Wind Power Integration in the Nuuk Energy System

Dimitrios Bizopoulos, Spyridon Koutsos, MSc
DTU Wind Energy

ABSTRACT: This paper examines the feasibility of the wind energy implementation in the area of Nuuk. In order to acquire the social perception of the wind energy, a public survey is conducted face-to-face in a sample of 220 citizens. The wind resource is assessed using 1-year wind data from a near-by meteorological mast. Moreover, based on the international standards, the extreme wind occurrence and the wind turbulence levels are estimated so as to choose the most suitable wind turbine of the market for the site of Nuuk. The V100-1.8MW wind turbine with Annual Energy Production (AEP) of 4.8527 GWh is chosen and analyzed economically for installation. The Simple Payback Time (SPT) and the Discounted Payback Time (DPT) with a discount rate of 6 % are estimated to 9.1 and 13.6 years, respectively. A sensitivity analysis was conducted on the electricity price and the capital of the investment indicating its profitability when the selling price of electricity is above the threshold of 0.04 €/kWh or the capital costs less than 3 million €. Finally, the contribution of only one wind turbine to the energy production of the Buksefjord hydroelectric power plant, which is currently the main power supplier of the city of Nuuk, lengthens its operation lifetime by 2 months.

KEY WORDS: Wind energy, public acceptance, wind resource, AEP, payback time.

1 INTRODUCTION

This research studied the feasibility of a wind turbine installation in the area of Nuuk which is the capital of Greenland and one of the smallest capital cities in the world with 16,454 inhabitants. It is located in southwestern coast approximately 240 km south from the Arctic Circle. This location corresponds to cold, snowy winters and cool summers giving an average year temperature of -1.42 ^{o}C [1].

The total energy supply of Nuuk in 2011 was 236 GWh with the 94.3 % covered by the Buksefjord hydroelectric power plant located 60 km southeast of Nuuk and operated by the National energy company of Greenland, Nukissiorfiit [2],[3]. The hydroelectric plant consisted of two generators of 15 MW each until 2008 when one more generator was installed yielding a power production of 45 MW [2].

Given the political decision of the local authorities and the government to extent the city the energy consumption in Nuuk has increased by 39 % since the beginning of the 21st century and is expected to increase by 45 % until 2030 leading the lake where the hydroelectric plant gets its water from to run dry by approximately 2026 [2].

The latter estimation increases the necessity for the city of Nuuk to prepare in the near future modern sustainable energy solutions in order to become energy independent. Thus, the aim of this study is to demonstrate the feasibility of the wind power implementation in the area of Nuuk in terms of climatic, economic and social conditions for further connection to the Buksefjord hydroelectric power plant.

Wind power projects often meet with severe opposition from the local community in countries including those in Europe, Asia and North America [4]. Thus, a public survey is conducted as well so as to estimate the knowledge of the people of Nuuk about the wind energy concept. The scope of this survey is to convince the stakeholders involved for a long-term local policy so as the people of Nuuk to be informed about the benefits and the impacts of the wind energy projects.

Moreover, the challenge of this project is to determine the wind turbine power production by mapping the wind resource of the area of Nuuk. Thus, the extreme wind occurrence and the wind turbulence levels of the region are critical factors in order to choose the wind turbine that stands the corresponding loads.

2 MATERIALS AND METHODS

2.1 Public survey

The public survey based on a questionnaire written in the two most widely spoken languages in Nuuk; Kalaallisut, which is the main dialect in West Greenland, and in the colonial language, Danish. It was conducted face-to-face on the busy street corners and in the mall of Nuuk in a sample of 220 citizens. The respondents were asked to sign the form in the end and state their age.

The questionnaire consisted of two simple but targeted questions with multiple choice answers.

The first question asks “How much do you know about wind energy?” with possible answers:

- “I know a lot about it”
- “I do not know anything about it”
- “I know a little about it”
- “I have heard about it”

The second question asks “What is your opinion of wind farm installation in the area of Nuuk?” with possible answers:

- “It is a really good idea”
- “It is a good idea”
- “I do not care”

- "It is a bad idea"
- "It is a really bad idea"

2.2 Meteorological mast

In order to proceed to the wind resource estimation, wind measurements from a meteorological mast in the area of Nuuk were retrieved from the climate expert Per Hangaard working for ASIAQ; a government organization whose the core task is to map the energy resources of Greenland [5].

