))-mean(WS_50), 6);

[parmhat] = wblfit(WS_50);

% Calculating weibull pdf
Weibull_pdf=k.*(X.^(k-1)./A^k).*exp(-(X./A).^k); % With calculated A %
k

% Weibull parameters obtained from WAsP:

A_WAsP = 6.0;
k_WAsP = 1.35;

weib_function = (k_WAsP/A_WAsP)*((X/A_WAsP).^(k_WAsP-1)).*exp(-
((X/A_WAsP).^k_WAsP));

% Plot probability density function and Weibull distribution

figure(2)
bar(pdf_windspeed)
hold on

figure(2)
plot(X,pdf_windspeed,'g--','LineWidth',2)
hold on

figure(2)
plot(Weibull_pdf,'r','LineWidth',2)
hold on

xlabel('Wind Speed (m/s)','FontSize',14,'FontWeight','bold')
ylabel('Probability (%)','FontSize',14,'FontWeight','bold')
title('Measured data and Weibull distribution','FontSize',16,...
    'FontWeight','bold')
```

```
legend('Measured data','Weibull distribution calculated', ...
    'Weibull distribution WAsP')
grid

%----------------------------------------------------------------------
-----
%Controlling Scalefactor A
%----------------------------------------------------------------------
-----

disp('Control of scalefactor,A')
disp('Percentage of wind speeds less than scalefactor,A')
size1=size(find(WS_50 < A),1);
size2=size(find(WS_50),1);
result=(size1/size2)*100

%The cumulative distribution function
figure(3)
cdfplot(WS_50)
grid
xlabel('Wind Speed (m/s)','FontSize',14,'FontWeight','bold')
ylabel('Probability','FontSize',14,'FontWeight','bold')
title('Cumulative Distribution Function - Wind
Speed','FontSize',16,...
    'FontWeight','bold')
Legend('CDF Wind Speed','Location','NorthWest')
axis([0 20 0 1])
grid

for Wind_Rose = 1
F=WS_50;
D=WD_50;

figure(4)
met=wind_rose(D,F,'dtype','meteo');
end
%----------------------------------------------------------------------
-----
% Temperature
%----------------------------------------------------------------------
-----
Mean_temperature=mean(T);

figure(5)
plot(T)
m_line = refline([0 Mean_temperature]);
set(m_line,'Color','r')
xlabel('Measurements','FontSize',14,'FontWeight','bold')
ylabel('Temperature','FontSize',14,'FontWeight','bold')
title('Temperature June 2007 - June 2009','FontSize',16,...
    'FontWeight','bold')
grid
axis([0 105264 -20 20])
end
```

Wind power output Site 1

```
%-----------------------------------------------------------------------
-----
% 11427 - Artic Technology
%
% Authors: Kristian Sæbø, Torkel D. Løland, Andreas G. Laukhamar
%          and Stian R. Manger(c)
%-----------------------------------------------------------------------
-----

%-----------------------------------------------------------------------
-----
% Annual wind farm production:
%-----------------------------------------------------------------------
-----

clc
clear all
close all

%-----------------------------------------------------------------------
-----
% Establishing an annual wind regime:
%-----------------------------------------------------------------------
-----

load Wind_Speed_Column15.mat
WS = data1(:,15);

WS_1 = data1(89002:152193,15);
WS_2 = data1(1:89001,15);
WS   = [WS_1;WS_2];
WAsP_hub_height_mean=5.97;
Mean_meas_height=mean(WS);
Upscale_factor=WAsP_hub_height_mean/Mean_meas_height
for i=1:length(WS)
   WS(i)=WS(i)*Upscale_factor;
end

%-----------------------------------------------------------------------
-----
% Power Outpu 10 min resolution:
%-----------------------------------------------------------------------
-----

WS_curve = [0:1:20];
PW_curve = [ 0 0 0 0 43 91 161 262 400 568 780 972 1041 1045 1045 1045
1045 1045 1045 1045 1045];

for i = 1:length(WS)
    if WS(i)> 20
        WS(i) = 0;
    end
end

Power_out = interp1(WS_curve,PW_curve,WS);