The meteorological mast is located at 64^{o}1046.4 N, 51^{o}4333.9 W and the cup anemometer is set 10 m above ground level. The measurements include one year 10 minute averages of the wind speed and direction for 2012.

Regarding the elaboration of the data, the MATLAB numerical computing software program was used.

The raw wind speed data were sorted according to the corresponding wind direction into 12 different sectors of 30^{o} each forming a wind rose of 360^{o}.

2.3 Annual Energy Production estimation

The first step was to acquire the mean value, μ_X, and the standard deviation, σ_X, of the wind speed data so as to estimate the Weibull parameters. The Weibull distribution probability density function (pdf) is described by the following formula

$$f_X(x) = k\frac{x^{k-1}}{A^k}\exp\left(-\left(\frac{x}{A}\right)^k\right) \quad (1)$$

In order to describe the wind speed distribution of the site both the form parameter, k, and the scale parameter A were computed by the following system of equations

$$\mu_X = A\Gamma(1+\frac{1}{k}) \quad (2)$$

$$\sigma_X^2 = A^2(\Gamma\left(1+\frac{2}{\kappa}\right) - \Gamma^2\left(1+\frac{1}{k}\right)) \quad (3)$$

Where the gamma function, Γ(x), is defined through

$$\Gamma(x) = \int_0^\infty t^{x-1}e^{-t}dt \quad (4)$$

In order to determine the energy production precisely the vertical wind shear which describes the variation of the wind speed with the elevation was also taken into account [6]. Thus, the power law profile was implemented as described by the following formula

$$\frac{U(z)}{U(z_r)} = \left(\frac{z}{z_r}\right)^{\alpha} \tag{5}$$

Where, $U(z)$, denotes the wind speed at height z, $U(z_r)$, is the reference wind at height z_r and, α, is the power law exponent which is a highly variable quantity and is estimated empirically to 1/7 [7].

The next step was to describe the power curve, P(U), of the wind turbine in the given site as

$$P(U) = P_{rated} * \begin{cases} (\frac{U}{U_{rated}})^3 & \text{for } U < U_{rated} \\ 1 & \text{for } U_{rated} < U < U_{cut-out} \\ 0 & \text{for } U > U_{cut-out} \end{cases} \tag{6}$$

Finally, the Annual Energy Production (AEP) was calculated by the sum of the AEP's of the twelve sectors using the following formula.

$$AEP_i = Tf_i \int_0^{\infty} p_i\,(U)P(U)dU \tag{7}$$

Where, T, denotes the time length of a year, f_i, is the wind frequency in each sector, $p_i(U)$, is the probability density of the wind in each sector and $P(U)$ is the power curve [6].

2.4 Site assessment

Before deciding on the appropriate wind turbine to be installed, the most important wind conditions such as the 50 year extreme wind occurrence and the turbulence levels of the given site must be estimated according to the international standards [8].

The extreme wind, $U_{50,}$ denotes the mean wind speed which on average is exceeded one time during a return period of 50 years by the 10 minute averages wind speeds, and is estimated by the following equation.

$$U_{50} = 5U \tag{8}$$

In addition to the extreme wind estimation, the allowable turbulence intensity was computed as well. With the reference to the IEC 61400-1, Ed.3 standard, the effective turbulence intensity must be lower than the representative turbulence intensity in a range from 0.6 times the rated velocity, U, to cut-out velocity [8]. The turbulence intensity, TI, is found from the next equation.

$$TI = \frac{\sigma_u}{U} \tag{9}$$

Where, σ_u, is the standard deviation computed by the product of the Charnock's constant, A_c, which is assumed to be 2.5, and the surface friction velocity, u_* [6],[7].

2.5 Wind turbine selection

In this study, two different wind turbines were examined for implementation in the Nuuk site; the Vestas V100-1.8MW and the Enercon E70-2.3MW [9],[10]. The key technical data of these wind turbines are summarized in the following table.

Table 1: Technical data of the V100 and the E70 wind turbines.

Technical data	**V100-1.8MW**	**E70-2.3MW**
Cut-in wind speed	4 m/s	2 m/s
Rated wind speed	12 m/s	16 m/s
Cut-out wind speed	20 m/s	28-34 m/s
Hub height	80 m	57 m
Wind class	IIA	IIA

The two main characteristics which led to examine the specific wind turbines are:

- The ice detection system.
- The low temperature operation down to -30 ^{0}C which is sufficient even for the record low temperatures ever occurred in Nuuk [1].

Their overall performance in terms of AEP, 50-year wind gust estimation and turbulence intensity were the critical factors so as a further economic analysis to be conducted.

2.6 Economic analysis

A financial economic analysis of the V100-1.8MW wind turbine installation was conducted for the operational lifetime of 20 years [11]. The latter follows the recommendations of the Danish Wind Industry Association.

The main parameters governing the wind turbine economics include the following:

- Capital investment (for planning & construction)
- Running costs (Operation & Maintenance and management)
- Revenue (electricity price, availability, wind, kWh)
- Project lifetime (turbine vs. investment)
- Discount rate (the time-value of money)

Regarding the capital investment, the parameters presented in Table 2 were considered. The values were estimated for the specific site of Nuuk with the reference to the costs of a typical 2 MW wind turbine installation in Europe [12]. In the total upfront price a 10 % is added for the transportation costs yielding the total capital investment to 2.43 Million €.

Table 2: Capital investment costs of the wind turbine installation in the Nuuk site.

	Investment (€)	**Share of Total Cost (%)**
V100-1.8MW wind turbine	1,607,400	75.6
Grid connection	196,200	8.9
Foundation	144,000	6.5
Land Rent	86,400	3.9
Electric installation	32,400	1.5
Consultancy	27,000	1.2
Financial Costs	27,000	1.2
Road Construction	19,800	0.9
Control Systems	7,200	0.3
Total	2,208,600	100

In order to calculate the payback time of the investment, two different methods were used; the Simple Payback Time (SPT) method and the Discounted Payback Time (DPT) method. The latter is more reliable due to the fact that accounts the time value of the money by discounting the cash inflows of the project.

The SPT was calculated by the following formula

$$\mathrm{SPT} = \frac{\mathrm{Investment}}{\mathrm{Annual\ average\ income}} \tag{10}$$

For each period, the Discounted Cash Inflow (DCI) was computed by

$$\mathrm{DCI} = \frac{\mathrm{R_t}}{(1+\mathrm{i})^{\mathrm{n}}} \tag{11}$$

Where, i, denotes the discounted rate, n, is the period to which the cash inflow relates and, $\mathrm{R_t}$, is the net cash flow. The cumulative cash flow was replaced by the cumulative discounted cash flow as follows

$$\mathrm{DPT} = \mathrm{A} + \frac{\mathrm{B}}{\mathrm{C}} \tag{12}$$

Where, A, denotes the last period with a negative discounted cumulative cash flow, B, is the absolute value of the discounted cumulative cash flow at the end of the period A and, C, is the discounted cash flow during the period after A [12].

Each cash inflow is discounted back to its Present Value (PV). Therefore, the Net Present Value (NPV) was estimated by the sum of all terms $R_t/(1+i)^t$ where, t, is the time of the cash flow

$$\mathrm{NPV(i,N)} = \sum_{\mathrm{t=0}}^{\mathrm{N}} \frac{\mathrm{R_t}}{(1+\mathrm{i})^{\mathrm{t}}} \tag{13}$$

The Internal Rate of Return (IRR) which is the discount rate that the NPV of a project becomes zero was estimated as well.

Moreover, the simple Cost of Energy (CoE) was calculated by

$$\text{CoE} = \frac{\text{Capital Costs+NPV}}{\text{AEP}\cdot\text{Life time}} \tag{14}$$

Due to the ice climate and that Nuuk is a remote area the availability factor; the fraction of the time that the wind turbine is able to generate electricity was assumed to be 95% which is in the range considered by recent studies [13].