Power_out_1 = Power_out(1:(length(Power_out))/3);
```

```
Power_out_2 = Pow-
er_out((length(Power_out))/3+1:length(Power_out)/3*2);
Power_out_3 = Pow-
er_out((length(Power_out))/3*2+1:length(Power_out)/3*3);

Power_out_total = [Power_out_1 Power_out_2 Power_out_3];

for i = 1:length(Power_out_total)
    Power_out_mean(i) = mean(Power_out_total(i,:));
end

Power_out_mean = Power_out_mean';

figure(1)
plot(Power_out_mean)
grid
axis([0 50731 0 1100])
xlabel('10 minute averages [s]','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Power Output WinWind WWD1','FontSize',16,'FontWeight','bold')

figure(2)
binned_plot(1:length(Power_out_mean),Power_out_mean)
axis([0 50731 0 800])
grid
xlabel('10 minute averages [s]','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Power Output WinWind WWD1','FontSize',16,'FontWeight','bold')

save('Power_out_mean_Site1','Power_out_mean')

%----------------------------------------------------------------------
-----
% Power Output Daily resolution:
%----------------------------------------------------------------------
-----

i = 6*24; % Measurement per day
for n=1:1
    Power_out_mean_daily(n) = sum(Power_out_mean(1:(n*i)-1))/i;
    for n=2:round(length(Power_out_mean)/i)
        Power_out_mean_daily(n) = sum(Power_out_mean((n-1)*i:(n*i)-
1))/i;
    end
end

figure(3)
plot(Power_out_mean_daily)
axis([0 365 0 800])
grid
xlabel('Days','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Power Output WinWind WWD1','FontSize',16,'FontWeight','bold')


figure(4)
binned_plot(1:length(Power_out_mean_daily),Power_out_mean_daily)
axis([0 365 0 500])
```

```
grid
xlabel('Days','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Power Output WinWind WWD1','FontSize',16,'FontWeight','bold')
```

Wind power output Site 2

```
%----------------------------------------------------------------------
-----
% 11427 - Artic Technology
%
% Authors: Kristian Sæbø, Torkel D. Løland, Andreas G. Laukhamar
%          and Stian R. Manger(c)
%----------------------------------------------------------------------
-----

%----------------------------------------------------------------------
-----
% Annual wind farm production:
%----------------------------------------------------------------------
-----

clc
clear all
close all

%----------------------------------------------------------------------
-----
% Establishing an annual wind regime:
%----------------------------------------------------------------------
-----

load Wind_Speed_Column15.mat

WS = data1(:,15);
WS_1 = data1(89002:152193,15);
WS_2 = data1(1:89001,15);
WS   = [WS_1;WS_2];
WAsP_hub_height_mean_site1=5.97;
Mean_ws_meas_height=mean(WS);
Upscale_factor=WAsP_hub_height_mean_site1/Mean_ws_meas_height
for i=1:length(WS)
   WS(i)=WS(i)*Upscale_factor;
end

% Transforming to hub height at site 2
WAsP_site2_mean_ws=7.31;
Upscale_factor_site2=WAsP_site2_mean_ws/mean(WS)

for i=1:length(WS)
   WS(i)=WS(i)*Upscale_factor_site2;
end

Mean_WS_Site2_Hub_height=mean(WS)

%----------------------------------------------------------------------
-----
% Power Outpu 10 min resolution:
```

```
%----------------------------------------------------------------------
-----

WS_curve = [0:1:20];
PW_curve = [ 0 0 0 0 43 91 161 262 400 568 780 972 1041 1045 1045 1045
1045 1045 1045 1045 1045];

for i = 1:length(WS)
    if WS(i)> 20
        WS(i) = 0;
    end
end

Power_out = interp1(WS_curve,PW_curve,WS);

Power_out_1 = Power_out(1:(length(Power_out))/3);
Power_out_2 = Pow-
er_out((length(Power_out))/3+1:length(Power_out)/3*2);
Power_out_3 = Pow-
er_out((length(Power_out))/3*2+1:length(Power_out)/3*3);

Power_out_total = [Power_out_1 Power_out_2 Power_out_3];

for i = 1:length(Power_out_total)
    Power_out_mean(i) = mean(Power_out_total(i,:));
end