As to the discount rate, it was assumed 6% due to the high risks involved, as there is not any previous experience in installing large-scale wind turbines in Greenland and due to project timing risk factor. The risk of the variation in AEP from year to year was considered as well.

Based on experience in Germany, Spain, the UK and Denmark, the O&M costs are generally estimated to be around 1.2 to 1.5 c€/kWh of wind power produced over the total lifetime of a turbine [12]. For the site of Nuuk the price of 1.5 c€/kWh was chosen.

The selling price is not fixed as there is no legislation in Greenland regarding wind turbines. The corresponding price in Denmark was considered where for onshore wind turbines connected to the grid after January of 2014 a cap of 0.58 DKK/kWh (0.07 €/kWh) is applied [14].

Due to the uncertainties in the price of electricity and the capital investment a sensitivity analysis of the NPV and the IRR was implemented.

3 RESULTS

3.1 Public acceptance

Regarding the people’s knowledge in Nuuk about the harvest of the wind energy it is found that only the 5 % of the respondents believes that knows a lot about it, while the 33 % states a little knowledge about it and the 25 % have heard about it. On the other hand, the 38 % of the citizens declares that does not know anything about it (Figure 1).

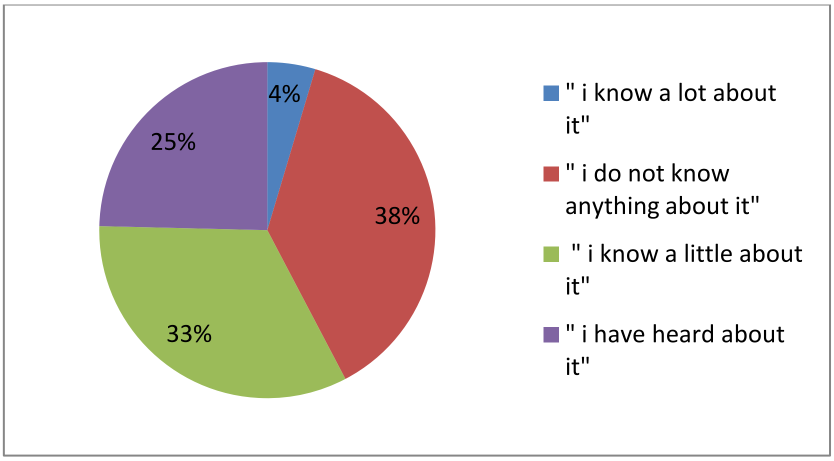

Figure 1: Percentage results of the four different answers to the question of the level of knowledge about Wind Energy.

Concerning the public opinion on having a wind farm near to their city, the 88 % is positive or very positive to this, while only the 4 % of the respondents thinks that is a bad or very bad idea. The rest 8 % of the people states that does not care about it (Figure 2).

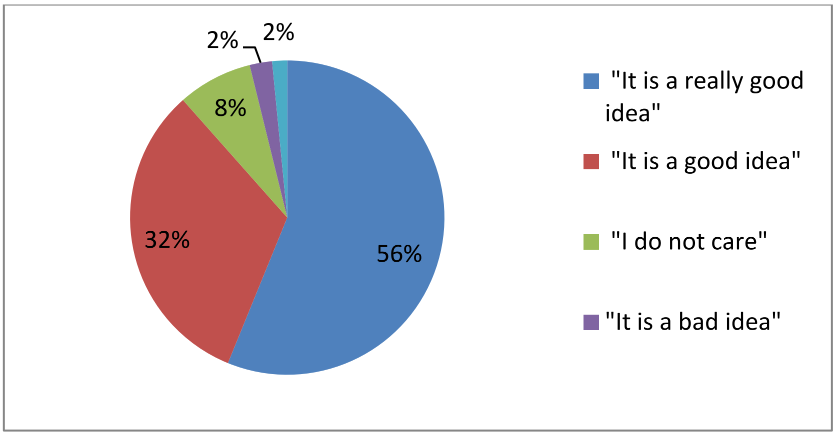

Figure 2: Percentage results of the five different answers to the question of wind farm installation in the area of Nuuk.