Power_out_mean = Power_out_mean';

figure(1)
plot(Power_out_mean)
grid
axis([0 50731 0 1100])
xlabel('10 minute averages [s]','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Power Output WinWind WWD1','FontSize',16,'FontWeight','bold')

figure(2)
binned_plot(1:length(Power_out_mean),Power_out_mean)
axis([0 50731 0 800])
grid
xlabel('10 minute averages [s]','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Power Output WinWind WWD1','FontSize',16,'FontWeight','bold')

save('Power_out_mean_Site2','Power_out_mean')
%----------------------------------------------------------------------
-----
% Power Output Daily resolution:
%----------------------------------------------------------------------
-----

i = 6*24; % Measurement per day
for n=1:1
    Power_out_mean_daily(n) = sum(Power_out_mean(1:(n*i)-1))/i;
    for n=2:round(length(Power_out_mean)/i)
        Power_out_mean_daily(n) = sum(Power_out_mean((n-1)*i:(n*i)-
1))/i;
```

```
    end
end

figure(3)
plot(Power_out_mean_daily)
axis([0 365 0 800])
grid
xlabel('Days','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Power Output WinWind WWD1','FontSize',16,'FontWeight','bold')


figure(4)
binned_plot(1:length(Power_out_mean_daily),Power_out_mean_daily)
axis([0 365 0 600])
grid
xlabel('Days','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Power Output WinWind WWD1','FontSize',16,'FontWeight','bold')
```

Energy system model Site 1

```
%---------------------------------------------------------------------
-----
% 11427 - Artic Technology
%
% Authors: Kristian Sæbø, Torkel D. Løland, Andreas G. Laukhamar
%          and Stian R. Manger(c)
%---------------------------------------------------------------------
-----

clear all
close all
clc

%---------------------------------------------------------------------
-----
% Energy System Model:
%---------------------------------------------------------------------
-----

Efficiency_el_boiler   = 0.99;
Efficiency_transformer = 0.95;
Total_efficiency       = Efficiency_el_boiler*Efficiency_transformer;
Critical_power_Gen_1   = 1080-150;
Critical_power_Gen_3   = 540-150;
El_price               = 3.33;
Heat_price             = 0.782/6;
Diesel_price           = 5.85;

% For Sensitivity Analysis
% Diesel_price=0.9*5.85;

load Power_out_mean_Site1
load Consumption_10min_For_Model
load Generator_1_Power
load Generator_1_Fuel
load Generator_3_Power
```

```
load Generator_3_Fuel

P_wind = Power_out_mean(:,1);
% For Sensitivity Analysis


% for i=1:length(P_wind)
%     P_wind(i)=P_wind(i)*0.9;
% end

Consumption = production_10min_1year(:,1);
P_exceed    = (P_wind-Consumption);




figure(1)
plot(P_exceed)
m_line = refline([0 0]);
set(m_line,'Color','r')
hold on
axis([0 50731 -1000 1000])
grid
xlabel('10 min averages','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Surplus/Deficit power including wind power',...
      'FontSize',16,'FontWeight','bold')

%----------------------------------------------------------------------
-----
% Vectors for oil saved or needed for heat and el generation:
%----------------------------------------------------------------------
-----

for i = 1:length(P_exceed)
    if P_exceed(i)> 0
        Power_saved_for_heat(i) = P_exceed(i).*Efficiency_el_boiler;
    end
    if P_exceed(i)< 0
        Power_needed_for_el(i) = P_exceed(i);
    end
end

Power_saved_for_heat = Power_saved_for_heat';
Power_needed_for_el = (Power_needed_for_el)';
Power_needed_for_el = Power_needed_for_el*(-1);

figure(2)
plot(abs(Power_saved_for_heat))
hold on
axis([0 50731 0 800])
grid
xlabel('10 min averages','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Surplus wind power','FontSize',16,'FontWeight','bold')


figure(3)
```

```
plot(Power_needed_for_el)
hold on
axis([0 50731 0 900])
grid
xlabel('10 min averages','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Required diesel generated
power','FontSize',16,'FontWeight','bold')