By sorting the results into three different age groups, the new generation in Nuuk (up to 35 years old) appears to know a little about wind energy and believes that is a good or very good idea the wind energy implementation in the site of Nuuk. On the other hand, the elder generations (35 to 55 years and above 55) have not heard about the wind power projects but at the same time are positive to the idea of a wind farm installation in Nuuk.

3.2 Wind resource assessment

The wind rose and the time series are demonstrated in Figure 3. As it is shown in the graph on the left, the main wind directions in the site of Nuuk are from the West and the East, with the stronger winds coming from the West. The mean wind speed of the site was estimated to 5.69 m/s and the standard deviation to 3.9 m/s.

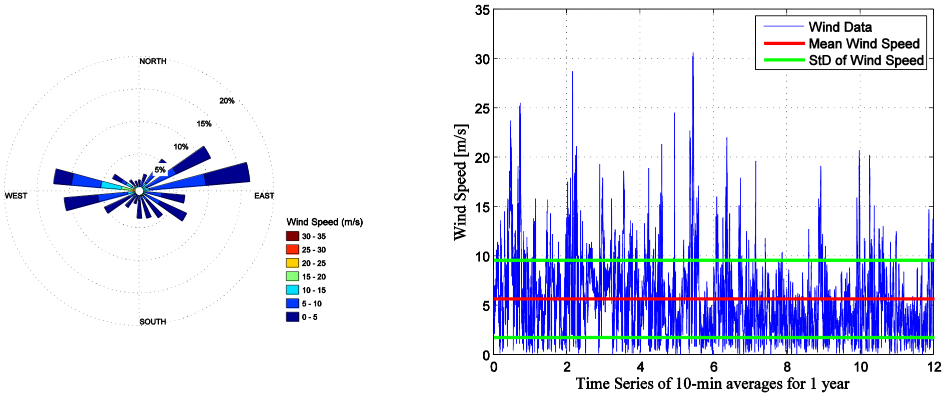

Figure 3: The Wind Rose (on the left) and the one-year Time-Series of the ten-minute horizontal wind averages (on the right) in the Nuuk site.

The pdf of the 10 minute averages of the horizontal wind speed in Nuuk site is presented in Figure 4. As it was expected, they follow the Weibull distribution with k=1.4805 and A=6.3024.

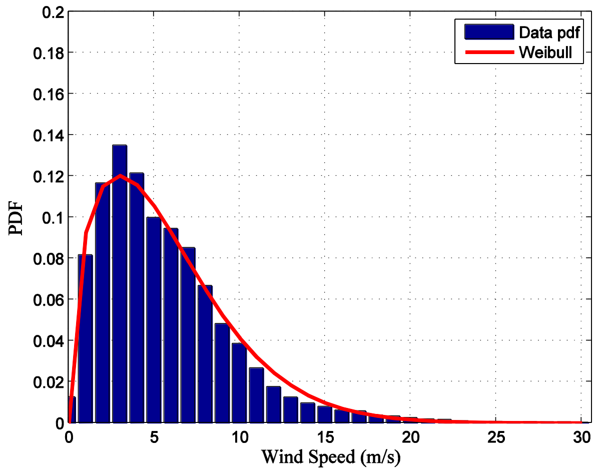

Figure 4: PDF of the 10 minute averages of the wind speed in Nuuk site compared to the Weibull distribution.

3.3 Wind turbine evaluation

The AEP of the V100-1.8MW and the E70-2.3MW was found 4.8527 GWh and 3.6407 GWh respectively. Additionally, the extreme wind values estimated to 38.32 m/s and 36.51 m/s, respectively. The turbulence intensity curves for the two wind turbines are presented in Figure 5.