%----------------------------------------------------------------------
-----
% Diesel needed for electricity generation with wind power included:
%----------------------------------------------------------------------
-----
Generator_3_Power = Generator_3_Power(1:1736);
Generator_3_Fuel  = Generator_3_Fuel(1:1736);

Generator_1_Power = Generator_1_Power(1886:4487);
Generator_1_Fuel  = Generator_1_Fuel(1886:4487);

for i = 1:length(Generator_1_Power(1:412))
    if Generator_1_Power(i) == 500
        Generator_1_Power(i) = 499.9;
    end
end

for i = 1:length(Generator_1_Power(1:1403))
    if  Generator_1_Power(i) == 750
        Generator_1_Power(i) = 749.99;
    end
end

for i = 1:length(Generator_3_Power(1:750))
    if Generator_3_Power(i) == 135
        Generator_3_Power(i) = 134.9;
    end
end

for i = 1:length(Generator_3_Power(1:1256))
    if Generator_3_Power(i) == 270
        Generator_3_Power(i) = 269.9;
    end
end

for i = 1:length(Power_needed_for_el)
    if Power_needed_for_el(i) < max(Generator_3_Power(:))
       Diesel_needed_for_el_gen_3(i) = interp1(Generator_3_Power,...
                                               Generator_3_Fuel,...
                                               Pow-
er_needed_for_el(i));
    else
       Diesel_needed_for_el_gen_1(i) = interp1(Generator_1_Power,...
                                               Generator_1_Fuel,...
                                               Pow-
er_needed_for_el(i));
    end
end
```

```
for i = 1:length(Power_needed_for_el)
    if Power_needed_for_el(i) < 540
        Generator_3(i) = Diesel_needed_for_el_gen_3(i);
    else
        Generator_1(i) = Diesel_needed_for_el_gen_1(i);
    end
end

figure(4)
plot(Generator_3,'b')
hold on
figure(4)
plot(Generator_1,'g')
hold on
grid
axis([0 length(Generator_3) 0 40])
xlabel('Average 10 min averages','FontSize',14,'FontWeight','bold')
ylabel('Fuel [l]','FontSize',14,'FontWeight','bold')
title('Diesel usage distribution and magni-
tude','FontSize',16,'FontWeight','bold')
legend('Generator 3 (540 kW)','Generator 1 (1080 kW)')

%-----------------------------------------------------------------------
-----
% Diesel needed for electricity generation without wind power includ-
ed:
%-----------------------------------------------------------------------
-----

for i=1:length(Consumption)

    if Consumption(i)>=min(Consumption) && Consumption(i) < 390
        Consumption_Gen_3(i) = Consumption(i);
    else
        Consumption_Gen_3(i)=999;
    end
    if Consumption(i)<= max(Consumption) && Consumption(i) > 390
        Consumption_Gen_1(i) = Consumption(i);
    else
        Consumption_Gen_1(i)=999;
    end
end

error_code=(find(Consumption_Gen_3==999))';
error_code_1=(find(Consumption_Gen_1==999))';

for i=error_code(:,1);
Consumption_Gen_3(:,i)=[];
end

for i=error_code_1(:,1);
Consumption_Gen_1(:,i)=[];
end

Diesel_needed_for_el_gen_pure_diesel_gen_1 = in-
terp1(Generator_1_Power,...
                                                     Genera-
tor_1_Fuel,...
```

```
                                                  Consump-
tion_Gen_1);
Diesel_needed_for_el_gen_pure_diesel_gen_3 = in-
terp1(Generator_3_Power,...
                                                  Genera-
tor_3_Fuel,...
                                                  Consump-
tion_Gen_3);

Diesel_needed_for_el_gen_pure_diesel =...
    sum(Diesel_needed_for_el_gen_pure_diesel_gen_1)+...
    sum(Diesel_needed_for_el_gen_pure_diesel_gen_3);

Diesel_needed_for_el_with_wind = sum(Diesel_needed_for_el_gen_1)+...
                                 sum(Diesel_needed_for_el_gen_3);

Fuel_savings_liter = Diesel_needed_for_el_gen_pure_diesel-...
                     Diesel_needed_for_el_with_wind

error_Gen_3_code =(find(Generator_3==0))';
error_Gen_1_code =(find(Generator_1==0))';

for i=error_Gen_3_code(:,1);
Generator_3(:,i)=[];
end

for i=error_Gen_1_code(:,1);
Generator_1(:,i)=[];
end

%----------------------------------------------------------------------
-----
% Annual share of the total fuel consumption:
%----------------------------------------------------------------------
-----
figure(22)
plot(Generator_3,'b')
hold on
plot(Diesel_needed_for_el_gen_pure_diesel_gen_3,'g')
hold on
plot(Diesel_needed_for_el_gen_pure_diesel_gen_1,'m')
hold on
plot(Generator_1,'k')
hold on
grid
legend('Fuel usage Generator 3 with wind',...
       'Fuel usage Generator 3 without wind',...
       'Fuel usage Generator 1 without wind',...
       'Fuel usage Generator 1 with wind')
xlabel('Annual share of the total fuel consumption
[%]','FontSize',14,'FontWeight','bold')
ylabel('Fuel [l]','FontSize',14,'FontWeight','bold')
title('Diesel usage distribution with and without
wind','FontSize',16,'FontWeight','bold')
axis([0 length(Generator_3) 0 40])

%----------------------------------------------------------------------
-----
```

```
% Income / Savings
%----------------------------------------------------------------------
-----

for i = 1:length(Fuel_savings_liter)
Fuel_savings(i)=Fuel_savings_liter(i)*Diesel_price;
end
Total_fuel_savings=sum(Fuel_savings)

for i = 1:length(Power_saved_for_heat)
Heat_income(i)=Power_saved_for_heat(i)*Heat_price;
end
Total_heat_income=sum(Heat_income)

Total_economical_benefit_yearly=Total_fuel_savings+Total_heat_income

To-
tal_economical_benefit_project_lifetime=Total_economical_benefit_yearl
y*20

%----------------------------------------------------------------------
-----
% Emissions reduced
%----------------------------------------------------------------------
-----

CO2_per_kWh_crude_oil=260/6; % g/kW,10min
http://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html
CO2_per_kWh_diesel=240/6; % g/kW,10min
http://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html

CO2_emission_reduced_crude_oil=sum(CO2_per_kWh_crude_oil.*...
Power_saved_for_heat)/1e6;

CO2_emission_without_wind=sum(CO2_per_kWh_diesel.*Consumption)...
/1e6
CO2_emission_with_wind_diesel=sum(CO2_per_kWh_diesel.*Power_needed_for
_el)...
/1e6
CO2_savings_diesel=CO2_emission_without_wind-
CO2_emission_with_wind_diesel

disp('Total CO2 emission reduced by implementing turbine [tonnes]')
Total_CO2_emission_reduction=CO2_emission_reduced_crude_oil...
+CO2_savings_diesel
```

Energy system model Site 2

```
%-----------------------------------------------------------------------
-----
% 11427 - Artic Technology
%
% Authors: Kristian Sæbø, Torkel D. Løland, Andreas G. Laukhamar
%          and Stian R. Manger(c)
%-----------------------------------------------------------------------
-----

clear all
close all
clc

%-----------------------------------------------------------------------
-----
% Energy System Model:
%-----------------------------------------------------------------------
-----

Efficiency_el_boiler    = 0.99;
Efficiency_transformer = 0.95;
Total_efficiency        = Efficiency_el_boiler*Efficiency_transformer;
Critical_power_Gen_1    = 1080-150;
Critical_power_Gen_3    = 540-150;
El_price                = 3.33;
Heat_price              = 0.782/6;
Diesel_price            = 5.85;

% % For Sensitivity Analysis
% Diesel_price=0.9*5.85;


load Power_out_mean_Site2
load Consumption_10min_For_Model
load Generator_1_Power
load Generator_1_Fuel
load Generator_3_Power
load Generator_3_Fuel

P_wind = Power_out_mean(:,1);
% For Sensitivity Analysis


% for i=1:length(P_wind)
%     P_wind(i)=P_wind(i)*0.9;
% end

Consumption = production_10min_1year(:,1);
P_exceed    = (P_wind-Consumption);

figure(1)
plot(P_exceed)
m_line = refline([0 0]);
set(m_line,'Color','r')
hold on
axis([0 50731 -1000 1000])
grid
```