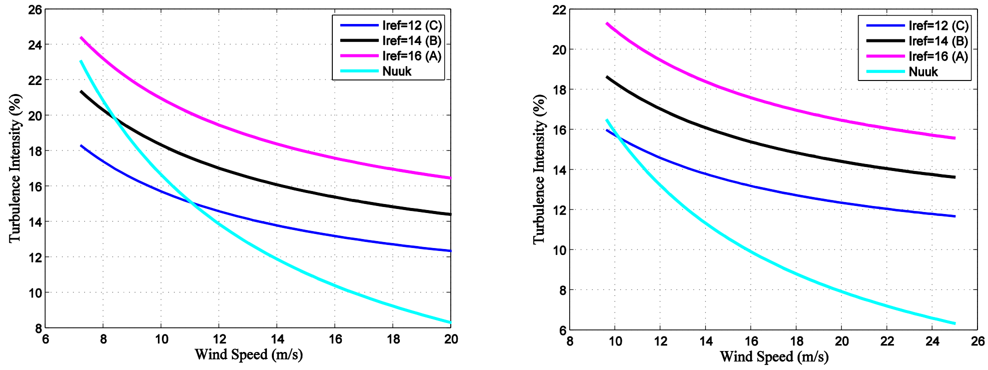

Figure 5: The turbulence intensity of the Vestas wind turbine (on the left) and the Enercon wind turbine (on the right) through the range from 0.6 times the rated velocity to cut-out velocity for the Nuuk site.

From the latter figure and the extreme wind values, it is resulted that both wind turbines are suitable for the site of Nuuk. However, due to the much higher AEP, the V100-1.8MW wind turbine is decided to be examined for implementation.

Finally, it was found that the V100-1.8 MW wind turbine installation will increase the lifetime of the Buksefjord hydropower plant by two months.

3.4 Economic evaluation

The simple payback time was found 9.1 years and the discounted payback time 13.6 years. The NPV was found 631305 € and the IRR yielded at 9% which is higher than the discount rate.

As it can be seen in Figure 4 in the sensitivity analysis of the electricity price the NPV becomes negative and the IRR less than the discount rate for prices less than close to 0.04 €/kWh (Figure 6).

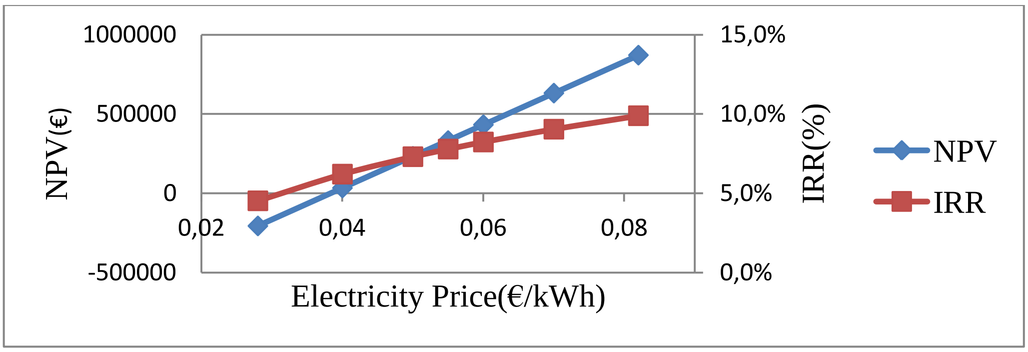

Figure 6: Sensitivity analysis of the electricity price in terms of NPV and IRR.

As to the sensitivity analysis of the capital investment the NPV becomes negative and the IRR less than the discount rate when the capital costs reach 3 Million € (Figure 7).

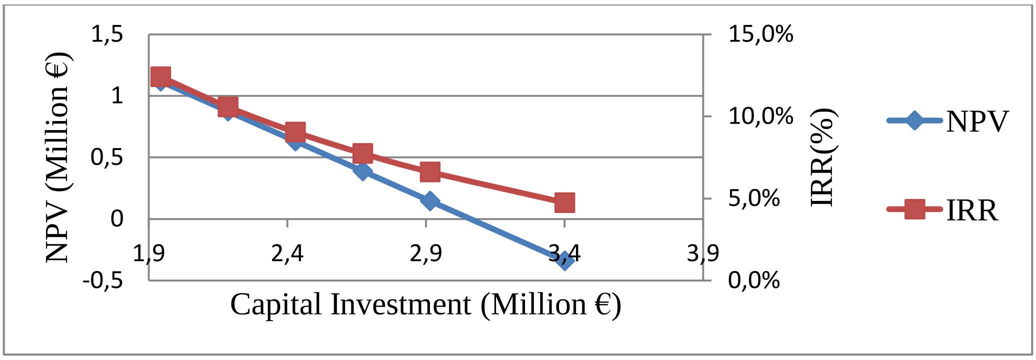

Figure 7: Sensitivity analysis of the capital investment in terms of NPV and IRR.