```
xlabel('10 min averages','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Surplus/Deficit power including wind power',...
      'FontSize',16,'FontWeight','bold')

%-----------------------------------------------------------------------
-----
% Vectors for oil saved or needed for heat and el generation:
%-----------------------------------------------------------------------
-----

for i = 1:length(P_exceed)
    if P_exceed(i)> 0
        Power_saved_for_heat(i) = P_exceed(i).*Efficiency_el_boiler;
    end
    if P_exceed(i)< 0
        Power_needed_for_el(i) = P_exceed(i);
    end
end

Power_saved_for_heat = Power_saved_for_heat';
Power_needed_for_el = (Power_needed_for_el)';
Power_needed_for_el = Power_needed_for_el*(-1);

figure(2)
plot(abs(Power_saved_for_heat))
hold on
axis([0 50731 0 800])
grid
xlabel('10 min averages','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Surplus wind power','FontSize',16,'FontWeight','bold')


figure(3)
plot(Power_needed_for_el)
hold on
axis([0 50731 0 900])
grid
xlabel('10 min averages','FontSize',14,'FontWeight','bold')
ylabel('Power [kW]','FontSize',14,'FontWeight','bold')
title('Required diesel generated
power','FontSize',16,'FontWeight','bold')

%-----------------------------------------------------------------------
-----
% Diesel needed for electricity generation with wind power included:
%-----------------------------------------------------------------------
-----
Generator_3_Power = Generator_3_Power(1:1736);
Generator_3_Fuel  = Generator_3_Fuel(1:1736);

Generator_1_Power = Generator_1_Power(1886:4487);
Generator_1_Fuel  = Generator_1_Fuel(1886:4487);

for i = 1:length(Generator_1_Power(1:412))
    if Generator_1_Power(i) == 500
        Generator_1_Power(i) = 499.9;
```

```
    end
end

for i = 1:length(Generator_1_Power(1:1403))
    if  Generator_1_Power(i) == 750
        Generator_1_Power(i) = 749.99;
    end
end

for i = 1:length(Generator_3_Power(1:750))
    if Generator_3_Power(i) == 135
        Generator_3_Power(i) = 134.9;
    end
end

for i = 1:length(Generator_3_Power(1:1256))
    if Generator_3_Power(i) == 270
        Generator_3_Power(i) = 269.9;
    end
end

for i = 1:length(Power_needed_for_el)
    if Power_needed_for_el(i) < max(Generator_3_Power(:))
       Diesel_needed_for_el_gen_3(i) = interp1(Generator_3_Power,...
                                               Generator_3_Fuel,...
                                               Pow-
er_needed_for_el(i));
    else
       Diesel_needed_for_el_gen_1(i) = interp1(Generator_1_Power,...
                                               Generator_1_Fuel,...
                                               Pow-
er_needed_for_el(i));
    end
end

for i = 1:length(Power_needed_for_el)
    if Power_needed_for_el(i) < 540
        Generator_3(i) = Diesel_needed_for_el_gen_3(i);
    else
        Generator_1(i) = Diesel_needed_for_el_gen_1(i);
    end
end

figure(4)
plot(Generator_3,'b')
hold on
figure(4)
plot(Generator_1,'g')
hold on
grid
axis([0 length(Generator_3) 0 40])
xlabel('Average 10 min averages','FontSize',14,'FontWeight','bold')
ylabel('Fuel [l]','FontSize',14,'FontWeight','bold')
title('Diesel usage distribution and magni-
tude','FontSize',16,'FontWeight','bold')
legend('Generator 3 (540 kW)','Generator 1 (1080 kW)')

%----------------------------------------------------------------------
-----
```

```
% Diesel needed for electricity generation without wind power includ-
ed:
%-------------------------------------------------------------------
-----

for i=1:length(Consumption)

    if Consumption(i)>=min(Consumption) && Consumption(i) < 390
        Consumption_Gen_3(i) = Consumption(i);
    else
        Consumption_Gen_3(i)=999;
    end
    if Consumption(i)<= max(Consumption) && Consumption(i) > 390
        Consumption_Gen_1(i) = Consumption(i);
    else
        Consumption_Gen_1(i)=999;
    end
end

error_code=(find(Consumption_Gen_3==999))';
error_code_1=(find(Consumption_Gen_1==999))';

for i=error_code(:,1);
Consumption_Gen_3(:,i)=[];
end

for i=error_code_1(:,1);
Consumption_Gen_1(:,i)=[];
end

Diesel_needed_for_el_gen_pure_diesel_gen_1 = in-
terp1(Generator_1_Power,...
                                                      Genera-
tor_1_Fuel,...
                                                      Consump-
tion_Gen_1);
Diesel_needed_for_el_gen_pure_diesel_gen_3 = in-
terp1(Generator_3_Power,...
                                                      Genera-
tor_3_Fuel,...
                                                      Consump-
tion_Gen_3);

Diesel_needed_for_el_gen_pure_diesel =...
    sum(Diesel_needed_for_el_gen_pure_diesel_gen_1)+...
    sum(Diesel_needed_for_el_gen_pure_diesel_gen_3);

Diesel_needed_for_el_with_wind = sum(Diesel_needed_for_el_gen_1)+...
                                 sum(Diesel_needed_for_el_gen_3);

Fuel_savings_liter = Diesel_needed_for_el_gen_pure_diesel-...
                     Diesel_needed_for_el_with_wind

error_Gen_3_code =(find(Generator_3==0))';
error_Gen_1_code =(find(Generator_1==0))';

for i=error_Gen_3_code(:,1);
Generator_3(:,i)=[];
```

```
end

for i=error_Gen_1_code(:,1);
Generator_1(:,i)=[];
end

%------------------------------------------------------------------------
-----
% Annual share of the total fuel consumption:
%------------------------------------------------------------------------
-----
figure(22)
plot(Generator_3,'b')
hold on
plot(Diesel_needed_for_el_gen_pure_diesel_gen_3,'g')
hold on
plot(Diesel_needed_for_el_gen_pure_diesel_gen_1,'m')
hold on
plot(Generator_1,'k')
hold on
grid
legend('Fuel usage Generator 3 with wind',...
       'Fuel usage Generator 3 without wind',...
       'Fuel usage Generator 1 without wind',...
       'Fuel usage Generator 1 with wind')
xlabel('Annual share of the total fuel consumption
[%]','FontSize',14,'FontWeight','bold')
ylabel('Fuel [l]','FontSize',14,'FontWeight','bold')
title('Diesel usage distribution with and without
wind','FontSize',16,'FontWeight','bold')
axis([0 length(Generator_3) 0 40])

%------------------------------------------------------------------------
-----
% Income / Savings
%------------------------------------------------------------------------
-----

for i = 1:length(Fuel_savings_liter)
Fuel_savings(i)=Fuel_savings_liter(i)*Diesel_price;
end
Total_fuel_savings=sum(Fuel_savings)

for i = 1:length(Power_saved_for_heat)
Heat_income(i)=Power_saved_for_heat(i)*Heat_price;
end
Total_heat_income=sum(Heat_income)

Total_economical_benefit_yearly=Total_fuel_savings+Total_heat_income

To-
tal_economical_benefit_project_lifetime=Total_economical_benefit_yearl
y*20

%------------------------------------------------------------------------
-----
% Emissions reduced
```

```
%----------------------------------------------------------------------
-----

CO2_per_kWh_crude_oil=260/6; % g/kW,10min
http://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html
CO2_per_kWh_diesel=240/6; % g/kW,10min
http://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html

CO2_emission_reduced_crude_oil=sum(CO2_per_kWh_crude_oil.*...
Power_saved_for_heat)/1e6;

CO2_emission_without_wind=sum(CO2_per_kWh_diesel.*Consumption)...
/1e6
CO2_emission_with_wind_diesel=sum(CO2_per_kWh_diesel.*Power_needed_for
_el)...
/1e6
CO2_savings_diesel=CO2_emission_without_wind-
CO2_emission_with_wind_diesel

disp('Total CO2 emission reduced by implementing turbine [tonnes]')
Total_CO2_emission_reduction=CO2_emission_reduced_crude_oil...
+CO2_savings_diesel
```