4 DISCUSSION

Regarding the public survey, the people of Nuuk appear, in general, not well informed about the wind energy concept and, simultaneously, welcome a wind power project near to their city. This contradictive result indicates that multiple local seminars should be organized so as to inform the people of Nuuk about the actual project and the wind energy in general.

Concerning the wind resource estimation, the small value of k indicates very variable winds as it is signified by the resulted wind rose. It has to be remarked, that the actual elevation, the orography, and the complex terrain should be considered as well but due to the lack of a digital wind map of the region this was not possible. However, taking into consideration the wind shear effect the AEP estimation of the examined wind turbines is reliable [7].

Usually banks and finance institutions require a pay-back time of 7 to 15 years [12]. After the investment is paid off, the cost of producing electricity from the wind energy is lower than any other fuel-based technology. But due to the uncertainties involved there are many risks for financial losses as it was presented in the sensitivity analysis. However, the results show that an investment in this project is profitable using both the simple payback method and the discount rate.

The extension of the operational life of the hydro power for 2 months could be considered as negligible but considering an installation of a large scale wind farm of 20 turbines its lifetime would extend by 3 years and 2 months.

5 CONCLUSION

To sum up, a long-term policy should be established in Nuuk so as to facilitate the local acceptance of the wind energy. The policy should encourage the local participation in the future wind energy projects so as the community to feel responsible for and proud of the wind farm. The latter could be done by offering the citizens of Nuuk shares at a special price [4].

In terms of the economics, a socio-economic analysis could be conducted as well. Apart from or as a section of Nukissiorfiit, a National wind power company could be set up so as the revenues of the project to return to the local community.

ACKNOWLEDGEMENTS

The authors would like to thank for the support their supervisor, Dr. Esben Larsen, the operation manager of Nukissiorfiit, Filip Sivertsen and Christian Jermiassen for his help during the public survey.

REFERENCES

[1] GRØNLANDS STATISTIC: http://bank.stat.gl/ (Page visited 2.Nov. 2013)

[2] Nukissiorfiit and ETP Consult A/S, 2012. *Strategiplan Nuuk, 2030.*

[3] Andersen J.R. and Teisen E., 1990. *Grønlands første store vandkraftværk.*

[4] Jegen et.al., 2013. *Social Acceptance of Wind Energy Projects*. IEA Wind RP14. January 2013.

[5] ASIAQ: http://www.asiaq.gl/ (Page visited 2.May. 2013)

[6] Berg J. et. al., 2012. *Notes for DTU course: Introduction to micrometeorology for wind energy.* September 2012.

[7] Manwell J.F. et.al., 2009. *Wind Energy Explained: Theory, Design and Application.* 2nd Edition. John Wiley & Sons, Ltd.

[8] International Electrotechnical Commission, 2005. *International Standard, IEC 61400-1*. 3rd Edition. 2005-2008.

[9] VESTAS: http://www.vestas.com/ (Page visited 24.Nov. 2013)
[10] ENERCON: http://www.enercon.de/de-de/ (Page visited 24.Nov. 2013)

[11] WEC, 1993 , *Renewable Energy Resourses: Opportunities and Constraints 1990-2020.* World Energy Council, London, UK.

[12] Krohn S. et.al., 2009, *The Economics of Wind Energy.* The European Wind Energy Association. March 2009.

[13] EWEA, 2004. *Wind Energy, The facts, Vols. 1-5.* The European Wind Energy Association, Brussels, Belgium.

[14] NordPoolSpot: http://www.nordpoolspot.com/ (Page visited 28.Oct. 2013).